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MASTERING PHYSICS

STUDENTS COMPANION

4th EDITION

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SENIOR ONE

S1.1 INTRODUCTION TO PHYSICS

Learning Outcomes

a) *Understand the meaning of physics, its branches and why it is important to study Physics (u, v/a))*
b) *Understand why it is important to follow the laboratory rules and regulations (u, v/a)*

INTRODUCTION

Physics is the scientific study of matter, motion, energy, and force. It seeks to understand the fundamental laws that govern the universe, from the smallest subatomic particles to the largest cosmic structures.
Physics is divided into two main branches: Classical Physics and Modern Physics.

Classical Physics

Classical physics, developed up to the early 20th century, describes phenomena at macroscopic scales and at speeds much slower than the speed of light. It includes:

- **Mechanics:** The study of motion and forces, including Newton's laws of motion.
- **Thermodynamics:** The study of heat, work, and energy transfer.
- **Electromagnetism:** The study of electric charges, currents, and their associated fields, as well as magnetism and light.
- **Energy:** The capacity to do work. Energy exists in many forms, such as kinetic, potential, thermal, chemical, and nuclear, and it can be converted from one form to another but never created or destroyed.

Modern Physics

Modern physics deals with phenomena at very high speeds, very small scales, or in very strong gravitational fields. It includes:

Relativity: Developed by Albert Einstein, this theory describes how space, time, gravity, and motion are interconnected, particularly at high speeds and in strong gravitational fields.

Quantum Mechanics: This theory explains the behavior of matter and energy at the atomic and subatomic levels, where particles can exhibit wave-like properties.

Branches of Physics

Physics can be classified into various branches, but classical physics is mainly concerned with energy and matter. The traditional branches of classical physics are Optics, Acoustics, Electromagnetics, and Classical mechanics. With the rapid development of physics, the scope of the subject is growing so large that it is not possible to cover physics under the above branches. A number of main branches of physics are discussed below.

Mechanics. Mechanics is the branch of physics that deals with the motion of an object without or with the reference of force. Mechanics can be further divided into two branches, namely quantum mechanics and classical mechanics. Quantum mechanics deals with the behaviour of the smallest particles like neutrons, protons, and electrons, while classical mechanics is the branch that deals with laws of motion of forces and physical objects.

Optics. This branch of physics deals with the behaviour, propagation, and properties of light. Optics can be simply described as the study of the behaviour of infrared light, visible light, and ultraviolet.

Thermodynamics. Thermodynamics deals with the study of heat and its relation with work and energy. Thermodynamics also deals with the transmission of heat energy by means of convection, conduction, and radiation.

Electromagnetism. Electromagnetism deals with the study of electromagnetic force like electric fields, light, magnetic fields, etc. There are two aspects of **Electromagnetism**, which are "**Electricity" and "Magnetism**".

Relativity. This branch of physics deals with the theorem that was formulated by Albert Einstein. The theory of relativity states that space and time are relative and all the motion must be relative to a frame of reference.

Acoustic. Acoustics deals with the study of sound and its transmission, production, and effects. Acoustics mainly involves the mechanical waves in gases, liquids, and solids, which include vibration, sound, ultrasound, and infrasound.

What are the Benefits of Studying Physics?

Studying physics offers numerous benefits, both personally and professionally. Some of these include:

- ♠ Developing your logical, mathematical, and abstract reasoning skills.
- ♠ Enhancing your understanding of other fields of knowledge, such as chemistry, biology, geography, and history.
- ♠ Broadening your scientific literacy and your view of the world.
- ♠ Stimulating your creativity and imagination while solving problems and designing solutions.
- ♠ Gaining teamwork, communication, and presentation skills.
- ♠ Preparing for careers in science, technology, engineering, and mathematics (STEM) related fields.
- ♠ Expanding your job opportunities in sectors like industry, energy, healthcare, education, and research.

Basic Laboratory Rules

Activity: To observe a laboratory and identify safety rules therein.

Your teacher will take you to the laboratory or science room; where you will be conducting physics experiments.

a) Identify some apparatus you may have seen before.
b) Identify some situations that may pose danger to learners while in the laboratory.
c) List at least five safety rules you may think of that should be observed while in the laboratory.
d) Compare and discuss your findings with other groups in your class

A laboratory is a room in which science experiments or investigations are conducted. While in the laboratory, you are expected to observe some measures to avoid occurrence of accidents that may harm them or the apparatus.

General basic physics laboratory rules focus on personal safety, correct equipment handling, and maintaining an organized workspace.

Personal Safety and Attire

- Wear closed-toe shoes and long pants. Tie back long hair, and avoid loose clothing or dangling jewelry that can catch on equipment.
- Wear safety goggles when using heat sources, projectiles, lasers, or breaking glass.
- Keep all food, drinks, and gum outside the laboratory to prevent chemical or electrical contamination.
- Act responsibly at all times. Running, joking, or practical jokes can cause serious accidents.

Equipment and Electrical Safety

- Ensure your hands are completely dry before touching electrical switches, plugs, or power supplies.
- Check cords, plugs, and equipment for damage before use. Report broken items immediately.
- Ask your instructor to check your electrical circuits before turning on the power.
- Never look directly into a laser beam or point it at anyone.

Workspace and Emergency Procedures

- Read procedures beforehand and strictly follow all verbal and written directions. Never perform unauthorized experiments.
- Locate the fire extinguisher, first aid kit, and emergency exits before starting work.
- Inform your instructor right away about any injuries, cuts, burns, or broken equipment.
- Turn off all utilities (gas, water, electricity) when finished. Clean your workstation and return all apparatus to its proper storage place.

Importance of following Laboratory rules and regulations

Following laboratory rules and regulations is essential to prevent physical injuries, protect personal health from toxic exposure, and maintain a secure working environment.

Reasons to follow lab rules

- Proper protocols stop fires, chemical spills, cuts, and burns before they happen.
- Rules ensure safe handling and disposal of dangerous biological and chemical materials, avoiding toxic absorption or contamination.
- Correct use of tools and glassware prevents expensive equipment damage.
- Adhering to institutional policies and safety laws avoids legal penalties or facility closures.
- Knowing safety equipment locations (like eyewash stations and showers) ensures fast responses during crises

First Aid Measures

Activity: To define first aid and interpret hazard symbols

Materials: First aid kit, chart-showing hazard symbols

(a) In groups of three, discuss what first aid is and why it is important to have adequate knowledge on first aid.

(b) Open the first aid kit provided to you and identify all the items in it and their uses.

(c) Now, discuss each hazard symbols shown on the chart provided and suggest why it is important to understand them.

Common Physics Lab Accidents & First Aid

- ♠ **Electric Shock:** Turn off the power source immediately or break contact using a non-conductive object (like dry wood or plastic) before touching the person.
- ♠ **Thermal or Electrical Burns:** Cool the affected area with cool (not ice-cold) running water for at least 10 to 15 minutes.
- ♠ Remove any tight jewelry or clothing before swelling starts, but do not pull away stuck fabric.
- ♠ **Cuts and Broken Glass:** Never handle broken glass with bare hands; use tools or thick gloves to sweep it up.
- ♠ **Eye Injuries:** Flush the eye continuously at an eyewash station with lukewarm water for at least 15 minutes if debris or a hazardous substance enters it. Seek professional medical evaluation.
- ♠ **Essential Lab Safety Preparation:** Locate the nearest first aid kit, fire extinguisher, and eyewash station before starting any experiment.
- ♠ Report all incidents, sparks, shocks, or injuries promptly to your instructor or lab supervisor.

S1.2 MEASUREMENTS IN PHYSICS

Learning Outcomes

a) Understand how to estimate and measure physical quantities: length, area, volume, mass, and time (u, s, g, s)
b) Explain how they choose the right measuring instrument and units; explain how to use the instruments to ensure accuracy (u,s)
c) Appreciate that the accuracy of measurements may be improved by making several measurements and taking an average value (gs, v/a)
d) Identify potential sources of error in measurement and devise strategies to minimize them (u, s, v/a)
e) Understand the scientific method and explain the Procedures used in relation to the study of physics(u)
f) Know that practical investigations involve a 'fair test', analysis, prediction and justification of results, and observations, and apply learning in practice (k, s)
g) Record data in graphs and charts and look for trends (u,s)
h) Understand and be able to use scientific notation and significant figures (u,s)
i) Understand density and its application to floating and sinking(u)
j) Determine densities of substances and relate them to purity (u, s,gs)
k) Understand the global nature of ocean currents and how they are driven by changes in water density and temperature (u,s)

Introduction

Measurement in physics is the method of comparing an unknown physical property to a fixed, standard unit to find its numerical value.

Physical Quantities: Any feature of an object or event that you can measure and use to state physical laws. It requires a number and a unit (for example, 5 meters).

Fundamental Quantities: Basic, independent building blocks that you cannot define using other quantities.

Derived Quantities: Formed by multiplying or dividing fundamental quantities, such as area or speed.

The Seven Fundamental Quantities , and their International System of Units (SI) uses seven base units:

- Length: Meter (m)
- Mass: Kilogram (kg)
- Time: Second (s)
- Electric Current: Ampere (A)
- Temperature: Kelvin (K)
- Amount of Substance: Mole (mol)
- Luminous Intensity: Candela (cd)
- Tools and Techniques

Length: Measured with rulers or tape measures (units like mm, cm, and m).

Volume: Measured with measuring cylinders or calculated using geometric formulas. Irregular objects use water displacement.

Time: Measured using analog or digital stopwatches.

Averaging: Taking multiple readings (like counting 10 oscillations of a pendulum) helps reduce random error.

Accuracy, Precision, and Uncertainty

Accuracy: How close a measured value is to the true value?

Precision: How close repeated measurements are to each other.

Uncertainty: The estimated doubt (± value) in any measurement caused by instrument limits or human reaction time.

Measurement is a technique in which the properties of an object are determined by comparing them to a standard quantity. Measurement is the essential metric to express any quantity of objects, things and events.

Types of Measurement and Measurement Units

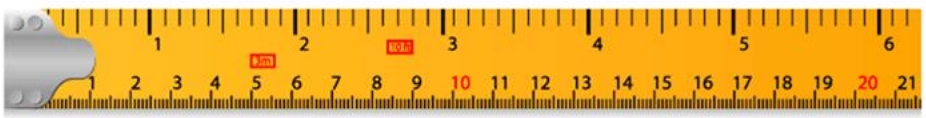
- Time: Units for expressing time include seconds, minutes, hours, days, weeks, months, years, etc.
- Length: Units for measuring length include millimetres, centimetres, meters, kilometres, etc.
- Weight: Units for expressing the weight of certain objects include grams, kilograms, tons, etc.
- Volume: Units for expressing volume include cm^3, m^3, litres, etc.
- Temperature: The major units of temperature include centigrade and Fahrenheit.

It is also possible to perform the conversion of units from one unit to another.

Measurement Instruments

Instruments are required to measure any type of quantity. For example, to measure weights we require a weighing machine, to measure length we require a scale or tape. Some measurements are given below:

Measurement Tape: The below figure shows the measurement tape that can be used to measure the length of objects or distances.



An instrument for measuring time: The clock is one of the instruments that can be used to measure time.

Applications of Measurement

Measurement is an important concept for the following situations.

- ♠ To construct buildings, we need to consider proper dimensions.
- ♠ For trading, purchasing, and selling of goods
- ♠ For preparing food, we generally take the ingredients in specific quantities
- ♠ For conducting scientific experimentations in labs
- ♠ To complete a certain task, time is the crucial thing to count.
- ♠ For formulating medicines and treating patients

LENGTH

Length is a measure of distance between two points. i.e. breadth, width, height, radius, depth and diameter are all lengths. S.I unit of length is metres (m). *Other units:* kilometres (km), centimetres (cm), millimetres (mm), Inches, yards, miles etc. km = 1000m, 1m = 1000cm = 1000000mm, 1cm = 10mm. Very small lengths are measured in micrometer and nanometers (nm). 1m = 1,000,000nm = 10^6 μm; 1m = 1,000,000,000nm = 10^9 nm

Example, Convert the following measurements.

(a) 20mm to metres.

1m =1000mm; 20mm = 0.02m

(b) 0.8m to centimeters

1m = 100cm; 0.8m = 0.8×100cm = 80cm

Length is measured using; Metre rule, Tape measure, Calipers, Micrometer screw gauge, and Thread.

CALIPERS: These are used to measure distance in solid objects where an ordinary metre rule cannot be applied. They are made out of pair of hinged steel jaws, which are closed until they touch the object in the desired position. Calipers are of two types namely:

i) Engineer's calipers,

ii) Vernier calipers

MICROMETER SCREW GAUGE: This is used to measure small distance such as diameter of pieces of wire, bicycle spoke pins, needles etc. The instrument measures up to 2 decimal places in mm. It consists of a spindle, which can be screwed, and it is fitted with a scaled thimble.

Activity

1. James found that the perimeter of his farming plot was approximately 200 strides. His stride was 0.75m long. What was the perimeter of the plot?
2. Estimate the width of your desk, classroom window and the classroom by counting how using the ruler or any possible measuring instrument in S.I units.
3. Suggest a method you can use to estimate the width of a page of your book.

MEASUREMENT OF AREA OF AN OBJECT

Area is the quantity that expresses the extent of a given surface on a plane. It is a derived quantity of length. The SI unit of area is the square metres, written as m^2. It can also be measured in multiples and sub-multiples of m^2, for example, cm^2 and km^2.

Area is a measure of the extent of a two-dimensional surface or shape. It quantifies the amount of space enclosed within the boundaries of a flat object, such as a rectangle, circle, or triangle.
Area is an important concept in various fields, including mathematics, physics, engineering, and everyday life.
Units of Area: Area is measured in square units, reflecting the number of unit squares that fit into the shape. Common units of area include:
Square meters (m^2) in the metric system. Square centimeters (cm^2) and square millimeters (mm^2) for smaller areas. Square kilometers (km^2) for large areas.
Square feet (ft^2) and square inches (in^2) in the imperial system. Acres and hectares for measuring land areas.

Calculating Area
The method to calculate the area depends on the shape of the object.
Name the different objects you know around you and establish their areas.

Importance and Applications of area.

- ♠ Calculating the area is crucial for designing floor plans, determining the number of materials needed (e.g., paint, flooring), and estimating costs.
- ♠ Farmers need to know the area of their fields to manage planting, fertilization, and irrigation effectively.
- ♠ The area of land and buildings is a fundamental factor in property valuation and transactions.
- ♠ Manufacturers calculate the area of fabric needed to produce garments and other textile products.
- ♠ In physics, area calculations are used in various contexts, such as determining the pressure exerted on surfaces (pressure = force/area) and in fluid dynamics.
- ♠ Understanding area helps in tasks like planning gardens, arranging furniture, and organizing spaces efficiently.

Visualization and Understanding:
Visualizing area often involves tiling a shape with unit squares. For instance, a rectangle with dimensions 3 meters by 4 meters can be covered by 12-unit squares of 1 square meter each, thus having an area of 12 square meters.

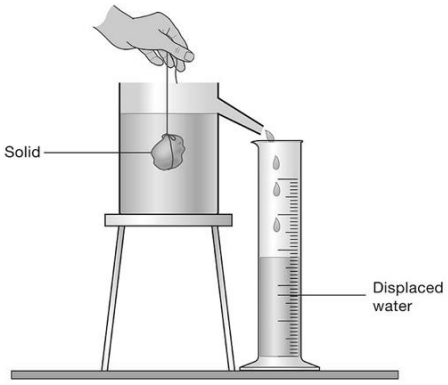
Practical Examples:
A rectangular garden: If the garden is 5 meters long and 3 meters wide, the area is $5 \times 3 = 15$ square meters.

VOLUME:
Volume is a measure of the amount of space an object or substance occupies.
It is a three-dimensional quantity, representing the extent of an object in the three dimensions of space: length, width, and height. The concept of volume applies to both solid objects and fluids (liquids and gases).

Units of Volume:
Volume can be expressed in various units, depending on the system of measurement:
Metric System:
Cubic meters (m^3), Liters (L), where 1 liter = 1 cubic decimeter (dm^3) = 1,000 cubic centimeters (cm^3), Milliliters (mL), where 1 milliliter = 1 cubic centimeter (cm^3).
NB: 1 Litre = $1000cm^3$, $1cm^3$ = $1000cm^3$, $1m^3$ = 100cm x 100cm x 100cm = $1,000,000cm^3$

Importance and Applications

Understanding volume is crucial in everyday activities like cooking (measuring ingredients), filling fuel tanks, and packing. Volume calculations are essential in various scientific fields, including chemistry (stoichiometry and reactions involving gases), physics (density calculations), and engineering (designing containers, buildings, and other structures). Dosage of liquid medications, blood transfusions, and intravenous fluids are often calculated based on volume. Industries dealing with liquids (e.g., oil, beverages) and gases need to measure and control volumes accurately for production, storage, and distribution.



Volume of irregular Shaped Objects

The volume of irregularly shaped objects is obtained by using the displacement method.

Procedure

An over flow can is filled with water

The irregular shaped object is tied onto a string and carefully lowered into the water in the overflow can. The water level is displaced.

The water flowing out of the can through the spout is collected using a measuring cylinder

The volume of the water collected is determined

The volume of the liquid displaced is equal to the volume of the irregular object (stone).

METHOD II

Procedure

Water is poured into a measuring cylinder and the volume noted on its scale.

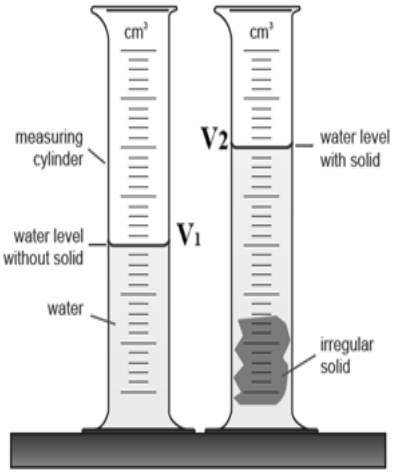
A thread is tied around the irregular object.

The solid (object) is lowered into the water in the cylinder and the 2nd reading noted.

Volume of the solid is obtained from,

V= Volume of 2nd reading - Volume 1st reading.

Therefore, $V = V_2 - V_1$



Volume of liquids

To measure fixed volumes, the following vessels are used:

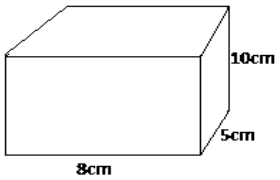
Volumetric flask, measuring cylinder, beaker, pipettes etc

To measure varying volumes, use a burette.

Activity:

1. Use the rectangular box below to answer questions that follow.

Find the volume;



(i) in cm^3

Volume = l x w x h

V= 8cm x 5cm x 10cm

V= **$400cm^3$**

(ii) In m^3

Volume in m^3

$1m^3 = 1000, 000\ cm^3$

$400cm^3$= **$0.0004m^3$**

2. A cuboid has dimensions 2cm by 10cm. Find its width in metre if it occupies a volume of $80cm^3$.

Solution

V=l x w x h , V=2cm x w x 10cm = $80cm^3$, W = 4.0cm

Width in metres

4cm = m = **0.04m**

3(a) Find the volume of water in a cylinder of water radius 7cm if its height is 10cm.

Volume = πr^2h = x 7cm x 7cm x10cm = **$1540cm^3$**

(c) The volume of the cylinder was $120m^3$.When a stone was lowered in the cylinder filled with water the volume increased to $15cm^3$. Find the height of the cylinder of radius 7cm.

Volume V = πr^2h, 12 = 7^2xh h = 0.078 cm

MASS

Mass is the property of a body that is a measure of its inertia, and that is commonly taken as a measure of the amount of matter it contains and causes it to have weight in a gravitational field.

Mass is a fundamental property of physical objects that quantifies the amount of matter they contain.

It is a measure of an object's resistance to acceleration when a force is applied, and it is a key component in understanding and describing the dynamics of objects and systems in physics.

Characteristics of Mass

Mass is a measure of inertia, which is the resistance of an object to changes in its state of motion. The more massive an object, the more force is required to accelerate it.

Mass determines the strength of the gravitational force an object experiences in a gravitational field. The gravitational force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them.

Mass is conserved in isolated systems, meaning it cannot be created or destroyed. This principle is fundamental in classical mechanics and is extended in the form of mass-energy equivalence in relativity. Inertia is actually not a force at all, but rather a property that all things have due to the fact that they have mass. The more mass something has the more inertia it has. You can think of inertia as a property that makes it hard to push something around.

Units of Mass:

Mass is measured in units such as kilograms (kg)

The base unit of mass in the International System of Units (SI).

Grams (g): Commonly used for smaller masses, where 1 kilogram = 1,000 grams.

Metric tons (t): Used for large masses, where 1 metric ton = 1,000 kilograms.

Pounds (lb): Used primarily in the United States, where 1 pound is approximately 0.453592 kilograms.

Types of Mass:

Inertial Mass: A measure of an object's resistance to acceleration when a force is applied. It is defined by Newton's second law of motion, F=ma, where F is the force applied, m is the inertial mass, and a is the acceleration.

Gravitational Mass: A measure of the strength of an object's interaction with a gravitational field.

Importance and Applications of mass:
Mass is the fundamental measure of matter in an object, while mass spectrometry is a powerful analytical technique used to identify and quantify molecules by measuring their mass-to-charge ratio.

Importance of Physical Mass

- ♠ Mass tells us how much substance is inside an object.
- ♠ Scientists measure mass in kilograms or grams using a balance.
- ♠ Mass determines an object's inertia and how strongly gravity pulls on it.

Importance of Mass Spectrometry

- ♠ Detects tiny amounts of a substance down to microscopic levels.
- ♠ It reveals how atoms connect inside complex molecules.

Applications of mass

- ♠ Medical Doctors use it to diagnose diseases and monitor patient breathing during surgery.
- ♠ Forensic Investigators use it to detect illegal drugs, poisons, and explosives at crime scenes.
- ♠ Pharmaceutical companies rely on it to check drug purity and study how medicines move through the body.
- ♠ Environmental Scientists use it to track pollutants in water and harmful chemicals in food.
- ♠ Biotechnology researchers use it to sequence proteins and analyze cellular changes.

TIME
Time is a fundamental concept that quantifies the progression of events from the past through the present to the future. It is a physical quantity that is continuous and measurable used to sequence events, compare the durations of events or the intervals between them, and quantify the motions of objects.
Time is the measure of the duration between events.

Characteristics of Time
Time is often perceived as moving in a linear fashion from the past to the present and into the future. Time can be measured using various units and instruments, with seconds being the base unit in the International System of Units (SI).
In most everyday contexts and classical physics, time is perceived as unidirectional and irreversible, meaning events move forward and cannot be reversed.
Units of Time: Time is measured in units such as seconds (s); the base unit of time in the SI system. Minutes (min): 1 minute = 60 seconds, Hours (h): 1 hour = 60 minutes = 3,600 seconds.
Days, weeks, months, and years: Larger units of time based on the Earth's rotation and orbit around the Sun.

Measurement of Time
Watches: Devices designed to measure and display time accurately. They range from mechanical clocks to electronic digital watches.
Atomic Clocks: Extremely precise timekeeping devices that use the vibrations of atoms (often cesium or rubidium) to measure time. These are used for scientific research and to maintain the accuracy of time standards.

Calendars: Systems for organizing days and larger units of time into a coherent structure. The Gregorian calendar is the most widely used today.

Applications of time
Time is essential for organizing daily activities, schedules, and routines. It helps in planning, coordinating, and managing tasks and events.
Accurate time measurement is crucial for experiments, observations, and the functioning of various technologies, including GPS, communication networks, and computer systems.
Time is a key variable in the laws of motion, thermodynamics, and quantum mechanics. It plays a crucial role in understanding the universe's structure and dynamics.
Time is a critical factor in financial markets, production schedules, project management, and service delivery.

Practical Examples:
Daily Activities: Waking up at 7:00 AM, attending a meeting at 2:00 PM, or catching a flight scheduled for 6:00 PM.
Scientific Experiments: Measuring the reaction time in a chemical experiment or the half-life of a radioactive substance.
Technological Systems: Synchronizing data across global networks using Coordinated Universal Time (UTC).

Scientific notation and significant figures
A number is in scientific form, when it is written as a number between 1 and 9 which is multiplied by a power of 10.
Scientific notation is used for writing down very large and very small measurements.
Example:
a) 598,000,000m = 5.98×10^{8}m
b) 0.00000087m = 8.7×10^{-7}m
c) 60220m = 6.022×10^{4}m

SIGNIFICANT FIGURES
Significant figures are the digits in a number that carry meaning contributing to its measurement accuracy. This includes all the non-zero digits, any zeros between them, and any trailing zeros in a decimal number.

Importance in Measurements
Significant figures reflect the precision of a measurement. When recording measurements, the number of significant figures indicates how accurate the measurement is.
The more significant figures in a number, the more precise the measurement is.

Rules for Determining Significant Figures
- ♠ Non-Zero Digits: Always significant. Example: 123.45 has five significant figures.
- ♠ Leading Zeros: Not significant; they only indicate the position of the decimal point. Example: 0.0032 has two significant figures.
- ♠ Captive (or trapped) Zeros: Zeros between non-zero digits are significant. Example: 1002 has four significant figures.
- ♠ Trailing Zeros: With a Decimal Point: Significant.

Example: 2.300 has four significant figures.

- ♠ Without a Decimal Point: Not significant unless explicitly indicated.
  Example: 2300 has two significant figures, but if written as 2300. (With a decimal), it has four significant figures.

Significant Figures in Calculations:

Addition and Subtraction:

The result should be reported with the same number of decimal places as the number with the fewest decimal places.

Example: 12.11 + 1.2 = 13.3 (one decimal place, matching the least precise term).

Multiplication and Division: The result should have the same number of significant figures as the number with the fewest significant figures in the calculation.

Example: 2.5 × 3.42 = 8.6 (two significant figures).

Rounding Rules:

When rounding a number to a certain number of significant figures: Look at the digit immediately after the last significant figure. If it's 5 or greater, round up the last significant figure.

If it's less than 5, keep the last significant figure as it is.

Exact Numbers:

Numbers that are counted (e.g., 3 apples) or defined quantities (1 inch = 2.54 cm) have an infinite number of significant figures and do not limit the precision of calculated results.

Use in Reporting Scientific Data: In scientific publications and data reports, using the correct number of significant figures ensures that the data is not over-interpreted and reflects the actual precision of the measurement instruments.

Common Mistakes: Overestimating the precision by reporting too many significant figures. Misinterpreting leading or trailing zeros.

Example:

If you measure a length as 0.00456 meters, the significant figures are 456, giving three significant figures. This indicates that the measurement instrument can measure to the nearest ten-thousandth of a meter. It helps in avoiding the illusion of precision where there is none, ensuring the accuracy and reliability of scientific results.

Activity

Write the following to the stated significant figures

a) 28.8 to 3 s.f b) to 2 s.f c) 4.027 x10^{-2} to 3 s.f

MASTERING PHYSICS

DENSITY

Density is a measure of how much mass is contained in a given volume. It is a key physical property of materials and substances and is defined as *the mass per unit volume*.

Formula for density: $\boldsymbol{density} = \frac{\boldsymbol{mass\ of\ substance}}{\boldsymbol{volume\ of\ the\ substance}} = \frac{\boldsymbol{m}}{\boldsymbol{v}}, \boldsymbol{\rho} = \frac{\boldsymbol{m(kg)}}{\boldsymbol{v(m^3)}}$

Units of Density

In the metric system, density is commonly expressed in kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3).

For example, water has a density of about 1 g/cm^3 or 1000 kg/m^3.

Characteristics of Density

The density of substances, especially gases, can change with **temperature** and **pressure**.

For example, heating a substance typically decreases its density because the volume increases while the mass remains constant.

Determining density allows for comparison of different materials. For example, lead is denser than aluminum, meaning a given volume of lead has more mass than the same volume of aluminum.

Practical Applications of density

- ♠ Cargo ships float because their hollow shapes lower their overall average density below that of water. Submarines use ballast tanks to adjust their water intake, changing their density to either sink or surface.
- ♠ Heating air inside a balloon makes it expand and become less dense than the cooler surrounding atmosphere, causing the balloon to rise.
- ♠ Crude oil has a lower density than seawater (0.85–0.90 g/cm^3 versus 1.025 g/cm^3 for water), allowing it to float on the surface so cleanup crews can contain and skim it.
- ♠ Engineers choose heavy, dense materials like steel (7.85 g/cm^3) for structural support frameworks and lighter materials where less load-bearing capacity is needed.
- ♠ Jewelers and manufacturers measure density via fluid displacement or digital meters to verify the purity of precious metals like gold (19.32 g/cm^3) or test petroleum quality.

Practical Examples

Water has a standard density of 1 g/cm^3 at 4°C. This property is often used as a reference point.

The density of air at sea level is approximately 1.225 kg/m^3. This value is important in fields like meteorology and aviation.

Gold has a high density of about 19.32 g/cm^3, which is why gold objects feel heavy for their size.

Different types of wood have varying densities. For example, balsa wood is less dense and therefore lighter than oak wood.

Calculating Density - Example

Imagine you have a metal block with a mass of 200 grams and a volume of 50 cubic centimeters.

Solution: This means the metal block has a density of 4 grams per cubic centimeter.

Understanding density is essential in many scientific, engineering, and everyday contexts, allowing for the assessment and comparison of different materials and their properties.

Other units for density: g/cm^3

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e.g density of iron metal is 0.8g/cm^3.This means that 8g of iron have a volume of 1cm^3.

Example:

Find the density of a substance of;

(i) Mass 9kg and volume 3m^3

(ii) Mass 100g and volume 10cm^3

Converting density from g/cm^3 to kg/m^3

The density of the substance in g/cm^3 is multiplied by 1000 in order to convert to kg/m^3.And to convert from kgm^{-3} to gcm$^{-3,}$ divide by 1000.

Example:

The density to water is 1.0g/cm^3. Find its density in kgm^{-3}.

Density = 1.0gm^{-3} = 1.0 x 1000kgm^{-3} = 1000kgm^{-3}.

1). A piece of steel has a volume of 12cm^3 and a mass 96g.Find its density.

(a) In g/cm^3

(b) Density 8g/cm^3

(b) 8g/cm^3 to kg/m^3

2) The oil level in a burette is 25cm^3. 50 drops of oil fall from a burette. If the volume of one drop is 0. 1cm^3.What is the final oil level in the burette.

Volume of one water drop = 0.1cm^3, Volume of 50 water drops = 0.1x 50cm^3 = 5cm^3

Final-level=25cm^3+5cm^3=30cm^3

As the volume of a material increases, its mass also increases.

Solids have the highest density → smallest distance between particles.

Liquids have medium density → medium distance between particles.

Gases have the lowest density → largest distance between particles.

What is density?

Someone might say that metal is heavier than air. But, it depends on how much of each material there is, a lot of air could be heavier than a tiny amount of metal.

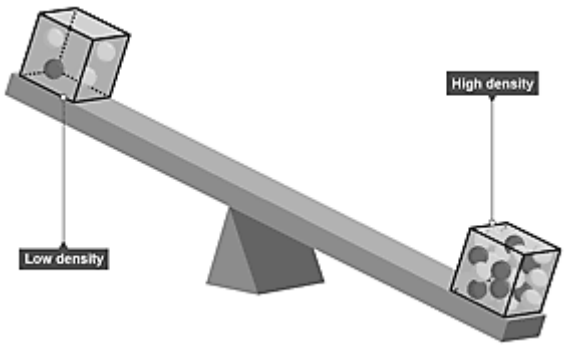
It is true however to say that metal is denser than air, and so for equal volumes of metal and air then the metal would be heavier.

Density is used to make a fair comparison between materials.

Density is a measure of how tightly the mass of an object is packed into the space it takes up.

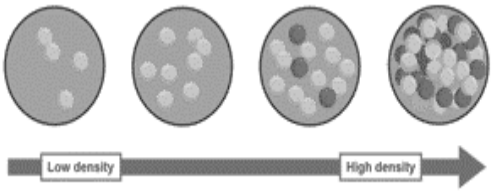
It can be calculated by dividing mass by volume.

It is a property of a material, and it is constant for a particular material, in other words; it does not matter how much of a material there is, it will always have the same density.



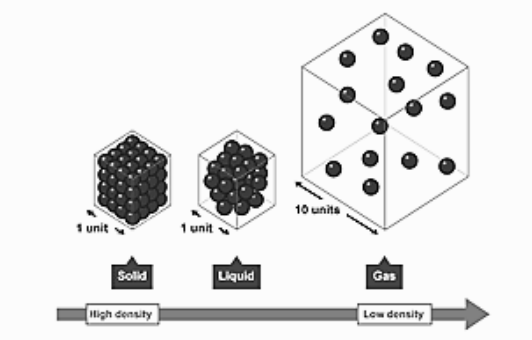
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Density is the mass per unit volume of a material – i.e density is the mass of 1 cm^3 or 1 m^3 of a material. The density of Aluminium is 2.7 g/cm^3 – this means that 1 cm^3 of aluminium has a mass of 2.7 g.



All matter contains particles.
The difference between the different states of matter is how these are arranged:

- ♠ In a solid, particles are packed close together in a regular structure - they vibrate about fixed positions.
- ♠ In a liquid, particles are packed close together but are not fixed in position – they are free to move past each other.
- ♠ In a gas, particles are very far apart and move randomly in all directions.



When solids are heated their density decreases. The spacing between the particles increases, but there is no change of mass. Therefore, a bigger volume has the same mass, which means the density is smaller.
Similarly, when liquids evaporate the density decreases as the spacing between particles increases greatly.

Material	Density / g/cm3
Aluminium	2.7
Iron	7.9
Ice	0.9
Water	1.0
Air	0.0013

If the mass is given in grams (g) and the volume is given in cm^3 then the density will have units of g/cm3. If the mass is given in kilograms (kg) and the volume is given in m^3 then the density will have units of kg/m^3.

Example
What is the density of a material if 450 cm^3 of it has a mass of 200 g?

$$density = \frac{mass}{volume} = \frac{200g}{450cm^3} = 0.440gcm^{-3}$$

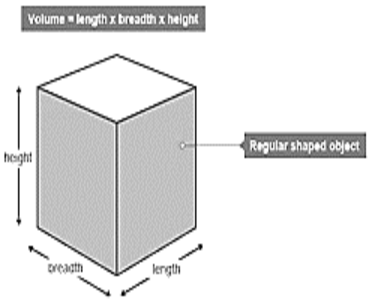
The density of the material is, $0.440gcm^{-3}$.

How to measure the density of regular-shaped objects

a) To calculate density, the mass and the volume of the material must be known.
b) If the object is a regular shape, the volume can be found by using a ruler to measure the length, breadth and height and using the equation:
$Volume = length\ x\ breadth\ x\ height$

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c) The mass can be found using a beam balance.
d) Then use the equation for $density = \frac{mass}{volume}$



How to measure the density of irregular-shaped objects

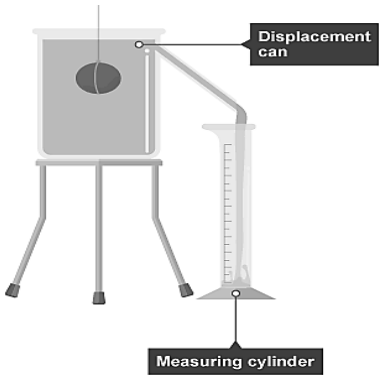
a) If the object has an irregular shape the mass can again be found using a beam balance, but the volume cannot be measured using a ruler.
b) The volume can be measured using a measuring cylinder or a displacement can.

$Volume\ of\ stone\ =\ Final\ volume\ -\ Initial\ volume$
$Volume\ of\ stone\ =\ 75\ cm^3 - 50\ cm^3 =\ 25\ cm^3$

c) The mass of the stone is measured using a beam balance and found to be 175 g.
d) Density of the stone is obtained from $density = \frac{mass}{volume}, \rho = 7gcm^{-3}$

The volume of larger irregular objects can be measured using a displacement can.

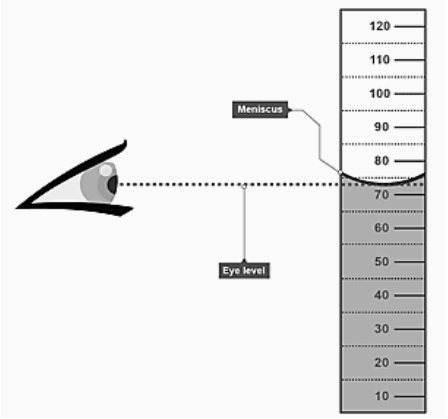
a) Place the stone on the beam balance and measure its mass.
b) Fill the displacement can until the water is level with the bottom of the pipe.
c) Place a measuring cylinder under the pipe ready to collect the displaced water.
d) Carefully drop the stone into the can and wait until no more water runs into the cylinder.
e) Measure the volume of the displaced water.
f) Use the measurements of mass and volume to calculate the density of the stone using the formula: $density = \frac{mass}{volume}$



How to measure the density of liquids

To find the density of a liquid the mass and the volume of the liquid must be known.

a) The volume of a liquid can be found using a measuring cylinder.
b) Place the measuring cylinder on a flat surface.
c) Pour the liquid to be measured carefully into the cylinder using a funnel if necessary.
d) The liquid's volume should be read at eye level, with the measuring line at the bottom of the meniscus.



It is not possible to pour the liquid directly onto a beam balance to find the mass.

a) Find the mass of an empty measuring cylinder and subtract this from the mass of the measuring cylinder with the liquid in it.
b) Place an empty, dry measuring cylinder on the beam balance.
c) Read and record mass in a suitable table in g.
d) Remove the cylinder from the beam balance.

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e) Pour 50 cm^3 of the liquid into it and place it on the balance again. Read and record mass in the suitable table.
f) To calculate the mass of the liquid, subtract the mass of the empty cylinder from the mass of the cylinder plus liquid. Record the mass in the table.
g) Then use the equation for density: $density = \frac{mass}{volume}$

Activity
An Olympic size swimming pool measures 50 m long, 25 m wide and has an average depth 2 m.
What is the mass of water in the pool if the density of water is 1000 kg/m^3?

How to determine density of liquids
i) The volume V of the liquid is measured using a measuring cylinder.
ii) The liquid is poured into the beaker of known mass, M_O.
iii) The mass M of the beaker containing the liquid is obtained using a beam balance.
iv) The density of the liquid will be
v) Density = $\frac{M-M_O}{V}$

Density of Air
i) A round bottomed flask is weighed when full of air and its weighed again after removing air with a vacuum pump.
ii) The difference gives the mass of air.
iii) The volume of air is obtained by putting water in the same flask and measures its volume using a measuring cylinder.
iv) The volume of water will be the volume of air
v) The density then calculated from; $density = \frac{mass\ of\ a\ substance}{volume\ of\ the\ same\ substance}$

Examples
A Perspex box has a 10cm square base containing water to a height of10 cm. a piece of rock of mass 600g is lowered into the water and the level rises to 12 cm.
What is the volume of water displaced by the rock, and the volume of the rock?
Volume of water displaced, V =L x w x h =10 x10 x (12-10) =200 cm^3
Volume of rock= volume of water displaced =200cm^3

Alternatively
Volume of water before adding the rock, V_1 = L x W x H = (10 x 10 x 10) cm = 1000cm^3
Volume of water after adding the rock V_2 = L x W x H = (10 x 10 x 12) cm^3 = 1200cm^3
Volume of water displaced V= $V_2 - V_1$= (1200 – 1000) cm^3 = 200cm^3
a) Calculate the density of the rock : Density = 3g/cm^3
1. A Perspex box having 6cm square base contains water to a height of 10cm. Find the volume of water in the box.
Volume of water in the box =L x w x h, V=6cm x 6cm x 10cm =360cm^3
2. A stone of mass 120g is lowered into the box and the level of water rises to 13cm.
(i) Find the new volume of water
=L x w x h =6cm x 6cm x 13cm =468cm^3
(i) Find the volume of the stone
Volume of the stone = Volume of displaced water = $V_2 - V_1$ =468 – 360cm^3 =108 cm^3

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(ii) Calculate the density of the stone. Density = 1.11 g/cm^3

3. A steel box of dimensions 100cm by 20cm by 40cm has a mass of 560g
Find its density (i) In g/cm^3 (ii) In kg/m^3

Volume = $lx\ w\ x\ h$ = (100 x 40 x 20) cm^3 = 80,000cm^3, Density = 0.007g/cm^3

(i) In kg/m$^{3:}$ Density = 0.007 x 1000 Density = 7kg/m^3

To investigate experimentally the relationship between the mass and volume of liquids and regular solids, and analyses and interpret the data gathered.

The main variables in a science experiment are the independent variable, the dependent variable and the control variables.

- ♠ The independent variable is what we change or control in the experiment.
- ♠ The dependent variable is what we are testing and are to be measured in the experiment.
- ♠ The control variables are what we keep the same during the experiment to make sure it is a fair test.

Variables in this experiment the:

- ♠ **Independent variable** is the volume of the object
- ♠ **Dependent variable** is the mass of the object
- ♠ **Controlled variables** are the material of the object and the temperature of the object.

Remember - these variables are controlled (or kept the same) because to make it a fair test, only 1 variable can be changed, which in this case is the volume of the object.

Equation, $density = \frac{mass\ (m)}{volume\ (v)}$

Understand: As the volume of the material increases, the mass will also increase.

Justification for the prediction:
The greater the volume of the object the greater the number of atoms present.
This will result in the object having greater mass.

Regular objects
Apparatus: Six regular objects of the same material but different volumes, a half-metre rule, a top pan balance.

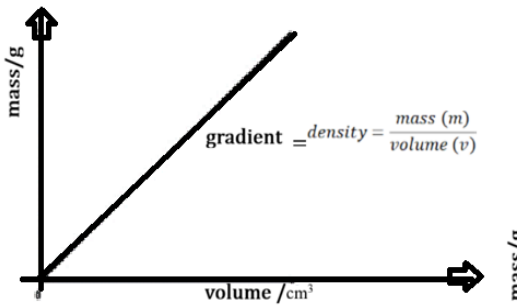
a) Select the smallest object. Measure the length (l), breadth (b) and height (h) using a half-metre rule.
b) Record the results in cm in a suitable table.
c) Repeat each of these measurements of length, breadth and height and calculate the average.
d) Using the average values of length, breadth and height, calculate the volume of the object using: Volume = length x breadth x height. Record the volume in cm3 in the table.
e) Place the object on the top pan balance. Record the mass in g in the table.
f) Repeat the procedure for the other five objects.
g) Plot a graph of mass (y-axis) against volume (x-axis).
h) Draw a line of best fit through the points.
i) determine the gradient of the graph density
j) Calculate the gradient of the graph and hence the density of the object.

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Conclusion

	Object 1	Object 2	Object 3	Object 4	Object 5	Object 6
M(g)						
l_1 (cm)						
l_2 (cm)						
b_1 (cm)						
b_2 (cm)						
Average b (cm)						
h_1(cm)						
h_2 (cm)						
Average height (cm)						
Volume (cm^3)						

1. The graph that as the volume of the object increases its mass also increases.
2. This agrees with our prediction. Since the line of best fit, is a straight line through the origin.
3. The volume of the object is directly proportional to its mass.
4. As the volume increases the mass of the object increases in direct proportion.
5. The gradient of the graph equals the density of the material.



Cause of error

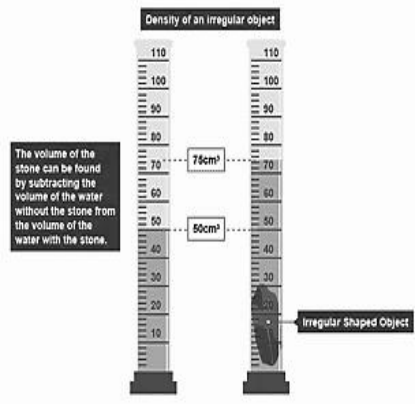
The main cause of error in this experiment is the measurement of length, breadth and height. This can be kept to a minimum by repeating each measurement and calculating the average.

Density of Liquids

Apparatus: A measuring cylinder, a beam balance, tap water.

Method: This experiment is very similar to the one for regular solids but there is a different way of measuring the mass and volume of the water.

a) Place an empty, dry measuring cylinder on the top pan balance.
b) Read and record the mass (g) in a suitable table.
c) Remove the cylinder from the top pan balance.
d) Pour $50cm^3$ of water into it and place it on the balance again.
e) Read the mass and record in the table.
f) To calculate the mass of the water, subtract the mass of the empty cylinder from the mass of the cylinder plus water. Record the mass in the table.
g) Read and record the volume of water from the measuring cylinder.
h) Repeat the procedure adding $50cm^3$ each time up to $300cm^3$ for 6 results.



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Safety

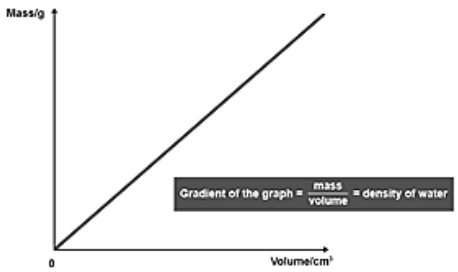
1) Water should not be poured into the measuring cylinder when it is on the top pan balance.
2) Water spilled on the electric balance could cause electric shock.
3) Always remove the measuring cylinder from the balance before adding water.

Results

Mass of empty measuring cylinder (g)	Mass of measuring cylinder + water (g)	Mass of water (g)	Volume of water (cm^3)

Graph

1. Plot a graph of mass (y-axis) against volume (x-axis).
2. Draw a line of best fit through the points.
3. The gradient of the graph = = density of water.
4. Calculate the gradient of the graph and hence the density of water.



Conclusion

- ♠ The line of best fit is a straight line through the origin.
- ♠ The volume of water is directly proportional to its mass.
- ♠ As the volume of water increases its mass increases in direct proportion.
- ♠ The gradient of the graph equals the density of water.

Errors

- ♠ The main cause of error in this experiment is reading the volume of water.
- ♠ Care should be taken to read the volume at eye level, with the measuring line at the bottom of the meniscus, with the measuring cylinder placed on a flat bench.
- ♠ The density of water changes with temperature so care must also be taken to keep the water at a constant temperature throughout the experiment.

Sinking and floating

An object or a liquid will float if it is less dense than the liquid beneath it.
Ice floats on top of water because the density of ice (0.9 g/cm^3) is less than the density of water (1.0 g/cm^3)
A ship floats on water because the average density of the ship (the metal from which it is made, cargo, people and air contained within it) is less than 1.0 g/cm^3.
Hot water floats on top of cold water because hot water is less dense than cold water.
Hot air rises because it is less dense than the surrounding cold air.

DENSITY OF MIXTURES

A mixture is obtained by putting together two or more substances such that they do not react with one another. The density of the mixture lies between the densities of its constituent substances and depends on their proportions.
It is assumed that the volume of the mixture is equal to the sum of the volumes of the individual constituents. $\boldsymbol{Density\ of\ mixture = \frac{mass\ of\ the\ mixture}{volume\ of\ the\ mixture}}$

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Suppose two substances are mixed as follows:

Substance	Mass	Volume	Density
X	M_1	V_1	$d = \frac{m_1}{v_1}$
Y	M_2	V_2	$d = \frac{m_2}{v_2}$

Then Density of the mixture: $\boldsymbol{density = \frac{m_1+m_2}{v_1+v_2}}$

Example: Two liquids x and y mixed to form a solution. If the density of x = 0.8gcm^{-3} and volume = 100cm^3, y = 1.5cm^{-3} and volume = 300m^3.Find;

(i) The mass of liquid x: =Density x Volume =0.8x100gcm^3 = 80g

(ii) The mass of liquid y: =Density x Volume =1.5 x 300 =450g

Density of a mixture, $\boldsymbol{density = \frac{450+80}{300+100} = 1.325 gcm^{-3}}$

Activity

1) A learner collects 100 cm³ of fresh water from Lake Victoria and mixes it with 100 cm³ of seawater during a school science activity. The density of fresh water is 1000 kg m⁻³, while the density of seawater is 1030 kg m⁻³. Task: Calculate the density of the mixture.

2) A metal workshop in Katwe makes bronze by mixing molten copper and tin. A technician prepares 100 kg of bronze containing 80% copper and 20% tin by mass. The density of copper is 8900 kg m⁻³, while the density of tin is 7000 kg m⁻³. Task: Calculate the density of bronze.

3) During a physics practical lesson, learners use a density bottle to find the density of an unknown liquid X. The empty density bottle has a mass of 17.5 g. When full of water, its mass is 37.5 g. When full of liquid X, its mass is 35.0 g. The density of water is 1000 kg m⁻³. Task: Find the density of liquid X.

Relative Density

Relative density, also known as ***specific gravity***, is *a dimensionless quantity that compares the density of a substance to the density of a reference substance*, typically water for liquids and solids, and air for gases. It indicates whether a substance is more or less dense than the reference substance without requiring units. The relative density (RD) is calculated using the formula:

$$RD = \frac{density\ of\ reference\ substance}{density\ of\ the\ substance}$$

For liquids and solids, the reference substance is usually water, which has a density of approximately 1 g/cm³ (or 1000 kg/m³) at 4°C.

Characteristics of relative density

Since relative density is a ratio of two densities, it has no units.

It allows for easy comparison of the density of a substance to the reference substance.

If R.D > 1, the substance is denser than the reference substance.

If R.D < 1, the substance is less dense than the reference substance.

When measuring relative density, it is important to specify the temperatures and pressures of both the substance and the reference substance, as density can change with these conditions.

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Applications of Relative Density:

- Helps in identifying materials and verifying their purity. For example, the relative density of pure gold is about 19.3.
- Used in industries like mining, oil, and chemicals to assess material properties.
- Determines whether an object will float or sink in a fluid. An object with an RD less than 1 will float in water.
- Used in quality control processes to ensure consistency and standards in manufacturing.
- The relative density of water is 1, as it is the reference substance. Ethanol has a relative density of about 0.79, meaning it is less dense than water and will float on it.
- Mercury has a relative density of about 13.6, making it much denser than water. This high density allows mercury to be used in barometers and other instruments.

Calculating Relative Density

Suppose you have a liquid with a density of 850 kg/m³. To find its relative density, compare it with to water: *This means the liquid has a relative density of 0.85 and is less dense than water*.

Importance of R.D in Different Fields:

a) Used to determine the concentration of solutions and the purity of substances.
b) Helps in studying the stratification of lakes and oceans where water density varies with temperature and salinity.
c) Essential in designing systems involving fluid flow, such as pipelines and hydraulics.

Ocean Currents and Water Density

Ocean currents are continuous large-scale, directed movements of seawater within the oceans, driven by various forces such as wind, Earth's rotation (Coriolis Effect), and temperature gradients, salinity differences, and tides resulting into differences in water density.

Water density is how tightly packed the molecules are in a given space.

Seawater density depends on two main factors:

- **Temperature:** Cold water is dense and heavy because its molecules move slowly and pack tightly together. Warm water is less dense and lighter because its molecules spread out.
- **Salinity:** Saltiness or the amount of dissolved salt in water. Dissolved salt adds mass without expanding the volume much, making salty water denser than fresh water.

How Density Drives Ocean Currents

Differences in temperature and salinity create global deep-water movements known as thermohaline circulation (or the global conveyor belt).

- Near the Polar Regions, ocean water gets very cold. When sea ice forms, it leaves salt behind in the surrounding water, sharply increasing its salinity.
- This cold, super-salty water becomes very dense and sinks to the ocean floor, initiating deep ocean currents that travel across the globe.
- As this heavy water sinks, it pushes deeper currents along the bottom of the ocean toward the equator, drawing in warmer surface water to replace it.

Surface Currents against Deep Currents

- **Surface Currents** occupy the top 10% of the ocean (down to about 400 meters) and are driven primarily by global winds and the Coriolis Effect. Upwelling occurs when deeper, colder and nutrient-rich water rises to the surface, often driven by wind patterns and changes in water density.

- **Deep Currents** make up the other 90% of the ocean and are driven strictly by the density differences of temperature and salinity. Down welling occurs when surface water sinks due to increased density, often due to cooling or increased salinity.

Impact of Ocean Currents on the Warming of the North Atlantic Due to Climate

Ocean currents like the Atlantic Meridional Overturning Circulation (AMOC) drive North Atlantic warming by transporting heat from the tropics northward, but global climate change is currently disrupting this vital system.

How Currents Warm the North Atlantic

- Warm surface currents (such as the Gulf Stream and North Atlantic Drift) carry heat and salty water from tropical regions straight toward Europe and the high northern latitudes.
- As this water reaches the North Atlantic, it releases large amounts of warmth into the atmosphere, which helps stabilize regional weather and maintain a mild climate in places like Northwest Europe.
- Cooled, dense water normally sinks in the far north and flows back south at deep levels, pulling more warm surface water behind it like a massive conveyor belt.

Climate Change Disruptions

- Rising global temperatures melt Greenland's ice and Arctic sea ice, dumping massive amounts of fresh water into the North Atlantic.
- This influx of fresh water lowers seawater density, preventing warm surface water from sinking properly and effectively stalling the deep-mixing engine that drives the current.
- As the AMOC slows down, it accumulates a strange "cold blob" of subpolar water due to reduced heat delivery, threatening abrupt regional shifts, altered rainfall belts, and severe weather anomalies.

S1.3 STATES OF MATTER

Learning Outcomes

a) *Understand the meaning of matter(u)*
b) *Understand that atoms are the building blocks from which all matter is made; appreciate that the states of matter have different properties (k,u)*
c) *Apply the particle theory to explain diffusion and Brownian motion and their applications(s)*
d) *Understand how the particle theory of matter explains the properties of solids, liquids and gases, changes of state, and diffusion(u)*
e) *Understand the meaning and importance of plasma in physics (u, v/a)*

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MATTER

Matter is any substance that has mass and takes up space, like atoms and molecules.
Matter exists in different phases like solid, liquid, gas, or plasma and can change between them.
Things like light and sound are not matter because they do not have mass and do not take up space.
Mass is a measure of the amount of matter in an object. It is an intrinsic property of matter that does not change regardless of the object's location in the universe. Mass gives matter inertia, the resistance to changes in motion, and is directly related to the gravitational force an object experience. The physical objects and materials around us like glass, water and the air manifest the existence of matter in its three states.

Phases of Matter

Matter can exist in various phases: solid, liquid, gas, or plasma. Most substances can transition between these phases based on the amount of heat the material absorbs (or loses). There are additional states or phases of matter, including Bose-Einstein condensates, fermionic condensates, and quark-gluon plasma.

The Particle Theory of Matter

The postulates of the particle theory of matter are given as:

- ♠ All matter is made up of tiny particles known as atoms.
- ♠ Particles of matter are constantly in motion.
- ♠ Particles of matter attract each other.
- ♠ Particles of matter have spaces between them.
- ♠ As temperature increases, particles of matter move faster.
- ♠ Atoms of the same element are essentially identical and atoms of different elements are different.

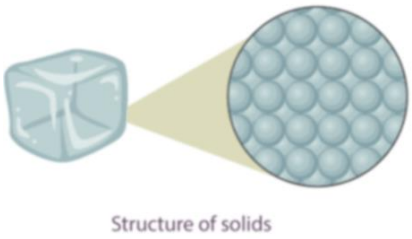
Different states of matter

The matter is made up of very tiny particles and these particles are so small that we cannot see them with naked eyes.
Matter exists in nature in different forms. Some substances are rigid and have a fixed shape like wood and stone; some substances can flow and take the shape of their container like water, while there are forms of matter that do not have definite shape or size such as air.
Matter can be classified into different categories based on the physical properties exhibited by them and the states in which they exist; these are called states of matter.

Following are the basic three states of matter: **Solid, Liquid,** and **Gas**
Apart from the three, there are two more states of matter, which we do not see in our everyday life. They are **Plasma** & **Bose-Einstein condensate**.
Changes in the characteristics of matter related with external influences such as pressure and temperature separate states of matter. A discontinuity in one of those qualities frequently distinguishes states: rising the temperature of ice, for example, generates a discontinuity at 0 °C (32 °F) as energy flows into a phase transition rather than temperature rise.

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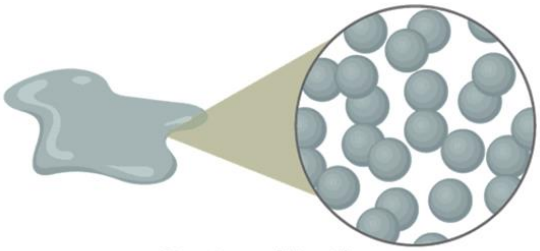
In solids,


Structure of solids

- Particles are tightly or closely packed.
- The gaps between the particles are tiny and hence it is tough to compress them.
- Solid has a fixed shape and volume.
- Due to its rigid nature, particles in solid can only vibrate about their mean position and cannot move.
- Force of attraction between particles is adamant.
- The rate of diffusion in solids is very low.

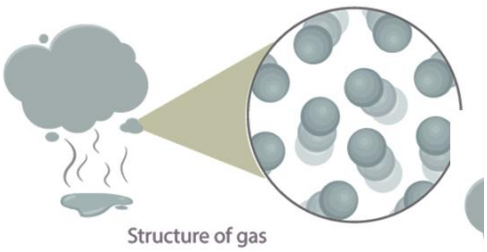
An example of solids: solid ice, sugar, rock, wood, etc.

In a liquid state of matter,


Structure of Liquids

- Particles are less tightly packed as compared to solids.
- Liquids take the shape of the container in which they are kept.
- Liquids are difficult to compress as particles have less space between them to move.
- Liquids have fixed volume but no fixed shape.
- The rate of diffusion in liquids is higher than that of solids.
- Force of attraction between the particles is weaker than solids.
- Example of a liquid state of matter: water, milk, blood, coffee, etc.

In gases,


Structure of gas

- Particles are far apart from each other.
- Force of attraction between the particles is negligible, and they can move freely.
- Gases have neither a fixed volume nor a fixed shape.
- The gaseous state has the highest compressibility as compared to solids and liquids.
- The rate is diffusion is higher than solids and liquids.
- The kinetic energy of particles is higher than in solids and liquids.

An example of gases: air, helium, nitrogen, oxygen, carbon dioxide, etc

Plasma

- Plasma is an ionized gas; it not generally seen form of matter.
- Plasma consists of particles with extremely high kinetic energy, and often at high temperatures..
- Electricity is used to ionize noble gases and make glowing signs, which is essentially plasma.
- Superheated forms of plasma are what stars are.
- Its formed when gases are heated to extremely high temperatures or subjected to strong electromagnetic fields, causing ionization of particles. Examples: Lightning, auroras, stars (like the sun), and fluorescent lights, neon signs, and plasma TVs are examples of natural and artificial plasmas.

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- ♠ Plasma finds applications in technologies like plasma cutting and welding, fluorescent lighting, plasma TVs, semiconductor manufacturing, and experimental fusion reactors.
- ♠ Plasma is a state of matter similar to gas but with ionized particles, meaning the electrons are separated from atoms. This creates a mixture of positively charged ions and free electrons.
- ♠ Plasma is electrically conductive and responds to magnetic fields.

Bose-Einstein Condensates (BEC)

- ♠ Discovered in 1995, Bose-Einstein condensates were made with the help of the advancements in technology.
- ♠ Carl Weiman and Eric Cornell cooled a sample of rubidium with the help of magnets and lasers to within a few degrees of absolute zero.
- ♠ At the said temperature, the motion of the molecules becomes negligible. As this brings down the kinetic energy, the atoms no longer stay separate, but they begin to clump together.
- ♠ As the atoms join, they form a super-atom.
- ♠ Light slows down as it passes through a BEC helping scientists to study more about the nature of light as a wave and particle.
- ♠ BEC's also show properties of a superfluid, which implies, that it flows without friction.

Kinetic theory

The Kinetic Theory of Matter states that:

- ✓ All matter consists of tiny particles (atoms or molecules) that are in constant motion.
- ✓ These particles move randomly due to their kinetic energy, and the motion increases with temperature.
- ✓ Particles collide with each other and with the walls of their container, but these collisions do not result in a loss of total kinetic energy.
- ✓ The volume of individual particles is very small compared to the space between them, especially in gases.
- ✓ In an ideal gas, particles are assumed to have no attractive or repulsive forces between them, except during collisions.
- ✓ The average kinetic energy of the particles is directly proportional to the absolute temperature (in Kelvin) of the substance.

This theory explains the behavior of matter, particularly gases, in terms of particle motion and energy.

Assumptions of the Kinetic Theory

- ♠ Particles are in constant, random motion.
- ♠ Particles possess kinetic energy due to their motion.
- ♠ Collisions between particles are elastic, meaning energy is conserved during collisions.
- ♠ The average kinetic energy of particles is directly proportional to temperature (Kelvin scale).

Particle theory to explain states of matter

- ♠ In gases, particles are widely spaced and move freely.
- ♠ They have high kinetic energy and are constantly moving in random directions.
- ♠ Gas particles collide with each other and the walls of the container, creating pressure.
- ♠ In liquids, particles are closer together compared to gases. They have moderate kinetic energy and move past each other, allowing liquids to flow.

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- ♠ Liquid particles also exhibit random motion but with less freedom compared to gases.
- ♠ In solids, particles are tightly packed and vibrate in fixed positions. They have low kinetic energy and limited movement. However, solid particles still vibrate and can transmit vibrations (heat) through the substance.

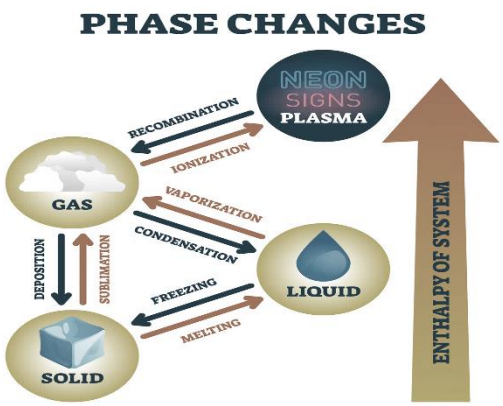
Changes of State of Matter (Phase Changes)

Water and Ice

When water and ice undergo changes in their state of matter due to heating and cooling, they demonstrate the fundamental principles of phase transitions. These processes include melting, boiling, condensing, and freezing.

Melting: Ice to Water

Melting occurs when solid ice is heated, causing it to change into liquid water.



Molecular Explanation:

Ice is a solid where water molecules are arranged in a fixed, crystalline structure, held together by strong hydrogen bonds. As heat is added to ice, the energy causes the water molecules to vibrate more vigorously. When the temperature reaches 0°C (32°F), the vibrations are strong enough to break some of the hydrogen bonds, allowing the molecules to move more freely. This marks the transition from solid to liquid.

Heat Absorption*:*

During melting, ice absorbs heat from the surroundings. This energy is used to break the intermolecular bonds between water molecules, rather than increasing the temperature.

This absorbed energy is known as the latent heat of fusion. The temperature of the substance remains constant at 0°C until all the ice has melted, after which the temperature of the liquid water begins to rise.

Boiling: Water to Steam

Boiling occurs when liquid water is heated to its boiling point, turning it into steam (water vapor).

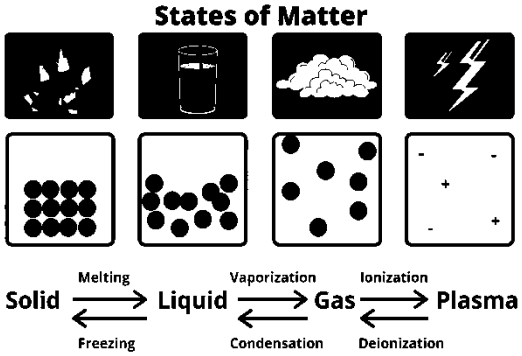
Molecular Explanation: In liquid water, molecules are close together but can move around each other freely. As heat is added, the molecules move faster, increasing the kinetic energy of the water. When the temperature reaches 100°C (212°F) at standard atmospheric pressure, the energy is sufficient to overcome the intermolecular forces completely, allowing the molecules to escape into the air as steam.

Heat Absorption:

During boiling, water absorbs a significant amount of heat, which is used to break the bonds that hold the molecules in the liquid state. This energy is known as the latent heat of vaporization. Like melting, the temperature remains constant at 100°C during the phase change until all the water has boiled off.

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Condensation: Steam to Water



Condensation is the reverse of boiling, where steam (water vapor) cools down and changes back into liquid water.

Molecular Explanation: As steam cools, the kinetic energy of the water molecules decreases. At a certain point, the molecules slow down enough that the intermolecular forces can pull them back together, forming liquid water. This occurs at the condensation point, which is the same temperature as the boiling point (100°C under standard conditions).

During condensation, steam releases the latent heat of vaporization to the surroundings. This released energy is the same amount that was absorbed during boiling. The temperature remains constant during condensation until all the steam has converted back into liquid water.

Freezing: Water to Ice

Freezing occurs when liquid water is cooled and changes into solid ice.

Molecular Explanation*:*

As liquid water-cools, the molecules lose kinetic energy and move more slowly.

At 0°C, the water molecules begin to arrange themselves into a crystalline structure, forming ice. The hydrogen bonds that were partially broken during melting are reformed, holding the molecules in a fixed position.

During freezing, water releases the latent heat of fusion, the same energy that was absorbed during melting. This energy is released into the surroundings as the water molecules settle into the solid structure. The temperature remains constant at 0°C during the phase change until all the water has frozen.

Why heat is taken in and given out during phase changes

Melting and Boiling (Heat Absorption)

Boiling: This is the process by which a liquid when heated changes to the gaseous state at a fixed temperature e.g. Pure water at 100^0c changes to vapour by the process of boiling. There is no change in temperature at boiling point because the heat supplied is used to weaken cohesive forces of attraction of molecules and the rest is converted to kinetic form of energy.

When a substance melts or boils, energy is required to break the intermolecular bonds that hold the particles in a solid or liquid state. This energy does not increase the temperature but is instead used to change the state of the substance. This is why heat is absorbed during melting and boiling.

Condensing and Freezing (Heat Release)

When a substance condenses or freezes, the intermolecular bonds are reformed. The energy that was absorbed during melting or boiling is now released back into the surroundings. This release of energy explains why heat is given out during condensation and freezing.

Importance of Changes of State in Everyday Life

Changes of state such as melting, freezing, condensation, and evaporation are essential in many everyday processes. They play crucial roles in maintaining life, influencing weather patterns, and supporting various practical activities.

Control of Body Temperature in Mammals

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Sweating and Evaporation: Mammals, including humans, rely on the evaporation of sweat to regulate body temperature. When the body overheats, sweat glands produce sweat, which is mostly water. As the sweat evaporates from the skin's surface, it absorbs heat from the body, cooling it down.

Breathing and Heat Exchange: Mammals also lose heat through the process of respiration. When air is exhaled, it often carries moisture from the lungs. The evaporation of this moisture helps cool the body. The balance between heat production (through metabolism) and heat loss (through evaporation and radiation) is vital for homeostasis.

Rain and the Water Cycle

- **Evaporation:** The water cycle is driven by changes in the state of water. The sun's heat causes water from oceans, lakes, and rivers to evaporate, turning it into water vapor (gas) that rises into the atmosphere.
- **Condensation:** As the water vapor rises and cools, it condenses into tiny droplets, forming clouds. This change of state from gas to liquid is crucial in cloud formation.
- **Precipitation**: When the droplets in clouds combine and grow large enough, they fall to the Earth as precipitation (rain, snow, sleet, or hail). This process returns water to the surface, replenishing water bodies and supporting life on land.

Freezing and Melting in the Water Cycle

In colder regions, precipitation can fall as snow or ice. This frozen water eventually melts during warmer periods, feeding rivers and lakes, contributing to the continuous cycle of water.

Cooling Drinks with Ice

Melting Ice*:* Adding ice to a drink cools it down through the process of melting. As the ice absorbs heat from the drink, it changes from a solid to a liquid, lowering the temperature of the drink. The melting process requires energy, known as the latent heat of fusion, which is absorbed from the drink, thus cooling it effectively.

Practical importance:

This is a practical application of phase change that people use daily, especially in warm weather, to keep beverages at a refreshing temperature.

Making Ice Cream

Freezing: The process of making ice cream involves freezing a mixture of cream, sugar, and flavorings. As the liquid mixture cools, it undergoes a phase change from liquid to solid. To achieve the right texture, ice cream is churned during freezing to prevent the formation of large ice crystals. This results in a smooth, creamy consistency.

Use of Salt in Ice Cream Making: Often, salt is added to ice surrounding the ice cream mixture to lower the freezing point of water. This allows the ice cream mixture to freeze at a lower temperature, speeding up the process and improving texture.

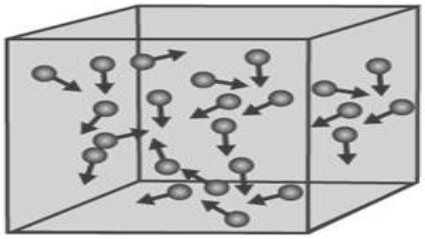
Brownian motion

Brownian motion is the random movement of particles suspended in a fluid (liquid or gas) as they collide with the fast-moving molecules of the fluid.

"Brownian motion refers to the random movement displayed by small particles that are suspended in fluids. It is commonly referred to as Brownian movement".

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This motion is a result of the collisions of the particles with other fast-moving particles in the fluid. It is a direct observation of the kinetic theory of matter.


Brownian Movement

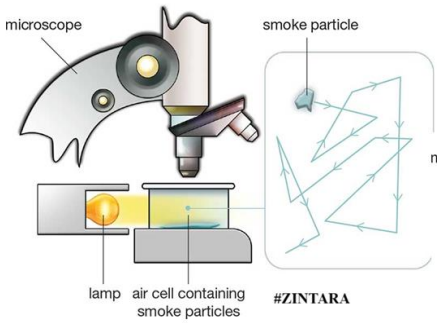
Brownian motion is named after the **Scottish Botanist Robert Brown**, who first observed **that pollen grains move in random directions when placed in water**. The random motion is caused by the uneven and continuous bombardment of the suspended particles by the molecules of the surrounding fluid, which are in constant motion. Brownian motion provided evidence for the existence of atoms and molecules and supported the kinetic theory of matter, which posits that matter is made up of small particles in constant motion.

Brownian motion experiment

When smoke particles are suspended in air and observed through a microscope. They seem to be in a state of continuous random motion. The smoke particles are seen as bright specks moving in continuous random motion. The bright specks are due to collision between smoke particles and gas molecules. The random motion is due to smoke particles colliding with air molecules, which were moving randomly.

When the temperature of the glass cell is increased the random motion increases (smoke particles are seen to move faster), showing that increase in temperature increase the kinetic energy of molecules.

Brownian motion is fundamental to understanding processes such as diffusion, where particles spread from areas of higher concentration to lower concentration, and is used in various scientific fields to study particle dynamics and fluid behavior.



Causes of Brownian motion

- The size of the particles is inversely proportional to the speed of the motion; i.e. small particles exhibit faster movements. This is because the transfer of momentum is inversely proportional to the mass of the particles. Lighter particles obtain greater speeds from collisions.
- The speed of the Brownian motion is inversely proportional to the viscosity of the fluid. The lower the viscosity of the fluid, the faster the Brownian movement.
- Viscosity is a quantity that expresses the magnitude of the internal friction in a liquid. It is the measure of the fluid's resistance to flow.

Effect of heat on Brownian motion

When the temperature of the smoke cell is increased, the smoke particles are seen moving faster.

Due to the increase in temperature, the molecules acquire kinetic energy. The kinetic energy is directly proportional to the velocity of the particles, hence increased velocity.

Diffusion

Diffusion is the process by which particles (such as molecules or ions) spread out from an area of high concentration to an area of low concentration. This movement occurs until the particles are evenly distributed, reaching a state of equilibrium.

Diffusion occurs down a concentration gradient, which means particles move from a region where they are more concentrated to a region where they are less concentrated.

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The steeper the concentration gradient, (the greater the difference in concentration between the two areas), the faster the rate of diffusion. Particles in liquids and gases are in constant, random motion due to their kinetic energy. This random movement is what drives diffusion, as particles naturally spread out to occupy all available space.

Diffusion continues until there is no net movement of particles, meaning the concentration of particles is the same throughout the space. At this point, dynamic equilibrium is achieved, where particles continue to move, but there is no overall change in concentration.

Diffusion in Gases

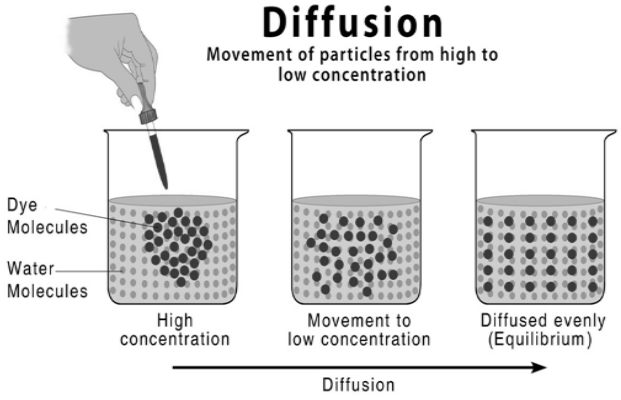
When you open a bottle of perfume, the scent molecules diffuse through the air. Initially, the concentration of perfume molecules is high near the bottle, but they gradually spread out and can be smelled throughout the room.

Diffusion in Liquids

If you drop a dye into a glass of water, the dye molecules will diffuse throughout the water until the color is evenly distributed. The dye moves from an area of high concentration (where it was dropped) to areas of lower concentration.

Biological Diffusion:

In living organisms, diffusion is crucial for processes such as gas exchange in the lungs, where oxygen diffuses from the alveoli (where its concentration is high) into the blood (where its concentration is low), while carbon dioxide diffuses in the opposite direction.



Importance of Diffusion

Diffusion is the spontaneous, passive movement of particles from an area of high concentration to an area of low concentration driven by thermal energy.

Why Diffusion Matters in Physics and Science

- Diffusion proves that atoms and molecules are in constant, random thermal motion.
- It drives systems naturally toward thermodynamic equilibrium and maximum entropy without requiring external energy.
- Based on **Fick's Laws of Diffusion**, it provides the physical framework for how matter and heat spread through gases, liquids, and solids.

Applications of diffusion

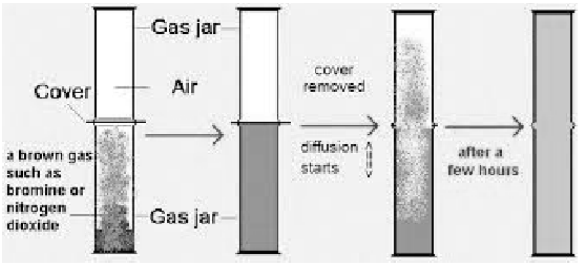
- Oxygen and carbon dioxide move across lung and cell membranes via simple diffusion to support respiration.
- Used in semiconductor manufacturing (doping silicon), metallurgy (alloy formation), and chemical purification.
- Controls atmospheric gas mixing, pollutant dispersion in water, and nutrient exchange in ecosystems.

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Demonstration of Diffusion in Gases

Two Gas jars, one full of nitrogen dioxide / bromine and the other gas full of air are joined together.

When the gas cover is removed, and the gases mix up, the whole become filled with the brown gas (Nitrogen dioxide). The lighter gas diffuses faster than the heavier gas.



Demonstration of diffusion in liquids

Activity: To visually demonstrate the process of diffusion in liquid using potassium dichromate crystals in water.

Materials Needed: *1 large transparent glass beaker or jar (500 mL or more), Distilled water, Spatula, Crystals of potassium dichromate, Dropper (optional), Stopwatch or timer, Ruler (for visual reference), Lab gloves and goggles (for safety), and White paper (placed under the beaker for contrast)*

Safety Precautions:

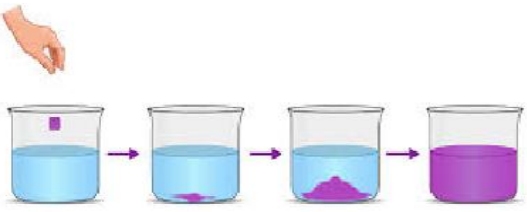
Potassium dichromate is toxic and a known carcinogen. Use gloves, goggles, and handle with care.
Avoid ingestion, inhalation, or contact with skin.
Dispose of the solution as hazardous chemical waste following school or institutional guidelines.

Procedure:

a) Place a clean, dry beaker on a stable table, and fill the beaker with approximately 300 mL of distilled water.
b) Let the water stand still for about 2 minutes to settle any disturbances.
c) Using a spatula, carefully place a small crystal (about 1–2 mm in size) of potassium dichromate gently at the bottom center of the beaker. Avoid disturbing the water.
d) Start the timer as soon as the crystal touches the bottom.
e) Observe the crystal over a period of 30 minutes to 1 hour.
f) Record observations at 5-minute intervals.
g) Watch how the bright orange color slowly spreads out from the crystal without stirring or external force.
h) Compare how far the color has diffused over time (use the ruler or graph paper behind the beaker for scale).
i) Repeat the experiment using cold and warm water to observe the effect of temperature on the rate of diffusion.
j) Try the same with a few drops of potassium dichromate solution instead of a solid crystal to compare diffusion patterns.

Observation and conclusion

The bright orange color will begin to slowly spread out from the crystal. Over time, the color will diffuse throughout the water, forming concentric circles or zones of decreasing intensity. Eventually, the entire solution may become uniformly orange, depending on the crystal size and time elapsed.



Explanation:

The experiment demonstrates diffusion in liquids. Initially, the potassium dichromate concentration is highest at the crystal's location. Molecules begin to move into the water spontaneously, spreading from

the region of higher concentration (near the crystal) to lower concentration (the surrounding water). This movement continues until equilibrium is reached, and the solution becomes uniformly colored.
No external mixing is needed because diffusion is a passive transport process driven by thermal motion of molecules. This experiment successfully demonstrates the process of diffusion in water using potassium dichromate. It provides a visual understanding of how substances move from areas of higher to lower concentration without stirring, emphasizing the natural and spontaneous nature of diffusion.

Factors Affecting the Rate of Diffusion

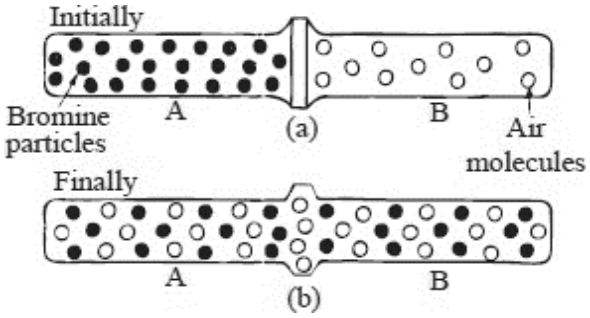
Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration, down a concentration gradient.
Several physical and chemical factors influence how quickly this process occurs.

- **Concentration Gradient**
  The concentration gradient is the difference in concentration between two areas.
  Effect: The greater the difference in concentration, the faster the rate of diffusion.
  Reason: A steeper gradient means more particles are moving from the high-concentration side to the low-concentration side per unit of time.
- **Temperature**
  Temperature is a measure of the average kinetic energy of particles.
  Effect: As temperature increases, the rate of diffusion increases.
  Reason: Higher temperatures provide particles with more kinetic energy, causing them to move faster and collide more frequently, which speeds up their spread.
- **Surface Area**
  This refers to the total area of the boundary (like a cell membrane) through which diffusion occurs.
  Effect: A larger surface area increases the rate of diffusion.
  Reason: More space is available for particles to pass through at any given moment. Cells often use microvilli or folding to maximize this area.
- **Diffusion Distance (Thickness)**
  The distance particles must travel to reach the other side.
  Effect: The shorter the distance, the faster the rate of diffusion.
  Reason: Particles reach their destination more quickly if the barrier is thin (e.g., the one-cell-thick walls of alveoli in the lungs).
- **Size of the Particles**
  Different substances have different molecular masses.
  Effect: Smaller, lighter particles diffuse faster than larger, heavier particles.
  Reason: Smaller particles require less energy to move and can navigate through gaps in membranes more easily than bulky molecules.
- **Medium of Diffusion**
  The state of matter through which the particles are moving.
  Effect: Diffusion is fastest in gases, slower in liquids, and extremely slow (or non-existent) in solids.
  Reason: In gases, particles are far apart and move freely with fewer obstructions compared to the closely packed particles in liquids.

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Comparison of Diffusion in Liquids and Gases

A gas jar containing brown bromine gas and covered with a sheet of cardboard is placed in contact with an open end of a gas jar of the same diameter with the mouth smeared with grease. The cardboard is removed and the jars pressed together tightly.



Observation and Explanation

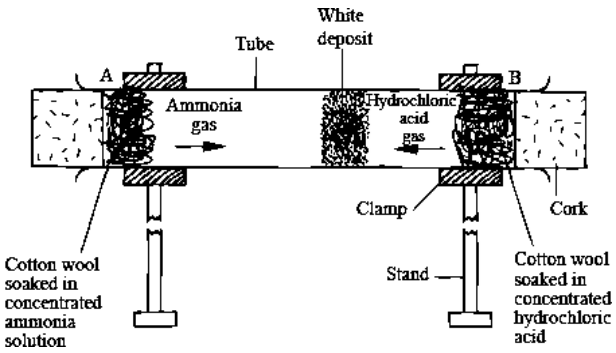
The bromine gas spreads into the gas jar B at a greater speed than it returns to gas jar A because of high concentration of bromine particles. Likewise, air spreads into gas jar A at greater rate than it returns to B because of high concentration of air particles in B. As shown in figure, a homogeneous pale brown mixture forms in the two jars and because this happen in a very short time, **suggesting that the random movement of the particles is more rapid in gases than diffusion in liquids**. Performing the same experiment with the jars held vertically instead of horizontally slows *down the rate of diffusion because of the different densities of the gases. The less dense gas diffuses much faster into the denser gas.* The characteristic smell of cooking gas used in laboratories can be detected when there is a leakage. This is because the gas diffuses into the air.

Investigate the rates of diffusion of ammonia gas and hydrochloric acid gas

a) Soak a piece of cotton wool in concentrated solution of hydrochloric acid and another in concentrated ammonia solution.
b) Care should be taken while handling the two solutions because of their burning effect on the skin.
c) Simultaneously insert the soaked cotton wool pieces at the opposite ends of the horizontal glass tube and cork it.

Observation and Explanation

A white deposit of ammonium chloride forms on the walls of the glass tube in the region nearer end B. This suggests that although both gases diffused, ammonia gas did so at a higher rate than the hydrochloric acid gas.



Conclusion

Different gases have different rates of diffusion. A gas of high density has heavier particles or molecules, hence moves more slowly than a lighter one.

Speed of Diffusion

Gases: Diffusion occurs much faster in gases than in liquids. This is because gas particles are further apart, with more kinetic energy and fewer collisions between particles, allowing them to spread quickly.
Liquids: In liquids, particles are closer together and move more slowly due to intermolecular forces, leading to slower diffusion rates.
Gases: In gases, the interaction between molecules is minimal because the particles are far apart, leading to a less frequent but faster spread of particles.
Liquids: In liquids, molecules interact more frequently due to closer proximity, which hinders the free movement of particles and slows down diffusion.

Density and Medium Resistance

Gases: The lower density of gases means there is less resistance to the movement of particles, which facilitates faster diffusion.

Liquids: The higher density and viscosity of liquids create more resistance, slowing down the diffusion process.

Examination question

During a science exhibition at a secondary school in Uganda, learners set up different practical activities to demonstrate how matter behaves in everyday life. In one corner of the laboratory, a teacher opens a bottle of perfume, and after some minutes learners at the back of the room are able to smell it. In another experiment, learners place a drop of food colour in cold water and another drop in hot water. They observe that the colour spreads faster in hot water.

On another bench, learners observe smoke particles under a microscope and notice that the tiny particles move randomly in different directions. Outside the laboratory, some learners observe dust particles moving irregularly in a beam of sunlight entering through a window. The teacher explains that these observations provide evidence that matter is made up of tiny particles.

In the school kitchen, water is being boiled for drinking. The learners observe bubbles forming and steam rising from the boiling water. Nearby, ice cubes placed in a basin melt into water, while a cold bottle of soda removed from a refrigerator forms water droplets on its outer surface. In the dormitory, learners also notice that wet clothes dry faster on a sunny and windy day than on a cold and calm day.

Using your knowledge of matter and the kinetic theory of matter, answer the questions that follow.

Task:

a) Explain why the smell of perfume spreads from the front of the classroom to learners seated at the back.

b) Using particle theory, explain why food colour spreads faster in hot water than in cold water.

c) Explain the cause of random motion of molecules.

d) Describe what happens to the particles of ice when it melts into water, and what happens to the particles of water when it changes into steam.

e) Explain why water droplets form on the outside of a cold soda bottle and why wet clothes dry faster on a sunny and windy day.

S1.4 EFFECTS OF FORCES

Learning Outcomes

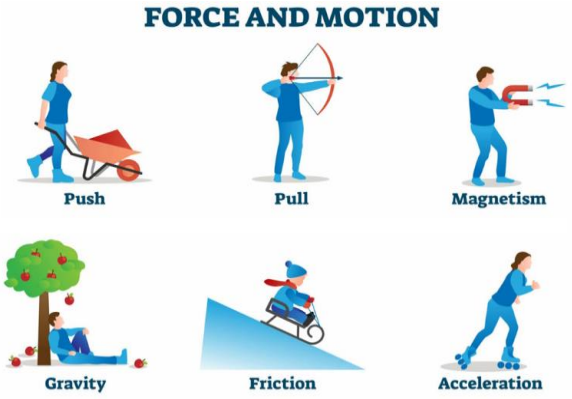
a) Know that a force is a push or a pull and that the unit of force is the Newton(k)
b) Know the effects of balanced and unbalanced forces on objects (k,s)
c) Understand the existence of the force of gravity and distinguish between mass and weight(u)
d) Appreciate that the weight of a body depends on the size of the force of gravity acting upon it (k, u, v/a)
e) Understand the concept of friction in everyday life contexts(u)
f) Understand the meaning of adhesion and cohesion as forms of molecular forces(u)
g) Explain surface tension and capillarity in terms of adhesion and cohesion and their application (u,v/a)

THE EFFECTS OF FORCES

Force is a vector quantity that causes an object to change its state of motion (speed up, slow down, remain stationary, or change direction) or alter its shape. It is a vector quantity, because it has both magnitude (size) and direction. The unit of force in the International System of Units (SI) is the newton (N).

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One newton is the force required to accelerate a 1-kilogram mass by 1 meter per second squared (1 N = 1 $kgms^2$).
Forces play a crucial role in determining the motion of objects. When a force is applied, it can initiate movement, halt it, accelerate, decelerate, or alter the direction of an object.
This push or pull is a vector quantity, meaning it has both magnitude and direction, which significantly influences how an object behaves in response to the force. There are various types of forces, including gravitational, frictional, and applied forces. Each type can produce different effects on an object's motion. For instance, unbalanced forces lead to changes in motion, while balanced forces maintain an object's state of rest or uniform motion.



Two natural forces that we have experienced are the force of gravity and magnetic forces. These two forces act at a distance and do not require direct contact between the objects to function.

Gravity produces a force that pulls objects towards each other, like a person towards the ground. It is the force that keeps the Earth revolving around the sun and it's what pulls you toward the ground when you fall. Magnetism produces a force that can either pull opposite ends of two magnets together or push the matching ends apart. A magnet also attracts (or pulls toward) objects made of metal.

Variety of forces and instances where they occur
Gravitational Force: The force of attraction between two masses. It keeps planets in orbit around the sun and causes objects to fall to the ground. The Earth's gravity pulling an apple down from a tree. Gravity is a natural force that pulls objects toward each other.

Importance of gravity
Gravity is what keeps planets in orbit around stars, moons in orbit around planets, and holds galaxies together. On Earth, gravity gives weight to physical objects and causes objects to fall toward the ground when dropped.

Distinguishing between Mass and Weight
Mass *is a measure of the amount of matter in an object*. It is a scalar quantity, meaning it has magnitude but no direction. The SI unit of mass is the kilogram (kg). Mass is an intrinsic property of an object and does not change regardless of location (whether on Earth, the Moon, or in space). It represents how much "stuff" is in an object, and it is directly proportional to the amount of inertia the object has (resistance to changes in its state of motion). Therefore, *mass is a measure of the amount of inertia contained in an object.*

Weight *is the force exerted on an object due to gravity. It is a vector quantity, meaning it has both magnitude and direction (toward the center of the gravitational source).* The SI unit of weight is the Newton (N), the same as any other force. Weight is calculated by multiplying the mass of an object by the acceleration due to gravity at a given location: $W = mg$ where: W is the weight of the object, m is the mass of the object, g is the acceleration due to gravity (g=10 m/s^2 on Earth).

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Example: An object with a mass of 10 kg has a weight of 10 kg×10 m/s^2=100 N on Earth.
Calculate the weight of the following:
(a) A box of mass 50 kg
(b) A boy of mass 2.5 kg
(c) A bull of mass 200 kg
(d) A stone of mass 12 g.
Solution
a) m = 50 kg, g = 10 ms^{-2}, W = mg = 50 x 10 **= 500 N**
(b) m = 2.5 kg, g = 10 ms^{-2}, **W =** = 2.5 x 10 =**25 N**
(c) m = 200 kg, g = 10 ms^{-2}, W = mg = 200 x 10 **= 2000 N**
(d) m = 12 g, =kg, g = 10 ms^{-2}, W = mg **=** 0.012 x 10 **W 0.12 N**

Differences
Mass is **constant** regardless of where an object is located, while weight **varies** depending on the gravitational field strength (which changes depending on where you are, such as on Earth, the Moon, or in space). Mass is a measure of the **amount of matter** while weight is the **force** exerted by gravity on that mass.

On Earth*:* A person with a mass of 70 kg will have a weight of 70 kg×10 m/s^2=700N. This means that the Earth's gravity is pulling the person downward with a force of 700 newtons.
On the Moon*:* The gravitational acceleration on the Moon is about 1.6 m/s^2, which is approximately 1/6th of Earth's gravity. The same 70 kg person on the Moon would have a weight of 70 kg×1.6 m/s^2=112 N. Although the person's mass remains 70 kg, their weight decreases because the Moon's gravitational force is weaker.

Why weight depends on the force of gravity
Gravitational Force Varies: The gravitational force exerted by a massive body like Earth depends on the mass of the planet and the distance from its center. The stronger the gravitational force (g), the greater the weight of an object. For example, Earth's gravity is stronger than the Moon's because Earth has more mass. As a result, an object will weigh more on Earth than on the Moon, even though its mass remains the same. Since weight is directly proportional to the gravitational force, any change in g results in a corresponding change in weight. If gravity is stronger (higher g), the weight increases. If gravity is weaker (lower g), the weight decreases. The object weighs less on the Moon because the Moon's gravitational force is weaker.

Outer Space: In the microgravity environment of outer space, where g is nearly zero, an object's weight would be nearly zero, making it effectively "weightless." However, its mass remains unchanged. This is why objects weigh differently on Earth, the Moon, or other celestial bodies, even though their mass remains constant. The stronger the gravitational force, the greater the weight; the weaker the gravitational force, the lesser the weight.

Balanced and unbalanced forces
Activity: To demonstrate balanced and unbalanced force in a tug of war
Material: A rope, 5 very strong boys, 5 very small boys
Procedures
i) Let the 5 very strong boys pull a rope on one end and 5 small boys pull on the other end.
ii) Observe and explain what happens.

iii) Suppose the boys on both sides are of equal strength. What would you observe?
iv) Discuss with your group members other different situations where balanced and unbalanced forces are experienced.

Observation

The rope moves to the side with the stronger boy, ones who applied a greater force than the weak ones. The pulling forces are said to be unbalanced. In case the two teams had equal strength or force, the rope will stay in the same place. The pulling force applied is said to be balanced or at equilibrium.

Similarly, if a book is placed on a table top, then, the gravity pulls the book vertically downward while the table support the book with a force acting vertically upwards. Since the two forces are of equal magnitude and in opposite directions, they balance each other. The book is said to be in equilibrium. There is no unbalanced force acting on the book and therefore the book maintains the state of rest. Also, there is no change in motion.

What are Balanced Forces?

If the resultant force of all the forces acting on a body sums up to zero, then the forces acting on the body are known as balanced forces. Let us look at some examples of balanced forces and understand how the body's state of motion remains unaffected.



Balanced Forces Examples

Suppose you are pushing a wall, and as expected, the wall does not move and neither do you. It means that you and the wall are exerting a balanced force on each other.

When the man pushes against the wall, the forces at play balance each other, and as a result, the wall does not move.

The image below shows a game of tug of war between equally matched opponents. Neither of the participating teams can pull the other team towards themselves due to balanced forces.

A game of tug of war with equally matched opponents is an example of balanced force

The image displayed above is a game of tug-of-war between two equally matched teams. Neither of the teams is able to pull the opposing team towards itself.
This is an example of balanced forces.



What are Unbalanced Forces?

When the resultant force acting on a body is not equal to zero, the forces acting on the body are known as unbalanced forces. The body acted upon by unbalanced forces changes its state of motion. Let us look at some examples of unbalanced forces to understand their nature better.

Unbalanced Forces

Let us consider the same tug of war example that we discussed in the previous section.
When the forces are balanced, neither of the teams, but if the rope moves away in a particular direction or if a team wins, then the forces applied by both teams are unbalanced. Practically anything that moves is

a result of the exertion of unbalanced forces on it. If you kick a football and it moves from one place to another, it means that the unbalanced troops are acting upon it.



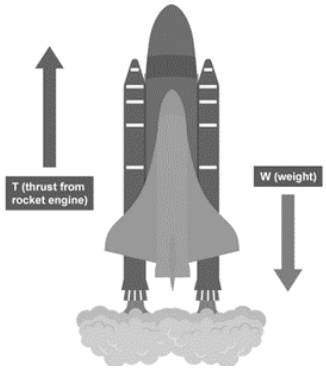
The ball moves from one place to another after it's kicked. This is an example of an unbalanced force.

The image below shows two people on a seesaw. The person on the right is significantly heavier than the person on the left, and the seesaw is effectively tilted towards him. This is an example of unbalanced forces.



One person significantly heavier than the other creates a condition of unbalanced forces in a seesaw.

This image shows two people on a seesaw. The person on the right is significantly heavier than the person on the left and the seesaw is effectively tilted towards him. This is an example of two unbalanced forces.

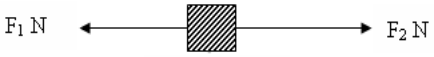


The lift-off of a space rocket is another example of an unbalanced force in action. The space rocket accelerates upwards from its launch pad. The *thrust* (T) from the *rocket* engines is greater than the *weight* (W) of the rocket system. Because force T is greater than the force W, the effect of one force does not cancel that of the other. The forces acting are unbalanced.

Two forces acting on a straight in opposite directions

Consider two forces F_1 and F_2 acting on body in opposite directions as shown in figure. Since the forces are acting in opposite directions, one is taken to be positive and the other negative.

Let F_2 be positive (East/Right) and F_1 be negative (West/left).



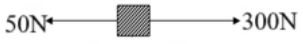
The resultant force, given by using the equation:

$F_r = F_1 + F_2$, $F_r = F_2 + (-)F_1$. $F_1 = F_2 - F_1$

Therefore, the resultant force, $F_r = F_2 - F_1$ in the direction of F_2.

Example:

Two forces 300 N and 50 N are acting on a body Q as shown in figure. Find the resultant force.



Solution

F_1 = 300 N, F_2 = 50 N Since the forces are acting in opposite directions, one is taken to be positive and the other negative. Let 300 N (East)be positive and 50 N(West) be negative

The resultant force, given by using the equation: $F_r = F_2 - F_1$ = 300 + -50 = 300 - 50

Fr = 250 N. *Therefore, the resultant force is **250 N** in the **direction** of 300 N (to the right).*

Example

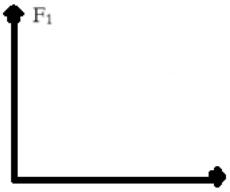
During a school compound cleaning activity, two boys are helping to move a heavy wooden block across a rough floor. They both pull the block horizontally in the same direction using ropes. One boy exerts a

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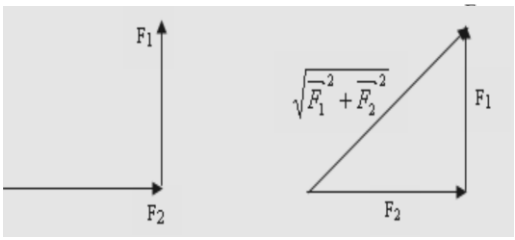
force of **800 N**, while the other boy exerts a force of **1000 N**. The frictional force between the block and the floor is **430 N**, acting opposite to the direction of motion.
Task: Using your knowledge of Physics;
a) Draw a labelled force diagram showing all the horizontal forces acting on the block.
b) Calculate the resultant horizontal force acting on the block.
c) State the direction of the resultant force acting on the block.

Solution
(b). Let the forward direction be positive since the frictional force opposes motion i.e. acts backwards in the negative direction.
Force exerted by the oxen = 800 N + 1000 N
Force exerted by friction = -430 N
The total force on the crate = 800 + 1000 – 430 N = 1370 N
The resultant force on the crate, F= 1370 N
(c) Since the force is positive its direction is forward.

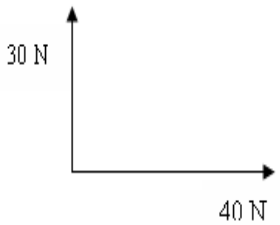
Triangle law of forces
The law states that "*if a body is acted upon by two forces that are at an angle to each other, the resultant of the forces is the third line drawn to complete the triangle".*
For example, if two forces of equal or unequal magnitude, one directed due east and the other directed due north act on an object at rest but free to move in the direction of the resultant force, the magnitude of the resultant force is shown by the length of the arrow representing the resultant force.



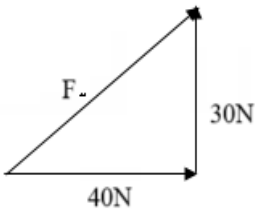
Consider the diagram in the figure in which two forces F_1 and F_2 act on a body. F_1 acts due north and F_2 act due east as shown.
Using the method of *head-to-tail* addition of vectors at right angle, the right-angle triangle is completed by using the tail of F_1 on the head of F_2 as shown in the diagrams below and the resultant force, Fr, is got by applying Pythagoras theorem as shown in the diagrams below.



Example
Two forces 30 N and 40 N act on a body of mass 20 kg at right angle to each other. Determine the resultant force.
Solution:
(a) A sketch diagram showing the forces



Applying the Triangle law of forces and head-to-tail addition of vectors, we complete the diagram as below.

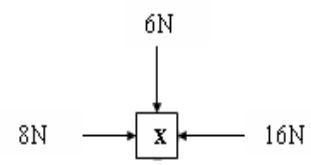


Using Pythagoras theorem $F^2 = 40^2 + 30^2$, $\sqrt{F^2} = \sqrt{40^2 + 30^2} = \sqrt{2500}$, **F=50N**

NB: By using a scale of 1cm =1N. Use a graph paper to determine the resultant force. By joining /extrapolating the point, measure the length F and its equal to the resultant force.

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Activity:



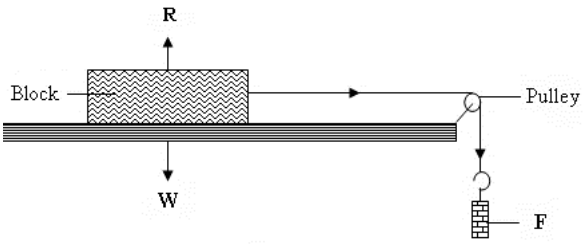
1.The diagram in the figure shows 3 forces of 8N, 6N and 16N acting on a particle X. Find the resultant force(F=10N).

2.A body of mass 5 kg is acted upon by two forces of 3 N and 4 N at right angles to one another. By graphical method, determine the resultant of the two forces.

Frictional Force: *Friction is the force that opposes the relative motion or tendency of such motion of two surfaces in contact.* It acts parallel to the surfaces and opposite to the direction of motion.

Experiment to Measure Static Friction

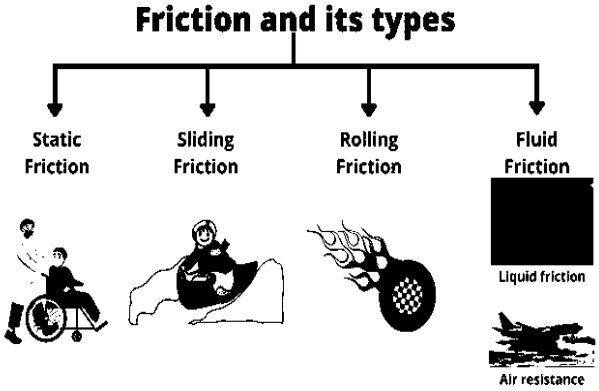
Static friction can be measured using the apparatus shown in figure below



a) Place a wooden block on a table and connect it by a light string passing over a smooth pulley on to a mass hanger.
b) Gradually increase applied force, **F**, by first adding 50 g until when the block is about to slide, continue adding small standard (known) 20 g or 10 g on to the mass hanger until the block just begins to slide or move.
c) Read and record force, **F,** (the total mass on the mass hanger) at the point when the block just begins to slide.

Observations

At first the block remained at rest as the force is increased. After some time, at certain value of the force on the pan, the block just begins to slip or slide in the direction shown on the diagram.



Explanation

When force, **F,** on the mass hanger was increased the frictional force that opposes the motion of the block also increases. As more and more weights were added to the mass hanger, the frictional force reached its maximum value for the two surfaces in contact and begun to slide.

The maximum value of the frictional force is equal to the total weight, F, on the mass hanger. This maximum frictional force is called ***limiting friction***.

Types of Friction

Static Friction: The frictional force that **prevents** two surfaces from sliding past each other. It must be overcome for motion to start.

Kinetic (Sliding) Friction: The frictional force that **opposes** the movement of two surfaces sliding past each other.

Rolling Friction: The frictional force that opposes the rolling of an object over a surface.

Fluid Friction: The frictional force that opposes the movement of an object through a fluid (liquid or gas).

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Friction in Everyday Life

Walking and Running: Friction between your shoes and the ground allows you to push off the ground and move forward. Without friction, your feet would slip, making walking or running impossible. On a slippery surface like ice, the friction is reduced, making it difficult to walk without slipping.

Driving and Braking: The friction between a car's tires and the road allows the car to move forward when the wheels rotate. When you press the brake pedal, the brake pads apply friction to the wheels, slowing the car down. On a wet or icy road, friction is reduced, which can cause the tires to skid, making it harder to control the vehicle.

Holding Objects: When you grasp an object, friction between your fingers and the object helps you hold onto it. The rougher the surface, the more friction, making it easier to grip. It is easier to hold a dry, rough object like a piece of wood than a wet, smooth object like a glass bottle.

Writing and Drawing: Friction between the tip of a pen or pencil and the paper allows you to write or draw. The friction causes the writing material (ink or graphite) to leave a mark on the paper. Writing on a smooth, glossy surface like glass is difficult because of the lack of friction.

Heating by Friction: When two surfaces rub against each other, the friction between them can convert kinetic energy into heat. This is why rubbing your hands together quickly can make them warm. In some traditional methods of starting a fire, sticks are rubbed together to create heat by friction, eventually igniting dry leaves or tinder.

Sports and Athletics: In many sports, friction plays a crucial role. For example, the grip of athletes' shoes on the track or field affects their performance. The design of sports equipment like balls and bats also considers friction. Soccer players wear cleats with spikes to increase friction between their shoes and the grass, improving their grip and preventing slipping.

Furniture and Appliances: Moving heavy furniture across a floor involves friction. Sliding friction occurs when you push the furniture, making it difficult to move. Rollers or casters reduce friction, making it easier to move heavy objects. Placing furniture sliders under heavy items like sofas reduces friction, allowing you to push or pull them with less effort.

Factors affecting Friction

Surface Texture: Rougher surfaces have higher friction because they have more microscopic bumps and irregularities that catch on each other. Sandpaper has more friction than smooth paper because of its rough texture.

Normal Force: The greater the force pressing two surfaces together, the higher the friction. This is why heavier objects experience more friction. Pushing a heavy box across the floor is harder than pushing a lighter one because the heavier box presses down more, increasing friction.

Surface Area: While surface area does not directly affect friction in most cases (since friction is generally independent of the contact area), it can play a role in certain situations, such as when dealing with pressure-sensitive surfaces. Wide tires on a car can increase friction slightly, improving grip on certain terrains.

Materials in Contact: Different materials have different coefficients of friction. For instance, rubber on asphalt has high friction, while ice on metal has low friction. Car tires are made of rubber, which provides good friction on asphalt, while skates are designed to minimize friction on ice.

Reducing and Increasing Friction

Lubrication: Applying a lubricant like oil or grease between two surfaces reduces friction by creating a thin layer that separates the surfaces, allowing them to slide more easily. Oil in a car engine reduces friction between moving parts, preventing wear and tear.

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Ball bearings: Bearing is a mechanical device for decreasing friction in a machine in which a moving part bears that is, slides or rolls while exerting force on another part. Steel ball bearings are used for example in an axle and shaft of the bicycle then the axle and shaft. When the ball bearings are used, the axle and shaft do not slide but roll over one another. Rolling friction is less than the sliding friction; therefore, friction is lessened by means of ball bearing.

Rollers Friction can be reduced by placing rollers between the two surfaces in contact.

Smoothening of surfaces in contact Friction can also be reduced by making rough surfaces smooth where necessary.

Streamlining refers to shaping of an object such that the layer of air easily slides off. Notable examples are seen in: - aeroplane, submarines, boats, fish, birds etc.

Friction as a Nuisance: Friction causes wear and tear on machine parts, leading to maintenance issues. It reduces efficiency by converting useful kinetic energy into unwanted heat.

Fluid Friction

Fluid Friction is a retarding force which acts on a body moving through a fluid. It is due to the internal friction existing between layers of fluids of a liquid in motion. It is caused by the attraction between the molecules of one layer and the molecules of another layer. The frictional resistance of a fluid (liquid or gas) opposing motion of a body moving through it is called viscosity.

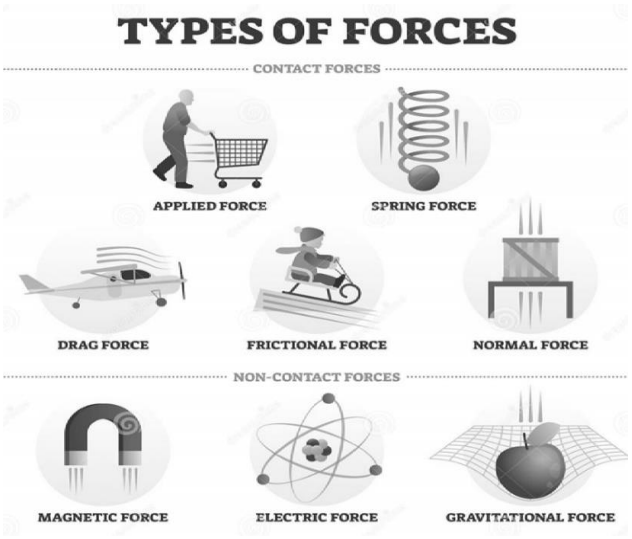
Factors which determine the magnitude of fluid friction

Unlike friction between solids‟ viscosity is proportional to the surface area and the velocity of the object moving through the fluid.

Nature of fluid. Viscosity depends on the type of fluid for example glycerin, engine oil, and natural honey flow much less easily from a vessel than liquids such as petrol, paraffin and water.

Temperature: Viscosity of liquids decreases as a temperature of liquid increases while that of gases increases with temperature.

Liquids which have high viscosity e.g. glycerin, engine oil are called vicious liquids and are used to make lubricants.



Contact and Non-Contact Forces

Contact Forces: These forces occur when two objects are physically touching each other.

These are kinds of forces which act on objects when they come into contact with one another. Remember, a force is either a push or pull. The forces are: *normal force, applied force, frictional force, tension force, spring force,* and *resisting force.*

Tension Force: The force transmitted through a string, rope, cable, or wire when forces acting from opposite ends pull it tight. The force in a rope holding a hanging object like a chandelier.

Normal Force: The support force exerted upon an object that is in contact with another stable object, example a book resting on a table experiences a normal force from the table that balances its weight.

Applied Force: A force that is applied to an object by a person or another object, like in pushing a door open or pulling a cart.

Air Resistance Force: A type of frictional force that acts against an object as it moves through the air like in a parachute slowing down a skydiver's descent.

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Magnetic Force: The force of attraction or repulsion that arises between electrically charged particles because of their motion. It is related to the magnetic fields generated by magnets. Example A magnet sticking to a refrigerator door.
Electrostatic Force: The force between charged particles. Like charges repel, while opposite charges attract. Example a balloon sticking to a wall after being rubbed on hair.

Non-Contact Forces: These are forces that occur even when the objects are not physically touching.
Examples gravitational Force: The Earth's gravity pulling objects toward its center.
Magnetic Force: A magnet attracting a metal object from a distance.
Electrostatic Force: A charged balloon attracting small pieces of paper without touching them.

Demonstrating the Effects of Forces on Objects
Forces can affect objects in several ways:
Change in Speed: A force can cause an object to accelerate (increase speed), decelerate (decrease speed), or come to a stop. Example applying the brakes to a moving car reduces its speed due to friction.
Change in Direction: A force can change the direction in which an object is moving. Example a soccer player kicking a ball causes it to change direction.
Change in Shape: A force can deform an object, temporarily or permanently. Example squeezing a rubber ball changes its shape, and stretching a rubber band elongates it.
Start or Stop Motion: A force can set an object in motion from rest or bring a moving object to a halt. Example pushing a stationary box causes it to start moving, while friction can stop it from moving.

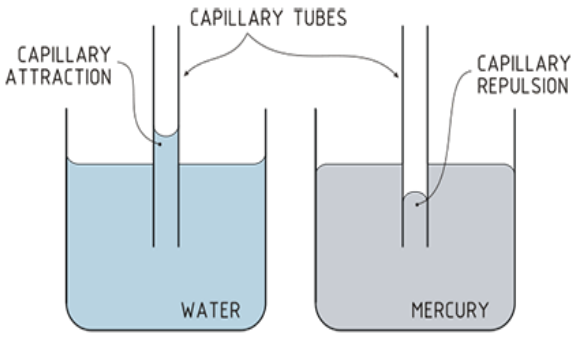
Examples of the Effects of Forces
Change of Movement:
Acceleration: Pressing the gas pedal in a car increases the speed of the car.
Deceleration: Applying brakes on a bicycle slows it down.
Change of Shape:
Compression: Squeezing a sponge compresses it, reducing its volume.
Tension: Stretching a rubber band increases its length.
Stopping an Object:
Frictional Force: A sliding book eventually stops due to the frictional force between the book and the table surface.
Air Resistance: air resistance slows down a falling object like a feather.

Molecular Behavior of Adhesion and Cohesion
Cohesion: *Cohesion is the attractive force between molecules of the same substance.* It is the force that holds molecules together within a material, like water molecules sticking to each other.
Molecular Behavior: Cohesion occurs because of intermolecular forces, such as hydrogen bonding, Van der Waals forces, or dipole-dipole interactions. In water, for instance, hydrogen bonds between the slightly positive hydrogen atoms of one water molecule and the slightly negative oxygen atoms of another water molecule create strong cohesive forces.
Adhesion: *Adhesion is the attractive force between molecules of different substances*. It is the force that causes one substance to stick to another, such as water molecules sticking to a glass surface.
Molecular Behavior: Adhesion occurs due to similar intermolecular forces as cohesion, but they act between different substances. For example, the polar nature of water allows it to form hydrogen bonds with the molecules of other polar substances, such as glass, which leads to adhesion.

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Molecular Mechanisms behind Cohesion and Adhesion

Cohesion in Water: Water molecules are polar, with a partial negative charge on the oxygen atom and partial positive charges on the hydrogen atoms. These polar charges allow water molecules to form hydrogen bonds with each other, leading to strong cohesive forces. This cohesion is responsible for phenomena like surface tension, where the surface of water resists external force because the water molecules are strongly attracted to each other.



Adhesion of Water to other surfaces: When water meets a different material, such as glass, the polar water molecules can form hydrogen bonds with the polar molecules of the glass surface. This interaction creates adhesion, which can be observed when water spreads out on a glass surface rather than forming droplets.

Practical implications of Cohesion and Adhesion

Capillary Action: Capillary action is the ability of a liquid to flow in narrow spaces without the assistance of external forces (like gravity). It occurs due to the combination of cohesive and adhesive forces.

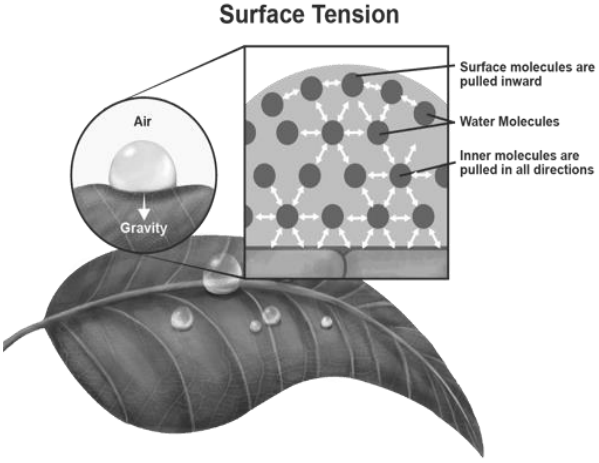
Adhesion causes the liquid to cling to the walls of a narrow tube or pore, while cohesion pulls other liquid molecules along, leading to the upward movement of the liquid.

Capillary action helps transport water from the roots to the leaves in plants through thin tubes called xylem. When you dip a paper towel in water, the water moves upward against gravity due to capillary action.

Wetting: Wetting occurs when a liquid spreads out over a solid surface, which is a balance between cohesion (which resists spreading) and adhesion (which promotes spreading).

If the adhesive forces between the liquid and the surface are stronger than the cohesive forces within the liquid, the liquid will spread out (wetting the surface). If cohesive forces are stronger, the liquid will bead up.

Water wets glass surfaces because the adhesive forces between water and glass are stronger than the cohesive forces within the water.



Waterproof Materials: On surfaces coated with hydrophobic (water-repellent) materials, water beads up instead of spreading out due to weak adhesion and strong cohesion.

Meniscus Formation: The meniscus is the curve seen at the surface of a liquid in response to its container. The shape of the meniscus depends on the balance between cohesion and adhesion. If adhesion is stronger (as with water in glass), the liquid will curve upwards (concave meniscus). If cohesion is stronger (as with mercury in glass), the liquid will curve downwards (convex meniscus).

Water in a Glass Tube: Water forms a concave meniscus in a glass tube because adhesion is stronger than cohesion in the glass.

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Mercury in a Glass Thermometer: Mercury forms a convex meniscus because it has stronger cohesive forces than adhesive forces with the glass.

Applications and Implications

In Biology: Plant Transport: Adhesion and cohesion are vital for the movement of water and nutrients in plants.

Adhesion and cohesion play roles in the behavior of water and other substances at cellular surfaces.

Paints and Coatings: The effectiveness of paints and coatings depends on adhesion to surfaces, which is why surface preparation is crucial.

Adhesives: Glues and tapes rely on strong adhesive forces to stick to surfaces and cohesive forces to stay intact.

In Technology: Microfluidics: The design of devices that manipulate small amounts of liquids relies heavily on controlling adhesion and cohesion at small scales.

Printing Technologies: Ink adhesion to paper or other materials is crucial for clear and lasting prints.

Behavior of liquids on the surface

When water is dropped on a glass surface, it wets it and spreads out in a thin surface because adhesive force between the water molecules and glass is greater than the cohesive force between water molecules. When mercury is dropped on a glass surface it forms spherical droplets or large flatten drop because cohesive forces between mercury molecules is greater than adhesive forces between mercury and glass.

Surface Tension: This is the effect of force on the surface of a liquid, which makes it behave like a stretched elastic skin. Surface tension is the result of the cohesive forces between liquid molecules at the surface. It causes the surface of a liquid to behave like a stretched elastic membrane. At the surface of a liquid, molecules experience a net inward force because they are only attracted to other molecules beside and below them. This creates a tension on the surface. Surface tension allows water to form droplets on surfaces. Small objects, like a paper clip, can float on the surface of water if they do not break the surface tension.

Activity: To demonstrate the presence and effect of surface tension in water by floating a metal needle on the water's surface despite its density being greater than that of water.

Materials Required: A clean glass or plastic bowl (transparent, 300 mL or more)**,** Clean water (distilled preferred)**,** A sewing needle or straight metal pin**,** small piece of tissue paper (approximately 2 cm x 2 cm)**,** Tweezers or forceps**,** Dropper (optional, for adding soap solution)**,** Dishwashing soap or detergent (for extension activity)**,** White paper (for visual contrast under the bowl)**,** Paper towels (for drying spills).

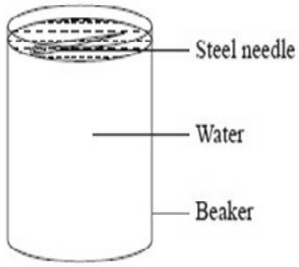
Safety Precautions:

- Handle needles carefully to avoid injury.
- Ensure no soap or oil is on your hands or tools before the experiment, as this affects the results.
- Work on a flat, stable surface.

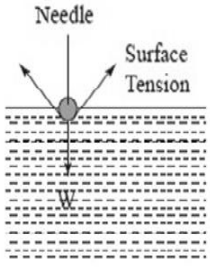
Procedure:

a) Fill the bowl with clean water up to 3/4 of its capacity, and allow the water to settle so the surface becomes calm and undisturbed.

b) Place a small piece of tissue paper flat on the water surface, and carefully lay the sewing needle horizontally on the tissue using tweezers, wait for 10–20 seconds.



(a) Steel needle floating on water



(b) Section through the needle

c) Try touching the surface near the needle i.e. cause the disruption of surface tension.
d) Add a tiny drop of liquid soap near the needle using a dropper or toothpick.
e) What do you observe of the needle and the water surface?

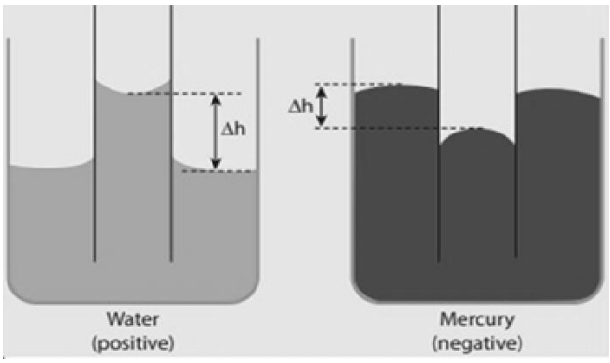
Observation and conclusion

- The needle remains floating on the water surface due to the water's surface tension.
- It is supported by the cohesive forces acting like an elastic film at the water surface.
- When soap is added, it reduces the surface tension, weakening the cohesive forces and causing the needle to sink.
- The needle does not float because it is less dense than water (it is actually denser); instead, it is held up by the water's surface tension. Water molecules at the surface are more attracted to each other than to the air above them. This creates a net inward force that acts like a stretched elastic membrane. When the needle is placed carefully on the tissue, it avoids breaking this surface and rests atop the water, demonstrating the surface tension in action.
- When soap is introduced, it reduces the cohesive forces by interfering with hydrogen bonding among water molecules. This lowers surface tension significantly and removes the water's ability to support the needle, which then sinks.

This simple experiment clearly demonstrates the presence of surface tension in water. It illustrates how water molecules stick together at the surface and how external agents like detergents can alter this property. The effect of surface tension is its ability to support small objects, such as water striders, allowing them to "float" on the surface without sinking. This occurs because the surface tension creates a sort of elastic layer that resists external forces. Surface tension helps in the development of pore structures in materials like coal, where it influences adsorption and wettability.
Surface tension is due to molecules on liquid surface being slightly further apart like those in a stretched wire. Therefore, experience attractive forces from their neighbors in liquid surface. The forces stretch the molecules on the surface, making it behave like a stretched elastic skin.

Ways of reducing of surface tension

Reducing the surface tension of water can be achieved through several methods that do not involve detergents. One effective approach is to mix vinegar with water. Adding a tablespoon or two of vinegar to a bowl before filling it with water significantly decreases surface tension, resulting in fewer bubbles forming on the surface.
Increasing the temperature lowers the surface tension, making it easier for the water to spread and interact with other substances. Spreading oil or oily compounds on the water's surface can also reduce surface tension, as these substances disrupt the cohesive forces between water molecules. Electrifying the water can lead to a reduction in surface tension. This method alters the molecular interactions within the water, promoting a more fluid surface.



Molecular theory of surface tension
Surface tension arises from the cohesive forces between liquid molecules, which are stronger at the surface due to the imbalance of intermolecular forces. Molecules within the liquid experience equal attraction

from all directions, while surface molecules are pulled inward, creating a "film" that behaves like a stretched elastic membrane. This tension influences phenomena such as droplet formation, capillary action, and the behavior of bubbles. e.g. the steel needle or the razor blade floats because the surface of the water

behaves like a fully stretched, thin, elastic skin. This skin always has a tendency to shrink, i.e., to have a minimum surface area or elastic membrane. The force which causes the surface of a liquid to behave like a stretched elastic skin is called surface tension. This force is due to the force of attraction between individual molecules of the liquid (cohesion).

The needle or the blade sinks when a drop of kerosene or soap solution is put in the liquid near the needle because the kerosene or soap solution reduces the surface tension of the water. When the tip of the needle is pressed into the water, it pierces the surface skin and sinks.

CAPILARITY/CAPILARY ACTION

This is the rising or depression of a liquid in a capillary tube or bore. The rise of water in a capillary tube is because the cohesive force between the water molecules is less than the adhesive force between molecules of glass and water. It is also for this reason that water spreads over glass surface.

When similar capillary tubes are dipped in mercury, each surface is depressed below the outside level of the beaker and the surface curves down wards. Mercury is depressed more in narrow tube than in a large one. This is because cohesive forces between molecules of mercury are greater than adhesive forces between molecules of mercury and glass. It is also for this reason that mercury does not wet glass but forms droplets on glass.

Application of capillarity

Capillarity, or capillary action, is a physical phenomenon where liquids move through narrow spaces without the assistance of external forces like gravity. This occurs due to the interplay of cohesive and adhesive forces, allowing liquids to rise or fall in small tubes or porous materials. The most common applications of capillarity is in everyday writing instruments, such as pens, where ink rises through the nib due to capillary action. Capillarity plays a crucial role in the natural world; for instance, it enables water to travel from the roots to the leaves of plants, ensuring their survival. Other applications include the functioning of blotting paper, which absorbs ink through capillary action, and the operation of kerosene lamps, where the fuel rises through the wick to sustain the flame.

Disadvantages of capillarity

- ♠ Capillary action can lead to unwanted mixing, undermining the desired outcomes.
- ♠ Controlling the flow rate of liquids through capillary action can be challenging. The rate at which a liquid move through narrow spaces is influenced by various factors, including tube diameter and liquid properties.
- ♠ House bricks and concrete are porous. Capillary action is likely to draw water upwards from the ground through them, making the building dump (wet). This problem is overcome by putting water proof layer made from plastic that is placed in the layers of bricks at the bottom of the house.

Sample: Item

1.A small glass capillary tube with an inner diameter of 1.0 mm is inserted vertically into a container of water at 20°C. The water wets the glass, and the contact angle between the water and the glass is 0°. A tiny droplet of water is observed at the surface of the liquid in the container, and a small insect is seen walking on the water's surface without sinking.

Task: Use your knowledge in physics to:

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i) Explain why the insect can walk on the water's surface without sinking.
ii) Describe the roles of adhesion and cohesion in causing the water to rise in the capillary tube.
iii) If the same capillary tube is placed in mercury, explain whether the mercury level will rise or fall in the tube.
iv) Explain how the interplay of adhesive and cohesive forces determines the shape of the water droplet on the container's surface.

2.A physics student is conducting an experiment to investigate the frictional forces acting on a wooden block placed on a horizontal wooden surface. The block has a mass of 10 kg and is subjected to two perpendicular forces; a horizontal force of 30 N and a vertical force of 40 N. The student wants to understand the concept of dynamic friction and how it differs from limiting friction, as well as determine the resultant force and acceleration of the block under these conditions.

Task: Using your knowledge of physics to;

(a) Explain what is meant by *dynamic friction*.
(b) Describe an experiment to determine the *limiting friction* between the wooden block and the horizontal surface.
(c) State any two factors that affect friction between the two surfaces.
(d) Using the given forces, determine
(i) the magnitude of the *resultant force* acting on the block,
(ii) the *acceleration* of the block, assuming the surface is frictionless.

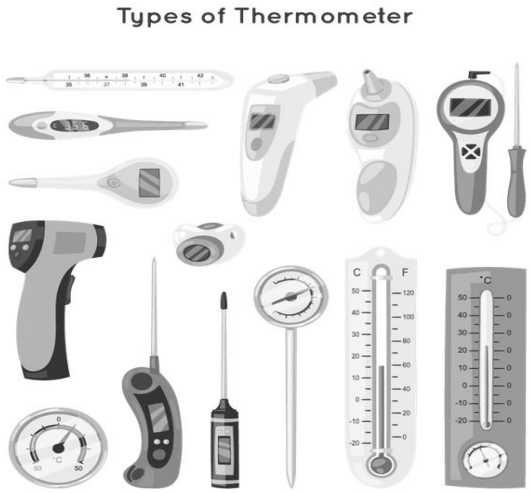
3.In a small village, residents rely on a network of narrow bamboo tubes to transport water from a nearby stream to their homes for daily use. A young science enthusiast, notices that water sometimes climbs up the inner walls of the bamboo tubes or forms droplets on leaves near the stream. Intrigued, she decides to study the different phenomena of *surface tension*, *cohesion*, *adhesion*, and *capillary action* to understand how they affect the water system, their practical uses, and potential dangers.

Tasks: Using your knowledge of physics; help to

(a) Explain the concepts of the different phenomena of the water in the bamboo tubes and on the leaves.
(b) Describe an experiment to demonstrate capillary action using a narrow glass tube and water from the stream.
(c) State any factors that affect surface tension and capillary action in this case.
(d) Discuss the practical uses of surface tension and capillary action in daily life in the village.
(e) Identify the potential dangers related to these phenomena in the village's water system or natural environment, and explain how it could be mitigated

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1.5 TEMPERATURE MEASUREMENTS



Learning Outcomes

a) Understand the difference between heat and temperature(u)
b) Understand how temperature scales are established(u)
c) Calibrate a thermometer and use it to measure temperature (s,u)
d) Compare the qualities of thermometric liquids (u, s,v/a
e) Describe the causes and effects of the daily variations in atmospheric temperature (u,v/a)

Introduction

Temperature measurement is the process of finding the current temperature for immediate use or future reference. It is important in many fields such as cooking, medicine, metallurgy, industries, meteorology, and space science.

Temperature is a measurable physical quantity that shows the average kinetic energy of particles in a substance. The common instrument used to measure temperature is a **thermometer**. Different devices are used depending on the purpose, including mercury thermometers, digital thermometers, infrared thermometers, thermocouples, and resistance temperature detectors.

Some thermometers measure temperature by direct contact, while others, such as infrared thermometers and thermal imaging devices, measure temperature from a distance. These are useful in health screening, industries, and scientific work.

Temperature control is important in food production, pharmaceuticals, electronics, and other industries to ensure safety, quality, and good performance. In meteorology, temperature readings help in weather forecasting and climate studies. Long-term temperature records also help scientists understand climate change, global warming, El Niño, and urban heat islands.

Calibration helps prevent errors that could compromise experiments, industrial production, or patient care. With so many instruments and scales, and such high stakes, another compelling question arises: Smart sensors embedded in medical devices, industrial machinery, and environmental monitors are now able to transmit real-time temperature data wirelessly to cloud platforms. These innovations improve efficiency, safety, and data accessibility.

Activity: Investigating the Relationship between Heat and Temperature

Materials Required: 2 metal containers or beakers (same size), Equal volumes (200 mL) of cold water and cooking oil, 2 thermometers (alcohol-based or digital), Electric heater or Bunsen burner with a tripod stand and gauze, Stopwatch or timer, Graph paper or chart for plotting results, and Safety goggles and gloves (for safety)

Procedure:

a) Place equal amounts (200 mL each) of cold water and cooking oil in two identical metal beakers, and insert a thermometer in each liquid.
b) Place both beakers on the tripod and gauze above the same heat source (or use two identical setups), and ensure the thermometer does not touch the bottom of the beaker.
c) Record the initial temperature of both the water and the cooking oil.

d) Begin heating both substances simultaneously while starting the stopwatch.
e) Every 1 minute for 10 minutes, record the temperature of each substance.
f) Turn off the heat source after 10 minutes.

Task: Answer the following Questions

1. Which liquid showed a faster increase in temperature? Why?
2. Were both liquids given the same amount of heat? How do you know?
3. Why do you think the temperatures changed at different rates?
4. What does this tell us about the specific heat capacities of water and cooking oil?
5. How does this experiment help you understand the difference between heat and temperature?

Observation and conclusions

Cooking oil heats up faster than water. Water, which has a higher specific heat capacity, takes longer to change temperature even with the same heat input. This demonstrates that heat (energy) and temperature (a measurement of energy per particle) are related but not the same. The same amount of heat can result in different temperature changes depending on the material. It reinforces the understanding that temperature is not the amount of heat a substance contains, but rather a measure of the average kinetic energy of its particles.

Heat is a form of energy between two systems or objects that results due to a temperature difference between two points. It is energy in transit and flows from a hotter object to a cooler one. Unit: Joules (J), Calories (cal).

Temperature is physical quantity that is a measure of the average kinetic energy of the particles in a substance. It represents how hot or cold an object is, independent of the object's size or material. Unit: Degrees Celsius (°C), Fahrenheit (°F), or Kelvin (K). Symbol: T.

Heat is a quantity of energy that flows into or out of a system during processes like conduction, convection, or radiation. Temperature is not energy but a scalar measure of thermal intensity. It reflects the energy state of a system.

Heat depends on:

Temperature difference: Heat flows due to a gradient (higher to lower temperature);

Mass: Larger masses contain more energy at the same temperature;

Material properties: Specific heat capacity affects how much heat a material absorbs or releases.

Temperature is independent of the object's mass or material. It only measures the energy per particle. Heat is measured using a calorimeter by observing changes in temperature and applying the formula: $Q=mc\Delta T$ where m is mass, c is specific heat capacity, and ΔT is the temperature change. Temperature: Measured directly using a thermometer or other sensors.

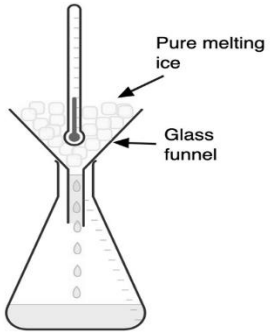
Heat is transferred between objects or systems by: **Conduction:** Through direct contact.i.e. Molecular movement (vibrations);

Convection: Through fluid Movement. **Radiation**: Through electromagnetic waves. Temperature does not transfer; it is the driving factor for heat transfer. When you heat water, energy (heat) flows from the flame to the water, increasing its internal energy. The temperature of the water increases as its particles move faster, reflecting the rise in average kinetic energy.

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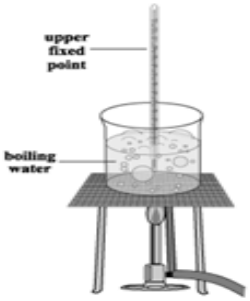
Activity: Exploring the Origins of Temperature Scales; Investigating the Fixed Points

Materials Required: Ice cubes**,** Hot water (near boiling)**,** Two glass beakers (500 mL)**,** Two thermometers (alcohol or digital)**,** A simple laboratory thermometer (Celsius)**,** Reference chart for Fahrenheit, Celsius, and Kelvin**,** Stopwatch or timer**,** Graph/chart paper and marker pens**.**



Procedure

a) Place crushed ice into one beaker and insert the thermometer.
b) Stir gently and wait 2–3 minutes.
c) Record the lowest stable temperature this is the freezing point of water (0°C).
d) Carefully pour hot (near-boiling) water into the second beaker.
e) Insert the second thermometer and observe the highest stable temperature (100°C).
f) Record the result after 2–3 minutes of stabilization.
g) Using a strip of paper or ink, mark 0°C at the freezing point and 100°C at the boiling point.
h) Divide the distance between into 100 equal parts to represent 1°C per interval.



Observation and conclusion

Two primary fixed points are established: the freezing point of water (the ice point) (0°C or 32°F) and the boiling point of water (the steam point) (100°C or 212°F). These points are chosen due to their reproducibility and ease of measurement, making them reliable benchmarks for temperature scales. The length of the liquid column in the thermometer at these temperatures allows for the accurate measurement of intermediate temperatures.

The distance between the freezing (**the ice point**) and **boiling points** is called the ***fundamental interval***; and can be divided into equal intervals, creating a consistent scale for temperature readings.

The **ice point** is defined as the temperature at which pure melting ice exists at normal atmospheric pressure.

This is the temperature of pure melting ice at standard atmospheric pressure. The standard atmospheric pressure is 76cmHg or 760mmHg **called Lower Fixed Point.**

The **steam point** is the temperature at which pure water boils / temperature of steam above water boiling under standard atmospheric pressure. **Called Upper Fixed Point**

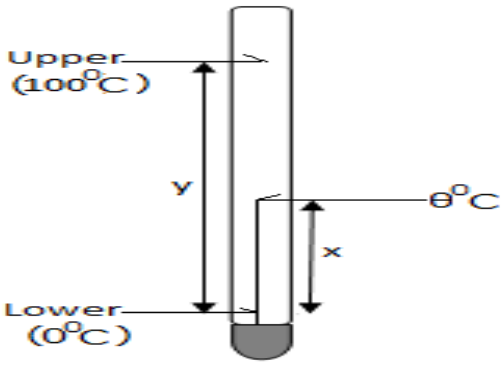
Triple Point of Water (273.16 K): A unique condition where water coexists as a solid, liquid, and gas. This is a universal reference point for the Kelvin scale, and **Absolute Zero**: The theoretical temperature where particle motion ceases, defined as 0 Kelvin (K) or −273.15°C.

Kelvin scale (K): Based on absolute zero (0 K) and the triple point of water (273.16 K). One Kelvin is the same size as one Celsius degree. Conversion: T(K)=T(°C) +273.15

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Use of Thermometric Properties

Thermometric properties are essential for measuring temperature across various fields, including manufacturing, scientific research, and medicine. These properties refer to physical characteristics that change with temperature, such as volume, resistance, and pressure. For instance, thermal expansion is a common thermometric property utilized in everyday applications, such as in thermometers and temperature-sensitive devices.



In manufacturing, precise temperature control is crucial for processes like metal forging and chemical reactions.

In scientific research, thermometric properties enable accurate data collection in experiments, ensuring reliable results.

In the medical field, thermometers that utilize these properties are vital for monitoring patient health, particularly in diagnosing fevers or other conditions.

Advancements in luminescence thermometry, which leverages the properties of materials like Nd3+ doped phosphors, showcase the growing potential of thermometric techniques.

Temperature scales are tied to measurable physical properties that change consistently with temperature.

Thermometric properties

Volume of a Liquid (e.g., mercury or alcohol in a thermometer): Liquids expand linearly with temperature.

Electrical Resistance: Resistance of a material (e.g., platinum in a resistance thermometer) changes with temperature.

Gas Pressure: The pressure of an ideal gas at constant volume is directly proportional to temperature.

Radiation Intensity: The intensity of thermal radiation emitted by an object relates to its temperature (used in pyrometers).

Using an un-calibrated thermometer to measure temperature:

To measure temperature with an un-calibrated thermometer, establish two fixed points: the melting ice point (0^0C column length,l_0) and the boiling water point (100^0C column length, l_{100}). Measure the column length at the unknown temperature (l_θ) and calculate using the linear formula: $Temperature = \frac{l_{100}-l_0}{l_\theta-l_0} x100^0C$.

Steps to Use an Un-calibrated Thermometer

Find the Ice Point (l_0): Place the bulb in pure melting ice. Once the liquid level stabilizes, measure the length of the column (l_0) from a consistent starting point.

Find the Steam Point (l_{100}): Place the bulb in steam above boiling water. Once the liquid level is constant, measure this length (l_{100}).

Measure Unknown Temp (l_θ): Place the bulb in the substance being measured and record the liquid length (l_θ).

Calculate: Use the lengths in the formula to interpolate the correct temperature.

$$Temperature = \frac{l_{100} - l_0}{l_\theta - l_0} x100^0C.$$

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$Temperature = \frac{x}{y} x 100^0 C.$

Hence, the temperature in an un-calibrated thermometer can be determined by measuring the increase and decrease in the length of the volume of mercury.

Example

If the length in ice (l_0) is 2cm, the length in steam (l_{100}) is12cm, and the length at an unknown temperature (l_θ) is7cm.

Response:

$Temperature = \frac{l_{100} - l_0}{l_\theta - l_0} x 100^0 C.$

$Temperature = \frac{7-2}{12-2} x 100^0 C = \frac{5}{10} x 100^0 C$

$Temperature = 50^0 C$

Fundamental interval is the difference between the upper fixed point and the lower fixed point. This is divided into a hundred equal parts to calibrate in Celsius scale and each is called a degree.

Activity:

1). In a rural health centre in Central Uganda, a nurse uses a clinical thermometer to monitor the temperature of hot water prepared for sterilising medical equipment during an outbreak prevention exercise. The top of the mercury thread rises 3 cm above the ice point mark on the thermometer scale. The fundamental interval (distance between the ice point and steam point) of this thermometer is 5 cm. Determine the temperature θ of the hot water in °C, and explain why this temperature reading is important for ensuring effective sterilisation in a real-life health setting.

2). A food processing factory in Kampala uses a special thermometer filled with liquid X to monitor the temperature of a fruit juice mixture during pasteurisation to prevent spoilage. The length of the liquid thread at the lower fixed point (ice point, 0 °C) is 2 cm, and at the upper fixed point (steam point, 100 °C) is 8 cm. At the unknown temperature θ of the juice mixture, the length of the liquid thread is measured as 6 cm. Determine the value of θ in °C, and discuss how accurate temperature control in this process helps maintain food safety standards for consumers in Uganda.

3). During a community weather monitoring project organised by the Uganda National Meteorological Authority in a village near Kampala, a student records the atmospheric temperature using a standard mercury thermometer. The length of the mercury thread is observed to be 7 cm above the ice point mark, while the fundamental interval of the thermometer is 20 cm.

(a) Calculate the unknown temperature θ in °C.

(b) Given that the length of the mercury thread for another reading is 4 cm above the ice point with the same fundamental interval, determine this second temperature value and explain how such daily temperature readings support farmers in planning irrigation and crop protection in real-life agricultural scenarios.

Thermometric liquids and their properties

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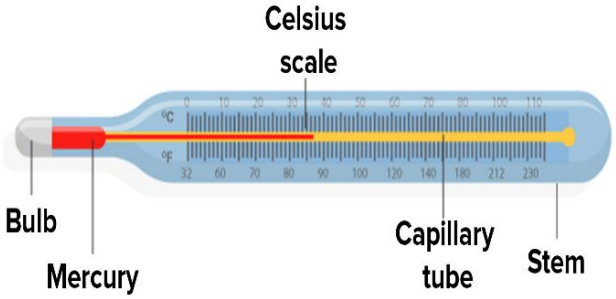
Thermometric liquids are essential for accurate temperature measurement in thermometers. The most common examples include **mercury** and **ethanol.**
Historically, mercury was favored due to **its high boiling point** and **low freezing point**, allowing it to remain liquid over a wide temperature range. However, its **toxicity** has led to a decline in its use, with ethanol becoming a popular alternative, especially in household thermometers. A good thermometric liquid must possess several key properties. It should have a *high boiling point* and a *low freezing point* to function effectively across various temperatures. Additionally, it should be *non-corrosive* to the thermometer's container and *non-toxic* to ensure safety. Visibility is also crucial; the liquid should be *opaque or colored for easy reading. Uniform thermal expansion* is another important characteristic, allowing for precise temperature readings. These properties ensure that thermometric liquids provide reliable and accurate measurements in various applications.

Water is not used as thermometric liquid

Water is not used as a thermometric liquid due to several significant limitations. The main reasons are:
Water expands irregularly: A good thermometric liquid should expand uniformly when heated. Water does not. Between **0°C and 4°C**, water contracts when heated instead of expanding. It has maximum density at **4°C**, so it gives unreliable readings.
It has a small range of measurement: Water freezes at **0°C** and boils at **100°C**. This means it cannot measure temperatures below 0°C or above 100°C, unlike mercury or alcohol.
It wets glass: Water sticks to the walls of the glass tube. This makes it difficult to read the level accurately because the meniscus is not sharp and clear.
It is a poor conductor of heat: Water responds slowly to temperature changes compared with mercury, so the thermometer may take longer to give the correct reading.
It is transparent: Water is colourless, so its level inside the thermometer tube is hard to see unless it is dyed.
Therefore, water is unsuitable as a thermometric liquid because it expands irregularly, has a limited temperature range, wets glass, responds slowly, and is difficult to read.

CLINICAL THERMOMETER

A clinical thermometer is used to measure body temperature in humans and animals. It usually has a thin glass tube with a bulb containing mercury or another liquid. Its normal range is about **35°C to 42°C**, suitable for detecting fever.



When placed in the mouth or armpit, body heat makes the mercury expand and rise through the tube. A constriction prevents the mercury from flowing back immediately, allowing the reading to be taken after removal. The thermometer is reset by shaking the mercury back into the bulb.

Digital and infrared thermometers are now common because they give quick readings, but traditional clinical thermometers are still trusted for accurate temperature measurement.

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Effect of heat on matter

When a solid is heated, its molecules vibrate faster and the cohesive forces weaken, causing it to melt into a liquid at its **melting point**. During melting, the temperature remains constant until all the solid has changed into liquid. Further heating makes the liquid particles move faster until the liquid changes into gas at its **boiling point**.

During boiling, the temperature also remains constant because the heat is used to overcome forces between molecules.

Heating also causes substances to expand. Gases expand the most, liquids expand moderately, and solids expand the least. Heat can also cause chemical changes such as combustion and decomposition. These effects are important in science, engineering, and construction because they affect how materials behave when heated.

Properties/qualities of a thermometer

The qualities of a good thermometer include:

Quick action – it should give temperature readings within a short time.

Sensitivity – it should detect even small changes in temperature.

Accuracy – it should give correct and reliable readings.

Low thermal capacity – it should absorb very little heat, so it does not affect the temperature of the body or substance being measured.

Wide temperature range – it should measure both low and high temperatures effectively.

Easy to read – the scale and liquid level should be clear and visible.

Atmospheric Temperature

Atmospheric temperature is the temperature of different layers of the Earth's atmosphere.

It is affected by factors such as solar radiation and altitude. The atmosphere has several layers: **troposphere, stratosphere, mesosphere, thermosphere, and exosphere**, each with different temperature changes. In the troposphere, temperature decreases with altitude, while in the stratosphere, it increases because of ultraviolet radiation absorbed by the ozone layer.

The Earth's average temperature has increased by about **2°F since 1850**, mainly due to human activities, affecting weather, climate, ecosystems, and human life. The atmosphere is made up of gases, water vapour, and aerosols such as dust and smoke. The ozone layer, found at about **20–25 km** above the Earth, protects living organisms from harmful radiation. At higher altitudes, lighter gases such as helium and hydrogen dominate, and some molecules form ions in the ionosphere.

Air humidity, or the amount of water vapour in the air, is also an important feature of climate.

Humidity is the amount of water vapour in the air. **Absolute humidity** is the mass of water vapour in a given volume of air or in a given mass of dry air, while **relative humidity** compares the actual amount of water vapour with the maximum amount the air can hold at saturation.

Clouds are formed when water droplets and ice crystals are suspended in the atmosphere. When these droplets become large, they fall as **rain, snow, or hail**. Very small rain droplets are called **drizzle**, while snow forms when air-cools below **0°C**.

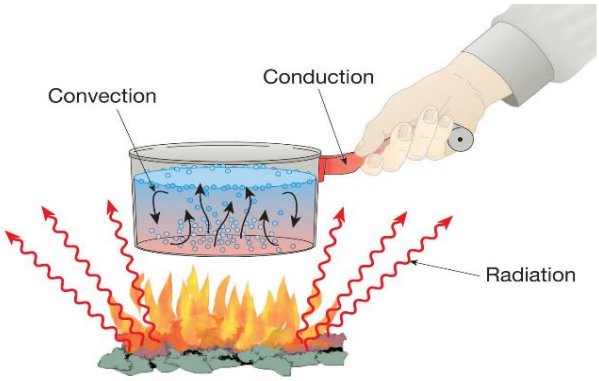
Atmospheric pressure is the force exerted by air on objects and the Earth's surface. It is caused by the weight of the air above a given point and is measured in **Pascals (Pa)**.

MASTERING PHYSICS

1.6 HEAT TRANSFER

Learning Outcomes

a) Understand how heat energy is transferred and the rate at which transfer takes place (u,s)
b) Understand what is happening at particle level when conduction, convection, and radiation take place and their application (k, u, v/a)
c) Understand that greenhouse effect and global warming are aspects related to heat transfer on the earth surface (u, v/a)



Introduction

Heat transfer is a fundamental concept in thermal engineering, focusing on the generation, use, and exchange of thermal energy between physical systems. It occurs due to temperature differences, with heat naturally flowing from hotter to cooler bodies. The three primary mechanisms of heat transfer are conduction, convection, and radiation. Conduction involves direct contact between materials, allowing heat to transfer through molecular interactions. Convection, on the other hand, occurs in fluids where warmer areas rise and cooler areas sink, creating a circulation pattern. Radiation is the transfer of heat through electromagnetic waves, allowing energy to travel through a vacuum. Understanding heat transfer is crucial in various applications, from designing efficient heating systems to improving industrial processes.

Heat is a form of energy, which is transferred from one place to another due to difference in temperature between the two points.

MODES OF HEAT TRANSFER

Activity: To describe the methods of heat transfer

Procedures

a) Study the figure adjacent that shows a person heating some liquid in saucepan over fire.
b) Identify the modes of heat transfer you can observe.
c) Discuss how each of the modes of heat transfer takes place, citing the states
d) of matter through which the processes take place.
e) Describe one application of each type of the above modes of heat transfer in
f) real life.
g) Present your findings to the rest of the class in a class discussion

Responses: There are three modes of heat transfer: conduction, convection and radiation. Conduction of heat is through solids, convection in fluids and radiation in gases

Heat is transferred in three different ways, namely; Conduction, convection and radiation **Conduction**
Conduction is the flow of heat from a region of high temperature to that of low temperature through matter without the movement of matter as a whole. e.g. in metals when they are heated their molecules vibrates faster along their mean position and pass on the heat to the molecules on the cooler parts of the metal. Electrons are always moving about the metal transfer from the hot to the cold end. Heat conduction is best in metals and worst in gases. Because of the distant spread of molecules in gases it is not highly possible to have heat transfer in gases

MASTERING PHYSICS

Activity: To design and investigate heat transfer in solids

Materials: A metal spoon, A beaker full of boiling water, Bunsen burner, and Wax

Procedures

a) This activity involves an investigation. You are required to set-up the apparatus by inserting a spoon inside water placed in a beaker placed on a source of heat (Bunsen burner).
b) Come up with a procedure and execute them to investigate the heat transfer in solids.
c) With the help of your colleagues or teacher carry out the investigation.
d) Write a report and discuss your findings in a class presentation.
e) How can the investigations be improved?
f) Besides the materials provided, which other locally available materials can be used to carry out the investigation?
g) Repeat the procedures with metal spoon waxed at the end. State the observation.
h) Why do you think the free end of the spoon gets hot after sometime? Explain.

Understand: *Solids transfer heat from one point to another. For instance, the free end of the spoon outside the beaker becomes hot. Heat energy is transferred from the inside to the outside through the metal spoon i.e. from a region of higher temperature to a region of lower temperature. This process of transfer of heat energy in solids is called conduction. Conduction is the transfer of heat from one substance to another that is in direct contact with it. In conduction there is no visible movement of the heated particles.*

Kinetic theory of conduction of heat

It should be noted that when temperature increases, the molecules have larger vibrations. This knowledge can help us understand the mechanism of conduction of heat. When the molecules at one end of a solid receive heat energy from the heat supply, they begin to vibrate vigorously. These molecules collide against the neighboring molecules and agitate them. The agitated molecules, in turn, agitate the molecules in the next layer and so on till the molecules at the other end of the solid are agitated. Thus, the heat is passed from one point to another till the other end becomes hot. Hence, in conduction, energy transfer takes place by vibration of the molecules. There is no actual movement of the heated particles.

Activity: To demonstrate that heat energy flows due to a temperature difference

Materials: An iron bar about metre long, drawing pins with holes drilled at equal intervals, Wax, Stand/clamp, water bath steps, and Bunsen burner

Procedures

a) Fill the holes of the iron bar partially with wax and insert the drawing pins into them.
b) At one end of the bar put a wooden screen and insert it in a water bath.
c) Heat the end points slowly and gradually.
d) After some time, note the temperature readings of the pins.
e) Are the drawing pins falling at the same time? Why do you think that is so?

Observations

The pin nearest to the Bunsen burner registers the highest rise in temperature, and the one farthest away registers the least temperature rise. When one end of the rod was inserted into boiling water, a large temperature difference is set up between the two ends and heat energy flowed from the region of higher temperature to that of lower temperature. Hence heat energy flows due to temperature difference and the pins fall slowly.

If the activity is repeated by replacing the hot water bath with a Bunsen burner flame (temperature of the bluish part of the flame is about 900˚C), the rise in temperature registered by each pin is higher. Hence

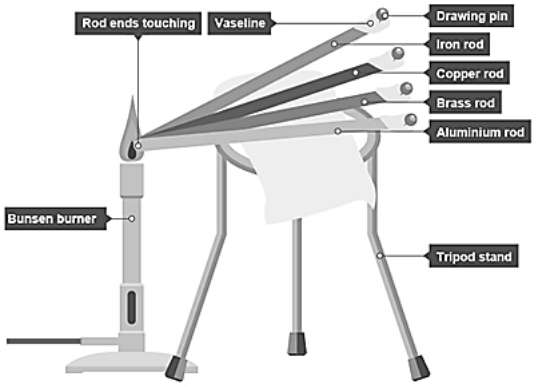
the higher the temperature difference, the higher the energy transfer and the pins fall this time faster. Heat energy flows in solids is due to temperature difference. The higher the temperature difference, the higher the energy flow.

Conclusions

- The conduction of heat and electricity in metals is influenced by several key factors. Pure metals typically exhibit superior conductivity compared to those with impurities.
- Impurities disrupt the flow of electrons, reducing overall conductivity.
- The physical dimensions of the metal, including its cross-sectional area and length, significantly affect conduction rates. A larger cross-sectional area allows more electrons to flow, enhancing conductivity, while a longer length can impede it.
- As temperature increases, the vibrational energy of atoms rises, which can scatter electrons and reduce conductivity. A greater temperature difference across the material can enhance heat transfer.

Activity: To show that heat transfer in solids depends on the material
Materials: A copper rod, Iron rod, Aluminium rod, 3 match sticks, Wax, Tripod stand, and A bunsen burner
Procedures

a) Take four rods, copper, aluminium, iron and brass rod of the same length and thickness.
b) Fix a light metal pin to one end of each rod using a little melted wax.
c) Place the rods on a tripod stand and heat the free ends of **different conductors** with a burner as shown in the figure. Observe what happens.
d) Which rod falls first? Which one falls last?
e) Why do you think they did not fall all of them at the same time?



#ZINTARA

Observation and conclusion

- The pins falls off from the copper rod first then aluminium and finally from the iron rod. When the temperatures of the other ends of the rods reach the melting point of wax, the pins falls off.
- The matchsticks do not fall off at the same time, because the energy transferred is not equal for all the rods.
- The pins from the copper rod is the first one to fall off showing that of the three metals, copper is the best conductor of heat followed by aluminium and then iron.
- A material or substance which has the ability to transfer heat through it is called a good conductor.
- Most metals are good conductors of heat e.g. copper etc. Substances like water, air, glass, wood, plastic, paper, etc. which have a poor ability to transfer heat are called poor conductors of heat. Poor conductors of heat are sometimes referred to as insulators

Explanation

- Copper is a better conductor of heat than aluminium and iron, so the pins on the copper strip fall first as heat travels faster.
- Iron is a poor conductor compared to copper and aluminium, so pins fall last on the iron strip.
- Heat conduction occurs when heat energy is transferred from the hot end to the cold end of a solid.

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- Conduction requires a solid medium because particles in solids are closely packed, allowing efficient transfer of heat energy.

Application of heat conduction

- Heat conduction is the transfer of heat through materials and is useful in daily life.
- In cooking, heat moves from the stove through metal utensils such as pans, helping food cook evenly.
- In medicine, hot water bags conduct heat to the body to relieve pain in muscles and joints. In electronics, heat conduction helps remove heat from computer processors and servers, preventing overheating and improving performance.

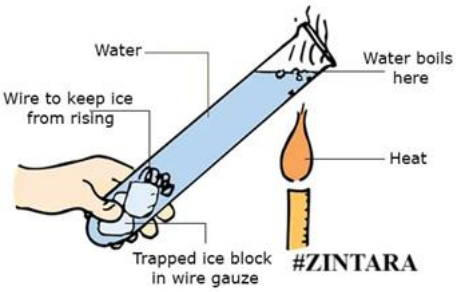
Explain why metals feel colder when touched than bad conductors

Metals feel colder than bad conductors such as wood or plastic do because they conduct heat very quickly. When touched, metals rapidly draw heat away from the skin, making them feel cold. Bad conductors transfer heat slowly, so they do not remove much heat from the skin and therefore feel warmer.
This happens because metals have free electrons that help transfer heat faster, while poor conductors, liquids, and gases transfer heat more slowly because their particles are farther apart and they lack free electrons.

Experiment to show that water is a poor conductor of heat

Procedure

a) Water is put in a test tube slanted as shown in the diagram above.
b) The upper part of the tube is heated and convection currents are seen at the top of the tube.
c) Water begins to boil from the top.



Observation and conclusion

Ice at the bottom remains not melted. This shows that water is poor conductor of heat.

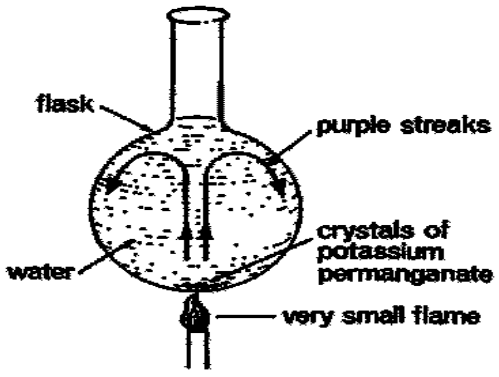
Heat transfer by convection

Activity: To observe convection current in water

Materials: A long straw, a crystal of potassium permanganate, A beaker containing water, and A bunsen burner

Procedures

a) With the help of a long straw, drop a small crystal of potassium permanganate to the right side of the bottom of a flask or a beaker containing water. What do you observe?
b) Heat the flask gently at the right side of the flask. Observe what happens.
c) What do you observe in the beaker when you continuously heat the water? Explain your observations.
d) Why do you think the potassium permanganate crystals behave in such manner?



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Observations

Coloured streaks are observed to rise from the bottom to the top. The crystal dissolves and the hot water of less density starts rising displacing the cold dense water down. The streams of physically moving warm liquid are called convection currents. Heat energy is transferred by the convection currents in the liquid. The transfer of heat by this current is called convection.

Kinetic theory of convection

Convection is involves heat transfer that occurs in fluids, including both liquids and gases. It's the movement of heated particles within the fluid, which creates a cycle of rising and sinking. When a fluid is heated, its molecules move faster and become less dense, causing them to rise. Equally, cooler, denser fluid sinks, leading to a continuous circulation pattern. This process is essential in various natural phenomena and everyday applications.

Convection is responsible for weather patterns, ocean currents, and even the functioning of household appliances like ovens and heaters. In a lava lamp, for example, the heated wax rises and cools, creating a mesmerizing display of convection in action.

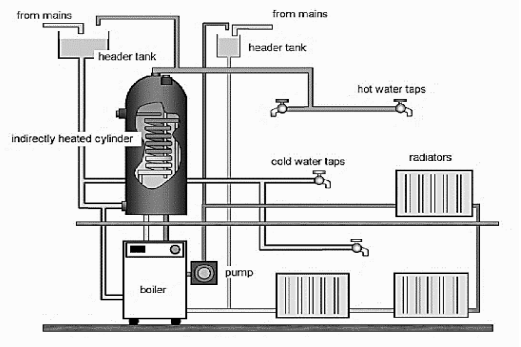
Explanation of convection currents

Convection currents are the continuous movement of liquids or gases caused by temperature and density differences. Warm fluid becomes less dense and rises, while cooler, denser fluid sinks to replace it. This movement helps transfer heat through the fluid.

They occur in boiling water, oceans, the atmosphere, lava lamps, and the Earth's mantle, where they influence weather, ocean currents, and tectonic plate movement.

Application of convection

In electric kettles: When warming a liquid, the heating element of an electric kettle is placed at the bottom.



Domestic hot water system:

Cold water is supplied to the boiler along the cold-water supply pipe.

On warming, the cold water in the boiler warms up, expands and becomes less dense, so it rises up.

As more cold water is supplied to the boiler, hot water is displaced upwards and supplied to the hot water taps along hot water pipes, and the cold water downwards.

The ventilation pipe is used to release steam.

Convection in gases

Activity: To investigate convection current in air

Materials: A box with a glass window, and two chimneys, candle, Smouldering pieces of wick

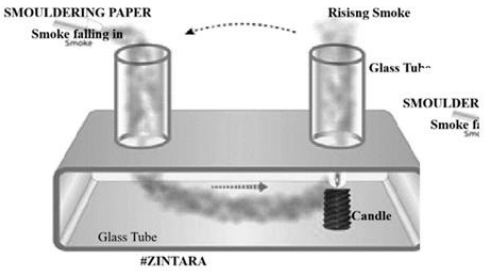
Procedures

A burning splint or piece of rope is blown out so that it is smoky.

When the smoky rope is held in air the smoke rises.

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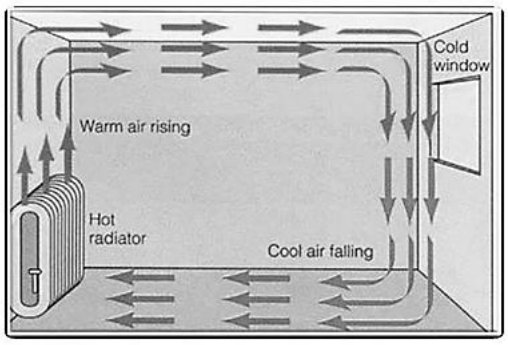
The rope is then held over both chimneys in turn as shown above. When the rope is held above the candle the smoke rises. When the rope is held above the other chimney the smoke is drawn down the chimney.
It then passes across the horizontal section and up through the chimney above the candle.



What is happening?
The candle flame heats the air around it. The hot air expands and increases in volume. The density of the air decreases, and it floats upwards, rising through the chimney. Cooler air is sucked in through the other chimney to replace the rising, warm air – convection current has been set up. The smoke from the smouldering rope shows the path of the cool air.

Applications
Early coal mines were ventilated with fresh air using a similar method.
Two shafts were dug down from ground level to the mine and a fire was lit beneath one of them.
As hot air rose upwards, fresh, clean, cool air was sucked down the other shaft and across the coal mine.
Mind you, lighting a fire in a coal mine did have some safety issues.

A convection current from a radiator



- A convection current in air close to a radiator
- Air close to the radiator is heated. It expands, becomes less dense and rises.
- It is replaced by the cooler, denser air which surrounds it.
- This air is in turn heated, expands becomes less dense and rises.
- The process continues, a convection current is set up and heat is transferred through the air and hence through the room.
- A radiator heats mainly by convection – not by radiation.

Application of convection in gases
Convection in gases is the transfer of heat through the bulk movement of air molecules, where warm air rises and cool air sinks due to differences in density. This principle is utilized across engineering, meteorology, and daily life.
Building Ventilation and Heating

- Hot gases from a fireplace are less dense than the outside air, causing them to rise up the chimney and draw fresh air into the room.
- Heaters are placed on the floor so that the heated air expands, becomes lighter, and rises, while cooler air sinks to be warmed.
- AC units are installed near the ceiling so that the cold, dense air they emit sinks naturally, cooling the entire room efficiently.
- Exhaust fans and ventilation vents are positioned near the top of walls to allow warm, stale air to escape.

Natural and Meteorological Phenomena

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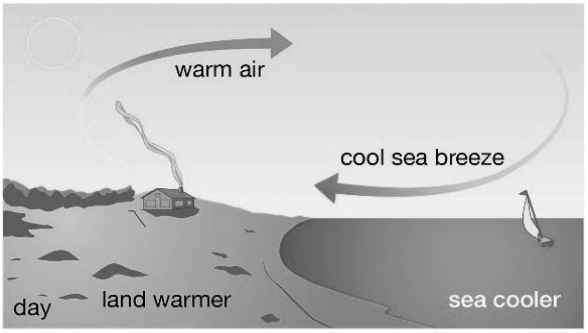
- ♠ During the day, the land heats up faster than the sea. The hot air over the land rises, and cooler air from the sea blows inland to take its place (Sea breezes).
- ♠ At night, the land cools down faster than the sea. The warmer air over the sea rises, drawing cooler air from the land out to the sea (Land breeze).
- ♠ Solar radiation unevenly heats the Earth's surface. This creates massive atmospheric convection currents that drive global winds and storm systems.
- ♠ Birds and glider pilots utilize "thermals" upward columns of warm, convecting air to stay aloft and gain altitude without expending energy.

Domestic and Industrial Appliances

- ♠ Convection ovens use a heating element and an internal fan to force the circulation of hot air, ensuring food cooks evenly.
- ♠ A burner inside the hot air balloon heats the air inside the balloon fabric. This air becomes less dense than the surrounding atmosphere, creating buoyant upward lift.

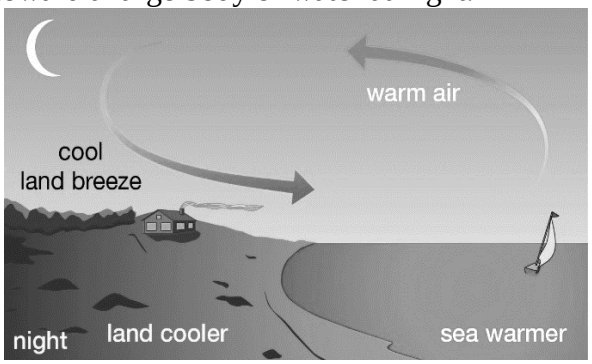
SEA AND LAND BREEZES

A sea breeze is a cool wind that blows from the sea onto the land during the daytime.



- ♠ The sun heats both the land and the water during the day.
- ♠ Land gets hot much faster than water because water takes longer to warm up.
- ♠ The air above the land gets warm, becomes light, and rises into the sky.
- ♠ Cooler, heavier air from above the sea rushes over to the land to take the place of the rising warm air

A land breeze is a local wind that blows from the land out toward a large body of water at night.



- ♠ After the sun sets, both the land and water begin to lose heat.
- ♠ Land cools down much faster than water because water has a higher heat capacity and retains heat longer.
- ♠ The air above the relatively warm sea stays warm and rises, creating a low-pressure area. Meanwhile, the air above the cooling land becomes cooler and denser, creating a high-pressure area.
- ♠ Cool, dense air moves from the high-pressure area over the land toward the low-pressure area over the water.

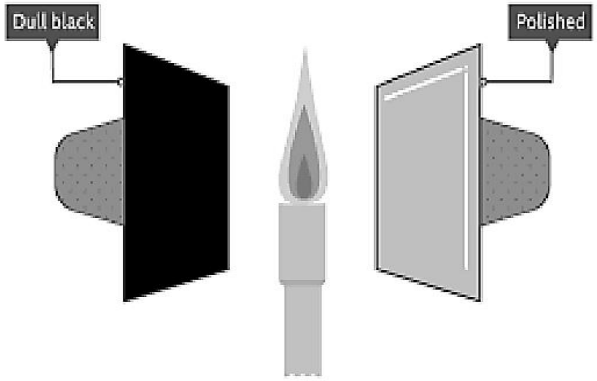
Ventilation: During hot days, rooms get heated up and it is why they are usually provided with ventilators above the floor, through which warm air finds its way out while fresh air enters through the doors and windows. In this way, a circulation of air convection is set up.

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RADIATION

Heat radiation is the transfer of heat from a hotter region to a cooler region by electromagnetic waves. It does not need a material medium, so heat can travel through air or even empty space.
For example, when you stand near a fireplace, you feel warm because heat reaches your body by radiation, not conduction or convection. Radiation can come from natural sources such as the Sun, cosmic rays, and radon gas, or from artificial sources such as X-ray machines. It is useful in medicine, astronomy, environmental science, and daily life, although some forms can be harmful if exposure is too high.

Activity: To demonstrate heat transfer by radiation
Materials: Thin tin lids painted black, Thumb tacks (match sticks), Wax, and A bunsen burner
Procedures Part
Absorbing radiation



When an object absorbs radiation, it heats up and its temperature will rise.
Two squares of aluminium are arranged as shown above. One is painted dull black; the other is polished and shiny. To ensure a fair test they are the same area and thickness and are placed the same distance from the Bunsen flame.
Two identical corks are stuck to the back of the plates using equal amounts of Vaseline or candle wax (control variables).
The Bunsen is lit. Quite quickly the cork attached to the black plate falls off. The cork behind the polished plate takes much longer to fall off.

Conclusion
Both plates receive the same quantity of radiation, but the black plate heated up more quickly. This tells us that a dull, black surface is a better absorber of radiation than a shiny, polished surface.
Key points
Dark matt surfaces are better at absorbing heat energy than light shiny surfaces.
Dark matt surfaces are better at radiating heat energy than light shiny surfaces.

Surface	Absorption	Emission
Dull, matt or rough	Good absorber of heat radiation	Good emitter of heat radiation
Shiny	Poor absorber of heat radiation	Poor emitter of heat radiation

Applications of heat radiations
Heat radiation (thermal radiation) transfers energy via electromagnetic waves without needing a medium.
Every day and Industrial Applications

- ♠ Solar panels and thermal collectors capture radiant energy from the sun to generate electricity or heat water.
- ♠ Cooking pan bottoms are often painted black because dark, dull surfaces are excellent absorbers of radiant heat.
- ♠ People wear white or light-colored clothes in summer to reflect radiant heat, and dark clothes in winter to absorb it.

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- ♠ Vacuum Flasks (Thermos) are silvered; shiny inner walls reflect thermal radiation back inward to minimize heat loss or gain.
- ♠ Satellites and space suits use reflective multi-layer insulation and radiating panels to manage extreme temperatures in a vacuum.
- ♠ Factories use infrared radiation for rapid drying, curing paints, and annealing metals.

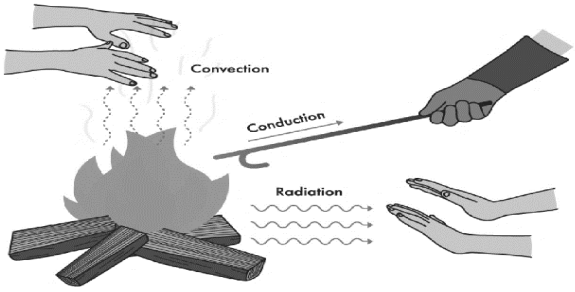
Medical and Safety Applications

- ♠ Thermal imaging cameras detect infrared radiation emitted by objects to locate people in the dark or identify building heat leaks.
- ♠ Medical tools measure skin radiation variations to assist in non-invasive diagnostics.

Radiators are often painted with white gloss paint, but they would be better at radiating heat if they were painted with matt black paint. They are painted white to make them look nicer. However, despite their name, radiators actually transfer most of their heat to a room by **convection** not radiation. So, radiators are the **wrong colour**, and have the **wrong name**.

Normally heaters need to be red hot before they are any good at heating by radiation

Procedures Part B



a) Take two thin tin lids, one with shiny inner side and the other with the inner side painted dull black.
b) Stick metal thumb tacks (or match sticks) on the outside of each lid using a little molten wax.
c) Keep a bunsen burner flame midway between the lids as shown in the figure.
d) Watch closely to and compare what happens to the two thumb tacks. Explain your observation.

Observations and Conclusion

As discussed in the case of the fireplace, the energy from the flame reaches the tin lid and the wax by a different mode other than conduction and convection. This third mode of heat transfer is called radiation. Radiation is the emission or transmission of energy in the form of a wave or particles through a material or space. Heat transfer from the sun travels through empty space (vacuum) and reaches the Earth. This energy is transferred by radiation. The surfaces of all luminous bodies emit radiation. A human face also emits some mild radiations.

While conduction and convection need a medium to be present for them to take place, radiation can take place without a medium. The amount of heat energy radiated depends upon the temperature of the body. In Activity, if the Bunsen burner is replaced by a candle flame, it will take a longer time for the wax to melt. The temperature of the candle flame is lower than that of a Bunsen burner. Heat transfer can take place without contact or in a vacuum. This method of heat transfer is called radiation.

Good and Bad absorbers of heat radiation

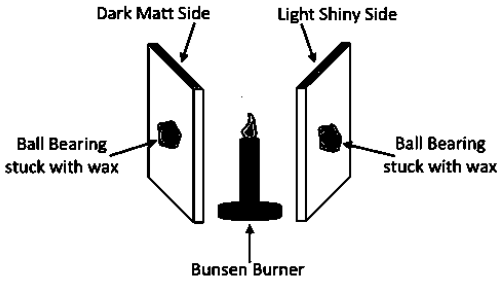
Heat radiation absorption varies significantly among materials, influencing thermal comfort and energy efficiency. Good absorbers, such as matte black surfaces, excel at absorbing and emitting heat. This is why people often wear dark clothing in winter; it helps retain warmth by absorbing heat radiation effectively. Shiny and light-colored surfaces, like white or silver, are poor absorbers and emitters of heat. They reflect most thermal radiation, making them ideal for hot weather, as they help keep the body cool. The relationship between absorption and emission is crucial; materials that are good at absorbing heat tend to be equally proficient at emitting it. Heat radiation absorption varies significantly among different

materials. Good absorbers, such as matte black surfaces, excel at absorbing and emitting thermal radiation. This is due to their strong coupling with the radiation field, allowing them to reach thermal equilibrium quickly.

Wearing dark clothing in winter helps retain warmth, as these fabrics absorb heat effectively. Poor absorbers, like shiny and light-colored surfaces, reflect most thermal radiation. This is why bright white clothes are recommended on hot days; they reflect sunlight, keeping the wearer cooler. Metals, while good conductors of heat, can also be poor absorbers if they have shiny surfaces, as they reflect visible light and thermal radiation.

Experiment about Heat Radiation

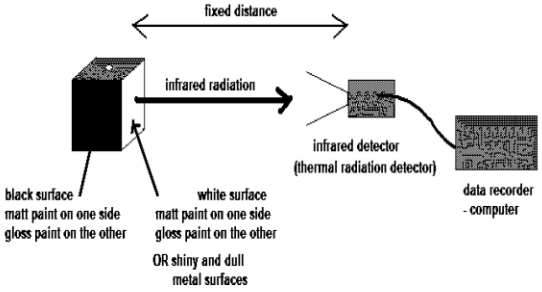
Some surfaces absorb heat radiation better than others as illustrated in the experiment.



- A source of heat is placed midway between a polished and dull surface.
- Cork is fitted with wax on the two surfaces and the experiment left standing for a few minutes.
- After a few minutes, the wax on the dull or black surface begins to melt and cork eventually falls off while the one on the polished surface remains not melted for some time.
- This shows that a dull black surface is a good absorber of heat radiation while a polished surface is a poor absorber of heat radiation because shiny surfaces reflect heat radiation instead of absorbing it.

Comparison of radiation of different surfaces

Requirements: - A Leslie tube



Thermopile is an instrument that converts heat energy into electrical energy. One side of the tube is dull black, the other is dull white and the last one is made shiny polished.

The tube is filled with hot water and radiation from each surface is detected by a thermopile. When the radiant heat falling on the thermopile is much, it registers a large deflection of the pointer.

With different surfaces of the tube made to face the thermopile one at a time, the following observations are noted:

The greatest deflection at the pointer is obtained when the dull black surface faces the thermopile. The least deflection is obtained when a highly polished shiny surface faces the thermopile. The dull surface is a good radiator or emitter of heat radiation while a polished shiny surface is a poor emitter of heat radiation.

Application of radiation

Heat transfer by radiation is the movement of thermal energy through electromagnetic waves without needing any particles or medium.

Common Applications

- Solar panels capture radiant energy from the sun to create electricity or heat water.
- Satellites and spacesuits use reflective shields and radiators to manage extreme heat in a vacuum.
- Restaurants and outdoor spaces use radiant heaters to warm people and objects directly instead of heating the air.

- Shiny, silvered inner walls reflect thermal radiation back inside to keep liquids hot or cold.
- Pipes or electric coils under a floor emit infrared waves that directly warm the room and objects above.

Black and dull surfaces

Black and dull surfaces are the best absorbers and emitters of thermal (infrared) radiation.

- Good Absorbers take in almost all the radiant heat that hits them rather than reflecting it.
- Good Emitters release stored heat energy much faster than shiny or light-colored surfaces.
- Poor Reflectors bounce back very little light or infrared radiation.

Examples

- A black car heats up much faster under the sun than a white car because it absorbs more radiant energy.
- Home radiators and refrigerator cooling fins are often painted dark or matte to maximize heat release.

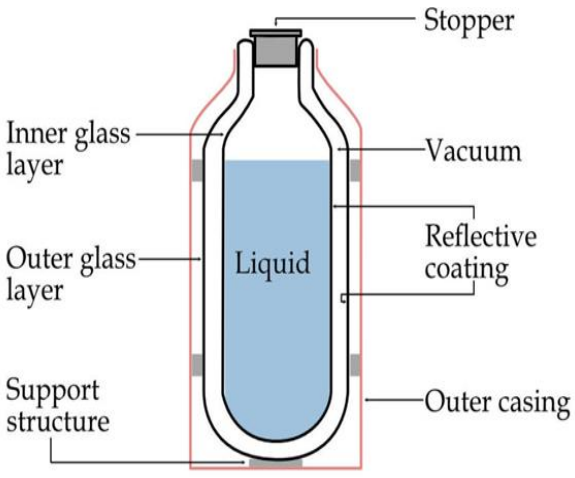
Polished and white surfaces

- Polished surfaces reflect light evenly at consistent angles because they are smooth and free of irregularities.
- White surfaces scatter light in multiple directions due to their rough texture, which creates a diffuse look rather than a mirror-like shine.
- Texture determines how light behaves, making polished surfaces look sharp and reflective, while flat surfaces look dull.
- Reflective colors like white and silver effectively block or retain heat, which is why they are used on summer clothing, buildings, roofs, fuel tanks, and teapots.

Applications of heat transfer

The vacuum flask

A vacuum flask is an insulating storage vessel that keeps hot liquids hot and cold liquids cold by preventing heat transfer.



How It Works

- Double walls: It uses two walls, usually made of glass or stainless steel, with an empty space or near vacuum-sealed between them.
- No conduction or convection: The vacuum stops heat from moving through the air between the inner and outer walls.
- Reflecting heat: The inner walls often have a reflective silver coating to block heat from escaping via radiation.
- Sealed lid: A tight lid stops heat from getting in or out from the top.

Common Uses

- In beverages for keeping coffee, tea, or water hot or cold during travel, work, or school.
- In science for storing liquefied gases like liquid nitrogen at very low temperatures.

- In food for transporting hot meals or cold items for lunch.

Through the function of the various parts of the vacuum flask, heat loss by conduction, convection and radiation are minimized.

- The cork. This minimizes heat loss by conduction and convection,
- Vacuum prevents heat loss by conduction and convection,
- Silvered walls minimize heat loss by radiation,
- Vacuum seal keeps air out of the vacuum,
- Asbestos anti-shock pad keeps the walls apart to avoid damage,

The thermos flask becomes useless when the vacuum seal breaks, because the vacuum will no longer exists and heat loss by conduction and convection will occur.

Choice of clothes

Clothing affects heat transfer through conduction, convection and radiation.

- During cold conditions, thick woolen clothes are preferred because they trap air, which is a poor conductor of heat and therefore reduces heat loss.
- During hot conditions, white or light-colored clothes are preferred because they reflect most heat radiation and keep the body cooler.
- During cold sunny conditions, dull black clothes absorb more heat radiation and help keep the body warm.
- During ironing, heat is transferred mainly by conduction from the hot metal iron to the cloth, so suitable heat-resistant fabrics should be used.

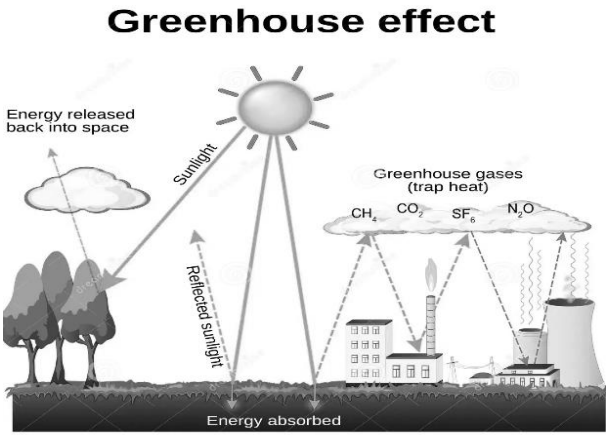
Therefore, the choice of clothing depends on the environmental conditions and the desired control of heat transfer

GREENHOUSE EFFECT AND GLOBAL WARMING

The greenhouse effect is the natural process where gases in a planet's atmosphere trap the sun's heat, keeping the surface warm enough to support life.

How It Works

- Sunlight passes through the atmosphere and reaches the Earth.
- The Earth's surface absorbs this energy and releases it back as heat (infrared radiation).
- Greenhouse gases catch and bounce some of this heat back toward the ground, stopping it from escaping straight into space. Main Greenhouse Gases include; Carbon dioxide, Methane, Water vapor, Nitrous oxide



Why It Matters

Without this natural layer, Earth would be freezing and empty, with an average temperature around -18°C instead of a comfortable 15°C. However, human actions like burning fossil fuels add extra gases into the air, trapping too much heat and causing global warming

Role of heat transfer in the greenhouse effect

Heat transfer drives the greenhouse effect through a continuous cycle of solar absorption, surface re-emission, and atmospheric trapping by greenhouse gases.

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How Heat Transfer Drives the Greenhouse Effect

- Sunlight travels through space as shortwave radiation (visible light) and strikes Earth's surface, warming the ground and oceans.
- The warmed Earth absorbs this solar energy and radiates it back upward as longwave radiation (infrared waves or heat).
- Greenhouse gases—such as carbon dioxide, water vapor, and methane—absorb this outgoing infrared radiation and re-emit it in all directions, sending a significant portion back down to the surface.
- Once the lower atmosphere and surface are warmed by this trapped radiation, conduction (direct contact with air molecules) and convection (rising warm air currents) distribute the thermal energy vertically through the lower atmosphere.

Global Warming

Global warming is the long-term rise in Earth's average surface temperature caused largely by human activities that release heat-trapping greenhouse gases.

Causes

- Using coal, oil, and gas for electricity, heat, and transport releases massive amounts of carbon dioxide.
- Cutting down trees reduces the planet's ability to absorb carbon dioxide, leaving more of it in the air.
- Farming practices, livestock, and factory production release powerful greenhouse gases like methane and nitrous oxide.

Effects

- Polar ice caps, glaciers, and permafrost are shrinking rapidly.
- Melting ice and warmer ocean waters cause sea levels to rise, threatening coastal communities.
- Heatwaves, severe droughts, heavy rainfall, and intense storms are becoming more frequent and severe.

How global warming relates to heat transfer

Global warming is fundamentally an imbalance in the Earth's radiative heat transfer, driven by how greenhouse gases alter the flow of energy into and out of the atmosphere.

The Role of Radiation

- The sun heats the Earth by sending energy through space via electromagnetic radiation.
- The Earth absorbs this solar radiation and emits it back toward space as longer-wavelength infrared radiation (heat).
- Greenhouse gases like carbon dioxide and methane absorb and re-emit this outgoing infrared radiation.

Instead of escaping freely into space, a large portion of this heat is redirected back down to the Earth's surface, raising the planet's average temperature.

Conduction and Convection in the Atmosphere

- Once the greenhouse effect warms the Earth's surface, heat moves to the lowest layer of air via direct physical contact (conduction).
- This heated air expands, becomes less dense, and rises into the atmosphere through convection currents.

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This circulating fluid movement distributes the trapped thermal energy throughout the global weather systems and up into higher atmospheric layers

Consequences of Global Warming and Heat Transfer

Global warming changes how Earth transfers and traps energy, leading to severe environmental and societal consequences.

Heat Transfer Mechanisms

- The sun sends shortwave energy to Earth. Earth absorbs this and releases it back as longwave infrared radiation (heat).
- Heat moves through the atmosphere and oceans via warm air/water currents (convection) and direct contact with the surface (conduction).
- Greenhouse gases like carbon dioxide and methane trap outgoing infrared radiation, acting like a thermal blanket that keeps the lower atmosphere warm. Human activities have intensified this natural process.

Consequences of Global Warming

- Earth's average surface temperature has risen by over 1°C since the late 19th century, resulting in more frequent and intense heatwaves.
- Glaciers and polar ice sheets are melting rapidly, which could raise sea levels by up to 1 meter or more by 2100 and displace hundreds of millions of people.
- Excess heat and fresh water from melting ice weaken major heat-transfer currents like the Atlantic Meridional Overturning Circulation (AMOC), threatening future weather stability.
- Storms are intensifying, droughts are lengthening, and marine ecosystems face massive damage, including widespread coral bleaching.
- Lower crop yields, infrastructure damage, and the spread of vector-borne diseases threaten global health and economic stability.

Disruption of Climate Systems

Disruption of climate systems refers to the large-winning, rapid shifts in global temperature, precipitation, and wind patterns driven primarily by human-emitted greenhouse gases.

Causes

Fossil Fuels: Burning coal, oil, and gas accounts for roughly 68% of greenhouse gas emissions.
Deforestation: Clearing forests eliminates vital carbon sinks, contributing to land-use emissions.
Industrial Agriculture: Livestock and synthetic fertilizers release massive amounts of methane and nitrous oxide.

Major Effects

- Global temperatures have risen by roughly 1.1°C to 1.5°C compared to pre-industrial levels.
- Heatwaves, severe droughts, heavier rainfall, and stronger storms occur with greater frequency and intensity.
- Melting glaciers and ice sheets have raised global sea levels by 8 to 9 inches, threatening coastal infrastructure.
- Critical ocean currents and polar systems face potential disruptions that could abruptly alter regional weather patterns for centuries

Examination item:

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A homeowner in Miami, Florida, is retrofitting their coastal house to improve energy efficiency amid increasingly hot summers and frequent heat waves linked to climate change. The property is close to the Atlantic Ocean, benefiting from daytime sea breezes that help cool the indoors naturally, but experiencing warmer nighttime land breezes that raise humidity levels. To cut down on air conditioning costs and lower greenhouse gas emissions, the retrofit includes upgrades like better insulation, ventilation systems, and solar features. Local deforestation for urban development has also raised nearby temperatures, amplifying concerns about how everyday heat management ties into global environmental issues.

Task: Based on the knowledge of physics,

(i) Explain the main mechanisms of heat transfer and relate them to practical elements of the home retrofit and broader climate challenges

(ii) Describe how heat energy is transferred in each mechanism and identify at least two factors that influence the rate of heat transfer for each. Provide an example from the retrofit, such as installing insulated walls or double-glazed windows, to show how managing these rates can reduce energy consumption.

(iii) At the particle level, explain the processes during conduction convection and radiation. For each, discuss a real-world application.

(iv) Describe how solar radiation interacts with Earth's surface and atmosphere, and explain how activities in the Miami area, intensify this process, leading to hotter local breezes and altered weather. Propose one practical mitigation step, that uses heat transfer principles to help address global warming.

S1.7 EXPANSION OF SOLIDS, LIQUIDS, AND GASES



Learning Outcomes

a) Understand that substances expand on heating, and recognize some applications of expansion (u,s)

b) Understand the effect and consequences of changes in heat on volume and density of water (u,s)

c) Know about the anomalous expansion of water between 0ºC and 4 ºC and its implications (u, k,v/a)

Introduction

- When substances are heated, their particles (atoms or molecules) gain kinetic energy and move more rapidly. This increased motion causes the particles to push farther apart from one another, leading to an increase in the substance's volume (**thermal expansion)**.
- Thermal expansion occurs because, as temperature raises, the bonds between the particles in solids, liquids, or gases allow for more movement.
- In solids, this movement is limited, but they still expand slightly. Liquids and gases, having weaker bonds, expand more significantly.
- The increase in size on heating of a substance is called **expansion.** On cooling, substances decrease in size. The decrease in size on cooling of a substance is called **contraction.**

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Solids (like metals) expand when heated, but the expansion is usually small. Metals exhibit a fascinating property known as thermal expansion, which causes them to increase in size when heated. This occurs because the heat energy causes the atoms within the metal to vibrate more vigorously, leading to an increase in the distance between them. While most metals expand when heated, some alloys exhibit unique behaviors, such as negative thermal expansion, where they contract instead.

When a solid (a metal) is subjected to heat, it: (a) Increases in length (Linear Expansion). (b) Increases in volume (Volume Expansion). (c) Increases in area (Surface Expansion).

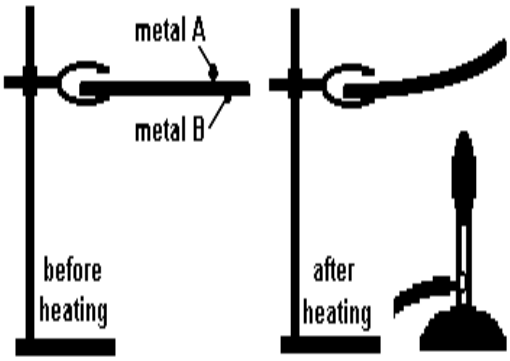
Liquids expand more noticeably than solids. A common example is mercury in a thermometer rising as it heats up.

Gases expand the most because their particles are far apart and free to move. This is why bridges have expansion joints, and why sealed containers can burst if heated too much, as the gas inside expands.

When heated, solids increase in size in all directions. Expansion of solids can be illustrated using a metal ball with a ring. The metal ball passes through the ring when it is cold but when heated, the ball does not pass through the ring any more, showing that it has expanded. It passes through the hole again when it cools, meaning that the metal contracts when it loses heat.

Activity: To compare rates of expansion and contraction of different solids

Materials: Thin metal rods of different metals, Source of heat, and G - clamp



a) Clamp one end of a long thin metal rod tightly to a firm support, with the end of the rod resting on a roller fitted with a thin pointer.

b) Heat the metal rod for some time. Observe and explain what happens to the rod.

c) Remove the burner and allow the rod to cool. What happens to the rod again after cooling? Does it reduce in size? Explain why.

d) Repeat the activity with other thin rods of different materials. Observe and explain what happens, accounting for any differences

Observation and conclusion

- ♠ The rod deflects in the anti-clockwise direction on heating and in the clockwise direction on cooling. The rod bends to different extents depending on the material.
- ♠ On heating, there is an increase in length (linear expansion) of the rods. The expanding rod moves upwards making it to deflects in a clockwise direction.
- ♠ On cooling, the rod contracts and decreases in length. The contracting rod moves downwards hence its deflects in the opposite direction (anticlockwise direction).
- ♠ Different solids (metals) expand and contract to different extents when heated by the same quality of heat.

Demonstrations of area and volume expansions

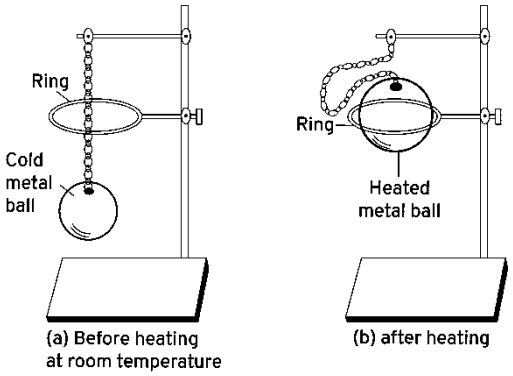
Activity: To demonstrate volume and surface expansion and contraction using the ball and ring apparatus

Materials: ball and a ring, Bunsen burner, and A bowl of cold water

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Procedure

a) Move the ball in and out of the metal ring at room temperature. What do you observe?
b) Keep the metal ball away from the ring and heat it for some time.
c) Try to pass the ball through the ring. Does the ball pass through the ring this time? Why?
d) Cool the metal ball in a bowl of cold water and try to pass the ball through the ring again. Does it pass through the ring? Explain why.



Observation and conclusion

- A ball and ring apparatus consists of a ball and ring both made of the same metal. At a room temperature, the ball and the metal ring have approximately the same diameter, thus the ball just passes through the ring.
- On heating, the metal ball expands. There is an increase in volume and surface area of the ball.
- As a result, the ball cannot pass through the ring.
- On cooling, contraction occurs and the original volume is regained. The ball can now pass through the ring again. This activity shows volume and surface area expansion and contraction in solids. Most solids expand on heating and contract on cooling.

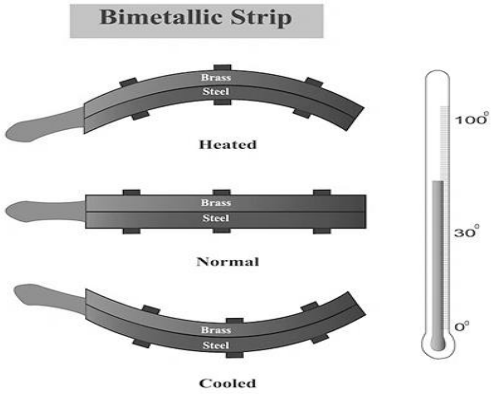
Why solids expand on heating?

According to particle theory of matter, Molecules of a solid are closely packed and are continuously vibrating about their fixed positions. When a solid is heated, the molecules vibrate with larger amplitude about the fixed position. This makes them to collide with each other with larger forces which pushes them far apart. The distance between the molecules increases and so the solid expands. The reverse happens during cooling.

Mechanism of contraction and expansion

Metals exhibit varying rates of expansion when subjected to the same temperature increase, a phenomenon that can be effectively demonstrated through a bimetallic strip experiment. This strip consists of two different metals, such as copper and iron, bonded together.

When heated, each metal expands at its own rate due to their distinct coefficients of thermal expansion. As a result, the strip bends, illustrating the concept of differential expansion.



Another engaging experiment involves heating a metal ball and a ring. When both are heated to the same temperature, the ball expands enough to no longer fit through the ring, displaying how thermal expansion affects solids. This experiment highlights the intuitive understanding of expansion, as the ball can pass through the ring when cooled.

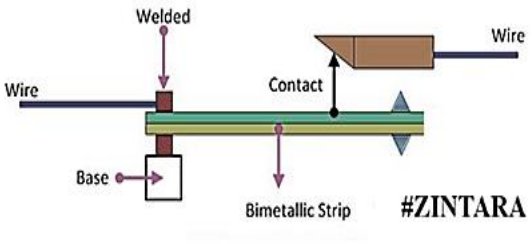
Different metals expand at different rates when equally heated, this can be shown using a metal strip made of two metals such as copper and iron bounded tightly together (bi-metallic strip) when the bi-metallic strip is heated, the copper expands more than iron and the strip bends.

Activity: To demonstrate the bending effect of expansion and contraction
Materials: bimetallic strip and Bunsen burner

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Procedure

a) Observe a bimetallic strip at a room temperature.
b) Take the bimetallic strip with the brass strip at the top and heat it with a bunsen burner flame for some time.
c) Observe what happens. Explain the observation. Sketch the shape of the bimetallic strip after heating.



d) Remove the flame and allow the bar to cool to a room temperature. What happens to the bimetallic strip? Sketch its shape after cooling.
e) Discuss with your friend what will happen if the bar is cooled below room temperature. Sketch the strip at that temperature

Observation and Conclusion

- When the bimetallic strip is heated, it bends downwards with the brass strip on the outer surface of the curvature. When the flame is removed and the bar left to cool to room temperature, the bar returns back to its initial state (straight).
- If the bar is cooled below room temperature, it bends upwards with the iron strip underneath.
- As the bimetallic strip is heated, brass expands more than iron. The large force developed between the molecules of brass forces the iron strip to bend downwards.
- On cooling below a room temperature, the brass contracts more than iron and the iron strip is forced to bend upwards. The force developed during expansion or contraction causes a bending of the metals.

Uses of a bimetallic strip (application of expansion of solids)

A bimetallic strip bends when heated or cooled because it joins two metals with different expansion rates, turning temperature changes into mechanical movement.

1) Two metals strips of different thermal conductivities such as brass and steel are joined together.
2) One metal expands or contracts faster than the other when the temperature changes.
3) Heating causes the strip to curve toward the metal with the lower expansion rate. Cooling causes it to bend the other way.

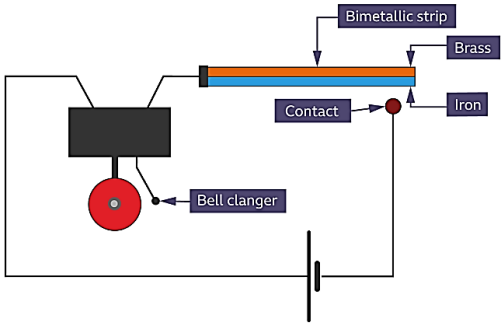
Common Uses

- In thermostats are found in irons, refrigerators, and room heaters to turn the power on and off. The strip bends as it gets hot, breaking the electrical circuit.
- In Fire alarms, Heat from a fire bends the strip until it touches an electrical contact, which completes the circuit and sounds the alarm.
- In Circuit breakers, Excessive electrical current overheats the strip, causing it to bend and cut off the power to protect household wiring.
- In Bimetallic thermometers; A coiled strip moves a pointer on a dial to show the temperature in ovens or industrial settings.
- Used in vintage clocks and marine chronometers to balance out time errors caused by changing weather temperatures.

Fire alarm: When there is a fire; the temperature rises, the brass expands more than the iron and will be on the outside of the curve, the strip bends down and touches the contact.
And the electric circuit is complete and the bell rings. Heat from the source makes the bi metallic strip bend and completes the electric circuit and the bell rings.

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Thermostat: This device makes temperature of appliances or room constant. The thermostat uses a bimetallic strip in the heating circuit of a flat iron.
When the flat iron reaches the required temperature, the strip bends and breaks the circuit at the contact and switches off the heater. The strip makes contact again after cooling a little and the heater is on again.
If the control knob screwed, the strip has to bend more to break the circuit and this needs higher temperature.



Disadvantages of thermal expansion
Thermal expansion causes structural damage, material failure, and operational hazards when objects change size due to temperature shifts.
Common Disadvantages

- **Buckling of Railway Tracks:** Steel tracks expand in hot weather. If workers leave no space, the tracks bend and can cause train accidents.
- **Cracking Glassware:** Pouring hot liquid into a thick glass causes the inner walls to expand faster than the outer walls, making the glass crack.
- **Sagging Power Lines:** Electric and telephone wires stretch and sag during hot days. They can snap when they contract and tighten during cold weather.
- **Pipe Bursts:** Metal pipes carrying hot steam or boiling water can crack or burst from high thermal stress.
- **Bridge and Building Damage:** Steel beams on bridges expand in the heat. This creates dangerous pressure that can crack concrete or bulge walls if engineers do not use rollers or expansion joints

Thermal expansion and contraction in liquids

Thermal expansion and contraction in liquids is the increase or decrease in their volume when they are heated or cooled.
Workings

- **Heating (Expansion):** Heat gives liquid particles more kinetic energy. They move faster and push slightly further apart because intermolecular forces are weak. The liquid takes up more volume.
- **Cooling (Contraction):** Removing heat lowers the kinetic energy. Particles slow down and move closer together. The volume of the liquid decreases.
- **Volume Only:** Liquids do not have a fixed shape. They only experience volume expansion, unlike solids, which can also expand in length or area.

Characteristics

- Liquids expand more than solids for the same temperature change because their internal bonds are looser.
- When heating a liquid in a glass flask, the liquid level may shortly drop first. This happens because the solid glass container gets the heat first and expands before the liquid does.
- Different liquids (like water, alcohol, and methylated spirit) expand at different rates due to varying internal bond strengths.

Examples

- Liquid Thermometers: Mercury or alcohol inside a glass tube expands and rises when it gets warm, showing a higher temperature.

- ♠ Cooling Systems: Car coolant expands as the engine heats up, which is why overflow reservoirs are necessary.

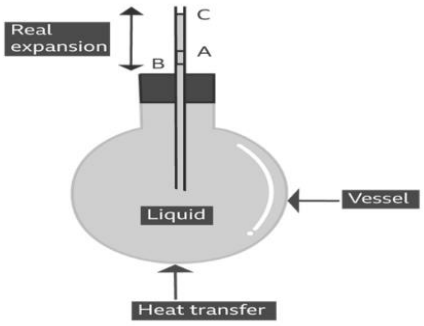
Experiment to demonstrate expansion in liquids

Activity: To demonstrate expansion and contraction in liquids

Materials: A glass flask, Coloured water, Tripod stand, A rubber stopper, Bunsen burner, Wire gauze, and long glass tubing

Procedures

a) Fill a glass flask with coloured water.
b) Fit the flask with a rubber stopper carrying a long narrow glass tubing. Note the initial level of water in the glass tube before heating.
c) Heat the water in the flask. What happens to the level of water at A immediately?
d) The heating starts and after a few minutes? Explain your observation.

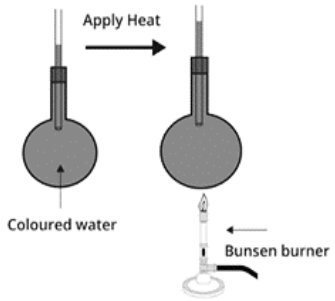


Observation and conclusion

In this activity, it was observed that at first the level of the coloured water in the tube drops to level B and then rises to level C. On heating, the glass flask is heated first and expands i.e. its volume increases. The level of water immediately drops from A to B. On continuous heating, water starts to expand hence water level rises up the tube from B to C. If the setup is allowed to cool below room temperature, the water level drops to a point lower than A and B. This shows that liquids expand on heating and contract on cooling.

Why liquids expand on heating?

Like solids, liquids expand when they are heated, but because the bonds between separate molecules are usually less tight, liquids expand more than solids. The water level in the capillary tube is initially at A. When the water is heated the liquid level initially falls to level B, before rising to level C and above. When the glass flask and capillary tube are first heated, they expand. This causes the volume of the flask to increase, and the liquid level falls to B. However, the liquid is quickly heated and starts to expand. It expands more than the solid glass and so the water level rises back to A and then up to, and beyond, C.



This shows that:

- Liquids expand when heated
- Liquids expand more than solids

This is the principle behind liquid-in-glass thermometers. An increase in temperature results in the expansion of the liquid which means it rises up the glass. The liquid used is usually alcohol or mercury.

Molecules are loosely packed in liquids. The force of attraction between the molecules is weaker than in solids. The molecules move freely in the liquid. On heating, the speed of the molecules increases. The collisions between the molecules increases the distance between them causing the liquid to expand.

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Water as matter

Water is considered matter because it has mass and takes up space. Water is made of two hydrogen atoms and one oxygen atom. Tiny particles called molecules make up every drop. Changing states does not change its chemical recipe.

The Three States of Water

Water is unique because it naturally exists in three states on Earth:

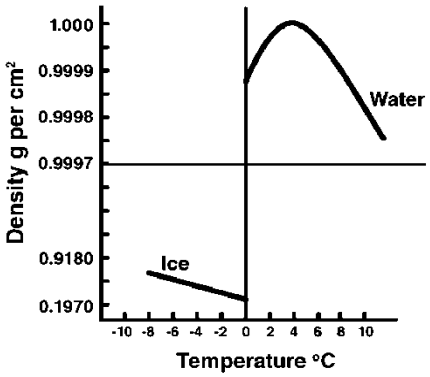
- Solid (Ice): Cold temperatures (below 0°C or 32°F) freeze water into a hard shape. Its molecules stay fixed in place.
- Liquid (Water): At normal room temperatures, water flows and takes the shape of whatever container holds it. Its molecules move around while staying close together.
- Gas (Vapor or Steam): Heating water to 100°C (212°F) turns it into an invisible gas or steam that fills the air. Its molecules move fast and spread far apart.

Changing States

- Melting and Freezing: Adding heat melts ice into liquid; removing heat freezes liquid into ice.
- Evaporating and Condensing: Heating liquid turns it into a gas (evaporation); cooling that gas turns it back into tiny liquid drops (condensation).
- Physical change only: These shifts change how the molecules act, but not what they are made of.

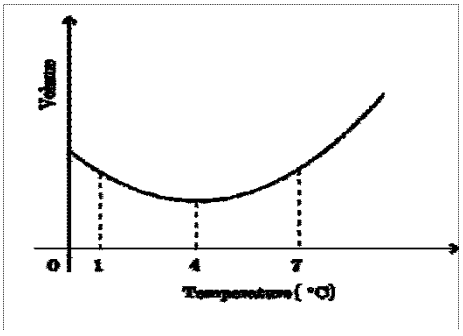
Anomalous Expansion of Water

The anomalous expansion of water is the unusual behavior where water expands instead of contracting when cooled from 4°C down to 0°C. While most liquids shrink and increase in density, as they get colder, water reaches its maximum density at 4°C and expands into a less dense, open crystalline structure as it nears freezing.



Why It Happens

- Normal Cooling (Above 4°C): Water acts like other liquids; as it cools, its kinetic energy drops and molecules pack closer together, reducing volume.
- The Turning Point (At 4°C): Water reaches its smallest volume and highest density (1.0 g/cm³).
- The Anomaly (0°C to 4°C): Hydrogen bonds force molecules into a wide, open hexagonal cage-like shape. This increases the volume and lowers the density, which is why ice floats.



Real Effects

- **Survival of Aquatic Life:** Lakes and ponds freeze from the top down. The densest water sinks to the bottom at 4°C, keeping a liquid layer underneath the floating ice sheet where fish and plants can survive.
- **Frost Wedging:** Water seeps into cracks in rocks. When it freezes and expands, it acts like a wedge, breaking the rocks apart over time.
- **Bursting Pipes:** Water trapped in household pipes expands during freezing winters, generating immense pressure that can rupture metal or plastic pipes.

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Application of anomalous behavior of water

- **Survival of Aquatic Life:** Lakes and ponds freeze from the top down. The densest water sinks to the bottom at 4°C, keeping a liquid layer underneath the floating ice sheet where fish and plants can survive.
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Disadvantages of anomalous behavior of water

- **Destruction of Plumbing Systems**
  Water trapped inside household or city pipes expands when freezing, building immense pressure that ruptures copper, plastic, and iron lines.
  Thawing pipes reveal major leaks, leading to expensive plumbing bills and severe indoor water damage.
- **Severe Vehicle and Engine Damage**
  If pure water freezes inside a car's cooling system, its expansion can crack the metal engine block or radiator.
  Motorists must use chemical coolants (glycol) to artificially lower the freezing point of water and prevent this expansion.
- **Damage to Infrastructure and Roads**
  Rainwater seeps into asphalt cracks during winter. As it freezes and expands, it forces the pavement upward and breaks it apart.
  Freezing water in the soil surrounding concrete foundations expands, causing structural shifting and cracks in buildings.
- **Destruction of Plant and Animal Tissues**
  The water inside living plant cells expands upon freezing, tearing the delicate cell walls and killing the plant tissue (frostbite).
  Sudden winter freezes can wipe out entire agricultural yields due to this localized cellular destruction.
- **Accelerated Soil and Mountain Erosion**
  While frost wedging helps create soil, it also triggers dangerous rockslides and landslides in mountainous areas by splitting cliffs apart.

Thermal expansion and contraction in gases

Unlike solids and liquids, gases do not have a fixed volume or shape. Therefore, thermal expansion and contraction in gases change based on the pressure and container holding them.
When a gas is heated, its molecules gain kinetic energy and move faster.

Ways Gases Expand or Contract

- Constant Pressure (Charles's Law): If the gas is in a flexible container (like a balloon), heating makes the fast molecules push the walls outward, increasing the volume.
- Constant Volume (Gay-Lussac's Law): If the gas is in a rigid container (like a scuba tank), the molecules cannot push the walls out. Heating increases the pressure instead.

Examples of Expansion (Heating)

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- Hot Air Balloons: Heating the air inside the balloon causes it to expand and become less dense than the surrounding cold air, creating lift.
- Tire Blowouts: Car tires can over-inflate and burst on hot summer days because the heat expands the air inside them.
- Aerosol Can Explosions: Leaving a spray can near heat causes the trapped gas to expand, creating high pressure until the metal ruptures.

Examples of Contraction (Cooling)

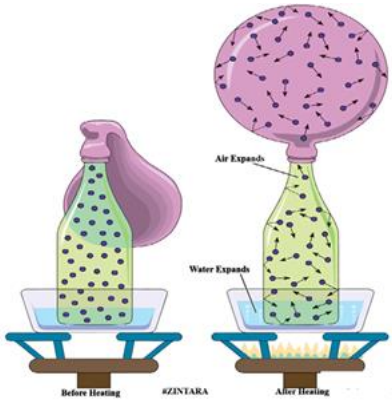
- The Shrinking Balloon: Placing an inflated balloon in a freezer causes the air inside to contract, making the balloon shrivel up.
- Imploding Plastic Bottles: If you fill a plastic bottle with hot air, cap it, and let it cool, the air inside contracts, and the outside atmospheric pressure crushes the bottle.
- Winter Tire Pressure Drop: Car tires often trigger "low pressure" dashboard warnings during the first cold week of winter because the cold air inside contracts.

Why Gases Expand More Than Liquids and Solids

- Gas molecules have almost no attractive forces holding them together.
- A small temperature increase causes a massive increase in molecular movement compared to tightly packed solids or liquids.

Activity: Experiment to demonstrate the thermal expansion of gases using a plastic bottle and a balloon in a container of hot water.

Apparatus: An empty plastic bottle, A balloon, A bowl or container, Hot water (from a tap or kettle, not boiling over), and Cold water (for the contrast step)



Procedure

a) Stretch the opening of the balloon.
b) Fit the balloon securely over the mouth of the empty plastic bottle.
c) Fill one container with hot water and another with cold water.
d) Place the bottom half of the plastic bottle into the container of hot water.
e) Observe what happens to the balloon.
f) Move the same bottle into the container of cold water and observe the change.

Observations

- In the hot water, the balloon starts to inflate and stand upright.
- In the cold water, the balloon deflates and goes limp.

Explanation

Heating a gas gives its molecules more kinetic energy. The molecules move faster and push further apart from each other, increasing the volume and pressure of the gas inside the closed system. Because the air needs more room, it fills and inflates the balloon. Cooling the gas reverses this effect: the molecules slow down, lose energy, and contract, causing the balloon to shrink back down

Why a gas expands on heating?

A gas expands when heated because heating increases the kinetic energy (movement energy) of its particles, causing them to move faster, push harder against each other and their container, and spread out.

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How heating causes expansion

- When heat is added to a gas, that thermal energy transfers to the gas particles.
- The particles gain speed and kinetic energy, causing them to zip around much faster.
- As they move quickly, the particles crash into the walls of their container more often and with greater force.
- If the container is flexible (like a balloon), this outward pushing force stretches it out, making the gas occupy a larger volume.

Why gases expand more than solids or liquids

- Unlike solids or liquids, gas particles have virtually no forces of attraction holding them together.
- Because they are already far apart and completely free to move, adding heat immediately translates into a large increase in the space they take up

Application of thermal expansion and contraction

Applications of Thermal Expansion

- Mercury or alcohol in **Thermometers** expands up a narrow tube as temperature rises to show readings.
- **Bimetallic strips use t**wo different metals to expand at different rates when heated, bending to flip switches in thermostats, ovens, and irons.
- Hot, expanded steel rivets are placed through metal plates; as they cool and contract, they pull the plates tightly together.
- **Hot air balloons are** heated; air inside the balloon expands, becomes less dense than the surrounding cold air, and creates lift.
- Metal components like axles are cooled to shrink and fit into wheels, forming an inseparable bond once they warm up and expand.

Applications and Engineering Considerations of Contraction

- Electrical cables are hung loosely with slack in summer so they do not snap when they contract and tighten in freezing winter temperatures.
- Small expansion gaps are left between rail segments to prevent the tracks from buckling and distorting on hot days.
- Large bridges feature interlocking metal expansion joints, roller supports to safely move as the structure expands, and contracts.
- Large industrial pipes include U-shaped expansion loops to absorb size changes without cracking the joints.
- Borosilicate glass (like Pyrex) expands and contracts very little when temperature changes, preventing it from shattering when heated.

Examination items

Item 1: The factory facilities uses a solar panel coated with different materials made of aluminum, copper, and are painted black. In order to test their heat absorption capacities, a thermometer is placed on each material to record the surface temperature at 10-minute intervals.

Task: As a physics student,

(a). How would you ensure accurate temperature readings for each material, considering environmental factors like wind and humidity?

(b). If the black paint reaches a temperature of 80°C while the aluminum reaches only 60°C under the same conditions, explain why this difference occurs.

Item 2: A water tank is connected to the solar panels to store heat energy for later use. The tank uses convection to transfer heat from the water at the top with a temperature 70°C while the one at the bottom has a temperature of 40°C. in order to study heat transfer further, a steel rod and a wooden rod were inserted partially into the water to observe the different conduction.

Task: As a physics student,

(a). Compare the rates of heat transfer through the steel rod and the wooden rod and explain the reason for the difference.

(b). How does the process of convection help maintain a relatively uniform temperature in the water tank over time?

Item 3: The facilities at solar energy storage system are made of steel pipe network that transports heated water and air. During the hottest times of the day, the steel pipes expand due to thermal energy. Similarly, the volume of the water and air also changes with temperature.

Task: As a physics student,

(a). If the steel pipe expands by 0.2% of its length when the temperature increases by 50°C, determine the original length of the pipe if the expanded length is 10.02 meters.

(b). Explain why the volume of air in the pipes changes more significantly than the volume of water when the temperature increases.

(b). Discuss how such thermal expansion might affect the long-term durability of the pipes and what design strategies can be employed to minimize potential damage.

S1.8 NATURE OF LIGHT:REFLECTION OF LIGHT AT PLANE SURFACES

Learning Outcomes

a) Know illuminated and light source objects in everyday life (u,s)
b) Understand how shadows are formed and that eclipses are natural forms of shadows (u)
c) Understand how the reflection of light from plane surfaces occurs and how we can make use of this (k, u, s,gs)

Light is a form of energy called electromagnetic radiation that can be detected by the human eye. It is the fastest phenomenon in the universe, traveling through a vacuum at exactly 300,000,000 meters per second. Light acts as both a wave and a stream of tiny, massless energy packets called photons.

The Visible Spectrum

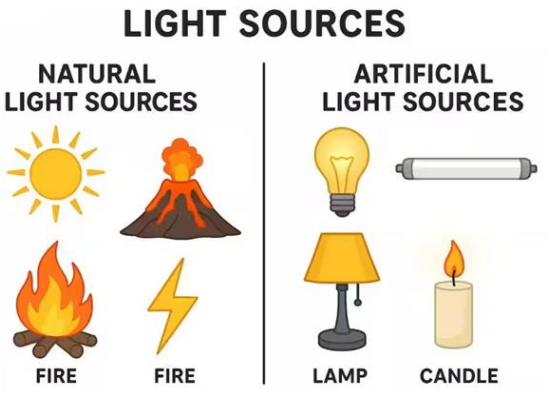
The human eye can only see a small portion of the entire electromagnetic spectrum. Between 400 nanometers (violet) and 700 nanometers (red). Sir Isaac Newton discovered that white light (like sunlight) splits into a rainbow of seven major colors: red, orange, yellow, green, blue, indigo, and violet. Ultraviolet (UV) light has wavelengths too short for us to see, while Infrared (IR) light has wavelengths too long. Some animals, like bees and mosquitoes, can see these invisible waves.

Properties of Light

- ♠ Light travels in straight lines unless it hits an object or changes mediums.
- ♠ We see objects because light bounces off them and enters our eyes.
- ♠ Objects can be transparent (letting all light pass through, like glass), translucent (letting partial light pass, like curtains), or opaque (blocking light entirely, creating shadows).

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Sources of Light



- **Natural sources:** The Sun, stars, lightning, and bioluminescent organisms (like fireflies or deep-sea jellyfish).
- **Artificial sources:** Man-made objects like LEDs, fluorescent tubes, incandescent bulbs, and digital screens. These sources work by converting electrical energy into visible light, making it possible to illuminate spaces at any time.

Light Sources and Objects

- Luminous sources: Objects that produce and emit their own light (the sun, stars, electric bulbs, and burning candles).
- Non-luminous sources: Objects that do not produce their own light but become visible by reflecting light from luminous objects (mirrors, the moon, and car reflectors).
- Transparent objects: Materials that allow light to pass straight through them clearly, letting you see through them (ordinary glass, pure water, and car windscreens.
- Translucent objects: Materials that allow only a small amount of scattered light to pass through, making objects on the other side blurry (frosted bathroom glass, tinted glass, and tracing paper).
- Opaque objects: Materials that block light completely and do not let any pass through, forming dark shadows (wood, concrete, and solid metal).

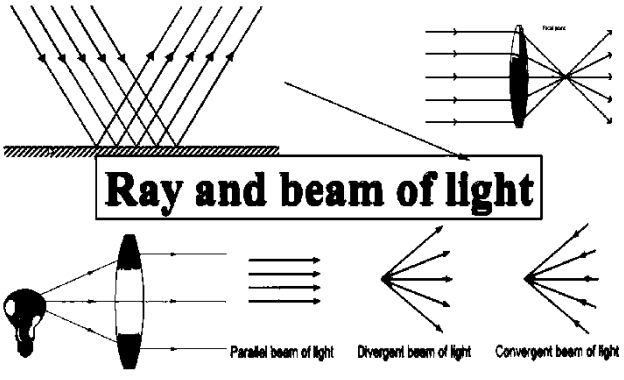
Interaction with Matter

These five processes describe how light and matter interact with each other in the physical world.

- **Absorption:** Dark colors absorb more light and turn it into heat. For example, black pavement gets very hot in the sun.
- **Emission:** Excited atoms release energy as light. For example, glowing neon signs or burning campfire embers produce light this way.
- **Transmission:** Transparent materials let light pass through them without stopping. For example, you can see clearly through a clean glass window.
- **Reflection:** Smooth, shiny surfaces bounce light off at a predictable angle. For example, looking into a bathroom mirror.
- **Scattering:** Rough or small particles throw light in many random directions. For example, air molecules scatter sunlight to make the daytime sky look blue.

RAYS AND BEAMS

A ray of light is a single, narrow line that shows the direction of travel for light energy, while a beam of light is a collection or bundle of many light rays.

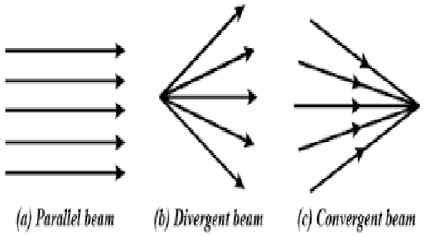


Definitions of Rays and Beams

- **Ray of light:** An imaginary, very thin line with an arrowhead that shows which way light is moving.
- **Beam of light:** A group or stream of multiple light rays traveling together.

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Types of Light Beams



- **Parallel beam:** Rays move side-by-side and never meet, like sunlight reaching the earth.
- **Divergent beam:** Rays spread outward in different directions from a single point source, like a flashlight or lamp.
- **Convergent beam:** Rays come from different places and meet at a single common point, like light passing through a magnifying glass.

Applications of rays and beams

Optical Instruments and Vision

- Vision and Imaging: The human eye relies on light rays bending through the cornea and lens to form images on the retina.
- Microscopes and Telescopes: Lenses and curved mirrors use convergent and parallel rays to magnify tiny microscopic cells or distant stars.
- Cameras: Ray tracing principles help design camera lens systems that focus light accurately onto digital sensors or film.

Telecommunications and Data

- Fiber Optics: Light beams travel through thin glass fibers using total internal reflection, sending high-speed internet and phone data over long distances with minimal signal loss.
- Laser Communication: Highly collimated (parallel) laser beams transmit signals through free space or fiber networks.

Industry and Medicine

- **Laser Cutting and Welding:** Concentrated, high-intensity laser beams melt or cut through hard materials like steel and titanium with high precision.
- **Medical Diagnostics and Surgery:** Lasers perform precise eye surgeries (like LASIK) and assist in medical imaging systems.
- **Scanners and Barcode Readers:** Divergent or scanning light beams read product codes at retail checkouts.
- **Energy and Illumination**
- **Solar Cells:** Photovoltaic solar panels capture incoming sun rays and convert the light energy directly into electrical power for homes and satellites.
- **General Lighting:** Visible light beams from bulbs, LEDs, and specialized lamps illuminate indoor and outdoor spaces.

RECTLINEAR PROPAGATION OF LIGHT

Rectilinear propagation of light means that light travels in a straight line through a uniform medium.

Definition

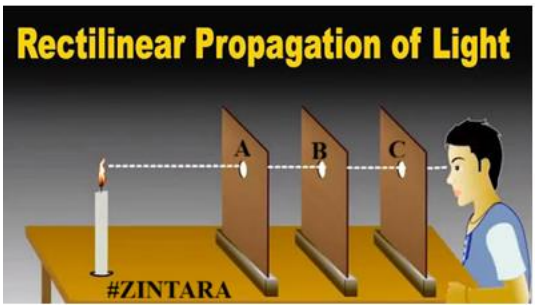
- **Rectilinear** means moving in a straight line.
- **Propagation** means spreading or moving forward.
- Light moves in straight paths as long as the medium (like air, water, or glass) has a uniform density.

Examples

- Opaque objects block light and create sharp shadows because light cannot curve around them.
- Rays of sunlight streaming through a window into a dusty room look like straight lines.

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- Lasers project a straight, narrow beam of light directly onto a target.



EXPERIMENT TO SHOW THAT LIGHT TRAVELS IN A STRAIGHT LINE

Procedure

a) Three (3) identical cardboards A, B and C each with a hole in its centre are arranged with the holes in a straight line as shown above.
b) A source of light is placed behind cardboard A and an observer in front of C.
c) The observer is able to see the light from the source because light travels in a straight line.
d) If one of the cardboards is displaced such that the holes are not in the straight line, the observer will see no light.

This shows that light travels in a straight line.

Formation of Shadows

A shadow is a dark area formed on a surface when an opaque object blocks the path of light.

How Shadows Form

Shadows happen because light travels in straight lines, a rule called rectilinear propagation. When light hits an object that it cannot pass through, that area behind the object stays dark.

You need three things to make a shadow:

- A light source (like the sun or a lamp).
- An object that blocks the light.
- A surface (like a wall or the ground) to catch the shadow.

Types of Materials

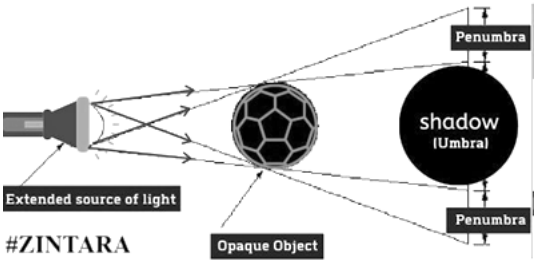
Materials react differently to light:

- Opaque objects block all light and make dark, clear shadows. Examples include wood and metal.
- Translucent objects let some light pass through and make faint shadows. An example is frosted glass.
- Transparent objects let all light pass through and make no shadow at all. An example is clear glass.

Parts of a Shadow

Depending on the light source, a shadow has specific parts:

- **Umbra:** The dark center part where the light is completely blocked.
- **Penumbra:** The lighter outer edge where the light is only partly blocked.



To see a visual demonstration of how light rays create these distinct shadow regions and interact with objects, watch this helpful explanation:

Why Shadows Change Size and Shape

Shadows are not always the same. Their size and shape change based on a few rules:

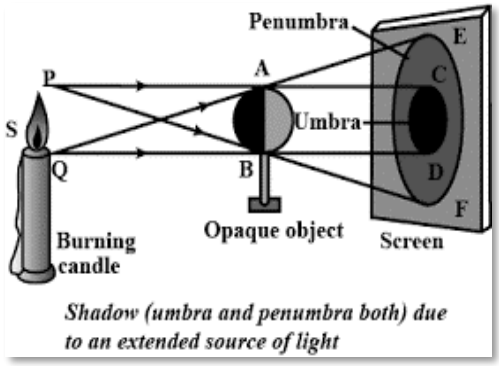
- Moving an object closer to the light source makes the shadow bigger. Moving it closer to the surface makes the shadow smaller.

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- Outdoor shadows change as the sun moves. Morning and evening sun is low in the sky, making long shadows. Noon sun is high overhead, making very short shadows.

Types of Shadows

Shadows are divided into different types based on physics, astronomy, and art depending on the light source and the object blocking the light.



Shadow (umbra and penumbra both) due to an extended source of light

Physics and Astronomy Shadows

When an opaque object blocks light, it creates distinct shadow regions depending on whether the light source is a single point or a wide, spread-out source.

- **Umbra:** The innermost, darkest part of a shadow where the light source is completely blocked.
- **Penumbra:** The lighter, outer part of a shadow where only part of the light source is blocked.
- **Antumbra:** The region beyond the umbra where the light source is completely blocked in the center, but a ring of light remains visible around the edges (seen during annular eclipses).

Shadows in Art and Drawing

Artists break down shadows into specific categories to give drawings a realistic, three-dimensional look.



- **Form Shadow:** The dark side of an object itself that faces away from the light source.
- **Cast Shadow:** The shadow projected by an object onto a nearby surface or the ground because the object blocks the light.
- **Core Shadow:** The darkest strip on an object where the light transitions completely into shadow.
- **Ambient Occlusion:** The very dark, soft shadow that forms in tight creases or tiny spaces where ambient light cannot squeeze in

Factors Influencing Shadow Formation

Shadow formation depends on key factors like the size of the light source, object distance, and the object's transparency.

Main Factors Influencing Shadows

- **Distance from Light Source:** Moving an opaque object closer to the light source makes the shadow larger, while moving it farther away makes the shadow smaller.
- **Size of the Light Source:** A small point source creates sharp shadows with total darkness (umbra), while a large, extended light source creates softer edges with partial darkness (penumbra).
- **Object Transparency:** Opaque objects block all light to cast dark shadows, translucent objects let some light through to cast faint shadows, and transparent objects cast no visible shadow.
- **Direction and Angle:** Changing the position or angle of the light source alters the shape, orientation, and length of the shadow.
- **Object Size and Shape:** Larger objects block more light and cast bigger shadows, and the shadow's outline matches the shape of the object.
- **Distance to the Screen**: Moving the object closer to the wall or screen makes the shadow sharper, while moving it away makes the shadow blurrier.

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Examples of Shadow Formation

- **Body Shadows in Sunlight:** Standing outside on a sunny day blocks the sun, casting your silhouette on the ground.
- **Hand Puppets:** Holding your hands close to a flashlight or wall lamp blocks the light to form animal shapes on a wall.
- **Tree and Leaf Patterns:** Sunlight shining through tree branches and leaves creates a complex pattern of light and dark patches on the ground.
- **Building and Object Shadows:** Streetlights or the sun hit large opaque structures like houses or cars, casting long shadows on the pavement

Importance of Shadows

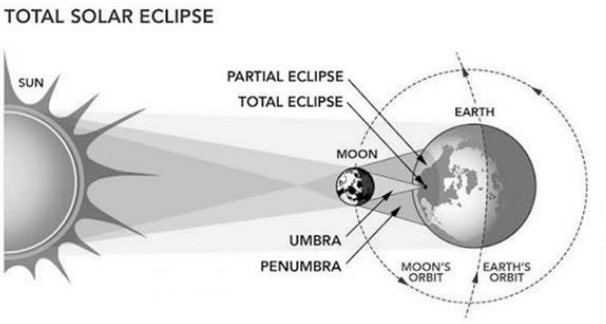
Shadow formation occurs when an opaque object blocks the path of light, proving that light travels in straight lines.

Importance of Shadow Formation

- **Proves Light Properties:** Shows that light travels in straight paths (rectilinear propagation) since it cannot bend around solid objects.
- **Temperature Regulation:** Provides natural cooling by blocking direct sunlight, which protects plants, animals, and human habitats from overheating.
- **Time Measurement:** Enabled ancient civilizations to track time and seasons using tools like sundials.
- **Astronomical Insight:** Explains major cosmic events like solar and lunar eclipses when celestial bodies pass through each other's shadows.
- **Art and Depth:** Helps artists create the illusion of three-dimensional volume and realistic depth in drawings and paintings.

ECLIPSES

An eclipse is an astronomical event where one celestial body moves into the shadow of another or blocks light from reaching it.



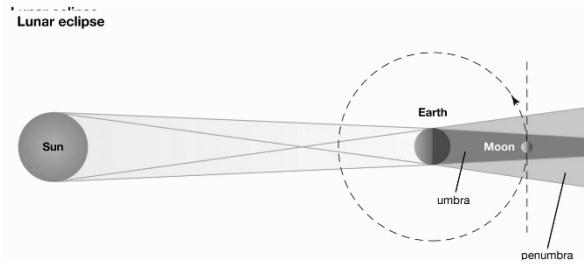
Solar Eclipses

A solar eclipse happens when the Moon moves directly between the Earth and the Sun, blocking all or part of the Sun's light.

- **Total:** The Moon completely covers the Sun.
- **Partial:** Only part of the Sun is blocked.
- **Annular:** The Moon is farther away and looks smaller, leaving a glowing ring of sunlight visible.

Lunar Eclipses

A lunar eclipse occurs when the Earth moves directly between the Sun and the Moon, casting a shadow across the lunar surface.



- **Total:** The entire Moon enters the darkest part of Earth's shadow (the umbra) and often glows a deep red or orange color.
- **Partial:** Only a portion of the Moon enters the umbra.

- **Penumbral**: The Moon passes through the faint outer shadow (the penumbra) and dims only slightly

Hybrid Solar Eclipse

A rare type of eclipse that transitions between a total and an annular eclipse along different sections of the path. In some areas, viewers may experience a total eclipse, while in others; they will see an annular eclipse.

Frequency and Observation

Solar eclipses are rarer for any given location on Earth because the path of totality is narrow. On average, a total solar eclipse occurs somewhere on Earth about every 18 months, but it may take several decades for one to be visible from the same location.

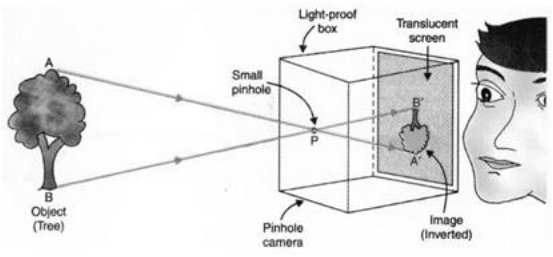
Lunar eclipses are more common than solar eclipses and are visible from anywhere on the night side of Earth. A total lunar eclipse occurs roughly once every 2.5 years from any given location.

Significance of Eclipses

Eclipses provide valuable opportunities for scientific study, such as observing the Sun's corona during a total solar eclipse or studying the Earth's atmosphere by analyzing the light filtered during a lunar eclipse. Eclipses are extraordinary celestial events that occur due to the specific alignment of the Sun, Earth, and Moon.

THE PINHOLE CAMERA

A pinhole camera is a simple, lens-free device made from a dark, lightproof box with a tiny hole on one side. Light from an object travels in straight lines through the hole and projects an upside-down, or inverted, image onto the opposite inner wall.



Principle operation

- Light from an object travels in straight lines known as rectilinear propagation.
- Rays from the top of an object go through tiny aperture (the pinhole) and hit the bottom of the screen. Rays from the bottom go to the top.
- Rays cross over, projecting an inverted (upside-down and reversed) image on the back screen.
- The image is dim and requires long exposure times because very little light enters the box.
- The tiny opening restricts stray light, which naturally focuses the scene.

Image Quality and Size

- A smaller pinhole makes a sharp picture, but let's in less light.
- A larger hole makes a bright picture, but looks blurry.
- Moving the back screen further away makes the image larger, but dimmer.
- Moving it closer makes the image smaller and brighter

Characteristics of images produced by Pinhole Cameras

A pinhole camera produces an **inverted, real image** on the opposite screen by allowing light to travel in straight lines through a tiny opening.

Image Characteristics

- **Real Image:** The projection can be caught directly on a translucent screen or photographic film.

- **Inverted (Upside Down):** Light rays from the top and bottom of the object cross at the pinhole, flipping the image vertically.
- **Size Variability:** The image can be smaller, equal to, or larger than the object, depending on the distance between the object and the pinhole versus the screen and the pinhole.
- **Dim Brightness:** Only a small amount of light enters the tiny aperture, making the resulting picture dim and requiring longer exposure times.
- **Deep Focus:** Objects placed at varying distances remain sharp on the screen, giving it a near-infinite depth of field.

Effects of Adjusting the Pinhole and Box

- **Smaller Pinhole** produces a sharper but much dimmer image (until extreme sizes cause diffraction blurring).
- **Larger Pinhole** lets in more light for a brighter image, but causes overlapping rays that make the picture blurry.
- **Longer Camera Box (greater screen-to-hole distance)** enlarges the image size while making it dimmer.
- **Multiple Holes** creates multiple overlapping and separate images on the screen.

Applications of Pinhole Cameras

Pinhole cameras are simple, lens-less devices that project an inverted image through a tiny aperture using straight-line light propagation.

Applications

- Safe Solar Viewing: Safely observe solar eclipses without eye damage by projecting an indirect image of the sun onto a screen.
- Solargraphy: Track and record the sun's trajectory across the sky over long periods, ranging from days to months.
- Artistic Photography: Create unique, dreamlike photographs with an infinite depth of field and a soft-focus aesthetic.
- Education: Demonstrate basic physics concepts in classrooms, including how light travels in straight lines and forms inverted images.
- Covert Surveillance: Utilize tiny pinhole lenses in security hardware because the discrete openings are hard to detect.
- Specialized Radiation Imaging: Apply pinhole optics in X-ray or gamma-ray astronomy where standard glass lenses cannot refract rays.

Activity: Building a Pinhole Camera

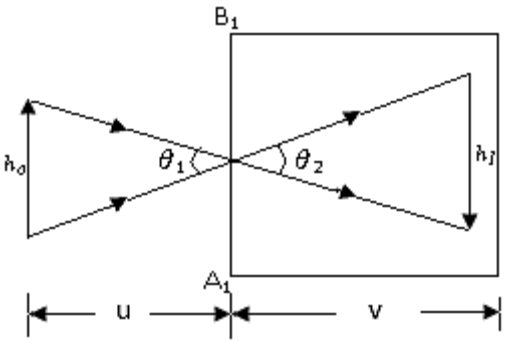
Materials: A simple pinhole camera can be constructed from a cardboard box or a tin can, a thin sheet of metal or foil for the pinhole, and photographic paper or film.

Construction: Cut a small hole in one side of the box or can for the pinhole. Attach the pinhole to the hole and seal the box to prevent any light leakage. Place the photographic paper or film on the opposite side of the box.

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Exposure: Point the pinhole camera at the desired scene and expose the photographic paper or film for the required amount of time. Develop the image according to the photographic process used. A pinhole camera is a simple yet powerful tool that demonstrates the fundamental principles of photography and optics. Its basic design, reliance on light, and ability to produce unique images make it a valuable educational and artistic device.

MAGINIFICATION: This is the ratio of image size to object size: By Proportionality; $m = \frac{v}{u} = \frac{h_1}{h_0}$, where V = image distance from pinhole to screen, and U= is the object distance from pinhole to object



Example

An object 2cm high forms an image on a screen of the pinhole camera. If the distance between the object and screen is 24cm and the distance between the object and the pinhole is 6cm find the magnification of the image and the size of the image.

Solutions

From $u + v = 24cm$, $u = 6cm$, then $v = 24 - 6 = 18cm$

$magnification = \frac{v}{u} = \frac{18cm}{6cm} = 3$,

$m = \frac{h_i}{h_o} = 3$, $3 = \frac{h_i}{2}$, $h_i = 3x2 = 6cm$

Activity

Item 1: A 2.0-meter-tall tree is standing 10 meters away from a pinhole camera. If the distance from the pinhole to the screen is 25 centimeters, calculate the height of the image formed on the screen

Item 2: A pinhole camera has a length of 20 cm. It captures an image of a building that is 30 meters tall. If the image size on the screen is measured to be 6.0 cm tall, how far away is the camera from the building?

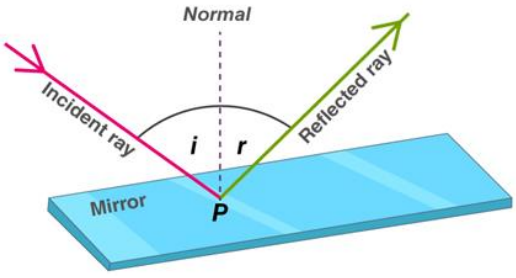
Item 3: A pinhole camera of length 15 cm forms a 4.0 cm high image of a candle placed at a certain distance. If the screen is pulled backward so that the new length of the camera box becomes 22.5 cm, what will be the new height of the candle's image?

REFLECTION OF LIGHT BY PLANE SURFACES

Reflection of light by plane surfaces occurs when light rays bounce back into the same medium after striking a flat, polished boundary like a plane mirror.

Terms and Definitions

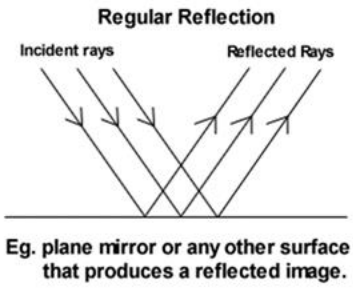
- Incident ray: The incoming light ray that strikes the surface.
- Reflected ray: The light ray that bounces away from the surface.
- Normal: An imaginary line drawn perpendicular (at a 90-degree angle) to the surface at the point where the light hits.
- Angle of incidence (i): The angle between the incident ray and the normal.
- Angle of reflection (r): The angle between the reflected ray and the normal.



MASTERING PHYSICS

The Laws of Reflection

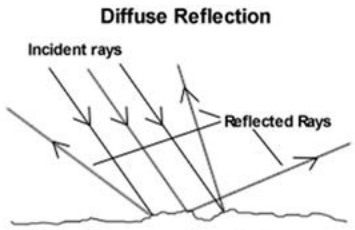
- The angle of incidence (i) is always equal to the angle of reflection (r).
- The incident ray, the reflected ray, and the normal all lie in the same flat plane.



Eg. plane mirror or any other surface that produces a reflected image.

Types of Reflection

- **Regular (Specular) Reflection**: Happens on smooth, shiny surfaces like mirrors. Incident parallel light rays are reflected in a single, orderly direction to form clear images.
- **Irregular (Diffuse) Reflection:** Happens on rough or uneven surfaces. Incident parallel light rays are reflected as scattered beam in many random directions, so no clear image forms.



This is like any surface that we can see but does not reflect an image

Properties of Images in a Plane Mirror

- **Virtual:** The image cannot be projected onto a physical screen.
- **Upright (Erect):** The image is right side up.
- **Same Size:** The image height matches the object height.
- **Equal Distance:** The image appears to be the exact same distance behind the mirror as the object is in front of it.
- **Laterally Inverted:** images are left and right reversed (your right hand looks like your left hand in the mirror).

The Nature of Plane Surfaces

A plane surface is a flat, smooth surface that reflects light in a predictable manner. Unlike curved surfaces, which can distort light, plane surfaces reflect light at a consistent angle, making them ideal for creating clear and accurate images. Common examples of plane surfaces include mirrors, calm water surfaces, and flat glass windows. These surfaces reflect light in a manner that adheres to the fundamental principles of geometric optics.

Laws of Reflection

First Law of Reflection: ***The angle of incidence is equal to the angle of reflection.***
Explanation: When a light ray strikes a plane surface, the angle at which it approaches the surface (the angle of incidence) is equal to the angle at which it bounces away from the surface (the angle of reflection). These angles are measured with respect to the normal, which is an imaginary line perpendicular to the surface at the point of incidence.
Second Law of Reflection: ***The incident ray, the reflected ray, and the normal the point of incidence all lie in the same plane.***
The path of the incoming and outgoing light rays, along with the normal to the surface, are all contained within the same plane. This ensures that the reflection is predictable and consistent.

Applications of Reflection by Plane Surfaces
Plane surfaces like flat mirrors use regular reflection to bounce light at equal angles, creating clear, upright, and virtual images.
Practical Uses

- **Looking Glasses:** Used in bathrooms, dressing tables, and salons for personal grooming and daily activities.

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- **Periscopes:** Placed at 45-degree angles inside tubes to allow people in submarines to see ships above the water surface.
- **Kaleidoscopes:** Arranged in an angled loop to reflect colorful glass pieces into repeating symmetrical patterns for entertainment.
- **Security and Safety:** Mounted at sharp road blind turns, store corners, and beneath vehicles to inspect for hidden objects or prevent collisions.
- **Solar Cookers:** Positioned to catch and redirect direct sunlight onto cooking vessels to concentrate thermal energy.

Scientific and Precision Instruments

- **Scientific Instruments:** Placed behind pointers in analog voltmeters and ammeters to eliminate **parallax error** (an error in reading a meter caused by the eye not being directly perpendicular to the pointer).
- **Optical Devices:** Used in single-lens reflex (SLR) cameras, microscopes, and optical benches to steer light paths accurately.
- **Illumination:** Placed behind bulbs in torchlights and flashlights to project a strong, directed beam of light forward

Application of diffuse reflection

Diffuse reflection scatters light or sound in many directions off uneven surfaces, making objects visible from any angle and reducing harsh glare.

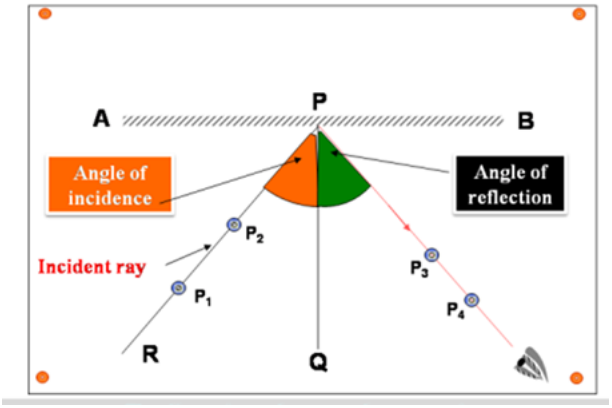
Applications

- Indoor Lighting & Architecture: Ceilings and matte walls scatter light evenly to illuminate rooms and eliminate bright hotspots.
- Photography & Film: Softboxes and umbrellas use diffuse surfaces to scatter flash or studio light, creating soft shadows and natural portraits.
- Acoustics & Sound Design: Acoustic diffusers on studio or auditorium walls scatter sound waves to improve sound quality and clarity.
- Reading & Displays: Matte paper and textured screens scatter reflected light, preventing harsh glare so text remains easy to read.
- Military & Hunting Camouflage: Textured fabrics and patterns scatter light to break up an object's outline and help it blend into the background.
- Spectroscopy (DRIFT): Diffuse reflectance infrared Fourier transform spectroscopy analyzes solid powders and rough samples without complex preparation.

Activity: to verify laws of reflection

Procedures

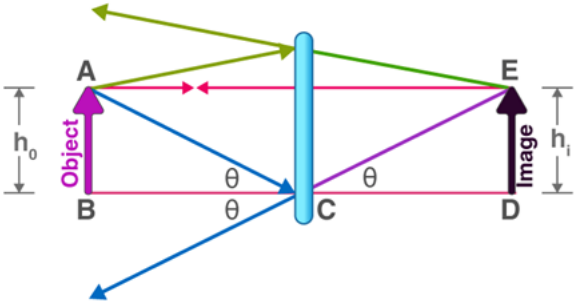
a) Draw lines AB and PQ perpendicular to each other on white sheet of paper.
b) Measure angle RPQ = 30^0 and draw line RP
c) Put the white piece of paper on the soft board. Fix pins P_1 and P_2 vertically
d) Insert a plain mirror along AB with the reflecting surface facing yo



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e) Looking through the plain mirror in the opposite side, fix pins P_3 and P_4 such that they appear to be in line with images of P_1 and P_2
f) Measure angle PQR=i and angle SPQ=r using a protractor
g) The procedures above are repeated for angle of incidence 45^0 and 40^0
h) It is observed that angle of incidence i is equal to angle of reflection and since RP, PQ and PS are drawn on the same sheet of paper, hence verifying the laws of reflection

NATURE OF IMAGE FORMED BY A PLANE MIRROR

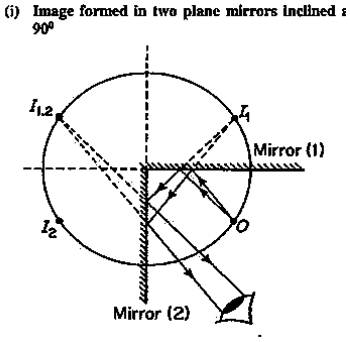


The image formed by a plane mirror is **virtual, erect (upright), of the same size as the object, laterally inverted, and formed at the same distance** behind the mirror as the object is in front of it.

Characteristics of the Image

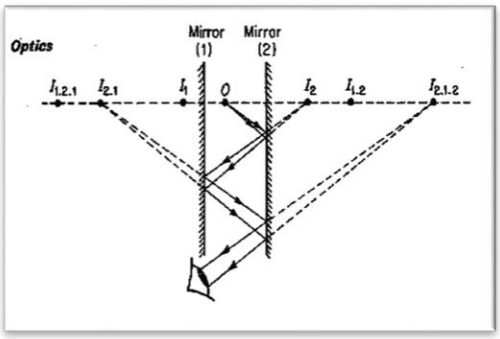
- **Virtual:** The light rays do not actually meet behind the mirror; they only appear to meet when extended backwards. Because of this, the image cannot be caught on a screen.
- **Erect (Upright):** The image is right side up, meaning if the top of an object points up, the top of the image points up as well.
- **Same Size:** The height and dimensions of the image are identical to the actual object (magnification is equal to 1).
- **Laterally Inverted:** The left side of the object appears as the right side in the image, and vice versa (left-right reversal).
- **Equal Distance:** The perpendicular distance from the object to the mirror equals the perpendicular distance from the image to the mirror

Images formed in two plane mirrors inclined at 90^0



When two mirrors are inclined at 90^0 to each other, images are formed by a single reflection in addition to two extra images formed by 2 reflections.

Image formed in parallel mirrors



An infinite number of images are formed when an object placed between two parallel mirrors. Each image seen in one mirror will act as virtual object to the next mirror.
The object O gives rise to image I_1 in mirror m_1 and I_2 on m_2 .I_1 acts as virtual object to give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror m_2. $I_{(1,2)}$ in mirror m_2 gives $I_{(1,2,1)}$ after reflection in m_1 while $I_{(2,1,2)}$ after reflecting in Mirror m_2.

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Image formed by an inclined mirror at an angle θ

The number of images formed by 2 mirrors inclined at an angleθ, is given by $\boldsymbol{n = (\frac{360}{\theta} - 1)}$**,**where n = number of images formed. When two mirrors are parallel, the angle θ between them is zero and the number of images formed between them is n = ∞ (infinite). This shows infinite number of images when two plane mirrors are parallel. The image lies in a straight line through the object and perpendicular to the mirrors.

1) Two plane mirrors are inclined at an angle 60^0 to one another. Find the number of images formed by these mirrors

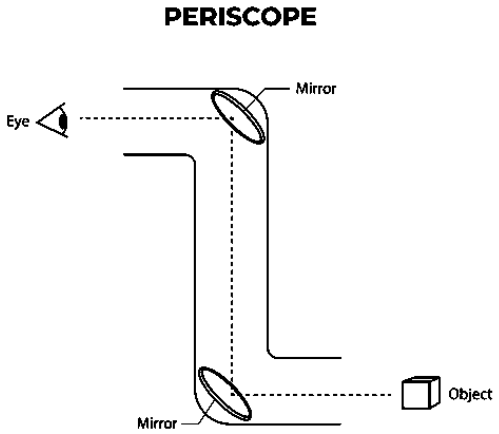
$n = (\frac{360}{\theta} - 1), n = \left(\frac{360}{60} - 1\right) = 5images,$

2) Two plane mirrors are inclined at an angle θ to each other. If the number of image formed between them is 9, find the angle of inclination θ.

$n = \left(\frac{360}{\theta} - 1\right), 9 = \left(\frac{360}{\theta} - 1\right), 9 + 1 = \left(\frac{360}{\theta}\right), \theta = \frac{360}{10} = 36\ images$

Periscope

A periscope works by using two angled mirrors or prisms inside a tube to bounce light around corners and obstacles so an observer can see things outside their direct line of sight.



Principle of Reflection

- Light from an object hits the top mirror at a 45-degree angle.
- The mirror reflects the light straight down the long tube at another 45-degree angle.
- The light reaches the bottom mirror, which is also angled at 45 degrees.
- This second mirror reflects the light straight out of the tube and into the viewer's eye.

Common Uses

- Sailors use periscopes to see above the water's surface while the ship stays safely hidden underwater.
- Soldiers historically used them to look over battlefield barriers without exposing themselves to enemy fire.
- Simple cardboard or plastic versions let people look over high walls or around crowded corners.
- Advanced modern military periscopes also add lenses for zoom magnification, stabilizing gyroscopes for moving ships, and digital sensors.

Plane mirrors are flat reflective surfaces used for personal grooming, room decoration, and various optical and scientific devices.

Other uses of plane mirrors include:

- Used as looking glasses in bathrooms and dressing tables.
- In periscopes: Placed at 45-degree angles to let people look over or around obstacles, such as in submarine navigation.

- ♠ **In Kaleidoscopes:** Arranged at angles to create colorful repeating patterns and optical designs.
- ♠ Placed beneath meter scales (like ammeters and voltmeters) to eliminate parallax error by aligning the pointer with its reflection.
- ♠ Directed to reflect and concentrate sunlight onto heating surfaces in Solar Cookers.
- ♠ Mounted on walls or in elevators to create an illusion of larger, brighter spaces

Activity:

1. Two plane mirrors are inclined at an angle 50^0 to one another. Find the number of images formed by these mirrors
2. Two plane mirrors are inclined at an angle θ to each other. If the number of image formed between them is 12, find the angle of inclination θ.

Examination item:

A group of senior physics students at Zintara Heights Academy is conducting an experiment to explore the laws of reflection. They use a ray box, a protractor, a plane mirror, and a white sheet of paper placed on a flat desk. One student directs a single ray of light from the ray box toward a vertically positioned plane mirror on the paper. The ray strikes the mirror at point P , forming an angle of 35° with the normal at that point. The students trace the incident and reflected rays on the paper and extend both backward to observe their symmetry relative to the mirror. Their observations are:

- The angle of reflection equals the angle of incidence.
- The incident ray, reflected ray, and normal lie in the same plane.
- The image formed is upright, laterally inverted, and appears behind the mirror.
- Increasing the angle of incidence results in an equal increase in the angle of reflection.

Task: Based on this experimental setup and observations,

a) Draw a clearly labelled diagram illustrating the experimental setup.
b) Using the students' observations, explain how the experimental results confirm the laws of reflection.
c) Describe the characteristics of the image formed by the plane mirror in this experiment, as observed by the students.
d) If the ray of light is rotated so that the angle of incidence becomes 60°, predict the new angle of reflection and provide reasoning based on the laws of reflection.
e) If the plane mirror is rotated by 10° about point P while keeping the incident ray fixed, qualitatively describe how the direction of the reflected ray changes. Explain your reasoning.
f) Discuss two practical applications of the laws of reflection in everyday life, providing a brief explanation of how each application relies on these laws.

MASTERING PHYSICS

SENIOR TWO

S2.1 WORK, ENERGY, AND POWER

Learning Outcomes

By the end of this topic, learners should be able to:

a) Understand that the Sun is Earth's main energy source and be able to **identify different forms** of energy. They should know that energy can change from one form to another while the total amount of energy is conserved.
b) Explain the benefits and drawbacks of solar energy, and distinguish between **renewable and non-renewable energy** resources, especially in the Ugandan context.
c) Calculate **work done** using force, distance moved, and time taken, and understand how objects can have energy because of motion or position.
d) Understand what **machines** are, describe how simple machines make work easier, and explain the **principles** behind how simple machines operate.

SUN AS SOURCE OF ENERGY

The sun is the primary source of energy for Earth, powering our weather, climate, and nearly all life through electromagnetic radiation.

How the Sun Generates Energy

The source of energy of the Sun is due to the conversion of hydrogen to helium based on nuclear fusion in its core, where extreme pressure and temperatures fuse hydrogen atoms into helium.
This continuous reaction releases massive amounts of heat and light that travel through space as solar radiation.

Natural Earth Systems Powered by the Sun

The water cycle depends entirely on the sun's energy to evaporate water into the atmosphere" before it returns as rain.

- ♠ Uneven heating of the Earth's surface and oceans creates temperature and pressure differences that drive global wind patterns and ocean currents.
- ♠ Plants capture sunlight through photosynthesis to produce food, forming the foundational base of almost all Earth's food webs and oxygen supply. Fossil fuels also derive indirectly from this ancient stored plant matter.

Human Harnessing of Solar Energy

- ♠ Photovoltaics (PV) cells use semiconductor materials like silicon to convert sunlight directly into usable electricity.
- ♠ Solar Thermal Systems absorb solar radiation to heat water for domestic use or generate high-temperature steam to turn turbines in power stations
- ♠ Solar energy is clean and renewable, but its supply remains intermittent and dependent on weather conditions and daylight availability.

DIFFERENT FORMS OF ENERGY

Energy is the ability to do work. It is measured in joules (J). Energy exists in different forms and can be transformed from one form to another.

Kinetic Energy: The energy possessed by a body because of its motion. **Formula:** $K.E = \frac{1}{2}mv^2$**.**

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Example: A 1,000 kg car moving at 20 m/s has Ek = ½ × 1,000 × 20² = 200,000 J.
Applications: Moving vehicles, Wind turbines, Hydroelectric power generation, Moving water turning turbines, and Hammers and moving tools

Gravitational Potential Energy: The energy stored due to an object's height above the ground. **Formula:** $P.E = mgh$.
Example: A 5 kg object raised 4 m has Ep = 5 × 10 × 4 = 200 J.
Applications: Water stored behind dams, Raised objects, hydroelectric power stations, Roller coasters, and Water tanks

Elastic Potential Energy: The energy stored when an elastic material is stretched or compressed. **Formula:** $E = ½kx^2$.
Example: A compressed spring stores elastic potential energy.
Applications: Springs in clocks, Car suspension systems, Bows and arrows, Catapults, and Shock absorbers

Thermal Energy: The internal energy associated with the random motion of particles in a substance. **Formula:** $Q = mc(T_2 - T_1)$.
Example: For 2 kg of water heated through 10 °C, Q = 2 × 4200 × 10 = 84,000 J.
Applications: Cooking, Ironing clothes, Heating homes, Steam engines, and Thermal power stations

Chemical Energy: The energy stored in the chemical bonds of substances and is released or absorbed during chemical reactions. **Formula:** $E = mq$ (for energy released by a fuel)**.**
Example: If 2 kg of fuel has a calorific value of 40 MJ/kg, E = 2 × 40 = 80 MJ.
Applications: Petrol and diesel engines, Food provides energy, Batteries, Firewood, Cooking gas, and Coal and natural gas

Electrical Energy: The energy transferred by moving electric charges.
Formula: $E = Pt = VIt$
Example: A 1,000 W heater operating for 60 s uses E = 1,000 × 60 = 60,000 J.
Applications: Lighting, Electric motors, Refrigerators, Computers, Electric heaters, and Charging phones

Light/Radiant Energy: The energy transferred by electromagnetic radiation.
Formula: $E = hf \ or \ E = hc/\lambda$.
Example: Sunlight carries radiant energy from the Sun to Earth.
Applications: Solar panels, Optical fibre communication, Lasers, Remote controls, X-ray imaging, and UV Sterilisation

Sound Energy: The energy transferred through a medium by vibrations. Sound requires a medium and cannot travel through a vacuum. **Formula:** $v = f\lambda; \ I = P/A$**.**
Example: A loudspeaker converts electrical energy into sound energy.
Applications: Communication, Loudspeakers, Musical instruments, Sonar, Medical ultrasound, and Hearing aids

Nuclear Energy: The energy stored in the nucleus of an atom. It can be released through fission, fusion or radioactive decay. **Formula:** $E = mc^2$**.**

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Example: In a nuclear power station, uranium nuclei undergo fission and release energy.
Applications: Nuclear power stations, Medical cancer treatment, Nuclear medicine, scientific research, and Spacecraft power systems

Magnetic Energy: The energy associated with a magnetic field. **Formula:** $E = \frac{1}{2}LI^2$ (for an inductor)**.**
Example: An electromagnet stores energy in its magnetic field.
Applications: Electric motors, Generators, Transformers, Electromagnets, Magnetic levitation, MRI machines, and Loudspeakers

Energy Transformations
Energy is often converted from one form to another rather than simply appearing or disappearing.

- ♠ Hydroelectric power station: Gravitational potential → Kinetic → Mechanical → Electrical
- ♠ Petrol engine: Chemical → Thermal → Kinetic
- ♠ Solar panel: Light → Electrical
- ♠ Electric bulb: Electrical → Light + Thermal

Law of Conservation of Energy
Energy cannot be created or destroyed; it can only be transferred or transformed.
Energy input = Useful energy output + Energy dissipated

RENEWABLE AND NONRENEWABLE ENERGY

Renewable resources can be replaced naturally within a short time, while non-renewable resources are limited and take a very long time to form.

Main Differences

Point	**Renewable Resources**	**Non-renewable Resources**
Meaning	Resources that are naturally replaced or replenished.	Resources that exist in limited amounts and are not quickly replaced.
Availability	Can continue if used and managed carefully.	Can become exhausted when used too much.
Formation time	Renewed in a short time, such as daily sunlight or seasonal crops.	Usually take millions of years to form, such as coal, oil, and gas.
Pollution	Usually produce less pollution and fewer greenhouse gases.	Often cause more pollution when extracted or burned.
Long-term use	Better for sustainability and future energy security.	Useful and powerful, but not sustainable forever.

Examples

Renewable	Non-renewable
Sunlight, wind, flowing water, trees, crops, biomass, animal waste, geothermal heat	Coal, petroleum, natural gas, uranium, gold, iron, copper, limestone

Applications and Uses

- ♠ Renewable resources are used for electricity generation, water supply, and irrigation, cooking, heating, transport fuels such as biofuels, farming, paper production, and construction wood.

- Non-renewable resources are used for electricity generation, vehicle fuels, cooking gas, manufacturing plastics, making steel and cement, producing fertilizers, and nuclear power generation.

Positive effects of renewable resources

- They usually reduce air pollution and greenhouse gas emissions.
- They support long-term energy security because they can be replenished.
- They help conserve the environment when managed properly.

Possible negative effects of renewable resources

- Large dams, solar farms, or wind farms may use large areas of land.
- Forests can be damaged if trees are cut faster than they are replanted.

Effects of non-renewable resources

- Burning fossil fuels releases carbon dioxide and other harmful gases.
- Mining and drilling can cause land degradation, water pollution, oil spills, and health problems.
- Because supplies are limited, heavy use can cause shortages and higher costs in the future.

Conclusion

- Renewable resources are generally cleaner and better for long-term sustainability.
- Non-renewable resources are powerful and widely used, but they can run out and often damage the environment. A responsible society should use resources carefully and increase the use of cleaner renewable options.

Primary energy sources are raw fuels and natural resources found directly in nature, while secondary energy sources are converted forms created by processing those primary resources.

Primary energy sources exist in the physical world without human-made conversion. They include both renewable and non-renewable resources.

- Fossil Fuels: Coal, crude oil, and natural gas.
- Renewables: Solar energy, wind power, flowing water (hydropower), geothermal heat, and biomass.
- Nuclear: Uranium and other radioactive minerals used for nuclear fission.

Primary energy sources are forms of energy found naturally in their original state.

Secondary energy sources often called energy carriers do not occur naturally. Humans manufacture them by transforming primary resources into more usable or transportable forms.

- Electricity is generated by using primary sources like coal, gas, wind, or water to power turbines.
- Refined Fuels like gasoline, diesel, and kerosene processed from crude oil.
- Other Forms including Hydrogen produced via electrolysis, manufactured heating, and chemical energy in batteries.

Secondary energy resources do not occur naturally. They are obtained from one or more primary energy resources

WORK DONE, FORCE, AND DISTANCE MOVED

Work Done

Work is done when a force causes an object to move through a distance in the direction of the force. Formula: $\boldsymbol{W = Fd}$, Where: W = work done, measured in joules (J), F = force, measured in newtons (N), d = distance moved in the direction of the force, measured in metres (m)

The SI unit of work is the joule (J). $1\,J = 1\,N \times 1\,m$

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A joule is the work done when a force of 1 newton moves a body through a distance of 1 metre.
1 joule =1 newton × 1 metre.
Bigger units used are kilojoules (1 kJ) = 1 000 J. Mega joule (1 MJ) = 1 000 000 J

Example:
A force of 20 N moves a box through a distance of 5 m.
$\boldsymbol{W = Fd, W = 20 \times 5, W = 100\,J.}$ Therefore, 100 J of work is done.

Force
Force is a push or pull that can change the motion, direction, or shape of an object.
The SI unit of force is the newton (N). Formula**:** $\boldsymbol{F = ma}$
Where F = force (N), m = mass (kg), and a = acceleration (m/s²).
Example: A body of mass 10 kg accelerates at 2 m/s².
$\boldsymbol{F = ma, F = 10 \times 2. F = 20\,N}$

Distance Moved
Distance moved is the length of the path travelled by an object. It is measured in metres (m). From $\boldsymbol{W = Fd}$: $\boldsymbol{d = \frac{W}{F}}$
Example: A force of 50 N does 500 J of work. Find the distance moved.
$\boldsymbol{d = \frac{W}{F}, d = \frac{500}{50}. d = 10\,m}$

Relationship between Work, Force and Distance

Quantity	Formula	SI Unit
Work done	W = Fd	Joule (J)
Force	F = W/d	Newton (N)
Distance	d = W/F	Metre (m)

If a force is applied to an object, but the object does not move, then no work is done.
Understand:

- **Direction Matters:** As noted by **Isaac Newton**, "Only force component parallel to displacement (d) does work." If the force is at an angle $\boldsymbol{\theta}$, we use the component of the force in the direction of motion. $\boldsymbol{W. d = F. d. cos\theta}$
- **Zero Work:** If an object does not move d = 0, or if the force acts perpendicular to the direction of movement, the work done is zero Joules.
- **Energy Transfer:** Doing work on an object transfers energy to it, often changing its kinetic or thermal energy store
- Greater force gives greater work done if distance is constant.
- Greater distance gives greater work done if force is constant.
- If there is no movement, no mechanical work is done, even if a force is applied.
- The force must have a component in the direction of movement for work to be done.

Consider lifting an object against gravity. The force applied is equal to the object's weight, and the work done is proportional to the height the object is lifted. Similarly, pushing a cart along a flat surface involves

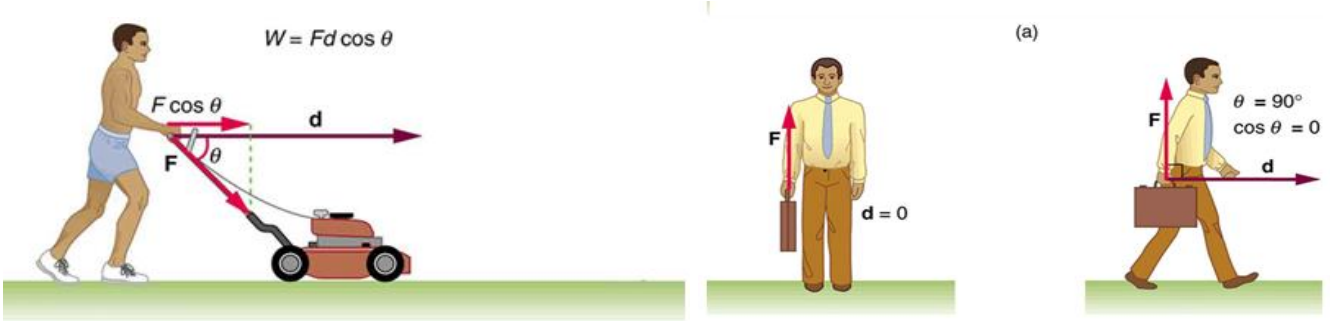
work done, provided the cart moves in the direction of the applied force. However, holding a stationary object does not constitute work because, despite the exertion of force, there is no displacement.

Example: Find the work done in lifting a mass of 2 kg vertically upwards through 10 m. (g = 10 m/s2)
Solution: To lift the mass upwards against gravity, a force equal to its own weight is exerted.
Applied force = weight = *m*g = 2kg × 10N/kg = 20 N
Work done = F × d = 20 N × 10 m = 200 Nm = 200 J

Example:
A horizontal pulling force of 60 N is applied through a spring to a block on a frictionless table, causing the block to move by a distance of 3 m in the direction of the force. Find the work done by the force.
Solution: The work done = F × d = 60 N × 3 m = 180 Nm = 180 J

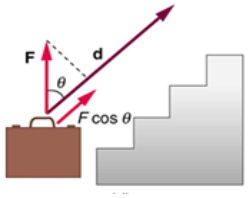
A horizontal force of 75 N is applied on a body on a frictionless surface. The body moves a horizontal distance of 9.6 m. Calculate the work done on the body.
Solution: Work = force × distance = 75 N × 9.6 m = 75 × 9.6 Nm = 720 J

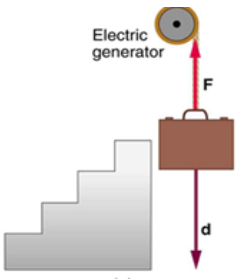
Interrelationship between Work, Force, and Distance
The work done on a system by a constant force is **the product of the component of the force in the direction of motion times the distance through which the force acts**. For one-way motion in one dimension, this is expressed in equation form as $\boldsymbol{W = Fd\cos\theta}$, where *W* is work, *F* is the magnitude of the force on the system, *d* is the magnitude of the displacement of the system, and θ is the angle between the force vector **F** and the displacement vector **d**.



Practical Applications

- **Lifting and Cranes:** Heavy loads are raised against gravity $\boldsymbol{W = mgh}$ on construction sites, where the work calculated determines the motor power and energy needed to lift steel beams or concrete.
- **Pistons and Gas Engines:** Thermodynamics utilizes pressure-volume work $\boldsymbol{W = P\Delta V}$ in car engines and industrial compressors, where expanding gases push pistons to generate mechanical motion.
- **Springs and Suspension:** Systems use elastic potential work $\boldsymbol{W = \frac{1}{2}kx^2}$ in vehicle suspension systems and industrial mechanical clocks to store and release controlled energy.





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- **Automotive Motion:** Most users agree "engine work is equal to the force multiplied by distance, while power is the rate at which work is done.". Vehicles convert fuel energy into mechanical work to overcome air resistance and friction.
- **Moving Objects:** Pushing shopping carts, pedaling a bicycle, or hammering a nail transfers physical energy directly into kinetic movement or material deformation

ENERGY

Energy is the capacity to do work or produce change. It exists in various forms, including kinetic, potential, thermal, chemical, and electrical. Energy powers natural processes and human activities, following the law of conservation, which states it cannot be created or destroyed, only transformed from one form to another.

Example:

A towing truck was used to tow a broken car through a distance of 30 m. The tension in the towing chain was 2 000 N. If the total friction is 150 N, determine. (a) Work done by the pulling force. (b) Work done against friction. (c) Useful work done.

Solution:

(a) Work done by the pulling force, $W = F \times d = 2\,000\ N \times 30\ m = 60\,000\ J$

(b) Work done against friction $W = F_r \times d$ (F_r is the frictional force) $= 150\ N \times 30\ m = 4\,500\ J$

(c) Useful work done, Useful work done $= Fd - F_r d = (60\,000 - 4\,500)\ J = 55\,500\ J$

FORMS OF ENERGY

The two main categories of energy are potential energy (stored energy) and kinetic energy (the energy of motion). All specific forms of energy fall under these two classifications.

According to the Law of Conservation of Energy, energy cannot be created or destroyed; it only transforms from one form to another.

Potential Energy (Stored Energy)

- Potential energy is stored energy based on an object's position, state, or chemical composition.
- Chemical Energy: Stored in the bonds of atoms and molecules. Examples include batteries, food, biomass, and fossil fuels.
- Mechanical / Elastic Energy: Stored in objects by tension, compression, or stretching. Examples include a compressed spring or a stretched rubber band.
- Nuclear Energy: Stored in the nucleus of an atom that holds protons and neutrons together. It is released through nuclear fission or fusion.
- Gravitational Energy: Stored in an object's height relative to a lower position. Examples include water behind a hydroelectric dam or a rock on a cliff.

Kinetic Energy (Energy of Motion)

- Kinetic energy is the working energy possessed by an object or particle due to its active motion.
- Radiant / Light Energy: Electromagnetic energy that travels in transverse waves. Examples include visible light, X-rays, gamma rays, and radio waves.
- Thermal (Heat) Energy: Generated by the rapid movement and vibration of atoms and molecules within a substance. Boiling water and geothermal hot springs are common examples.
- Electrical Energy: Delivered by the movement of tiny charged particles called electrons through a conductor. Lightning and household electricity are standard examples.
- Motion / Mechanical Energy: The movement of macroscopic objects from one place to another. Examples include wind, a flying bird, or a moving vehicle.

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- Sound Energy: Produced when a force causes an object to vibrate, transferring energy through a medium (like air or water) in longitudinal waves

Kinetic Energy

Kinetic energy is the energy an object possesses due to its motion.

Any physical object that moves from a microscopic atom to a massive spacecraft—carries kinetic energy.

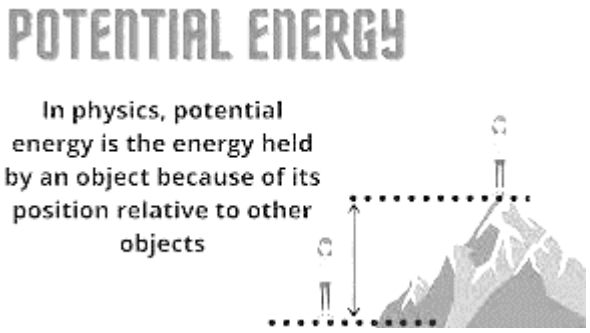
The standard equation for translational kinetic energy is: $K.E = \frac{1}{2}mv^2$

K.E= Kinetic energy measured in Joules (J),
m= Mass of the object measured in kilograms (kg),
v= Velocity (or speed) of the object measured in meters per second (m/s)

If the speed of the object is doubled for a given mass, it will have four times the kinetic energy. This is because kinetic energy is directly proportional to speed squared.

Examples of Kinetic Energy

- A flowing river: "A river flowing at a certain speed exhibits kinetic energy as the water possesses both velocity and mass."
- A moving car: A vehicle cruising down a highway has high kinetic energy determined by its weight and speed.
- A falling object: An apple dropping from a tree accelerates toward the ground, increasing its kinetic energy as speed builds up.
- A flying airplane: High mass combined with high cruising speed results in massive kinetic energy.



Practical Applications

- Wind Turbines: Capture the kinetic energy of moving air masses and convert it into electrical energy.
- Hydroelectric Dams: Use the kinetic energy of rushing water to spin turbines and generate power.
- Regenerative Braking: Modern electric vehicles capture the kinetic energy normally lost during braking and convert it back into electrical energy to recharge the vehicle's battery.

Exercises

Find the kinetic energy of a 1000kg car traveling at a velocity of $20ms^{-1}$

Formula:$K.E = \frac{1}{2}mv^2$, $K.E = \frac{1}{2}x1000x20^2J = 200{,}000joules$

A sports ball with a mass of 0.5kg has a kinetic energy of 100J. What is its speed?

$\boldsymbol{K.E = \frac{1}{2}mv^2, K.E = \frac{1}{2}x0.5xv^2J = 100joules}$

$\boldsymbol{v^2 = \frac{2x100}{0.5}, v = \sqrt{400} = 20ms^{-1}}$

Potential Energy: The energy an object possesses due to its object's position, state, or configuration.

Its stored energy based on an object's position, state, or configuration. It is "stored" work waiting to be released.

Gravitational Potential Energy

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Energy stored due to an object's height in a gravitational field.

$\boldsymbol{GPE = mgh}$, $\boldsymbol{m = mass\ (kilograms, kg)}$, $\boldsymbol{g = gravitational\ acceleration}$, **and** $\boldsymbol{h = height\ (meters, m)}$

Elastic Potential Energy

Energy stored as a result of deformation of an elastic object (like stretching or compressing).

Formula: EPE = $P.E = \frac{1}{2}kx^2$, $k = spring\ constant\ (Newtons\ per\ meter, N/m)$, and $x = displacement\ from\ original\ shape\ (meters, m)$

Chemical Potential Energy

Energy stored in the chemical bonds of atoms and molecules. It is released during chemical reactions.

Applications

- ♠ **Hydroelectric Dams:** Water stored high up in a reservoir holds massive GPE. When released, it falls, turning into kinetic energy to spin turbines and generate electricity.
- ♠ **Archery:** Pulling back a bowstring stores PE in the bow limbs. Releasing the string instantly converts that energy into kinetic energy to launch the arrow.
- ♠ **Roller Coasters:** A motorized chain pulls a coaster train to the top of the first hill, maximizing its GPE. Gravity then takes over, converting that stored energy into speed (kinetic energy) as it plunges.
- ♠ **Mechanical Watches:** Winding a watch compresses an internal mainspring, storing EPE. The watch slowly releases this energy over time to move the gears and hands.

Example

1. A 60kg diver stands on a platform 10m above a swimming pool. Calculate the diver's gravitational potential energy relative to the water surface.

$\boldsymbol{Identify\ variables: m = 60kg, h = 10m, g = 10ms^{-2}}$

$\boldsymbol{Apply\ formula: GPE = mgh, P.E = 60x10x10 = 600J}$

2. A spring inside a pogo stick has a spring constant of 12,000N/m. A rider jumps down and compresses the spring by 0.1meters. How much elastic potential energy is stored in the spring?

$\boldsymbol{Identify\ variables: k = 12,000N/m, x = 0.1m.}$

$\boldsymbol{Apply\ formula: P.E = \frac{1}{2}kx^2, P.E = \frac{1}{2}x12000x0.1^2 = 60J}$

3. Calculate the work done by a weight lifter in raising a weight of 400 N through a vertical distance of 1.4 m.

$\boldsymbol{Work\ done\ against\ gravity = Force\ x\ displacement = mg \times h = 400\ N \times 1.4\ m = 560\ J}$

4. A force of 200 N was applied to move a log of wood through a distance of 10 m. Calculate the work done on the log.

$\boldsymbol{W = F \times d = 200\ N \times 10\ m = 2\,000\ J}$

Activity:

A Senior Two Physics class visited a community project in their village to study how work is done in everyday activities. During the visit, they observed the following situations:

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A farmer pushed a sack of produce with a force of 12 N through a distance of 15 m in the direction of the force. At a nearby well, a person pulled a bucket of mass 10 kg steadily through a vertical distance of 15 m. On the road near the project site, a car moved at uniform speed through a distance of 40 m while experiencing a resistive force of 3000 N. Later, a student of mass 50 kg climbed a staircase of vertical height 6 m. In the workshop, another student pushed a wooden block with a force of 20 N through a distance of 9 m. Take g = 10 N/kg.

Task: Use the knowledge of physics to;
(a) Calculate the work done by the farmer in pushing the sack of produce.
(b) Determine the work done by the person in pulling the bucket from the well.
(c) The car moved with uniform speed while the resistive force acting on it was 3000 N.
(i) State the forward driving force acting on the car.
(ii) Explain your answer in (c)(i).
(iii) Calculate the work done by the driving force.
(iv) State the useful work done by the car.
(d) Calculate the work done by the student in climbing the staircase.
(e) Calculate the work done on the wooden block in the workshop.

POWER

Power is the rate at which work is done or the rate at which energy is transferred or converted.
It measures how quickly work can be performed or energy can be used.
Mathematically, $= \frac{work\ done}{time} = \frac{Force\ x\ distance}{time} = \boldsymbol{FV}$, where: P is the power, W is the work done, t is the time taken, and F is the force and V is the velocity.
The SI unit of power is the *watt* (W), where $1W=1Js^{-1}$. If 100 joules of work is done in 10 seconds, the power is 100 J10 s=10 W. Other units: Kilo watt (kW), Megawatt (Mw); 1 kW = 1000w, 1MW = 1000, 000W
A watt is the power developed when one joule of work is done in one second. i.e. $1W = 1Js^{-1}$.

Example
What is the power of a boy lifting a 300 N block through 10 m in 10 s?
Force = 300 N, Distance = 10 m, Time = 10 s
Work done by the boy = F ×d = 300 ×10 = 3 000 J. $\boldsymbol{Power = \frac{W}{t} = \frac{3000J}{10s} = 300W}$

Relationship between Work, Energy, and Power

Work and Energy: Work is a means of transferring energy. When work is done on an object, energy is transferred to or from that object. The work-energy theorem states that the work done on an object is equal to the change in its kinetic energy.
Energy and Power: Power quantifies how quickly energy is used or transferred. Higher power means more energy is used or transferred in a given amount of time.

Examples
Work: Lifting a weight off the ground involves doing work against the force of gravity.
Energy: A roller coaster at the top of a hill has high potential energy, which converts to kinetic energy as it descends.
Power: A high-powered engine can do more work in a shorter time, enabling a car to accelerate rapidly.

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Estimating the power of an individual climbing a flight of stairs

Activity: To estimate the power of an individual climbing a flight of stairs

Materials: stopwatch, weighing machine, tape measure

Procedures

a) Find a set of stairs that you can safely walk and run up. If there are no stairs in your school, create some at garden.
b) Count their number, measure the vertical height of each stair and then find the total height of the stairs in metres.
c) Let one member weigh himself/herself on a weighing machine and record the weight down.
d) Let him/her walk then run up the stairs. Using a stopwatch, record the time taken in seconds to walk and running up the stairs.
e) Calculate the work done in walking and running up the stairs.
f) Let each group member do the activity. Do different members in walking and running up the stairs the same do the work?
g) Explain the disparity of work done by various group members.
h) Calculate the power developed by each individual in walking and running up the stairs.
i) Which one required more power, walking or running up the flight of stairs? Why?

Understand: From your discussion, you should have established that: Height moved up (s) = Number of procedures (n) × height of one step (h)**,** s = n × h = nh. Time taken to move height (s) = t.$Power = \frac{work\ done\ against\ gravity}{time} = \frac{mgh}{t} = \frac{Wh}{t} = \frac{Wnh}{t}$, where, P = power, W = weight, h = height of first step, n = number of Procedures If s is in metres, W in newtons and t in seconds then power is in ***watts***.

Example:

A girl whose mass is 60 kg can run up a flight of 35 Procedures each of 10 cm high in 4 seconds. Find the power of the girl. (Take g = 10 m/s^2).

Solution: Force overcome (weight) = mg = 60 kg × 10 N/kg = 600 N. Total distance = 10 × 35 = 350 cm = 3.5 m

Work done by the girl = F × d = 600 × 3.5 = 2 100 J.

Power $= \frac{\text{work done}}{\text{time}} = \frac{2100\text{J}}{4\text{s}}$. The power of the girl is **525 W**

ACTIVITY:

During a school fitness and practical Physics activity, learners investigated how **power** depends on the work done and the time taken. Janelle, whose mass is **42 kg**, ran up two flights of stairs in **10 seconds**. The landing was **5.0 m vertically above** her starting point. In another activity, Student A lifted a **50 N** box from the floor to a height of **0.40 m** in **2.0 seconds**, while Student B lifted a **40 N** box from the floor to a height of **0.50 m** in **1.0 second**.

Take **g = 10 N/kg**.

Task: Use the knowledge of Physics to:

(a) Calculate the work done by Janelle in running up the stairs.
(b) Determine the power developed by Janelle during her run.
(c) Calculate the work done by Student A in lifting the box.
(d) Calculate the power developed by Student A.
(e) Calculate the work done by Student B in lifting the box.
(f) Calculate the power developed by Student B.
(g) State which student developed more power and give a reason for your answer.

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MECHANICAL FORMS OF ENERGY

It is the sum of potential energy and kinetic energy that is the energy associated with the motion and the position of an object, known as Mechanical energy.

Thus, we can derive the formula of mechanical energy as $Mechanical\ Energy = Kinetic\ Energy + Potential\ Energy$

$$M.E = \frac{1}{2}mv^2 + mgh$$

Activity 1

During a school sports and science practical activity, learners investigated how the mass and speed of moving bodies affect their kinetic energy. They observed a moving object of mass 2 kg travelling at 4 m/s, a boy of mass 60 kg running at 10 m/s, and a ball of mass 50 kg having kinetic energy of 3125 J.

Task: Use knowledge of physics to:

(a) Calculate the kinetic energy of the body of mass 2 kg moving at 4 m/s.

(b) Determine the kinetic energy of the boy of mass 60 kg running at 10 m/s.

(c) A ball of mass 50 kg has kinetic energy of 3125 J. Calculate the speed at which the ball is moving.

(d) From your answers, state one factor that affects the kinetic energy of a moving body.

Expected responses:

Item	Working	Expected Answer
(a)	$K.E = 1/2\,mv^2$ $K.E = 1/2 \times 2 \times 4^2$ $K.E = 1 \times 16$ $K.E = 16\,J$	16 J
(b)	$K.E = 1/2\,mv^2$ $K.E = 1/2 \times 60 \times 10^2$ $K.E = 30 \times 100$ $K.E = 3000\,J$	3000 J
(c)	$K.E = 1/2\,mv^2$ $3125 = 1/2 \times 50 \times v^2$ $3125 = 25v^2$ $v^2 = 3125/25 = 125$ $v = \sqrt{125} = 11.18\,m/s$	11.2 m/s, approximately 11 m/s
(d)	The kinetic energy of a moving body depends on the mass of the body and the speed of the body.	Mass and speed

Activity 2

During a school Physics practical lesson, learners investigated how the height and mass of an object affect gravitational potential energy. They observed that a stone of mass 8 kg was lifted through a height of 2 m, while a girl of mass 40 kg stood on a raised platform 15 m above the ground. **Take g = 10 m/s².**

Task:

(a) Calculate the potential energy gained by the stone when it is lifted through a height of 2 m.

(b) Determine the potential energy possessed by the girl when she is 15 m above the ground.

(c) From the activity, state two factors that affect the gravitational potential energy of a body.

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Expected Answers

Part	Working	Answer
(a)	$P.E = mgh$ $P.E = 8 \times 10 \times 2$ $P.E = 160\,J$	160 J
(b)	$P.E = mgh$ $P.E = 40 \times 10 \times 15$ $P.E = 400 \times 15$ $P.E = 6000\,J$	6000 J
(c)	Gravitational potential energy depends on the mass of the body and its height above the ground.	Mass and height.

ENERGY INTERCHANGE

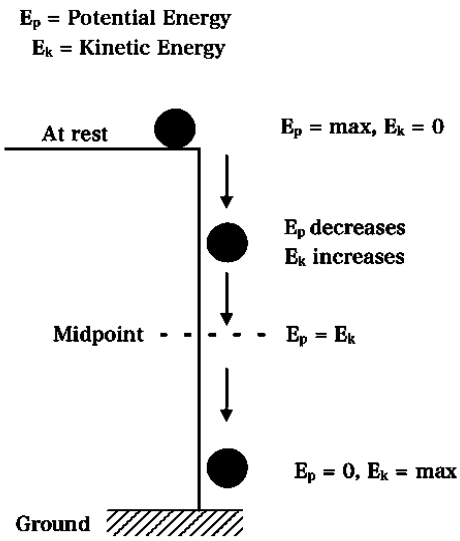
Potential Energy (PE): Stored energy based on an object's position or height. $P.E = mgh$

Kinetic Energy (KE): The energy an object has due to its motion.$K.E = \frac{1}{2}mv^2$

Conservation of Energy: In an isolated system without friction, mechanical energy $M.E = PE + KE = mgh + \frac{1}{2}mv^2$ never changes, as an object loses height, PE drops and KE rises by the exact same amount.

How the Interchange Works

- **Falling Objects:** PE converts to KE as objects fall. At the highest point of a drop, PE is at its maximum and KE is zero. Right before hitting the ground, height is zero, meaning PE is zero and KE reaches its maximum.
- **Pendulums and Rollercoasters:** Energy shifts back and forth endlessly. Energy is transferred back and forth between these two stores as the pendulum swings. When a rollercoaster climbs a hill, KE turns into PE. When it drops down the other side, PE turns back into fast motion (KE).
- **Friction and Losses:** Air resistance and friction turn a small fraction of mechanical energy into thermal energy or sound, meaning total PE at the start equals total KE at the end only in an ideal, frictionless world



In the gravitational field energy changes from one form to another. The stone has maximum potential energy at **TOP** where it is at rest above the ground.

At the mid-point, the stone has both potential and kinetic energy and when it hits the ground at the **BOTTOM**, it losses all the potential energy.

This potential energy is converted to kinetic energy, which is maximum as it hits the ground.

P.E at the top = K.E at the bottom, $\boldsymbol{mgh = \frac{1}{2}mv^2}$, $\boldsymbol{2gh = v^2}$, $\boldsymbol{v = \sqrt{2gh}}$, where V is the speed with which the stone hits on the ground.

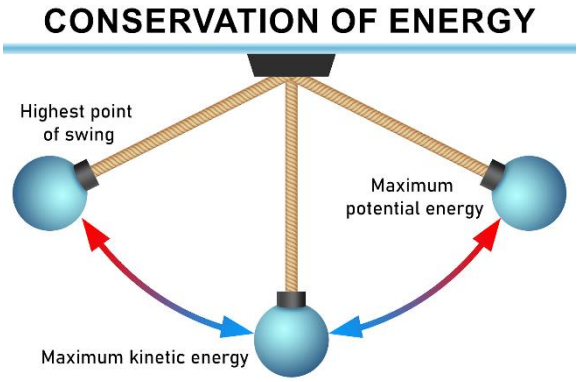
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Example.
A stone of mass 1kg falls from rest at height of 120m above the ground
(a).Find its potential energy before it begins to fall.
(b).If the stone falls with a velocity of 2m/s, find its Kinetic energy.
(c).Find the velocity with which it hits the ground.
Hint: g = 10 m/s².
(a) Potential Energy
Formula: PE = mgh
$Given: m = 1\,kg, g = 10\,m/s^2, h = 120\,m$
$\boldsymbol{PE = 1 \times 10 \times 120}$
$\boldsymbol{PE = 1200\,J}$
$\boldsymbol{Answer: PE = 1200\,J}$

(b) Kinetic Energy
$Formula: KE = ½mv^2$
$Given: m = 1\,kg, v = 2\,m/s$
$\boldsymbol{KE = ½ \times 1 \times (2)^2, KE = ½ \times 4, KE = 2\,J}$
$\boldsymbol{Answer: KE = 2\,J}$

(c) Velocity when the stone hits the ground
$Using\ the\ equation: v^2 = u^2 + 2gs$
$Given: u = 0\,m/s, g = 10\,m/s^2, s = 120\,m$
$v^2 = 0^2 + 2 \times 10 \times 120, v^2 = 2400, v = \sqrt{2400},$
$v = 48.99\,m/s$
$\boldsymbol{v = 49.0\,m/s\ downward}$

PRINCIPLES OF CONSERVATION OF ENERGY



It states that **energy can neither be created nor destroyed but can be transformed from one form to another**.
The principle of conservation of energy explains ***that the total energy in an isolated system remains constant over time***. This means that energy cannot be created or destroyed; it can only change forms. For instance, potential energy can be converted into kinetic energy, but the total amount of energy remains unchanged. For example, in a closed system, the energy provided must equal the energy transferred to the surroundings.

Activity
1. Explain why a swinging pendulum eventually stops after sometime.
(i) Describe the energy changes that occur at an instant the stone is released from a height h to the ground.
(ii)Given that, the height in b (i) was 20m. Calculate the speed with which the stone hits the ground.
2. Boy climbs some stairs. Each step raises 20cm and there are 10 steps, if the boy has a mass of 50kg (a). How much work does he do in climbing the stairs?
(b). Calculate the power developed if he took 10 seconds in climbing.

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3. A machine lifts a load of 2500N through a vertical height of 3m in 1.5s. Find
   (i) The power developed by a machine,
   (ii) Using the same power how long would it take to lift 6000N through a vertical height of 5m
4. A force of 500N displaced a mass of 20kg through a distance of 4m in 5 seconds; find
(i). the work done (ii). power developed
5. A pump is rated 400W. How many kilograms of water can it raise in one hour through a height of 72m?

MACHINES

A Simple Machine

A mechanical device that changes the direction or magnitude of a force is known as a simple machine. They are defined as simple mechanisms that use mechanical advantage to multiply force. Simple machines have few or no moving parts to modify motion and force. Let us learn more about the six simple machines in the following few sections.

Simple machines enhance our ability to perform work efficiently, making everyday tasks easier and more manageable. When using a machine, a force is applied at one point (**EFFORT**) to overcome another force (**LOAD**) at another point. A machine is used to convert energy from one form to another and amplify the force used.

PRINCIPLE OF MACHINES

The principle of machines is fundamentally rooted in the law of conservation of energy, which states that **energy cannot be created or destroyed, but can only be transformed**.

- For an ideal machine, the work output is equal to the work input, meaning that the energy used to perform a task is conserved throughout the process.
- **Machines operate on the concept of mechanical advantage, allowing a smaller effort to move a larger load over a greater distance.** Simple machines include levers, pulleys, and inclined planes, which enhance efficiency and reduce the effort required to perform work.
- Machines are designed to facilitate tasks by altering the direction and magnitude of forces, making it easier to overcome resistance. **It states that a small force applied (effort) moves a large distance to produce a bigger force that moves a load through a small distance**.

TERMS USED IN MACHINES

Simple machines use a force called an effort to overcome a resistance called a load, making work easier by changing the size or direction of a force.

Load (L or W): The load in simple terms is the weight of the body, e.g. 480 Newton. It is the force exerted by the machine or the object being moved, measured in newtons (N).

Effort (E): Effort (E) is the force applied to the machine, measured in newtons (N).

Mechanical Advantage (MA): Mechanical advantage is the ratio of the load to the effort applied. It tells you how much the machine multiplies your force.

Formula: $\boldsymbol{M.A} = \frac{\boldsymbol{load}}{\boldsymbol{effort}} = \frac{\boldsymbol{L}}{\boldsymbol{E}}$; Units: None, because it is a ratio of two forces.

Velocity Ratio (VR): Velocity ratio is the ratio of the distance moved by the effort to the distance moved by the load.

Formula: $\boldsymbol{V.R} = \frac{\textbf{Distance moved by effort}}{\textbf{Distance moved by load at the same time}}$

Units: None, because the distance units cancel out.

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Work Input and Work Output

Work Input ($work_{in}$): The work done on the machine by the effort. Calculated as $effort\ x\ effort\ distance$

Work Output ($work_{out}$): The useful work done by the machine on the load. Calculated as $load\ x\ load\ distance$

Energy Wasted

In real machines, total work input (Wi) equals work output (Wo) in ideal systems. However, in real-world systems, the work output is always less than the work input because of friction and other losses. This missing energy is energy wasted, usually converted into heat by friction between moving parts.

Formula: $\boldsymbol{Energy\ wasted = Work\ input - Work\ Output}$

Efficiency (η): Efficiency is the ratio of useful work output to total work input, usually written as a percentage.

Formula: $\boldsymbol{efficiency}\ (\eta) = \frac{\boldsymbol{work\ output}}{\boldsymbol{work\ input}}\boldsymbol{x100}\%$

An ideal machine has an efficiency of 100% (MA = VR), while a real machine has an efficiency of less than 100% due to friction

In practice, the efficiency of a machine is always less than 100%. Because some energy is wasted or lost in overcoming friction between the movable parts of a machine. Some energy is wasted or lost in lifting useless loads e.g. strings in pulleys. The efficiency of a machine can be increased by lubricating the movable parts of the machine i.e. oiling and greasing, by using light materials for useless loads.

Example

During the construction of a school water tank, a worker uses a simple machine to lift a 480 N load through a vertical distance of 1 m. The worker applies an effort of 200 N and moves the effort through a distance of 1.5 m. Calculate:

a) The mechanical advantage of the machine.
b) The velocity ratio.
c) The work output.
d) The work input.
e) The efficiency of the machine

Understand :

$$Mechanical\ Advantage\ (MA) = \frac{Load}{effort},$$

$$Velocity\ Ratio\ (VR) = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load},$$

$$Efficiency\ = (\frac{M.A}{V.R})\ \times\ 100\%$$

$$Work\ =\ Force\ \times\ Distance$$

$$Effort\ =\ 200\ N, effort\ distance\ =\ 1.5\ m, load\ =\ 480\ N, load\ distance\ =\ 1\ m$$

$$MA\ =\ 480\ /\ 200\ =\ 2.4$$

$$VR\ =\ 1.5\ /\ 1\ =\ 1.5$$

$$Work\ output\ =\ 480\ \times\ 1\ =\ 480\ J$$

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$Work\ input\ =\ 200\ \times\ 1.5\ =\ 300\ J$
$Efficiency\ =\ (480\ /\ 300)\ \times\ 100\ =\ 160\%$
$Note$: $An\ efficiency\ of\ 160\%\ is\ physically\ impossible\ for\ a\ real\ machine.$

A school maintenance worker uses a lever to move a heavy metal gate. The resistance offered by the gate is 50 N, while the worker applies an effort of 10 N. The effort moves through a distance that gives the lever a velocity ratio of 6.Determine:
a) The mechanical advantage of the lever system.
b) The efficiency of the lever system.

$Load\ =\ 50\ N, effort\ =\ 10\ N, VR\ =\ 6$
$MA\ =\ 50\ /\ 10\ =\ 5$
$Efficiency\ =\ (5\ /\ 6)\ \times\ 100\ =\ 83.3\%$

At a construction site, a worker uses a simple machine to lift a 20 kg bag of cement. An effort of 50 N is applied to the machine. When the effort moves through 25 cm, the bag of cement rises through 5 cm. Taking g=10 N/kg, calculate:

a) The mechanical advantage of the machine.
b) The velocity ratio.
c) The efficiency of the machine.

$Effort\ =\ 50\ N, load\ =\ 20\ kg, effort\ distance\ =\ 25\ cm, load\ distance\ =\ 5\ cm$
$Weight\ of\ load\ =\ mg\ =\ 20\ \times\ 10\ =\ 200\ N$
$MA\ =\ 200\ /\ 50\ =\ 4$
$VR\ =\ 25\ /\ 5\ =\ 5$
$Efficiency\ =\ (4\ /\ 5)\ \times\ 100\ =\ 80\%$

During the construction of a classroom, workers use a simple machine to raise a 200 N concrete slab. An effort of 100 N is applied, and the effort moves through a distance of 4 m. The machine has a velocity ratio of 5.

Find:

a) The distance through which the concrete slab moves.
b) The work input to the machine.
c) The work output.
d) The amount of energy wasted by the machine.

$Effort\ =\ 100\ N, load\ =\ 200\ N, effort\ distance\ =\ 4\ m, VR\ =\ 5$
$MA\ =\ 200\ /\ 100\ =\ 2$
$VR\ =\ effort\ distance\ /\ load\ distance$
$5\ =\ 4\ /\ load\ distance, therefore\ load\ distance\ =\ 0.8\ m$
$Work\ input\ =\ 100\ \times\ 4\ =\ 400\ J$
$Work\ output\ =\ 200\ \times\ 0.8\ =\ 160\ J$
$Energy\ wasted\ =\ 400\ -\ 160\ =\ 240\ J$

A farmer uses a simple machine to lift a 900 N water pump onto a raised platform. The pump moves through a vertical distance of 2 m when an effort of 300 N is applied. The machine is known to be 75% efficient.
Calculate:

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a) The mechanical advantage of the machine.
b) The velocity ratio.
c) The work output.
d) The work input.
e) The efficiency of the machine.

$Efficiency = 75\%, effort = 300\,N, load = 900\,N, load\ distance = 2\,m$
$MA = 900 / 300 = 3$
$75 = (3 / VR) \times 100, therefore\ VR = 4$
$Work\ output = 900 \times 2 = 1{,}800\,J$
$Work\ input = 1{,}800 \times 100 / 75 = 2{,}400\,J$
$Efficiency = 75\%$

At a farm, workers use a simple machine to load a heavy sack of produce onto a truck. An effort of 100 N moves through 12 cm, causing a 400 N load to move through 2 cm.
Calculate:

a) The mechanical advantage.
b) The velocity ratio.
c) The work input.
d) The work output.
e) The efficiency of the machine.

$Effort = 100\,N, effort\ distance = 12\,cm, load = 400\,N, load\ distance = 2\,cm$
$MA = 400 / 100 = 4$
$VR = 12 / 2 = 6$
$Work\ input = 100 \times 0.12 = 12\,J$
$Work\ output = 400 \times 0.02 = 8\,J$
$Efficiency = (8 / 12) \times 100 = 66.7\%$

A community uses an electrically powered water pump to raise 2,000 kg of water from a well to an elevated storage tank 22 m above the ground. The pump operates at an efficiency of 80%.Taking g=10 N/kg, calculate the work input required by the pump.
$Water\ pump\ raises\ 2{,}000\ kg\ through\ 22\ m, efficiency = 80\%$
$Weight\ of\ water = 2{,}000 \times 10 = 20{,}000\,N$
$Work\ output = 20{,}000 \times 22 = 440{,}000\,J$
$80 = (440{,}000 / Work\ input) \times 100$
$Work\ input = 440{,}000 \times 100 / 80 = 550{,}000\,J$

A school gardening club uses a simple machine to move a 60 N load of soil from one part of the school garden to another. The soil is raised through a vertical distance of 2 m. The effort applied is 20 N, and the effort moves through a distance of 8 m.
Calculate the efficiency of the machine.
$8. Load = 60\,N, load\ distance = 2\,m, effort = 20\,N, effort\ distance = 8\,m$
$Work\ output = 60 \times 2 = 120\,J$
$Work\ input = 20 \times 8 = 160\,J$
$Efficiency = (120 / 160) \times 100 = 75\%$

MASTERING PHYSICS

A simple machine raises a load of 300kg through 0.5m when an effort of 150N is applied through a distance of 12.5m. Calculate the work input into machine, work output by the machine and efficiency of the machine.

$Load = 300\,kg, load\ distance = 0.5\,m, effort = 150\,N, effort\ distance = 12.5\,m$

$Weight\ of\ load = 300 \times 10 = 3{,}000\,N$

$Work\ input = 150 \times 12.5 = 1{,}875\,J$

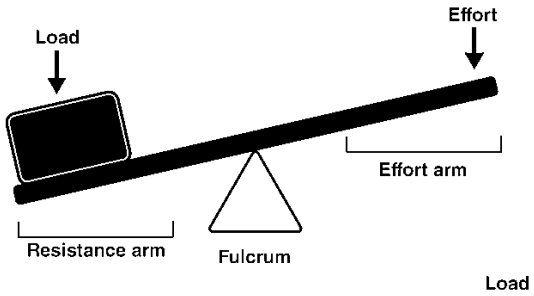
$Work\ output = 3{,}000 \times 0.5 = 1{,}500\,J$

$Efficiency = (1{,}500 / 1{,}875) \times 100 = 80\%$

Simple machines are fundamental devices that simplify work by utilizing principles of mechanical advantage and leverage. They allow users to apply a smaller force over a greater distance, making tasks more efficient. **The six primary types of simple machines include the lever, inclined plane, wedge, screw, pulley, and wheel and axle**. Each of these machines operates by altering the direction or magnitude of the force applied. For instance, a lever consists of a rigid beam pivoting around a fulcrum, enabling a small input force to lift a heavier load. Similarly, a pulley changes the direction of the force, allowing for easier lifting of objects. While simple machines do not reduce the total work required, they make it more manageable by redistributing the effort needed.

LEVERS

A lever is a simple machine made of a rigid beam that pivots around a fixed point called a fulcrum to multiply force, distance, or speed.



Classes of Levers

Levers are grouped into three classes based on where the fulcrum, load (resistance), and effort (input force) are located. FLE 123 (Fulcrum in 1st, Resistance/Load in 2nd, Effort in 3rd):

- First-Class Lever: The fulcrum is in the middle between the effort and the load. It can change the direction of force and multiply either force or speed. Examples: Seesaw, crowbar, scissors, pliers.
- Second-Class Lever: The load is in the middle between the fulcrum and the effort. It acts as a force multiplier, meaning a small effort moves a heavier load. Examples: Wheelbarrow, nutcracker, bottle opener.
- Third-Class Lever: The effort is in the middle between the fulcrum and the load. It multiplies speed and distance rather than force. Examples: Tweezers, fishing rod, human forearm, baseball bat.

Mechanical Advantage (MA)

Mechanical advantage is the factor by which a machine multiplies the input force.
Mechanical Advantage (MA): Ratio of Load to Effort; formula: Effort Arm / Load Arm.
An MA greater than 1 means you use less effort to move a heavy load. An MA less than 1 means you gain speed or distance rather than force.

Velocity Ratio / Velocity Ratio (VR)

Velocity Ratio (often called Ideal Velocity Ratio or IMA) is the ratio of the distance moved by the effort to the distance moved by the load.

$V.R = Distance\ moved\ by\ effort / Distance\ moved\ by\ load.$

Efficiency

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Efficiency measures how well a machine converts input work into useful output work. Because of friction, no real machine is 100% efficient.

$Efficiency\ (\eta)\ =\ (MA\ /\ velocity\ ratio)\ x\ 100\%$

Applications

- ♠ Construction & Lifting: Crowbars and jacks lift heavy concrete or stones.
- ♠ Gardening & Landscaping: Wheelbarrows move heavy soil and plants with less back strain.
- ♠ Kitchen & Household: Nutcrackers, bottle openers, and scissors make cutting and cracking effortless.
- ♠ Sports & Anatomy: Human arms and legs use muscle insertions as third-class levers for swift movements like throwing or kicking.

Activity

1. A construction worker uses a 1.5-meter-long crowbar to pry up a heavy concrete slab. He places a small stone pivot (fulcrum) 0.3 meters away from the concrete slab, leaving the remaining length of the crowbar as the effort arm. The concrete slab exerts a downward load force of 1,200N.

Calculate:

a) The length of the effort arm (1.2m).
b) The Velocity Ratio (VR) of the crowbar setup (4).
c) The ideal effort force required to lift the slab (assuming 100% efficiency) (300N).

If friction at the pivot reduces the actual Mechanical Advantage (MA) to 3.5, calculate the actual effort force he must apply (343N).

2.A gardener uses a wheelbarrow to move a load of soil weighing 600N. The center of gravity of the soil (the load) is located exactly 0.4 meters away from the wheel axle (the fulcrum). The handles of the wheelbarrow are 1.2 meters away from the axle.

Due to friction in the wheel bearings, the wheelbarrow is only 80% efficient.

Calculate:

a) The Velocity Ratio (VR) of the wheelbarrow(3).
b) The Mechanical Advantage (MA) of the wheelbarrow taking its efficiency into account (2.4).
c) The effort force the gardener must apply upward on the handles to lift the load (250N).

3.A mechanical crane arm operates as a third-class lever. The pivot point is at the base. A hydraulic piston applies an upward effort force 2.0 meters away from the pivot. The crane arm extends out to a total length of 10 meters, where it holds a cargo container weighing 4,000N.

During the lift, the hydraulic piston has to exert an actual effort force of 25,000N.

Calculate:

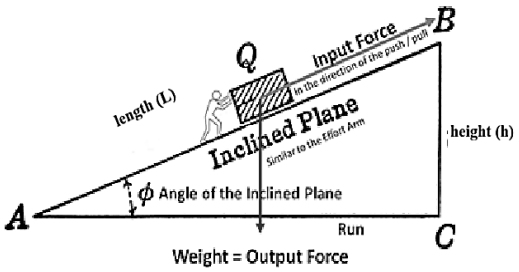
a) The Velocity Ratio (VR) of the crane arm (0.20).
b) The actual Mechanical Advantage (MA) achieved by the crane (0.16).
c) The percentage efficiency of this crane system (80%).

Understand: *The stated geometry gives VR=0.20, hence, the calculated efficiency is 80%. This is mathematically consistent with the given dimensions and forces, however, a third-class lever normally has a mechanical advantage less than 1*

The Inclined Plane

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An **inclined plane**, commonly known as a ramp, is a flat surface tilted at an angle to the horizontal. It is a simple machine used to lift heavy loads by moving them over a longer distance rather than lifting them straight up vertically.



Types of Inclined Planes

- **Standard Ramp:** A stationary tilted surface used to move objects up or down (a wheelchair ramp).
- **The Wedge:** A portable, double-sided inclined plane that moves *under* or *into* an object to split, cut, or hold it in place (an axe, knife, or doorstop).
- **The Screw:** An inclined plane wrapped around a central cylinder or shaft in a spiral pattern. The spiral ridges are called threads (wood screws, jar lids).

Mechanical Advantage (MA): Mechanical Advantage is the factor by which the ramp multiplies your input force, allowing you to lift a heavy object with less effort.

$$Mechanical\ Advantage = \frac{Load\ (weight\ of\ the\ object)}{Effort\ (force\ applied\ up\ the\ ramp)}$$

An MA greater than 1 means you need less force to move the object upward compared to lifting it vertically. However, you must push it over a longer distance.

Velocity Ratio (VR): Velocity Ratio (also known as the Ideal Mechanical Advantage or IMA) is the theoretical advantage of the machine if there were zero friction. It depends strictly on the physical dimensions of the ramp.

$$Velocty\ Ratio = \frac{Length\ of\ the\ incline\ (L)}{vertical\ height\ of\ the\ incline\ (h)} = \frac{L}{h}$$

A longer, shallower ramp gives a higher VR, making the climb easier but longer. A steeper ramp gives a lower VR, requiring more force over a shorter distance.

Efficiency

Efficiency measures how much of the work put into the machine is converted into useful output work. In the real world, friction between the object and the ramp always reduces efficiency below 100%.

$$\boldsymbol{Efficiency\ (\eta) = \frac{M.A}{V.R} x100\%}$$

$$\boldsymbol{Efficiency\ (\eta) = \left(\frac{work\ output}{work\ input}\right) x100\% = \left(\frac{Load\ x\ load\ distance\ (h)}{Effort\ x\ effort\ distance\ (L)}\right) x100\%}$$

$$\boldsymbol{Efficiency\ (\eta) = \left(\frac{Lx\ h}{ExL}\right) x100\%}$$

Applications and Examples

- **Wheelchair Ramps:** Allow buildings to be accessible by converting a steep vertical step into a gradual, manageable slope.
- **Loading Ramps:** Used to roll heavy boxes, vehicles, or livestock onto trucks and cargo planes.
- **Switchback Roads:** High-mountain highways wind back and forth in zigzag slopes rather than going straight up, allowing cars with standard engines to climb steep mountains.
- **Playground Slides:** Utilize the inclined plane downward, using gravity to move a person safely from a high platform to the ground.

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- **Stairs and Escalators:** Gradual, stepped inclined planes that allow humans to lift their own body weight to upper floors efficiently
- **Wedges and Screws:** A wedge is two inclined planes back-to-back (like an axe blade), and a screw is an inclined plane wrapped around a metal cylinder.

Work done along an inclined plane

Activity: To determine the work done along an inclined plane

Materials: *Spring balance, one piece of wood of about 10 cm, a wedge, ruler, trolley/ piece of wood/mass hanger/stone.*

Procedures

a) Make an inclined plane by putting a piece of wood on a wedge.
b) Attach the mass hanger to a spring balance (calibrated in newtons).
c) Measure the length of the incline and its height, and record it down ***d* (cm) and h(cm)**
d) Pull the spring balance with its object on from the bottom of the incline and note down the force used in pulling **F(N)**
e) Change the length in cm to m and find the work done using the formula, *work = Fd = (J)*
f) Using the above skills, approximate the amount of work you do when climbing a slope of 100 m long.

Observation and conclusion

Work done by the applied force is given by Work done = **Fd**.

The work done against the gravitational force is given by *Work done = weight of the object x vertical height.* $\boldsymbol{Work = mgh}$.

If the inclined plane is **frictionless force:** ***Work done by the applied force = work done against gravity.***

In case there is some frictional force opposing the sliding of the object along the plane:

$Work\ done\ by\ the\ applied\ force > Work\ done\ against\ gravity$

$$\boldsymbol{Work\ done\ against\ friction = Work\ done\ by\ applied\ force - work\ done\ against\ gravity}$$

Example

A box of mass 100 kg is pushed by a force of 920 N up an inclined plane of length 10 m. The box is raised through a vertical distance of 6 m.

Determine (i) the work done by the applied force, (ii) the work done against the gravitational force. (iii) the difference in work done. Why do the answers to (i) and (ii) in part (a) differ?

Responses:

(a) (i) Work done by the applied force = $F \times d = 920\,N \times 10\,m = 9\,200\,J$

(ii) Work done against gravity = $F \times d = mg \times h = 100\,kg \times 10\,N/kg \times 6\,m = 6\,000\,J$

(iii) The difference in work done = $9\,200\,J - 6\,000\,J = 3\,200\,J$. This work done is used to overcome the friction between the box and surface of the incline plane. The useful work done is 6 000 N.

Activity:

1. A box of mass 50 kg is pushed with a uniform speed by a force of 200 N up an inclined plane of length 20 m to a vertical height for 8 m.

Calculate the: (a) Work done to move the box up the inclined plane. (b) Work done if the box was lifted vertically upwards.

2. A body of mass 85 kg is raised through a vertical height 6 m through an inclined plane with base length of 8m. Calculate the:(a) Slant distance.(b) Work done by the force 150 N.(c) Work done, if the body was

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lifted vertically upwards. (d) Work done against friction. (e) Frictional force between the body and the track.

3. A block of mass 60 kg was raised through a vertical height of 7 m. If the slant height of a frictionless track is 21 m, and the force used to push the block up the plane is 800 N, calculate the work done in pushing the block.

4. A car engine offers a thrust of 2 500 N to ascend a sloppy road for 1.1 km. At the top of the slope, the driver realized that the attitude change was 200m. If the mass of the car is 1.2 tonnes, calculate the; (a) Work done by the car engine. (b) Work done against resistance.

5.A brick of weight 20N is lifted through a height of 3m along a smooth inclined plane of length 15m by applying an effort of 5N. Calculate the efficiency.

6.A woman uses an inclined plane to lift a load of 500N through a vertical distance of 4m. the inclined plane makes an angle of 30° to the horizontal. If the efficiency of the inclined plane is 72%, calculate the effort need to raise the load.

7. An effort of 50N is used to move a 300N box along an inclined, which rises vertically 1m for every 8m distance along the plane. Find the efficiency of the inclined plane.

8. A trolley of weight 10N is pulled from the bottom to the top of the inclined plane by a steady force of 2N. If the height and the distance moved by the force are 2m and 20m respectively, calculate the efficiency of the inclined plane.

9.A delivery driver uses a 4.0-meter-long ramp to roll a heavy crate from the ground onto the bed of a truck, which is 1.0 meter high. The crate weighs 1,200N (Load). The driver has to push with a force of 400N (Effort) parallel to the ramp to move it up.

Calculate:

a) The Velocity Ratio (VR) of the ramp (4).
b) The actual Mechanical Advantage (MA) achieved by the driver (3).
c) The percentage efficiency of the ramp system (75%).
d) The amount of energy wasted as heat due to friction if the total work output is 1,200 Joules(400J).

10.An industrial factory needs to lift a heavy steel flywheel weighing 3,000N to a raised platform that is 2.5 meters high. They build a custom metal ramp that has a Velocity Ratio (VR) of 5.0. Due to the smooth metal rollers used under the flywheel, the ramp operates at an impressive 75% efficiency.

Calculate:

a) The total length of the metal ramp (12.5m).
b) The actual Mechanical Advantage (MA) of the ramp (3.75).
c) The effort force required to roll the flywheel up this ramp (800N).

11.Dock workers are loading cargo onto a ship using a ramp. The ramp is 6 meters long and reaches a height of 2 meters. A worker pushes a 900N box up the ramp. Because the ramp is rough wood, a massive amount of friction is present, making the ramp only 50% efficient.

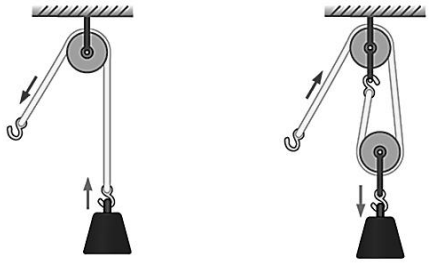
Calculate:

a) The Velocity Ratio (VR) of the ramp (3).
b) The actual Mechanical Advantage (MA) (1.5).
c) The Effort force the worker must exert to successfully push the box to the top (600N).

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PULLEYS

A pulley is a simple machine consisting of a wheel (called a sheave) with a grooved rim through which a rope, cable, or chain runs. It is used to lift heavy loads by changing the direction of the applied force or multiplying the force.



Classes / Types of Pulleys

Pulleys are categorized into three primary systems based on how they are configured:

- **Fixed Pulley:** The axle of the pulley is anchored to a permanent support and does not move.

  Function: It only changes the direction of the force (pulling down to lift an object up), making work ergonomically easier. It does not multiply force. Examples: Flagpoles, window blinds, traditional clotheslines.

- **Movable Pulley:** The axle of the pulley is attached di rectly to the load and moves along with it.

  Function: It acts as a force multiplier, cutting the required effort in half. However, you must pull twice the length of rope. Examples: Construction cranes, zip lines.

- **Block and Tackle (Combined System):** A combination of fixed and movable pulleys working together. It drastically reduces the required effort by distributing the weight across multiple supporting ropes. Examples: Sailing ship rigging, heavy workshop garage lifts, crane hooks.

Mechanical Advantage (MA)

Mechanical Advantage is the factor by which the pulley system multiplies your input force.

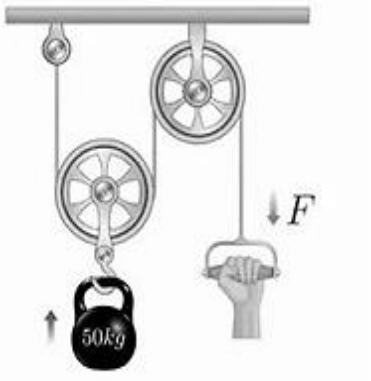
$$\boldsymbol{MechanicalAdvantage = \frac{Load\ (L = output\ force)}{Effort\ (E = input\ force)}}$$

Due to friction in the wheels and the weight of the moving pulleys themselves, the actual MA is always less than the theoretical Velocity Ratio.

Velocity Ratio (VR)

Velocity Ratio (or Ideal Mechanical Advantage) is determined solely by the geometry of the system.

$$\boldsymbol{V.R = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load} = \frac{E.D}{L.D}}$$



For a pulley system, the VR is simply the total number of rope segments directly supporting the moving load.

- Fixed Pulley: VR = 1 (Only 1 rope segment holds the load; you pull 1 meter of rope to lift the load 1 meter).
- Single Movable Pulley: VR = 2 (2 rope segments support the load; you pull 2 meters of rope to lift the load 1 meter).
- Block and Tackle: VR = (where N is the number of pulleys / supporting ropes).

Efficiency

Efficiency measures how much input work is successfully converted into lifting the load. Friction in the bearings and the stiffness of the rope reduce efficiency.

$$\boldsymbol{Efficiency = \frac{MA}{VR} x100\%}$$

Applications and Examples

Pulleys are foundational to heavy lifting and transport infrastructure:

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- **Construction Cranes** utilize massive block and tackle configurations to lift steel beams weighing thousands of kilograms with relatively small motors.
- **Elevators** use a system of heavy-duty cables and fixed pulleys connected to counterweights to smoothly transition passengers between floors.
- **Gym Equipment:** Cable-crossover machines use fixed pulleys to direct weight stacks upward while you pull downward, outward, or sideways.
- **Sailing Vessels:** Sailors use block and tackle systems to manually pull down high-tension sails against heavy oceanic winds.
- **Well Water Buckets:** A single fixed pulley mounted over a water well allows someone to pull downward comfortably to lift a heavy bucket of water straight up.

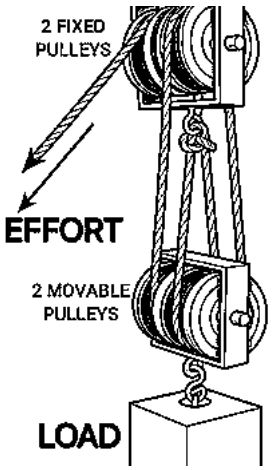
BLOCK AND TACKLE PULLEY SYSTEM

This is the type of pulley system where two or more pulleys are combined to form a machine with high velocity ratio and high mechanical advantage.

It consists of two blocks namely; Fixed block, and Movable block. A single rope called the "tackle" joins these blocks.

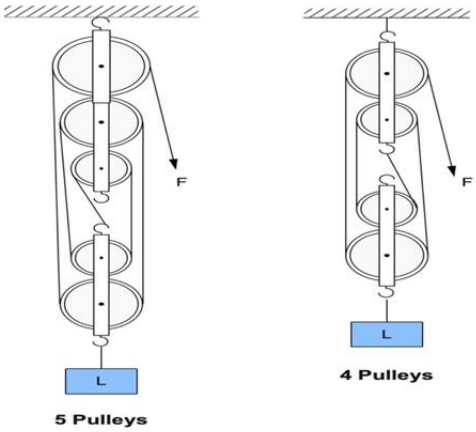
Understand:

- Velocity ratio is equal to the number of strings supporting the movable block.
- Velocity ratio is also equal to the number of pulleys on the system.
- The effort applied is equal to the tension in each string supporting the movable block.
- For an odd number of pulleys in the system, the fixed block should have one more pulley than the movable block.
- For an even number of pulleys in the system, the fixed and the movable blocks should have the same number of pulleys.



PASSING THE STRINGS (ROPES):

- If the number of pulleys is odd (velocity ratio is odd), the string must be tied and start from the movable block.
- If the number of pulleys is even (velocity ratio is even), the string must be tied and start from the fixed block.



Understand :

$$\textbf{Mechanical Advantage } (MA) = \frac{\textbf{Load}}{\textbf{effort}},$$

$$\textbf{Velocity Ratio } (VR) = \frac{\textbf{Distance moved by effort}}{\textbf{Distance moved by load}},$$

$$\textbf{Efficiency} = \left(\frac{M.A}{V.R}\right) \times 100\%$$

$$\textbf{Work} = \textbf{Force} \times \textbf{Distance}$$

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Activity

1). At a construction site, a block and tackle pulley system is used to lift a load of **220 N** when an effort of **110 N** is applied.

a) State the **velocity ratio** of the pulley system. (2)
b) Calculate the **mechanical advantage** of the system. (2)
c) Determine the **efficiency** of the pulley system. (100%)
d) Comment on the performance of the system based on your answer. (2 marks)

2). In a warehouse, a pulley system with a **velocity ratio of 5** is used to lift a **load of 500 N**. The effort applied is **200 N**.

a) Draw a **neat and labelled diagram** showing a possible arrangement of the pulley system. (4 marks)
b) Calculate the **efficiency** of the system. (50%)
c) State one reason why the efficiency is less than 100%. (2 marks)

The main reason is **Friction between the rope and pulley bearings Friction between the rope and pulley bearings.**

Other acceptable answers include: Weight of the pulleys, Friction between the rope and pulley , and Bending of the rope

3). A man uses a block and tackle pulley system to raise a load of **720 N** through a height of **10 m** using an effort of **200 N**. The pulley system has a **velocity ratio of 5**.

a) Calculate the **efficiency** of the pulley system. (72%)
b) Determine the **energy wasted** during the lifting process. (2800J)
c) Suggest one way of reducing energy losses in such a system.

Lubricate the pulley bearings to reduce friction. Other acceptable answers include using low-friction bearings or maintaining the rope and pulleys properly.

4). A pulley system in a school workshop has a **velocity ratio of 5** and is **60% efficient**. It is used to lift a **load of 60 kg** through a vertical height of **2 m**.

a) Calculate the **effort applied** to the system. (200N)
b) If the weight of the pulley system is **4 N**, determine the **actual efficiency** of the system. (60.4%)
c) Explain why the weight of the pulley system affects efficiency.
   - ♠ The pulley itself has to be lifted or supported by the system. Therefore, **some of the input energy is used to overcome the weight of the pulley rather than lifting the useful load**.
   - ♠ Hence, the heavier the pulley system, the greater the energy required and the lower the useful efficiency.
   - ♠ Pulley weight increases the load and causes more input energy to be used

5). A block and tackle pulley system is used to lift cargo of mass **2000 kg** at a harbour. The system has a **velocity ratio of 5** and an **efficiency of 80%**.

a) Sketch a **possible arrangement** of the pulley system. (4 marks)
b) Calculate the **mechanical advantage** of the system. (4 marks)
c) Determine the **effort required** to lift the cargo. (4 marks)

6). In a motor garage, an effort of **125 N** is used to lift a load of **500 N** through a height of **2.5 m**. The distance moved by the effort is **15 m**.

a) Calculate the **efficiency** of the pulley system. (4 marks)
b) Compare the **input work** and **output work**. (2 marks)
c) State one cause of energy loss in the system. (2 marks)

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7). In a rural community, an effort of **50 N** is required to raise a load of **200 N** using a pulley system of **velocity ratio 5**. The load is raised through a height of **120 cm**.

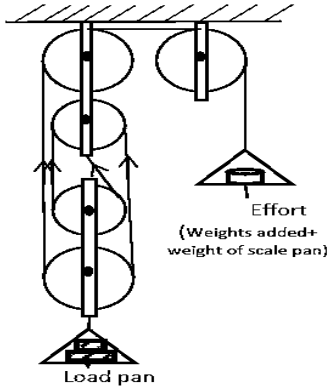
a) Draw a **neat and labelled diagram** of the pulley system. (4 marks)
b) Calculate the **efficiency** of the system. (3 marks)
c) Determine the **work wasted** during the lifting process. (3 marks)
d) Suggest one improvement to increase the efficiency of the system. (2 marks)

8). In a school physics laboratory, learners use a **simple pulley system** to lift a small load during a practical lesson on **simple machines**. The pulley system has a **velocity ratio of 3** and supports a **load of 20 N**. During the experiment, the **tension in each supporting string is measured to be 8 N**. When the load is lifted, it rises through a vertical distance of **2 m**.

Tasks:

a) Calculate the **efficiency** of the pulley system.
b) Determine the **distance moved by the effort** as the load rises through 2 m.
c) Calculate the **weight of the lower pulley** in the system.
d) State one factor that may cause the efficiency of the pulley system to be less than 100%.

To determine how the mechanical advantage and efficiency of a pulley system vary with the load



Objectives

- Measure the effort force needed for different loads using a pulley system.
- Calculate the mechanical advantage (MA), velocity ratio (VR), and efficiency for each load.
- Plot graphs to show how MA and efficiency vary with the load.

Apparatus

Pulley blocks (upper fixed block and lower movable block), Strong string or inextensible cord, Slotted masses with a hanger load (W), Spring balance or newton meter (to measure effort (E), Metre rule or tape measure, and Stand and clamp

Procedure

a) Set up the pulley system (such as a block and tackle system with a known velocity ratio, (VR = 4).
b) Record the velocity ratio (VR), which is the number of rope strands supporting the movable block.
c) Start with a small load (W), such as (0.2kg) or (2.0N) (including the weight of the load hanger).
d) Pull the free end of the string gently with the spring balance to lift the load at a steady, uniform speed.
e) Read and record the steady effort (E) shown on the spring balance.
f) Repeat the measurement for increasing values of load (W), adding equal increments of weight (2N, 4N, 6N, 8N, 10N).
g) Record all values in a data table.

Observations and Sample Data Table

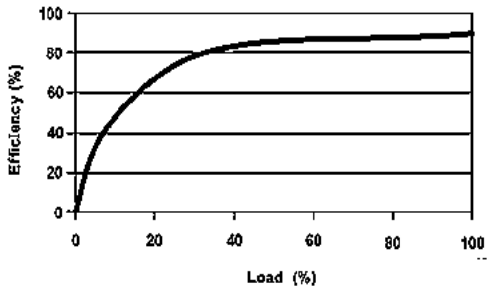
Load=mg(N)	Effort(N)	MA=L/E	VR	Efficiency=(MA/VR)x100%
2.0	0.8	2.50	4.0	62.5%
4.0	1.4	2.86	4.0	71.5%
6.0	1.9	3.16	4.0	79.0%
8.0	2.4	3.33	4.0	83.3%
10.0	2.9	3.45	4.0	86.2%

MASTERING PHYSICS

Analysis and Variation with Load

Variation of Mechanical Advantage:

As the load (W) increases, the mechanical advantage (MA) increases. Because the fixed frictional resistance in the bearings and strings remains constant, meaning it takes up a smaller fraction of a larger load's force distribution.

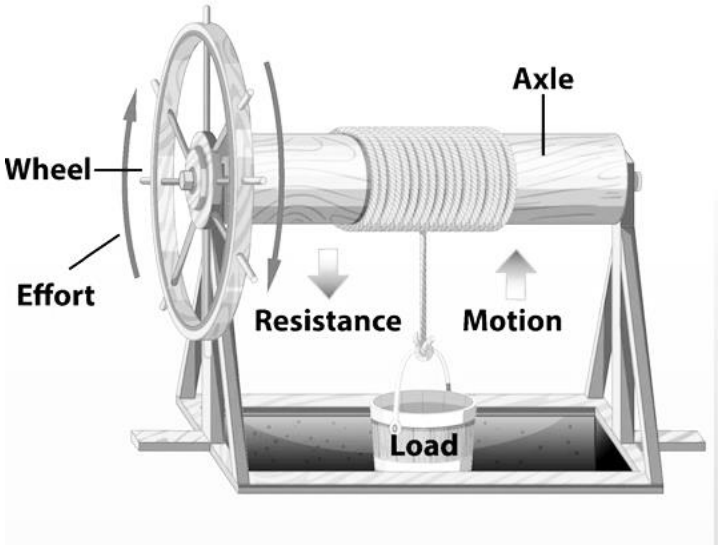


Variation of Efficiency:

- Efficiency increases rapidly at first with small loads, then increases more slowly and tends toward a maximum limit at higher loads.
- For small loads, the work done against friction is a very large percentage of the total work input, resulting in low efficiency.
- As the load grows larger, useful work output becomes much greater compared to the constant frictional losses.

WHEEL AND AXLE

A wheel and axle is a simple machine made of a large wheel fixed to a smaller axle so that both rotate together around the same center point.



Force Applied to the Wheel: You turn the large wheel to spin the smaller axle. This increases your force (Mechanical Advantage > 1), but you must turn the wheel a greater distance. (A doorknob or a steering wheel).

Mechanical Advantage (MA): Mechanical advantage is the factor by which a machine multiplies the applied force.

$$\boldsymbol{Mechanical\ Advantage\ (MA) = \frac{Load}{Effort}}$$

Because the wheel's radius is larger (R) than the axle's radius (r), turning the wheel gives you MA greater than 1.

Velocity Ratio (VR): Velocity ratio is the ratio of the distance moved by the effort to the distance moved by the load in the same time.

$$\boldsymbol{Velocity\ Ratio\ (VR) = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load}}$$

$$\mathbf{V.R} = \frac{\boldsymbol{radius\ of\ wheel}}{\boldsymbol{radius\ of\ axle}} = \frac{\boldsymbol{circumference\ of\ wheel}}{\boldsymbol{circumference\ of\ axle}} = \frac{\boldsymbol{R}}{\boldsymbol{r}}$$

In an ideal machine with no energy loss, the velocity ratio equals the mechanical advantage.

Efficiency: Efficiency tells you how well the machine converts input work into useful output work.

$$\boldsymbol{Efficiency} = \left(\frac{\boldsymbol{M.A}}{\boldsymbol{V.R}}\right) \times \mathbf{100\%}$$

MASTERING PHYSICS

Real wheels and axles have friction (rubbing resistance) at the center joint. Because of friction, the output work is always less than the input work. Real efficiency is always less than 100%.

Applications

- **Doorknobs:** Turning the large knob (wheel) easily turns the small metal rod (axle) inside the door.
- **Steering Wheels:** A small turn of your hands on the big steering wheel applies a large force to turn the car's front axle.
- **Screwdrivers:** The wide handle acts as the wheel, and the thin metal shaft acts as the axle to drive screws into wood.
- **Well Windlasses:** Turning a large crank handle (wheel) pulls a heavy bucket of water up using a small rolling cylinder (axle).
- **Bicycles:** Pedals and the front gear chain ring act as a wheel and axle system connected to the rear wheel.
- **Pencil Sharpeners:** Turning the crank handle spins the inner cutting blades.

The wheel and axle is a mechanical device that simplifies movement by reducing friction. It consists of a circular wheel attached to a central axle, allowing the wheel to rotate around the axle. This design enables heavy loads to be transported with minimal effort, as the wheel rolls over surfaces rather than dragging.

Understand: Velocity ratio of a wheel and axle is given by $\boldsymbol{V.R = \frac{circumference\ of\ wheel}{circumference\ of\ axle} = \frac{2\pi R}{2\pi r} = \frac{R}{r}}$**, and** $\boldsymbol{Mechanical\ Advantage = \frac{Resistance\ to\ be\ overcome(L)}{Applied\ force\ (E)}}$

ACTIVITY

1.At a construction site, workers use a wheel-and-axle machine to raise heavy building materials from the ground to an upper floor. The wheel has a radius of 50 cm, while the axle has a radius of 10 cm. When an effort of 100 N is applied to the wheel, the machine successfully lifts a load of 400 N.

Task:

a) Determine the velocity ratio (VR) of the wheel-and-axle machine (5).
b) Calculate the mechanical advantage (MA) of the machine (4).
c) Determine the efficiency of the machine (80%).
d) Explain one reason why the machine is not 100% efficient.

2.In a rural community, residents use a wheel-and-axle mechanism to draw water from a deep well. The wheel has a radius of 40 cm, while the axle has a radius of 10 cm. A person applies an effort of 20 N and is able to raise a bucket of water weighing 60 N.

Task:

a) Calculate the velocity ratio of the wheel-and-axle system (4).
b) Calculate the mechanical advantage (3).
c) Determine the efficiency of the system (75%).
d) State two practical factors that may reduce the efficiency of the water-drawing system.

3.A mechanic at an automobile garage uses a wheel-and-axle hoisting system to lift heavy vehicle components. The wheel has a radius of 40 cm, while the axle has a radius of 4 cm. During one operation, the mechanic applies an effort of 200 N and lifts a load of 800 N through a certain height. The efficiency of the machine is 50%.

Task:

a) Calculate the velocity ratio of the machine (10)

MASTERING PHYSICS

b) Calculate the mechanical advantage of the machine (4).
c) If the machine receives 4,000 J of input energy, calculate the useful output energy (2000J).
d) Calculate the energy wasted during the operation (2000J).
e) Suggest one way the mechanic could reduce energy losses in the machine.

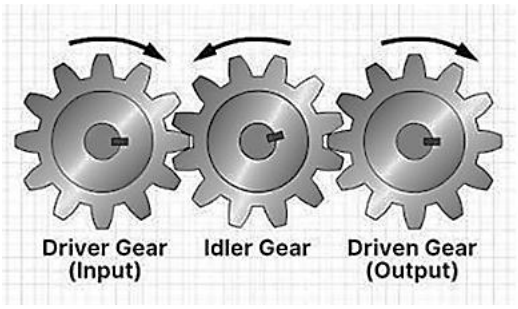
4.At a workshop, a technician constructs a wheel-and-axle machine for lifting heavy equipment. The wheel has a diameter of 20 cm, while the axle has a diameter of 4 cm.
Task:

a) Calculate the velocity ratio of the machine (5).
b) If the machine operates at 100% efficiency, determine its mechanical advantage (5).
c) In actual use, the mechanical advantage is found to be less than the value calculated in (b). Explain why this happens in a real machine.
d) State two sources of energy loss in the machine.

5.Workers at a construction site use a windlass to raise a load of 480 N from a construction pit. The worker applies an effort of 200 N at right angles to the handle. The distance from the axis of rotation to the point where the effort is applied is 33 cm, while the radius of the axle is 11 cm.
Task:

a) Calculate the velocity ratio of the windlass (3).
b) Calculate the mechanical advantage of the windlass (2.4).
c) Determine the efficiency of the windlass (80%).
d) Explain why the worker has to apply an effort at right angles to the handle.
e) Suggest one maintenance practice that can improve the efficiency of the windlass.

GEARS



Gears are toothed wheels that mesh together to transfer rotational power and motion from one shaft to another. They act as simple machines that can change the speed, torque (turning force), and direction of a power source.
Gears and machine performance metrics evaluate how mechanical systems transmit force, speed, and energy.
Gears are rotating machine parts with cut teeth that mesh together to transmit rotational force, speed, and direction between different parts of a system.

- ♠ Driver Gear: The input gear turned by a power source or hand.
- ♠ Driven Gear: The output gear rotated by the driver gear.
- ♠ Gear Ratio: The proportion of teeth on the driven gear compared to the driver gear

$$\boldsymbol{Gear\ ratio} = \frac{\boldsymbol{driven\ teeth}}{\boldsymbol{driver\ teeth}}$$

Mechanical Advantage (MA): Mechanical advantage is the factor by which a machine multiplies an applied input force to overcome a resistance load.

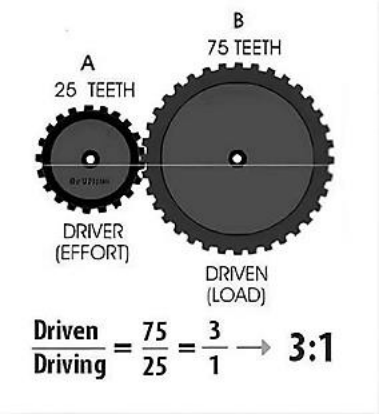
$$\boldsymbol{Mechanical\ Advatange} = \frac{\boldsymbol{Load\ (output\ force)}}{\boldsymbol{Effort\ (Input\ force)}}$$

An MA greater than 1 means the machine outputs more force than you put in, usually by trading away speed or distance.

MASTERING PHYSICS

Velocity Ratio (VR): Velocity ratio is the ratio of the distance moved by the effort to the distance moved by the load in the same time interval, or the ratio of input speed to output speed. It depends entirely on the geometry of the machine.

$$\boldsymbol{Velocity\ Ratio} = \frac{\boldsymbol{distance\ moved\ by\ effort}}{\boldsymbol{distance\ moved\ by\ load}} = \frac{\boldsymbol{input\ speed}}{\boldsymbol{output\ speed}}$$



Efficiency: Efficiency measures how well a machine converts input work or energy into useful output work, lowered in practice by friction and heat.

$$\boldsymbol{Efficiency}\ (\eta) = (\frac{\boldsymbol{M.A}}{\boldsymbol{V.R}}) \times \mathbf{100}\%$$

Real machines always have an efficiency under 100% because energy escapes as thermal energy or sound due to friction.

Applications

- **Automotive Transmissions:** Changing gear ratios to balance low-speed high torque (for starting/climbing) and high-speed low torque (for cruising).
- **Bicycles:** Using differing sprocket/gear sizes to let riders pedal easily while achieving high wheel speeds.
- **Industrial Machinery & Robotics:** Using worm gears or gearboxes for precise movement control, heavy lifting, and rotational speed reduction.
- Industrial machinery also heavily relies on gears for functions like conveyor systems, pumps, and mixers, where precise control of speed and torque is necessary.
- Gears are utilized in household appliances, and aerospace technology, showcasing their versatility across multiple sectors.
- Daily life applications like applied in clocks, bicycles, motor cycles, watches, and motors.

In gears; the effort is applied to the shaft of the small gear (wheel) called a driving wheel, the load is applied to the shaft of the large gear (wheel) called a driven wheel. The more the number of teeth on the gear, the less the speed of rotation of the gear and the less the number of teeth on the gear, the higher the speed of rotation of the gear. Therefore, the fastest gear is the driving wheel with the smallest number of teeth.

Understand:

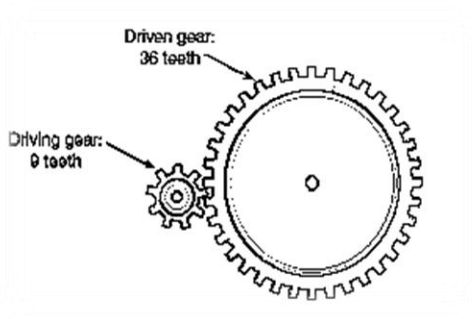
$$\boldsymbol{Velocity\ ratio\ of\ a\ gear\ system} = \frac{\boldsymbol{number\ of\ teeth\ of\ the\ driven\ gear}}{\boldsymbol{number\ of\ teeth\ of\ the\ driving\ wheel}}$$

$$\boldsymbol{V.R} = \frac{\boldsymbol{speed\ of\ driver\ gear}}{\boldsymbol{speed\ of\ drivinen\ gear}}$$

$$\boldsymbol{M.A} = \frac{\boldsymbol{Output\ Torque}}{\boldsymbol{Input\ Torque}}$$

MASTERING PHYSICS

If two simple machines are combined together, the overall velocity ratio is equal to the product of the individual velocity ratios of the two machines.



$$\textbf{Velocity ratio} = \frac{\textbf{driven gear}}{\textbf{driving gear}} = \frac{\mathbf{36}}{\mathbf{9}} = \mathbf{4}$$

Example

1.A driving gear has **20 teeth** and turns a driven gear with **50 teeth**. If an effort overcomes friction such that the actual mechanical advantage measured is **2.0**, find the velocity ratio and the efficiency of the system.

$$\textbf{Velocity ratio of a gear system} = \frac{\textbf{number of teeth of the driven gear}}{\textbf{number of teeth of the driving wheel}}$$

$$VR = \frac{50}{20} = 2.5 \quad \textbf{Efficiency } (\eta) = \left(\frac{\textbf{M.A}}{\textbf{V.R}}\right) \times \mathbf{100\%} = \frac{\mathbf{2}}{\mathbf{2.5}}\mathbf{x100\%} = \mathbf{80\%}$$

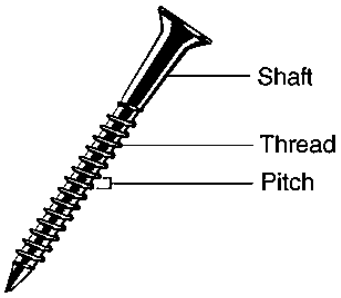
2.A machine lifts a load of **150N** using an effort of **50N**. The effort moves a distance of **6m** while the load moves **1.5m**. Calculate the MA, VR, and Efficiency.

$$MA = \frac{load}{effort} = \frac{150N}{50N} = 3, \quad VR = \frac{distance\ of\ effort}{distance\ of\ load} = \frac{6m}{1.5m} = 4$$

$$\textbf{Efficiency } (\eta) = \left(\frac{\textbf{M.A}}{\textbf{V.R}}\right) \times \mathbf{100\%} = \frac{\mathbf{3}}{\mathbf{4}}\mathbf{x100\%} = \mathbf{75\%}$$

SCREWS

A screw is a simple machine that is essentially an inclined plane wrapped around a central cylinder. It converts rotational force (torque) into linear force and movement.



- A screw is a simple machine made of an inclined plane wrapped around a central cylinder, turning rotational force into linear force.
- A shaft with helical ridges called threads that moves forward or backward when rotated.
- The two primary functions of a screw are to hold things together or to lift objects. The threading around the shaft in a screw makes it an efficient tool to hold things together.
- A few examples of screws include screw, bolt, clamp, spinning stool, and spiral staircase. A car jack is an example of a screw used to lift something.
- The ridges wrapped around the cylinder are called **threads.**
- The distance between two adjacent threads is called the **Pitch (P).**

Mechanical Advantage (MA): The Mechanical Advantage (MA) of a screw is the factor by which it multiplies the input force. Because a screw is a modified inclined plane, its ideal mechanical advantage is very high. It allows a small rotational force to lift or hold a massive load.

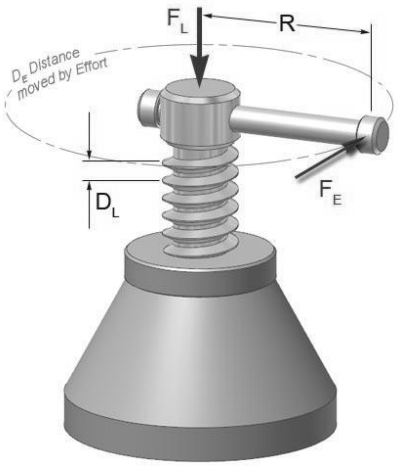
$$\textbf{Mechanical Advantage} = \frac{\textbf{Output force } (F_L)}{\textbf{Input Force } (F_E)}$$

Velocity Ratio (VR): The Velocity Ratio (VR) (or Ideal Mechanical Advantage) is the ratio of the distance moved by the effort to the distance moved by the load.

MASTERING PHYSICS

When you turn a screw one full rotation ($\boldsymbol{circumference = 2\pi R}$), where R is the radius of the screwdriver handle or wrench),
The screw moves forward by a distance equal to exactly one pitch (P).

$$\boldsymbol{VR = \frac{distance\ moved\ by\ effort}{distance\ moved\ by\ load\ (D_L)} = \frac{2\pi R}{pitch} = \frac{2\pi R}{P}}$$



Because the pitch (p) is usually very small compared to the circumference of the handle ($2\pi R$), the VR of a screw is extremely high.

Efficiency (η): Efficiency is the ratio of useful work output to total work input.

$$\boldsymbol{Efficiency\ (\eta) = \frac{MA}{VR} x100\%}$$

Screws have low mechanical efficiency (often below 50%) due to massive friction between the threads and the surrounding material.
While low efficiency sounds bad, it is actually a crucial design feature for fasteners. High friction creates a self-locking mechanism, meaning the screw stays tightly in place and will not unwind on its own when the input force is removed.

Applications

Screws are used for two primary functions: **fastening materials together and lifting heavy loads/transmitting power.**



Fastening & Holding

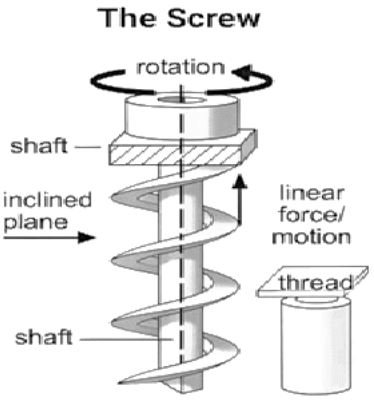
- **Wood Screws and Bolts**: Used to hold furniture, construction materials, and machinery together.
- **Bottle Caps and Jar Lids:** Utilize wide screw threads to seal containers tightly.
- **Light Bulbs:** Edison-base light bulbs screw into sockets to create a secure electrical and physical connection.
- Wood screws are designed for fastening wood, while concrete screws are tailored for securing objects to concrete surfaces.
- Specialized screws like lag screws are used in heavy-duty applications, such as fixing structural components in construction. Screws find applications across diverse industries, including automotive, aerospace, and electronics.
- Assembling machinery, securing components like gears and bearings, and even in furniture construction.

Lifting & Power Transmission

- **Car Scissor Jacks:** Convert the easy rotational spinning of a crank into a massive upward linear force to lift automobiles.
- **Archimedes 'screw:** An ancient device still used today in wastewater treatment plants and irrigation to lift water upward via a rotating spiral tube.
- **Clamps and Vises:** Workshops use large screws to tightly clamp wood or metal pieces in place for cutting or drilling.

MASTERING PHYSICS

Understand:



- ♠ *An effort is applied on the handles of those devices above to drive the screw (load) in and out of the material.*
- ♠ *When the handle moves through one complete turn (complete circular path), the screw enters or leaves the wood through a distance equal to the pitch of the screw.*
- ♠ *Distance moved by the effort in one complete turn is equal to the circumference of a circle described by the handle, where radius, R of the circle is equal to the length of the lever arm.*
- ♠ *Distance moved by the load (screw) in one complete turn is equal to the pitch of the screw (Pitch).*

$$\boldsymbol{Velocity\ ratio\ of\ a\ screw} = \frac{\boldsymbol{circumference}}{\boldsymbol{pitch}} = \frac{\boldsymbol{2\pi R}}{\boldsymbol{pitch}}$$

Understand

- ♠ The velocity ratio of the screw is always very large because the length of the handle is very big compared to the pitch of the screw.
- ♠ The efficiency is always very low because screws have a very high friction since the threads are very rough helping screws to firmly hold materials together.

Example

1.At an automobile repair workshop, a mechanic uses a screw jack to raise a vehicle so that he can inspect its tyres and suspension. The jack has a lever arm 56 cm long and the screw has a pitch of 4 cm.
Task: Calculate the velocity ratio (VR) of the screw jack.

Response:

Velocity ratio of the screw jack
Given: Lever arm length, r=56 cm, Pitch, p=4 cm
For one complete revolution, the effort moves through the circumference of the circular path:
Distance moved by effort=2πr, $\boldsymbol{VR} = \frac{\textbf{distance moved by effort}}{\textbf{distance moved by load}} = \frac{\boldsymbol{2\pi r}}{\boldsymbol{Pitch}} = \frac{\textbf{2x3.14x56}}{\textbf{4}} = \boldsymbol{88}$

2.A mechanic uses a screw jack to raise a car while changing a damaged tyre. The screw has a pitch of 5 cm. The handle moves through a circular path of circumference 10 cm during one complete turn. The jack operates at an efficiency of 85% and raises a load of 890.8 N.
Task: Determine the velocity ratio of the screw jack. the mechanical advantage of the jack, hence, explain what the efficiency informs the mechanic about the performance of the jack.

Response

Screw jack used to change a damaged tyre
Given: Pitch =5 cm, Circumference of handle path =10 cm, Efficiency =85%, Load =890.8 N

$$\boldsymbol{VR} = \frac{\boldsymbol{distance\ moved\ by\ effort}}{\boldsymbol{distance\ moved\ by\ load}} = \frac{\boldsymbol{10}}{\boldsymbol{5}} = \boldsymbol{2}$$

The effort moves 10 cm in one revolution, while the load moves one pitch, 5 cm.

Mechanical advantage

Efficiency is related to MA and VR by $\eta = \frac{MA}{VR} x100\%$,
Therefore, $\boldsymbol{MA} = \frac{\boldsymbol{\eta \times VR}}{\boldsymbol{100}}, \boldsymbol{MA} = \frac{\boldsymbol{85x2}}{\boldsymbol{100}} = \boldsymbol{1.7}, \boldsymbol{MA} = \boldsymbol{1.7}.$
Finding the effort: $\boldsymbol{MA} = \frac{\boldsymbol{Load}}{\boldsymbol{effort}}, \boldsymbol{1.7} = \frac{\boldsymbol{890.8}}{\boldsymbol{effort}}, \boldsymbol{effort} = \frac{\boldsymbol{890.8}}{\boldsymbol{1.7}} = \boldsymbol{524N}$

MASTERING PHYSICS

Meaning of the 85% efficiency

An efficiency of 85% means that 85% of the energy supplied by the mechanic is converted into useful work for lifting the vehicle, while about 15% is lost, mainly through friction in the screw and other moving parts.

Performance comment: The jack is reasonably efficient, but some energy is lost due to friction.

3.A technician uses a screw mechanism to lift a heavy machine part during maintenance. The screw has a pitch of 5 mm. An effort of 30 N is applied to a handle of radius 50 cm, causing the handle to make one complete revolution. The screw raises a load of 750 N.

Task: Calculate the efficiency of the screw mechanism.

Response

Given: Pitch =5 mm=0.005 m, Handle radius =50 cm=0.5 m, Effort =30 N, Load =750 N

One complete revolution

For one revolution, the effort moves through: $\boldsymbol{C = 2\pi r = 2 \times 3.142 \times 0.5 = 3.142\ m}$

The load moves through one pitch: $P = 0.005\ m$

Therefore:$\boldsymbol{VR = \frac{C}{P} = \frac{3.142}{0.005}}$, $\boldsymbol{VR = 628.4}$ $MA = \frac{Load}{Effort}$ Therefore, $\boldsymbol{MA = \frac{750}{30} = 25}$, $\eta = \frac{MA}{VR} x100\%$,

Therefore,$\boldsymbol{\eta = \frac{25}{628.4} x100\%}$, $\boldsymbol{\eta = 3.98\%}$.

The very low efficiency is mathematically correct from the given data. A screw with a 5 mm pitch and a 50 cm handle radius gives a very large velocity ratio, while the actual mechanical advantage is only 25.

Activity

4.A garage mechanic uses a screw jack with a lever arm of 56 cm to raise a vehicle. The distance between two successive threads of the screw is 2.5 mm. The jack raises a load of 800 N and has an efficiency of 25%.

Task: Calculate the velocity ratio of the screw jack, and determine its mechanical advantage, hence, suggest one way the mechanic could improve the efficiency of the jack.

5.A technician is testing a screw mechanism used in a small lifting device. The handle is 14 cm long and the screw has a pitch of 20 cm. An effort of 5 N is applied through the handle to raise a load of 15 N.

Task: Calculate the efficiency of the screw mechanism.

6.During a practical lesson in an engineering workshop, learners examine a screw used in a mechanical device. The screw has six successive threads. The distance between the first and sixth threads is 0.12 mm. The screwdriver handle attached to the screw has a circular path of diameter 0.28 m.

Task: Determine the velocity ratio of the screw mechanism.

7.A mechanic uses a screw jack to raise a car for servicing. The screw has a pitch of 2.5 mm and the jack has a lever arm 56 cm long. The mass of the car is 790 kg. The jack operates at an efficiency of 75%. Take g = 10 N/kg.

Task:

a) Calculate the velocity ratio of the screw jack.

b) Determine the mechanical advantage.

c) Calculate the effort required to raise the car.

MASTERING PHYSICS

8.A mechanic is tightening a bolt on a motorcycle engine. The bolt has a pitch of 1 mm. He uses a spanner whose handle is 80 cm long.
Task: Calculate the velocity ratio of the screw mechanism, and explain why using a longer spanner makes it easier to tighten the bolt.

9.A mechanic wants to construct a screw jack for lifting vehicles in a small garage. A prototype screw jack has an efficiency of 70%. An effort of 20 N is used to raise a vehicle weighing 5,000 N. The screw has a pitch of 2 mm.
Task: Calculate the length of the lever arm required.

10.A farmer uses a screw-operated lifting device to raise a 200 kg load during the repair of farm machinery. The screw has a pitch of 2.5 cm. An effort of 50 N is applied to a screw arm of length 20 cm. Take g = 10 N/kg.
Task: Calculate the efficiency of the screw mechanism, and state one advantage of using a screw mechanism when lifting heavy farm equipment.

11.A mechanic uses a screw jack to lift a car during a suspension repair. The screw has a pitch of 2.5 mm. A force of 100 N acts at a distance of 7 cm from the axis of rotation of the handle. The jack lifts a car weighing 792 kg. Take g = 10 N/kg.
Task: Calculate the efficiency of the screw jack. If the mechanic notices that the jack becomes difficult to operate over time, suggest two possible causes of reduced efficiency.

Wedge

A wedge is a simple machine that consists of two inclined planes placed back-to-back. A portable inclined plane moves into an object to force it apart, lift it up, or hold it in place.
Unlike a ramp (where the object moves along the stationary machine), with a wedge, the machine itself moves to do the work. It converts a forward linear force into a lateral (sideways) splitting force.
Velocity Ratio (VR): The Velocity Ratio (VR) (also known as the Ideal Mechanical Advantage) represents the theoretical factor by which the wedge multiplies your input force, assuming zero friction. It is determined entirely by the dimensions of the wedge:

$$\boldsymbol{VR = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ Load} = \frac{Length\ of\ the\ wedge(L)}{Thickness\ of\ the\ wedge\ (T)}}$$

Long, thin wedges have a high VR and require less effort to split an object.
Short, thick wedges have a low VR and require more effort, but they spread the material apart much faster.
Mechanical Advantage (MA): The Mechanical Advantage (MA) is the actual ratio of the output splitting force to your input driving force.

$$\boldsymbol{MA = \frac{Output\ Force\ (Splitting\ Force)}{Input\ Force\ (Driving\ Force)}}$$

In a perfect world, MA would equal VR. However, because wedges encounter extreme resistance when driving into solid materials, the actual MA is significantly lower than the VR.

Efficiency (η): Efficiency measures how much of your input work is converted into useful output work.

$$\boldsymbol{Efficiency = \frac{MA}{VR} x100\%}$$

Wedges have very low efficiency because they generate a massive amount of friction against the material they are penetrating. Much of your input energy is lost as heat and sound.

MASTERING PHYSICS

However, just like screws, this low efficiency is highly beneficial. High friction prevents the wedge from slipping backward or popping out of the material when you stop hitting it, allowing it to stay firmly in place (self-locking).

Understand: *While friction reduces efficiency, it is actually* ***essential*** *for wedges. Without friction, a wedge would violently pop backward out of a log or under a door the moment you stop pushing it.*

Applications

Wedges are incredibly versatile and are primarily used for three functions: cutting/splitting, lifting heavy loads, and holding things in place.

Cutting, Splitting, and Piercing

- Axes and Mauls: Used to split logs along the wood grain.
- Knives, Scissors, and Razors: Feature micro-wedges at their edges to cleanly slice through food, paper, or hair.
- Nails and Needles: Pointed tips that act as multi-sided wedges to part fibers or materials so they can penetrate deeply.
- Chisels: Used by woodworkers and stone masons to chip away material.

Holding and Securing

- Doorstops: Slid under a door; the friction and wedge shape lock the door firmly against the floor.
- Shims: Thin wedges used in carpentry to level furniture, windows, or cabinets during installation.

Lifting

Heavy Machinery Wedges: Driven under heavy equipment or blocks of stone to lift them slightly off the ground so lifting straps can be placed underneath.

Example:

A cook at a primary is using an **axe** to split a thick log of firewood with an axe head that is **20 cm long** and has a blunt back thickness of **5 cm**.

Task: Determine the efficiency of the axe.

Response:

$$\boldsymbol{VR = \frac{length}{thickness} = \frac{20cm}{5cm} = 4}$$

This means for every 4 cm the axe drives down into the wood, it pushes the wood fibers apart by 1 cm.

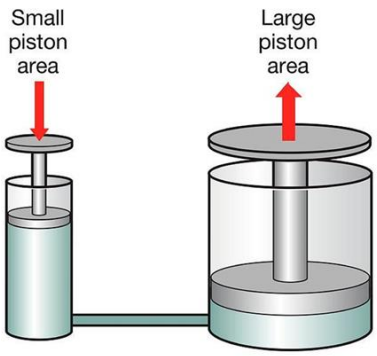
Mechanical Advantage (MA) & Efficiency: $\boldsymbol{MA = VRx\,efficiency = 4x0.25 = 1}$

Because driving metal into raw wood creates immense friction, a wedge might operate at an efficiency of only **25%**. Even with high friction reducing the theoretical force, the sharp tip concentrates your swing's impact into a tiny surface area, creating immense pressure that easily ruptures the wood fibers

HYDRAULIC SYSTEMS (PRESS OR LIFT)

A hydraulic press operates on Pascal's principle, which states that pressure applied to a confined fluid is transmitted undiminished throughout the fluid. This mechanism allows a small force applied on a smaller piston to generate a much larger force on a larger piston, enabling the press to perform heavy-duty tasks.

A basic hydraulic system consists of two cylinders of different sizes connected by a pipe filled with an incompressible liquid (usually oil). The smaller cylinder has an **Input Piston** (**Effort**), and the larger cylinder has an **Output Piston** (**Load**).

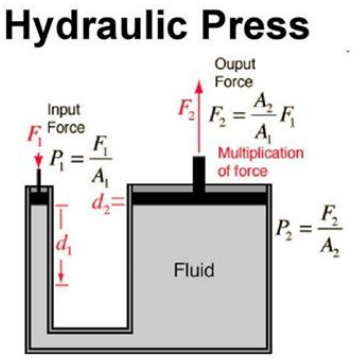


MASTERING PHYSICS

Velocity Ratio (VR): The ratio of the distance moved by the effort piston to the distance moved by the load piston. $\boldsymbol{VR=\frac{Area\ of\ Output\ piston\ (A_L)}{Area\ of\ input\ Piston(A_E)}}$, $\boldsymbol{VR=\frac{{A_2}^2}{{A_1}^2}, VR=\frac{r_L^2}{r_E^2}, VR=\frac{D_L^2}{D_E^2}}$

Where, A_E = area of the effort piston, A_L = area of the load piston, r_E = radius of effort piston, r_L = radius of load piston, D_E = diameter of effort piston, and D_L = diameter of load piston

To lift a heavy load a tiny distance, the small input piston must push down through a very long distance.



Mechanical Advantage (MA): The ratio of the heavy output force (Load) to the small input force (Effort). $\boldsymbol{MA=\frac{Output\ Force\ (F_2)}{Input\ Force\ (F_1)}}$. Because the internal liquid pressure is equal everywhere;$P=\frac{F}{A}$, making the output piston larger creates a **massive mechanical advantage**

Efficiency. The ratio of useful work output to total work input of the machine.

Hydraulic systems are **highly efficient (often 90% to 95%)** because liquids have minimal internal friction, though slight seal friction and fluid resistance cause minor losses.

Applications of hydraulics

Hydraulic systems are used anywhere massive forces must be controlled smoothly or heavy weights need lifting:

- **Hydraulic Lifts:** Used in automotive repair shops to hoist cars into the air and in elevators for low-rise commercial buildings.
- **Hydraulic Presses:** Massive industrial machines used for stamping sheet metal, crushing scrap cars, forging heavy steel parts, or molding plastics.
- **Heavy Construction Machinery:** The moving arms of excavators, bulldozers, and dump trucks rely entirely on hydraulic cylinders to dig and dump heavy earth.
- **Braking Systems:** The foot brakes in cars use a master cylinder (small piston) to push fluid down to the brake calipers (large pistons) to clamp onto the wheels and stop the car.

Example

Imagine a Car Shop Hydraulic Lift lifting a vehicle for an oil change. The small input piston has a cross-sectional area of **0.01m²** , and the large lifting piston has an area of 0.25m². Assuming high-grade hydraulic seals give the lift an **efficiency of 92%**, If a technician applies a force of **500 N** (roughly 50 kg of force) to the input pump,

Task: Determine the VR, MA and Output force the lift generates.

Response:

$Velocity\ Ratio\ (VR)=\frac{\text{output area}}{\text{input area}}=\frac{0.25}{0.01}=25.$

This means if you pump the small piston down by **25 cm**, the heavy car will only rise by **1 cm**.

$Mechanical\ Advantage\ (MA)=VRx\ Efficiency=25x0.92$

$Output\ force=500x23=11500N$

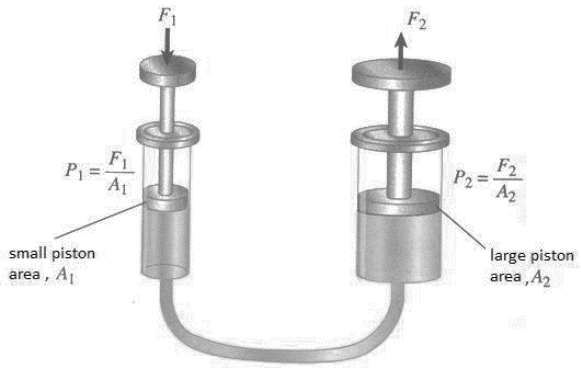
This is easily enough force to lift a **1,150 kg compact car**.

OPERATION OF THE SYSTEM

It's a device used to lift a large load using a small effort.

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When an effort is applied on the small piston; the volume of the liquid pushed down by the small piston is equal to the volume of the liquid lifts up the large piston with the load, since the pistons are circular, their areas equal to the area of a circle.
This means that the velocity ratio depends on the relative sizes of the pistons, where a larger output piston area compared to the input piston area results in a smaller movement (or velocity) of the output piston, but a higher mechanical advantage**.**



Example
A hydraulic press has a small piston of diameter **5 cm** and a large piston of diameter **25 cm**. Calculate its velocity ratio.
$\boldsymbol{VR = \frac{D_L^2}{D_E^2}, VR = \frac{25^2}{5^2} = \frac{625}{25} = 25}$. This means the **effort piston moves 25 times as far as the load piston** for the same volume of liquid displaced.
Understand: *For an ideal hydraulic press;* $MA = VR$*, for a real hydraulic press, because of friction and other losses.* $VR = \frac{\text{Area of large piston}}{\text{Area of small piston}}$*, and* $Efficiency = \frac{MA}{VR} x100\%$

A hydraulic press has a plunger diameter of **4cm** and a ram diameter of **20cm**. If an effort force of **150N** is applied to the plunger, find the Velocity Ratio and the maximum Load lifted assuming the machine is 100% efficient.
$VR = \frac{D^2}{d^2} = \frac{20^2}{4^2} = \frac{400}{16} = 25$
Calculate Load
Since efficiency is 100%, MA = VR= 25.
$MA = \frac{Load}{Effort}, 25 = \frac{Load}{150N}, \boldsymbol{\underline{Load = 3750N}}$

ACTIVITY
1.The radius of the effort piston of a hydraulic lift is 1.4cm while that of the load piston is 7.0cm. This machine is used to raise a load of 1200N. Given that the machine is 80% efficient, calculate the velocity ratio and Effort applied.
2.A hydraulic press is used to lift 400N using an effort of 20N. The diameter of the large cylinder is 100cm and the diameter of the small cylinder is 10cm. Find efficiency
3. A hydraulic machine has a ram cylinder (large cylinder) of diameter 30cm and a pump cylinder (small cylinder) of diameter 2cm. If the effort applied to the small piston is 70N and the efficiency of the machine is 80%, calculate the Velocity ratio and Load lifted.
4.A hydraulic machine has a large cylinder of 30cm and a small cylinder of 1cm. Given that the machine is 80% efficient and that the effort applied on the small piston is 50N, calculate the Maximum load that can be raised.
5. The area of the effort piston of a hydraulic lift is 562 while that of the load piston is 2242N.This machine is used to raise a load of 300kg through a height of 2.5mm. Given that the machine is 75% efficient, calculate the velocity ratio Effort applied and distance moved by the effort.

MASTERING PHYSICS

S2.2 TURNING EFFECT OF FORCES, CENTRE OF GRAVITY, AND STABILITY

Learning Outcomes

a) Understand the turning effect of forces and its applications (u, s,v/a)
b) Understand and apply the concept of centre of gravity (u, s,v/a)

Introduction

- The turning effect of forces, also known as **torque**, describes how forces can cause an object to rotate around an axis.
- When a force is applied at a distance from the pivot point, it generates a turning effect proportional to both the magnitude of the force and the distance from the pivot, known as the **lever arm**.
- **The turning effect of a force (torque or moment of force) is a measure of how effectively a force can cause an object to rotate around an axis or pivot point.**
- When you apply a force to an object that is fixed at a certain point (called the pivot or fulcrum), the force can cause the object to turn.
- The magnitude of the turning effect depends on two main factors: the size of the force applied and the perpendicular distance from the pivot to the line of action of the force.

$$\boldsymbol{Moment\ (Torque)\ = Force\ x\ Perpendicular\ distance\ from\ the\ pivot}$$

- SI Unit: **newton-meter (Nm).**
- Direction: Moments can act in either a clockwise or an anticlockwise direction.
- Torque (τ) is expressed as: $\boldsymbol{\tau = F \times d \times sin(\theta)}$; where: **F** is the magnitude of the force applied, **d** is the perpendicular distance from the line of action of the force to the axis of rotation (this is also known as the lever arm or moment arm), and **θ** is the angle between the force vector and the line from the pivot to the point where the force is applied.

Terms used in Moments

- Magnitude is the size, length, or numerical value of a physical quantity without regard to its direction.
- **Direction:** The path or orientation along which a force acts or a rotation occurs (such as clockwise or counterclockwise).
- **Lever Arm:** The perpendicular distance from the pivot point (axis of rotation) to the line along which the force acts.
- **Torque:** The measure of the force that can cause an object to rotate about an axis, calculated by multiplying the force by its lever arm.
- **Equilibrium**: For an object to be in rotational equilibrium, the sum of all torques acting on it must be zero. This principle is used in static equilibrium problems where objects are not accelerating or rotating.

The Principle of Moments:

For an object in rotational equilibrium (balanced), the sum of the clockwise moments about any point equals the sum of the anticlockwise moments about that same point.

Applications

We use the turning effect of forces daily to make tasks easier by increasing the distance (d) to reduce the effort force (F) required:

- Doorknobs are placed on the opposite side of the hinges (the pivot). This maximizes the distance, making it much easier to push or pull the door open.

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- A longer spanner provides a larger turning effect on a tight bolt, allowing you to loosen it with less effort.
- Crowbars and Bottle Openers act as levers where a small input force over a long distance generates a massive output force close to the pivot to lift heavy objects or pop caps.
- In seesaws; a heavier child sits closer to the center (pivot) while a lighter child sits further away to balance the turning moments.
- Pushing a door open at its edge
- Using a fork to twist pasta
- Pedaling a bicycle
- Balancing a seesaw on a playground

Examples

1.A mechanic uses a spanner of length 0.25 meters to loosen a nut. If they apply a perpendicular force of 80 N to the end of the spanner, calculate the turning effect.

Solution:

Given F = 80N, d = 0.25m

Formula: $Moment = Fd$

Calculation: $Moment = 80x0.25 = 20Nm$

2.A uniform see-saw is pivoted at its center. A child weighing 400 N sits 1.5 meters to the left of the pivot. Where must a second child weighing 300N sit on the right side to balance the seesaw?

Solution: from $Moment = Fd$

Anticlockwise Moment (Left Child): $400Nx1.5m = 600Nm$

Clockwise Moment (Right Child): $300xd_2Nm$

By the Principle of Moments:

$600Nm = 300xd_2Nm. d_2 = \frac{600}{300} = 2m$

The second child must sit exactly 2.0 meters away from the pivot.

Understand: Several experiments have been done on several tools and machines and proved that:

(a) The longer the handle, the lesser the effort used when using the machines.

(b) The shorter the handle, the more the effort used while working with the tools and machines.

Therefore, the manufacturers always design tools and machines such as bottle openers, see-saw, water taps, spanners and wheelbarrows with longer handles so that very little effort be used in working with them.

The turning effect of a force also known as torque or the moment of a force depends on how and where a force is applied to an object around a fixed point called the pivot or fulcrum.

The three primary factors that affect the turning of a force:

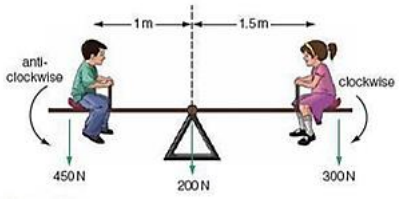
- **Magnitude of the applied force (F):** The larger the force applied, the greater the turning effect. For example, pushing a heavy door with more strength makes it swing open much faster.
- **Perpendicular distance from the pivot (d):** The further away from the pivot the force is applied, the easier it is to turn the object. This is why doorknobs are placed on the opposite side of the hinges, and why a long spanner makes it easier to loosen a tight nut.

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- **Angle of application (θ):** The turning effect is greatest when the force is applied at a right angle (90^0) to the object. If you pull or push parallel to the object (directly toward or away from the pivot), the turning effect is zero.

Moment of a force about a point is the product of the force and the perpendicular distance of its line of action from the pivot. S.I unit is Nm

The Principle of Moments, also known as the Law of Moments states that:
For an object to be in equilibrium under several forces, the sum of the clockwise moments about a pivot must equal the sum of the counterclockwise moments about the same pivot.



This means that if an object is balanced (not rotating), the turning effects of the forces acting in one direction (clockwise) must be exactly balanced by the turning effects of the forces acting in the opposite direction (counterclockwise).

- **Moment of a Force is** the turning effect of a force. It is given by the formula: Moment=Force x Perpendicular Distance from the Pivot The unit of moment is Newton-meters (Nm).
- **Clockwise Moment:** When a force causes an object to rotate in the direction of a clock's hands, it is a clockwise moment.
- **Counterclockwise Moment:** When a force causes an object to rotate in the opposite direction to a clock's hands, it is a counterclockwise moment.

Principle of Moments Formula:

Mathematically, ∑Clockwise Moments=∑Counterclockwise Moments
$F_1 \times d_1 + F_2 \times d_2 + \cdots = F_3 \times d_3 + F_4 \times d_4 + \ldots$, Where: F_1, F_2, are forces causing clockwise rotation, d_1, d_2, are the corresponding perpendicular distances to the pivot, F_3, F_4, are forces causing counterclockwise rotation, and d_3, d_4, are their corresponding perpendicular distances to the pivot.

Example:
1.A coffee table of mass 22 kg and length 1.6 m long is to be lifted off the floor on one of its shorter sides to slip a carpet underneath. Calculate the maximum force needed to lift the table.
Solution:
Taking the movement about point A: Sum of Clockwise moments = Sum of Anticlockwise moments
220 N × 0.8 m = F × 1.6 m,
$\Rightarrow F = \frac{220 \times 0.8}{1.6} = 110N$. ***The minimum force required = 110 N***

2.Consider a seesaw where a 60 N child sits 2 m from the pivot on one side, and a 40 N child sits on the other side. To balance the seesaw, we can find the distance the second child should sit from the pivot.
Using the principle of moments:

- → *Clockwise Moment=Counterclockwise Moment*
- → For the 60 N child: $60\,N \times 2\,m = 120\,Nm$
- → Let d be the distance for the 40 N child: $40N \times d = 120\,Nm$
- → Solving for d: $d = 120\,\frac{Nm}{40N} = 3m$, so, the 40 N child should sit 3 meters from the pivot to balance the seesaw.

MASTERING PHYSICS

3.A 100cm meter rule is pivoted at its center 50cm mark. A 10N weight hangs at the 30cm mark. Where must you hang a 20N weight to balance the rule?

→ Find the distance of the 10N weight from the pivot: $distance = 50cm - 30cm = 20cm$

→ Calculate the anticlockwise moment: $Moment = 10Nx\left(\frac{20}{100}\right) = 2Nm$

→ Set up the clockwise side to match 2Nm using the 20N weight: $Force\ x\ distance = 2Nm$

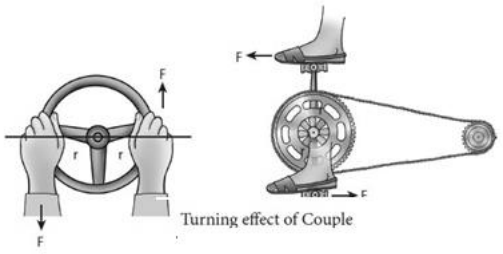
→ $\mathbf{20Nxd = 2Nm}$

→ $\boldsymbol{d = \frac{2}{20} = 0.10m = 10cm}$

→ Hang the 20N weight 10cm on the opposite side of the pivot at 60cm mark.

Couple: ***A couple is a pair of equal and opposite parallel forces that act on an object along different lines of action to produce rotation only.***

$\boldsymbol{Couple = F \times AB \times \sin\alpha}$



Turning effect of Couple

Characteristics of a Couple

- **Zero Net Force:** Because the two forces are equal in size and point in opposite directions, they cancel each other out completely. This means a couple produces zero linear acceleration.
- **Pure Rotation:** Even though the linear forces cancel, their offset lines of action create a turning effect. The object twists or rotates without moving its center of mass from place to place.
- **Independent of a Pivot:** Unlike a single force whose moment depends on where you place your pivot point, the turning effect of a couple is the same everywhere on the rigid body.

Moment of a Couple (Torque)

The turning effect of a couple is called its **moment or torque**.

You calculate it by multiplying the magnitude of one of the forces by the perpendicular distance between their lines of action. $Moment = Fd$,

- F = magnitude of one of the forces (measured in newtons, N),
- d = perpendicular distance between the two parallel forces, called the "**couple arm**" (measured in meters, m)

SI Unit: **newton-metre (Nm**)

Examples

- **Steering Wheel:** Pushing up with one hand and pulling down with the other hand on opposite sides of the wheel.
- **Screwdriver or Wrench:** Twisting a tool handle using balanced, opposing finger or hand forces.
- **Jar Lids:** Opening a lid by applying equal and opposite pressure with your thumb and fingers

Activity

1. Describe an experiment to investigate the principle of moments using two known masses and a uniform metre rule.

2. A uniform metre rule is suspended at the 50 cm mark and a stone at the 0 cm mark. The metre rule is balanced horizontally when a mass of 100 g is suspended at the 30 cm mark. Calculate the weight of the stone.

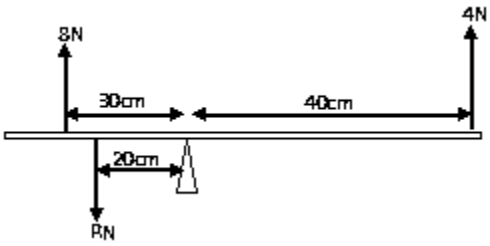
3. Janell and Jemison are seated at 3 m and 2 m respectively from the centre of a seesaw on one side and Jane at 4 m from the centre on the other side. The seesaw is balanced horizontally. Find the weight of Jane, if the masses of Janell and Jemison are 40 kg and 30 kg respectively.

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4. A uniform metre rule is balanced horizontally at its centre. When a mass of 5 g is suspended at the 4 cm mark, the rule balances horizontally if a mass M is suspended at 30 cm mark. Calculate M.

Examples:

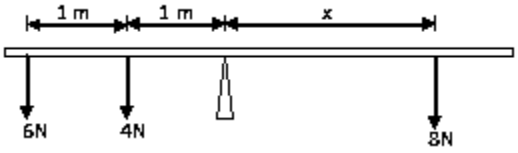
1. Forces of 8N, PN and 4N act on a body as shown;
Find the value of P if the system is in equilibrium.



Sum of Anti-clockwise moments = Sum of clockwise moments

$$4\,x\,40 + p\,x\,20 = 8\,x\,30, P = 4N$$

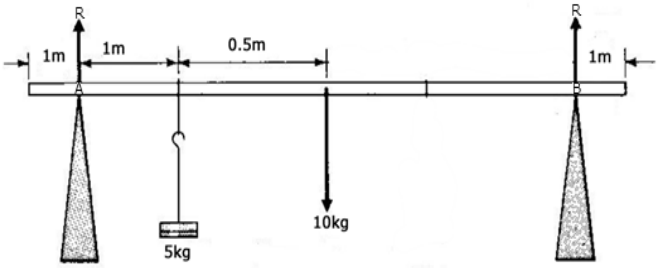
2. Forces below act on the plank as shown
If the body is in equilibrium find the distance x



Anti-clockwise = clockwise moments

$6\,x\,2 + 4\,x1 = 8\,x, x = 2m$

3.Two workers are carrying a uniform wooden beam during construction work in a village. The beam is 5 m long and has a mass of 10 kg. Each worker supports the beam 1 m from either end.
While moving, a load of 5 kg is placed on the beam at a point 2 m from one end**.**



Task: Using principles of moments and equilibrium**,** determine the force supported by each worker**,** and explain how the position of the load affects the distribution of forces between the two workers**.**

Identify key variables

→ Length of beam = 5 m
→ Workers are at: 1 m from left end, 1 m from right end → position = 4 m from left end
→ Weight of beam acts at its center → **2.5 m from left end**
→ Load (5 kg) is **2 m from one end** (assume from left end unless stated)

Convert masses to weights

Take g = 10, N/kg
→ Weight of beam = 10x10 = 100N
→ Weight of load = 5x10 = 50N

Let forces be R_1 = force by left worker, and R_2 = force by right worker
Apply equilibrium of forces,
$R_1 + R_2 = 100 + 50 = 150$,

Take moments about left worker (at 1 m)

Distances from left worker:
→ Beam center: (2.5 - 1 = 1.5 , m)
→ Load: (2 - 1 = 1 , m)
→ Right worker: (4 - 1 = 3 , m)

Clockwise moments = Anticlockwise moments:
→ $3R_2 = (100x1.5) + (50x1)$
→ $3R_2 = 150 + 50 = 200$,
→ **R_2=200/3=66.7N**, **R_1 = 150 - 66.7 = 83.3N**

Final Answers
→ Force by **left worker** = **83.3 N**

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→ Force by **right worker** = **66.7 N**
→ The worker closer to the **heavier load supports more weight**.
→ Load position affects balance: moving the load toward one worker increases their effort.
→ This principle is widely applied in **construction, transport, and machine design**.

ACTIVITY

1). During a school laboratory activity, learners use a **metre rule** to investigate balance and material properties. The metre rule has a **uniform width of 2.5 cm** and **thickness of 0.5 cm**. The rule is suspended using a string at the **78 cm mark**. To keep it balanced, a **mass of 150 g** is hung at the **100 cm mark**.
TASK: Use the knowledge of physics to;
(a) Calculate the mass of the metre rule.
(b) Determine the density of the material of the metre rule.
(c) Find the tension in the supporting string.

Solution: (a) **118g,** (b) **944kg/m^3** and (c) **2.68N**

2).At a roadside fruit stall, a vendor uses a wooden metre rule as a simple balancing tool to estimate weights. He supports the metre rule on a nail fixed at the 20 cm mark on a wooden post.
To balance the rule horizontally, he places a 240 g packet of sugar at one end of the metre rule. The rule remains perfectly balanced.
Task: Using the knowledge of physics:
a). Use a well labelled diagram to show the pivot at the 20 cm mark**,** The 240 g mass at one end and locate the centre of gravity of the metre rule
b). Determination the mass and the weight of the metre rule

Solution: Mass = 160 g and Weight = 1.6 N

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Center of gravity and Equilibrium

Learning outcomes

a) Definition of centre of gravity and centre of mass.
b) Determination of centre of gravity of regular and irregular objects.
c) Effects of the position of centre of gravity on stability of objects.

The center of gravity (cog) is the point in a body or system where the entire weight of the object can be considered to be concentrated for purposes of analysis.
When a force such as gravity acts on an object, it is as if all the mass of the object is located at this single point. Understanding the center of gravity is crucial for maintaining balance and stability in structures and moving objects.

Conditions for Equilibrium: There are three conditions for an object to be stable:

♠ The object should have a broad base.
♠ The Centre of gravity should be as low as possible.
♠ The vertical line drawn from the centre of gravity should fall within the base

Conditions necessary for a body to be in a state of mechanical equilibrium.

♠ The sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point.

- ♠ Sum of forces in any one direction is equal to the sum of forces acting in the opposite direction.

Importance of the Principle of Moments:

a) Engineering and Construction ensures structures like bridges, cranes, and buildings are stable and balanced.
b) Helps in designing levers, gears, and other rotating systems for effective functioning.
c) From using wrenches to balance scales, the principle is applied in various practical situations.

Balance and Stability:

- ♠ If the center of gravity is low and close to the base of an object, the object tends to be more stable.
- ♠ If the center of gravity is high or located away from the base, the object is less stable and more prone to tipping over.
- ♠ **Boats:** Standing or leaning raises/shifts the centre of gravity, making the boat unstable and likely to tip.
- ♠ **Seesaws:** A seesaw balances when the **centre of gravity of the system is directly above the pivot**.
- ♠ **Cars and trucks:** A **low centre of gravity** increases stability and reduces the risk of overturning.
- ♠ **Gymnastics and sports:** Athletes control their body position and centre of gravity to maintain balance or improve performance.
- ♠ **Cranes and buildings:** The centre of gravity must remain **within the base of support** to prevent toppling.
- ♠ **Aircraft:** The position of the centre of gravity affects the aircraft's **stability and control**.
- ♠ **Robots:** A low centre of gravity helps robots remain stable while moving or carrying loads.
- ♠ **Cranes and lifting machines: Counterweights** are used to position the centre of gravity for greater stability.

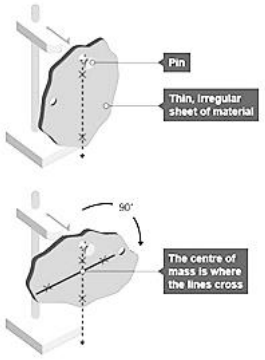
Understand: *An object is stable when its centre of gravity lies within its base of support. A lower centre of gravity generally gives greater stability.*

Activity: To determine the centre of mass of an irregular lamina using a plumbline

Materials Needed: The irregular object (a cardboard cut-out), a piece of string, a plumb line (a string with a weight at the end), a pin or nail, and a marker

Procedure:

a) Make three holes H_1, H_2, and H_3 on an irregularly shaped lamina as close as possible to the edges and far away from each other. The holes should be large enough to allow the lamina turn freely when supported through a drawing pin.
b) Suspend the lamina on the clamp using the drawing pin through each hole at a time.
c) Suspend a plumbline (a thin thread with a small weight at one end) from the point of support, H_1, and draw the line of the
d) Plumbline on the lamina by marking two points A and B far apart and joining them.
e) Repeat the steps with the support H_2 and mark the point M where the two lines intersect.
f) Check the accuracy of your method by suspending the lamina at H_3. What do you observe? Explain.
g) Compare the cog determined experimentally and that you guessed earlier**.**



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h) The plumbline pass through M (the mid-point). Check the results again by balancing the lamina about point M. What do you observe?

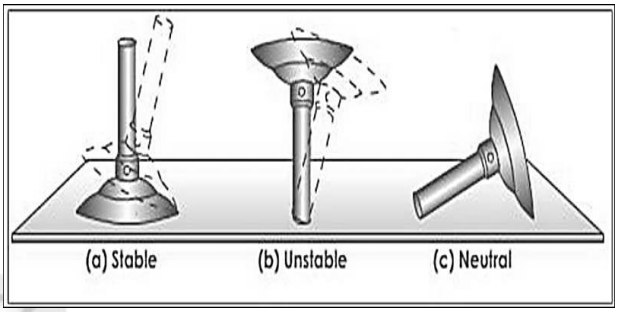
Observation and conclusion

The lamina balances horizontally at point M. Point M is the centre of gravity of the lamina. This activity proves that when a body is freely suspended it rests with its centre of gravity vertically below the point of suspension.

Activity: To investigate the three states of equilibrium

Materials: plastic thistle funnel, bench

Procedures



a) Place the funnel upright with the wider mouth resting on the bench (i).
b) Displace the funnel slightly upwards and then release it. What do you observe? Explain the behaviour of the funnel in terms of the changes in the position of centre of gravity.
c) Place the funnel upright with the narrower mouth resting on the bench (ii).
d) Displace the funnel slightly with your finger. What about change of state of the funnel? Explain the behaviour of the funnel in terms of the change in position of its centre of gravity in this activity.
e) Place the funnel horizontally (iii).
f) Displace the funnel gently by tapping it with a finger. What do you observe? Explain the behaviour of the funnel in terms of the change in position of the centre of gravity when displaced slightly.

Observation and conclusion

- When a body is resting with its centre of gravity at the lowest point, it is very stable. When displaced slightly; its centre of gravity is raised and when it is released, the object falls back to its original position to keep its centre of gravity as low as possible. This type of equilibrium is known as stable equilibrium. Thus, the funnel in Activity above Fig (i) was in **stable equilibrium**.
- **Stable Equilibrium:** If the body is slightly disturbed, it returns to its original position. This usually occurs when the center of gravity is low and the base of support is wide.
- When an object is resting with its centre of gravity at a very high position from the base support, it is unstable. When displaced slightly, it continues to fall up to the lowest possible position in order to lower its centre of gravity. This state of stability is known as unstable equilibrium. The funnel in Fig (ii) was in **unstable equilibrium**.
- **Unstable Equilibrium:** If the body is disturbed, it moves further away from its original position. This occurs when the center of gravity is high or the base of support is narrow.
- When an object is resting such that the position of its centre of gravity remains at the same vertical position even when the object is displaced, it is said to be in neutral equilibrium. The funnel in Fig (iii) was in **neutral equilibrium**.
- **Neutral Equilibrium:** If the body is disturbed, it remains in its new position. This is typical for objects that have a flat surface, like a sphere on a flat plane.

Understand

- *A body is in equilibrium when the sum of the forces and the sum of the moments acting on it are zero.*

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- ♠ *A system is in stable equilibrium when, if displaced from its equilibrium position, it experiences a net force or torque that acts in the opposite direction of the displacement. This tendency to return to the original state signifies stability, much like a ball resting at the bottom of a bowl.*
- ♠ *Unstable equilibrium occurs when a slight disturbance leads the system further away from its original position. For instance, a ball balanced on top of a hill exemplifies this, as any small push will cause it to roll away.*
- ♠ *A stable equilibrium ensures that systems can maintain their state, while unstable equilibrium indicates a propensity for change, highlighting the dynamic nature of physical systems.*
- ♠ *The stability of a body refers to its ability to maintain equilibrium and resist disturbances that might cause it to tip, fall, or rotate.*

Factors affecting Stability: Stability refers to an object's ability to maintain its equilibrium when subjected to external forces.

- ♠ **Centre of Gravity:** A lower centre of gravity makes an object more stable. The object is most stable when the centre of gravity lies directly above the centre of the base. If the line of action of the weight moves outside the base, the object topples.
- ♠ **Base of Support:** A wider base generally increases stability. An object remains stable when its centre of gravity lies within the base of support.
- ♠ **Distribution of Mass:** A low and wide object is more stable than a tall, narrow one because its centre of gravity is lower. For objects with several contact points, the centre of gravity should lie within the area formed by the contact points.
- ♠ **Tipping Point:** Tipping occurs when the vertical line through the centre of gravity falls outside the base of support.
- ♠ **Moving Objects:** For vehicles and other moving objects, stability is also affected by speed, momentum, acceleration, deceleration, and other forces.

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Activity: To investigate the relationship between position of centre of gravity of a body and its stability

Discuss (in group) why:

a) Buses sometimes carry heavy luggage at their roof tops.
b) Buses have their luggage bonnets located underneath.
c) A person carrying two buckets full of water is more stable that one carrying one bucket
d) Discuss and compare your explanations with your partner and report to the whole class.

Observation and conclusion

A body is more stable when its heavy part is as low as possible since it lowers the position of the centre of gravity. If the heavy part of the body is at high position or if the light part of the body in high position is made heavier than the lower position, the body becomes unstable and thus likely to topple over and can cause accidents like in the case of a vehicle carrying heavy luggage at its roof top.

Applications of stability and centre of gravity

Stability and centre of gravity (CG) are key in field of engineering, vehicle safety, product design, and sports. To maximize stability, objects are generally designed to have a low centre of gravity and a wide base of support. This ensures that the line of action of the weight remains within the base, preventing the object from toppling over.

1. Vehicle and Transportation Design

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- ♠ **Racing Cars (Formula 1)** are built exceptionally low to the ground with wide wheelbases. This lowers their CG, allowing them to take sharp turns at high speeds without flipping over.
- ♠ **Double-Decker Buses** carry heavy loads on two levels. To prevent tipping, the heavy engine and chassis are placed as low as possible. Passengers are also limited on the upper deck to keep the overall CG low.
- ♠ **Cargo Ships and Sailing Boats** use heavy ballast (often water or lead weights) in their lowest hulls. This keeps the CG deep underwater, allowing the ship to self-right even when tilted by massive ocean waves.

2. Infrastructure and Structural Engineering

- ♠ **The Leaning Tower of Pisa** remains standing because its vertical line drawn from the centre of gravity still falls inside its foundational base. If the tower leans so far that this line falls outside the base, it will collapse.
- ♠ **Construction Cranes** use massive concrete counterweights at the opposite end of the lifting arm. This keeps the combined CG firmly over the crane's central, anchored base.
- ♠ **Robots** are designed with stability in mind to prevent tipping during movement or when carrying loads. In imaging technologies such as MRI and X-rays. These techniques rely on stable magnetic fields and precise measurements to produce accurate diagnostic images, aiding in effective patient treatment.
- ♠ Stability is vital in renewable energy systems, such as wind turbines and solar panels. Ensuring these systems remain stable under varying environmental conditions maximizes efficiency and energy output.

3. Sports and Human Biomechanics

- ♠ **Wrestlers and Martial Artists:** Athletes deliberately widen their stance and bend their knees to lower their CG. This makes it significantly harder for an opponent to knock them off balance.
- ♠ **Gymnasts and Tightrope Walkers:** Tightrope walkers often carry a long, heavy, dipping pole. The pole lowers their overall centre of gravity (sometimes below the wire itself) and increases their rotational inertia, making balancing much easier.

4. Household Objects

- ♠ **Bunsen Burners and Desk Lamps** are constructed with heavy cast-iron or weighted bases. This ensures that even if they are bumped, the CG stays low and well within the base area, preventing fires or damage.
- ♠ **Toy Tightrope Walkers / Balancing Toys** utilize heavy weights that extend below the pivot point. Because the centre of gravity is below the support point, the toy is in stable equilibrium and will always return to its upright position.

Assessment

A double deck bus vehicle which was travelling from Kampala to Gulu was seen carrying heavy goods on its roof top and some of its excess passengers in the vehicle were standing while extra others seated on a three-legged stool design than a four legged one. The passengers of a double-decker bus were not allowed to stand on the upper deck. Whenever one is descending from the moving vehicle, it is advisable to spread out his/her legs.

Task: Use the knowledge of Physics to:

(a) Discuss why it's not good for the vehicle to carry goods on its roof top / rack.
(b) Why are passengers supposed to spread their legs?
(c) Why are passengers on second floor not supposed to stand as opposed to those on first deck
(d) Why was the stool with three legs as opposed to four legs?

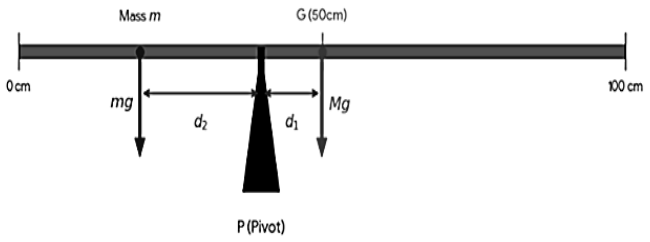
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To determine the mass of a uniform metre rule using the Principle of Moments using a known mass.
Understand:

- ♠ Because the metre rule is **uniform**, its center of gravity lies exactly at its midpoint the **50.0 cm mark**.
- ♠ **Balancing with a Known Mass**: The standard laboratory procedure to find the unknown mass (M) of the metre rule using a single known mass (m).

Apparatus Required: Uniform metre rule**,** Pivot (knife edge or wedge)**,** Known mass m=50g or 100g**,** Thread or mass hanger



Procedure

a) Balance the empty metre rule horizontally on the knife-edge. Record this position. For a uniform rule, it will be at or very close to the **50.0 cm mark**.
b) Move the pivot away from the center of gravity to a new position (P). The rule will tilt because its weight $W = Mg$ creates an unbalanced moment.
c) Suspend the known mass (m) on the lighter side (the side opposite to where the center of gravity lies) and adjust its position until the metre rule rests perfectly **horizontal** again.
d) Measure the distance d_1 from the pivot (P) to the center of gravity (G).
e) Measure the distance d_2 from the pivot (P) to the center of the known mass (m).

Calculations & Theory
When the rule is balanced horizontally:
$\boldsymbol{Anticlockwise\ Moment = Clockwise\ Moment}$
$\boldsymbol{mgxd_2 = Mgxd_1, md_1 = Md_2}$
Solving for the unknown mass (M) of the metre rule: $\boldsymbol{M = m\left|\frac{d_1}{d_2}\right|}$

Precautions for Accuracy

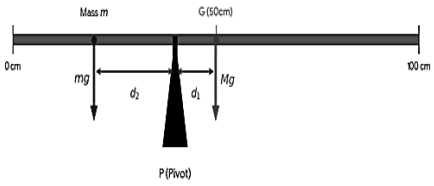
- ♠ **Avoid Parallax Error:** Read the markings on the metre rule by keeping your eyes directly above the scale line.
- ♠ **Ensure Horizontality:** Ensure the rule is perfectly horizontal before taking measurements (you can check alignment using a spirit level or relative to a horizontal bench line).
- ♠ **Account for Loops/Strings:** If using heavy thread to hang the mass, its weight should be negligible or factored into the known mass.

To determine the mass of a uniform metre rule using a graphical method, you take multiple readings by changing the position of the known mass and the pivot to find a precise average value from a linear slope.
Apparatus: *Uniform metre rule**,** Pivot (knife edge or wedge)**,** Known mass m=50g or 100g**,** Thread or mass hanger*

Procedure

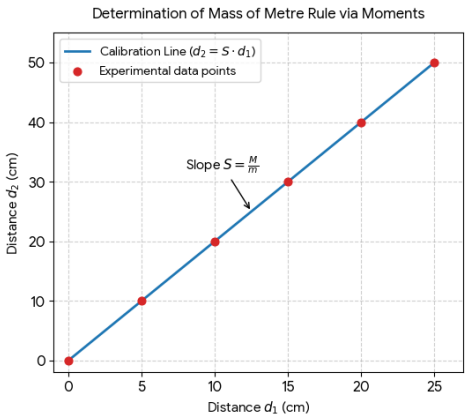
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a) Balance the metre rule horizontally on the pivot.
b) Read and record this position (it should be very close to the 50.0 cm mark).
c) Shift the pivot to a position (P) (at the 40.0 cm mark). The rule will tilt.
d) Suspend a single known mass (m) on the short side. Slide it until the rule balances horizontally.



e) Shift the pivot (P) to a new position (38.0 cm, 36.0 cm, 34.0 cm, 32.0cm and 30.0cm).
f) Each time, adjust the position of the known mass (m) to restore horizontal balance.
g) Read and record for each of the values; $\boldsymbol{d_1}$, the distance from the pivot (P) to the center of gravity (G=50.0cm).
h) Read and record for each of the values; $\boldsymbol{d_2}$, the distance from the pivot (P) to the position of the known mass (m).
i) Plot a graph of $\boldsymbol{d_2}$ (vertical axis) against $\boldsymbol{d_1}$ (horizontal axis).
j) Drawing the best-fit straight line through your data points. It should pass through the origin (0,0).
k) Calculate the gradient (S) of the line using two far-apart points on the line;

$$Slope = \frac{\Delta d_2}{\Delta d_1}$$



Final Calculation

l) Since the gradient $\boldsymbol{slope = \frac{M}{m}}$, calculate the mass of the metre rule (M) using: $M = slope\ x\ known\ mass\ (m)$
m) (Ensure your units match. If your known mass (m) is in grams, your final answer (M) will be in grams).

Theory of the experiment

From the Principle of Moments; Anticlockwise Moment=Clockwise Moment; $\boldsymbol{md_1 = Md_2}$

To turn this into a standard straight-line equation: $y = mx$, we isolate $\boldsymbol{d_2}$: $d_2 = \left(\frac{M}{m}\right) d_1$

Comparing this to the equation of a straight line passing through the origin $y = (m)x$

- ♠ y-axis variable: distance $\boldsymbol{d_2}$ (cm or m)
- ♠ x-axis variable: distance $\boldsymbol{d_1}$ (cm or m)
- ♠ Gradient (Slope): $\boldsymbol{slope = \frac{M}{m}}$

To determine the mass of a nail using a 50g known mass and a uniform metre rule by a graphical method, you can use the principle of moments (lever principle).

Apparatus: Uniform metre rule**,** Knife edge (or pivot)**,** Known mass,m_1)**,** Unknown mass (the nail,m_2)**,** Thread or mass hangers

Procedure

a) Balance the empty metre rule horizontally on the knife-edge. Record this position as (G) (the center of gravity). For a uniform rule, this should be close to the 50cm mark.
b) Place the knife-edge firmly at a new, fixed pivot position (P), away from (G) (at the 40cm mark.

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c) Suspend the known $m_1 = 50g$ on one side of the pivot.
d) Suspend the nail m_2 on the opposite side of the pivot.
e) Adjust the position of the nail until the metre rule rests horizontally in perfect balance.
f) Measure the distance d_1 from the pivot (P) to the 50g mass.
g) Measure the distance d_2 from the pivot (P) to the nail.
h) Repeat for the procedure for multiple readings, keep the pivot (P) and the 50g mass fixed (maintaining a constant distance -d_1.
i) Shift the nail to a new position, and adjust the pivot position (P) to re-balance the rule. Repeat this to obtain at least 5 to 6 different pairs of distances $d_1 \; and \; d_2$
j) Record your data in a table with columns for $d_1 \; (cm) and \; d_2(cm)$
k) Plot a graph of d_1 on the vertical axis (y-axis) against d_2 on the horizontal axis (x-axis).
l) Draw a straight line of best fit passing through the origin (0,0).
m) Determine the gradient (S) of the straight line using two well-spaced points on the line: $slope = \frac{d_1}{d_2}$

Assessment

A farmer is transporting a heavy sack of maize using a wheelbarrow. The wheelbarrow has a mass of 20 kg, while the maize sack has a mass of 60 kg. The centre of gravity of the wheelbarrow is 0.6 m from the wheel, while that of the maize sack is 1.2 m from the wheel. The handles are 1.5 m from the wheel. Hint: Take g=10 N/kg

Tasks: Using the knowledge of physics to:

a) Determine the force the farmer must apply at the handles to keep the wheelbarrow in equilibrium (**560N**).
b) Explain what would happen to the stability of the wheelbarrow if the farmer moved the maize sack further away from the wheel.
c) Explain why the wheelbarrow is more stable when the load is placed low and close to the wheel.
d) The farmer wants to carry the load safely over rough ground. Suggest two ways of improving the stability of the wheelbarrow and give a reason for each.

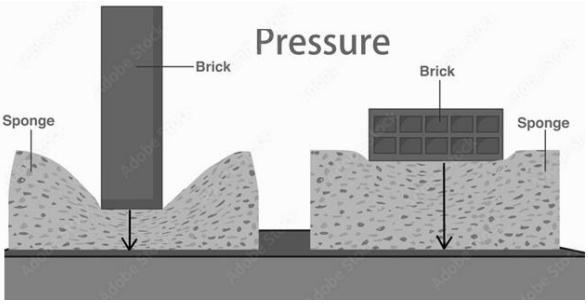
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S2.3 PRESSURE IN SOLIDS AND FLUIDS

Learning Outcomes

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a) Understand that pressure is the result of a force applied over an area (u,s)
b) Understand the effect of depth on the pressure in a fluid and the implications of this (u,s)
c) Understand the nature of the atmosphere and how atmospheric pressure is measured (u,s)
d) Know the structure of the atmosphere and the significance of the different layers (k, u,v/a)
e) Understand the use of the Bernoulli effect in devices like aerofoils and Bunsen burner jets(u)
f) Understand the concept of sinking and flotation in terms of forces acting on a body submerged in a fluid(u)
g) Understand and apply the Archimedes' principle in different situations (u, s,v/a)



Pressure in solids

- Pressure in solids is defined as the **force exerted normally or perpendicularly per unit area**, represented by the formula; $P = F/A$, where P is pressure in pascals, F is the force in newtons, and A is the area in square meters.
- When a force is applied to a solid, it creates stress on the material, which can lead to deformation or failure if the pressure exceeds the material's strength.
- SI unit is **Nm^{-2} or newton per square metre or Pascal**. Other units: kilo Pascal (kPa) or kilo newton per metre squared
- The pressure increases when the surface area is decreased, since pressure is inversely proportional to area of contact, i.e. $P \propto \frac{1}{A}$, provided force or thrust (weight) is kept constant.

This can be demonstrated using a needle and a nail, sharp panga against blunt panga, high-heeled shoe against gumboots, bicycle tire against tractor tire, etc.

- When the same force is applied at the top of the needle and nail, one tends to feel more pain from the needle than the nail, and the rest applies. This is because surface area of the bottom of the needle is smaller therefore, the pressure is high.
- The increase in pressure when the surface area is decreased explains why a tractor can easily move in a muddy area than the bicycle. For the same reasons of pressure reduction, its why dams or house foundations are built with wider bases than the top.

Example

A car piston exerts a force of 400N on a cross-sectional area of $40cm^2$. Find the pressure exerted by the piston.

Force =400N, A=40cm^2; Convert into SI units first: $\boldsymbol{A = 40cm^2 = \frac{40}{10000} m^2 = 0.004m^2}$, **P=F/A**

$$\boldsymbol{P = \frac{400N}{0.004m^2} = 10000Nm^{-2}}$$

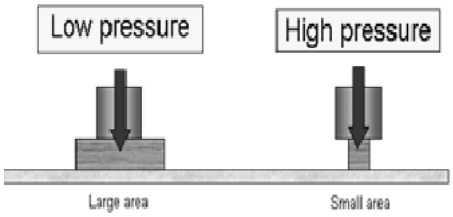
A woman of mass 80kg stands on a floor. If the area of contact of her high-heeled shoe on the floor is $0.045m^2$, find the maximum pressure exerted by the woman's shoe on the floor.

Mass, m=80kg, **Force= weight = mg =80x10=800N**. **A=$0.045m^2$,**

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From, $\boldsymbol{P = \frac{F}{A}}$**,** $\boldsymbol{P = \frac{800N}{0.045m^2} = 17,777.8Nm^{-2}}$



Determining Maximum and Minimum Pressure

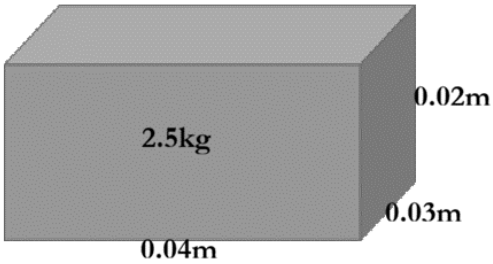
From the formula, $P = \frac{Force}{Area}$, increase in pressure results to a sudden decrease in area and vice versa.

Maximum pressure: To obtain maximum pressure, the area should be small.

$P_{Max} = \frac{Force}{Smallest\ Area}$

Minimum pressure: To obtain minimum pressure, the area should be large.

$P_{Min} = \frac{Force}{Largest\ \ Area}$



A mineral water box of mass 2.5kg and dimensions by 0.04m by 0.03m by 0.02m as shown in the figure is carried on the shoulders of a teenager. Determine the the greatest pressure, and the least pressure exerted by the box on the shoulders of the teenager. Explian which side is likey to make him fail more main or less, and why. How can the pain be reduced.

$\boldsymbol{F = mg = 2.5x10 = 25N}$;

$\boldsymbol{Largest\ area = l \times w\ = 0.04 \times 0.03\ = 0.0012m2}$

$\boldsymbol{Smallest\ area = w \times h\ = 0.03 \times 0.02\ = 0.0006m2}$

$Maximum\ pressure\colon\ P_{Max} = \frac{Force}{Smallest\ Area} = \frac{25N}{0.0006m^2} = 41666.7Pa$

$Minimum\ pressure\colon\ P_{Min} = \frac{Force}{Largest\ \ Area} = \frac{25N}{0.0012m^2}$

$= 20833.3Pa$

He is likely to feel more pain when box is resting on 0.03m by 0.02m short side (width and height) section and less pain when resting on the long side section of 0.04m by 0.03m. Carrying it on the head will help in spreading the weight than on the shoulders.

Activity:

1. A local motor vehicle garage is repairing a heavy truck and constructing a new service bay. During the work, the mechanics observe that different parts of the vehicle and the building are designed in specific ways to safely withstand pressure. They examine the car piston, the brake pedal, the tyres of the truck, and the foundation of the workshop building. The car computer systems found out that the car pistons exerts a force of **200 N** on a cross-sectional area of **40 cm²**. The brake pedal has a cross-sectional area of **5 cm²** and experiences a pressure of **40,000 Pa**.

Tasks: Using your knowledge of Physics;

(a) Calculate the pressure exerted by the piston.

(b) Calculate the force applied on the pedal.

(c), explain why the workshop building has a wider foundation than its upper part.

(d) Explain why heavy carriage trailers are fitted with larger tyres at the front than at the rear.

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2. A warehouse manager is training new employees on the safe storage of heavy boxes. During the training, the workers are required to establish the different dimensions of boxes, of which box P measures 5 m × 1 m × 2 m and has a weight of 60 N while resting on the floor, and box Q has dimensions 6 m × 2 m × 4 m and with weight of 400 N on the same surface. They are supposed to establish and decide the most appropriate storage arrangement system that is durable and long lasting without affecting the contents of the boxes.

Tasks: As a physics student, help to

a) Determine the minimum pressures exerted by the boxes P and Q on the floor.

(b) Determine the maximum pressures exerted by the box P and Q

c) Determine the density of each box, and find out, which is heavier and lighter, and has great effect on the durability of the box and the floor

PRESSURE IN LIQUIDS

Pressure in liquids is defined as the force exerted per unit area. This pressure arises from the weight of the liquid above an object, leading to an increase in pressure with depth. The formula for calculating this pressure is given by $P = h\rho g$, where P is pressure, ρ (rho) is the fluid density, g is the acceleration due to gravity, and h is the depth of the fluid. As liquid particles are in constant motion, they collide with surfaces, exerting pressure on them. Liquid pressure is influenced by depth and density.

Variation of Pressure with depth inside the fluid :

At equilibrium, Force balancing in vertical direction

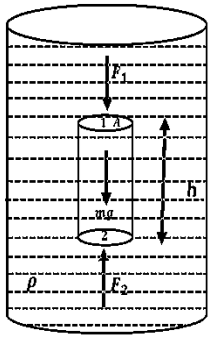
$F_1 + mg = F_2$

$\Rightarrow F_2 - F_1 = mg$

$\Rightarrow (P_2 - P_1).A = mg \quad (\because F = P.A)$

$\Rightarrow (P_2 - P_1).A = \rho.A.hg$

$\Rightarrow (P_2 - P_1) = \rho hg$



Consider a column of liquid of density, $\boldsymbol{\rho}$, to a height, **h,** above the base in a cylinder as shown; the pressure on the surface of the base of cross-sectional area, **A**, is due to weight, $\boldsymbol{W = mg = \rho vg = \rho Ahg}$, of the liquid above it.

Pressure, $P = \frac{F}{A} = \frac{w}{A} = \frac{\rho Ahg}{A} = \boldsymbol{\rho hg}$**,** exerted on the walls of the container is the same in all directions and depends on; **depth (h)** of the liquid and **density (ρ)** of the liquid

Understand

$Volume\ of\ liquid = Volume\ of\ cylindrical\ container = area\ of\ circular\ base \times height$, V=$\boldsymbol{Ah}$,

$Mass\ of\ liquid = density\ liquid \times volume\ of\ liquid$, m=$\boldsymbol{\rho Ah}$,

$Force\ exerted\ by\ liquid$ at the base $= mass \times acceleration\ due\ to\ gravity, \boldsymbol{F = \rho Ahg}$

Pressure**,** $\boldsymbol{P = \frac{F}{A} = \frac{w}{A} = \frac{\rho Ahg}{A} = \rho hg}$

1. The density of liquid X is 800kgm^{-3}. It was poured in a container to a depth of 400cm. Calculate the pressure it exerts at the bottom of the container.

Covert 400cm into metres, $\boldsymbol{h = \frac{400}{100}}$**=4m, gravity, g=10Nkg^{-1},** $\boldsymbol{P = \rho hg = 800x4x10 = 32,000Pa}$

2. The tank contains mercury at a depth of 5m and water at a depth of 8m. The density of mercury is 13600kgm^{-3} and that of water is 1000kgm^{-3}. Find the total pressure exerted at the bottom.

$\boldsymbol{P = \rho hg, P = P_{water} + P_{mercury} = 1000x8x10 + 13600x5x10 = 80000 + 680000 = 760,000Pa}$

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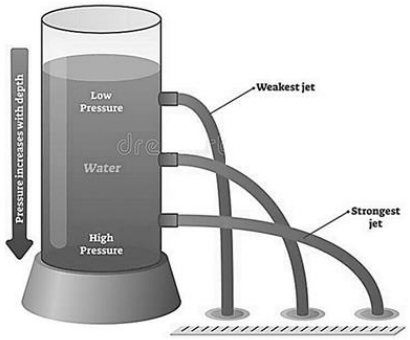
Activity
A cylindrical vessel of cross section area 50cm^2 contains mercury to a depth of 2 cm. Calculate the pressure that mercury exerts on the vessel and the weight of water in the vessel. (**Density of mercury =13600kgm^{-3}**)

Factors affecting pressure in liquids:
From,$\boldsymbol{P = \rho hg}$, pressure at any point in a liquid is the same in all directions and it depends on the following factors:

- ♠ Pressure increases with an increase in the depth of the liquid and vice versa. The higher the depth of the liquid, the more the weight of the liquid thus increasing the pressure exerted by the liquid.
- ♠ Denser liquids exert more pressure than less dense liquids.
- ♠ Liquid pressure is higher in areas where acceleration due to gravity is high.

Experiment to show that pressure in liquids increases with increase in depth (h)

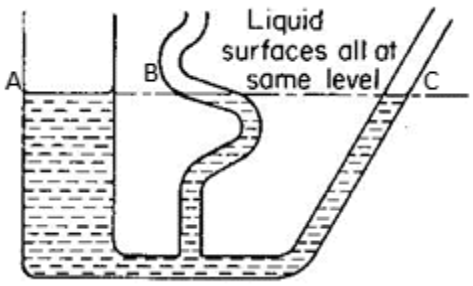
a) Three equally sized holes A, B and C were made on a tall can at different depths h_1, h_2 and h_3 as shown in the figure above.
b) The holes are blocked with cork, and then the vessel is filled with water.
c) The holes are then opened at the same time and the jetting of water from the holes observed, and water jets noted.



Observation

- ♠ The speed with which water spurts out is greatest for the lowest jet near the bottom than from the middle and the top, showing that pressure increases with depth.
- ♠ This explains why water storage tanks are put at high-level ground and the taps at the bottom of the tanks so that water comes through the taps at a very high pressure.
- ♠ Water supply often comes from a reservoir, which is at a high ground level. Water flows from the reservoir through the pipes to the taps, which are far below the level of the water reservoir. This increases the pressure at which water is supplied.

Experiment to show that pressure is independent of cross section area and shape of container
The liquid is allowed into the tubes A, B and C as shown in the figure. The liquid reaches the same height h in all the tubes.
Since the tubes are of different cross-sectional area and shape. It follows that pressure does not depend on shape and cross-sectional area.

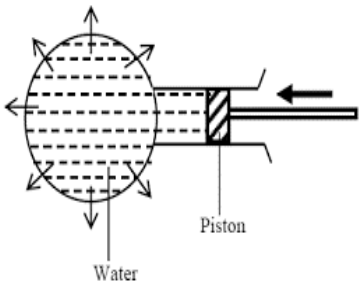


PASCAL'S PRINCIPAL OR LAW OF LIQUID PRESSURE
The principle of transmission of pressure in liquids, known as Pascal's Principle, **states that any change in pressure applied to an enclosed fluid is transmitted equally throughout the fluid.**

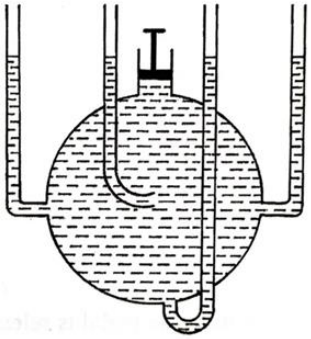
This means that if pressure is applied at any point in a confined liquid, the same pressure change is felt equally at every point within that liquid.
Pascal's Principle is used in hydraulic systems. For instance, in hydraulic lifts, a small force applied to a small area can create a much larger force over a larger area, allowing heavy objects to be lifted with minimal effort.

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This principle highlights the incompressibility of liquids (all liquids are incompressible), which allows for efficient pressure transmission. Pascal's Principle has practical applications in various engineering fields like hydraulics and fluid mechanics. It works on an assumption that the fluid is incompressible.



To verify the principle of transmission of pressure in liquids, one can conduct a simple experiment based on Pascal's Law. ***This principle states that when pressure is applied to a confined fluid, it is transmitted equally in all directions.***

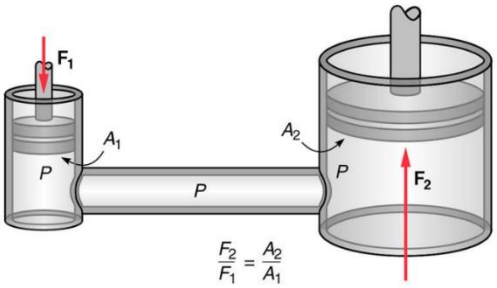


For the experiment, take a closed container filled with water and attach several small tubes to it at different heights. When pressure is applied to the water in the container, observe the water level in each tube.
The water will rise to the same height in all tubes, demonstrating that the pressure is transmitted uniformly throughout the liquid. It serves as a fundamental concept in hydraulics, where understanding pressure transmission is crucial for designing systems like hydraulic lifts and brakes.
The piston is moved in such way that it pushes "the plunger" to compress the liquid. The pressure caused is transmitted equally throughout the liquid. This can be observed by having all holes pouring out the liquid at the same rate when the piston is pushed in; hence, *pressure in liquid is equally transmitted.*

Application of the Pascal's principle

- Applications include **hydraulic lifts, cars brakes, hydraulic presses, bulldozers, hydraulic cranes, and hydraulic car jacks, shock absorbers (cylinders).**
- In hydraulic machines, a small force applied at one point of an incompressible liquid produces a larger force at the points of the liquid. Therefore, a small force is used to lift heavy materials like cars, enabling the compression of metals and plastics efficiently.
- In medical devices like syringes and blood pressure monitors. In syringes, the principle allows for the easy injection of fluids, while in blood pressure monitors, it helps measure the pressure exerted by blood on the vessel walls, providing vital health information.

HYDRAULIC PRESS/MACHINE



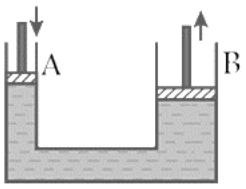
A hydraulic press consists of two connected cylinders of different bores, filled with a liquid or any other incompressible fluid and fitted with piston shown in the figure. When the force F_1 is exerted on the liquid via piston,A_1, the pressure produced is transmitted equally through out to piston, A_2,, which supports a load F_2,.
The force created at,A_2, raises the load squeezing a hard substance.
Therefore;$\boldsymbol{P_1 = P_2 = P}$; $\frac{F_2}{F_1} = \frac{A_2}{A_1}$; From $\boldsymbol{Area = \pi r^2 = \frac{\pi d^2}{4}}$ (for circular pistons)
$\boldsymbol{P_1 = P_2}$; $\frac{F_1}{F_2} = \frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} = \frac{d_1^2}{d_2^2}$.

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If the cross-sectional areas of small piston and large piston have the same units, there is no need of converting into SI units if the units are the same.

The cross-sectional area of the piston A = $2m^2$ and the force applied at piston A is 10N. Calculate the force on B, given the cross-section area as $150m^2$



$\frac{F_2}{F_1} = \frac{A_2}{A_1}$; $\frac{150}{2} = \frac{F}{10}$; $F = 10x75 = 750N$, **force of Piston B**

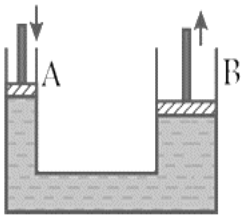
Determine the weight P, lifted by the piston of area $480cm^2$ with a force of 20N acting on piston whose area is $40cm^{2.}$

$\frac{F_2}{F_1} = \frac{A_2}{A_1}$; $\frac{480}{40} = \frac{F}{20}$; $F = 20x12 = 240N$, **weight on Piston P**

Determine the weight W raised by a force of 56N applied on a small piston area of $14m^2$. Take the area of the large piston to be $42m^2$

$\frac{F_2}{F_1} = \frac{A_2}{A_1}$; $\frac{42}{14} = \frac{W}{56}$; $W = 3x56 = 168N$, **weight W**

If the radius of a circular piston A is 7cm and radius of circular piston B is 56cm. When the force exerted on piston A is 77N, find the force exerted on piston B.



$\frac{F_A}{F_B} = \frac{r_A^2}{r_B^2}$; $\frac{F}{77} = \frac{56^2}{7^2}$; $F = 64x77 = 4928N$

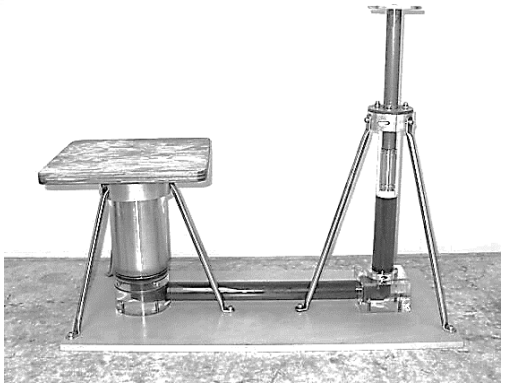
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ACTIVITY

A force of 32N applied on a piston of area 8cm2 is used to lift a load W acting on large area of 640cm2. Determine the value of W. In a hydraulic press system, a force of 1200N is applied to small circular piston of area 30.0cm2. The Hydraulic press system was designed to produce a force of 25KN, determine the radius of the large piston

Hydraulic lift

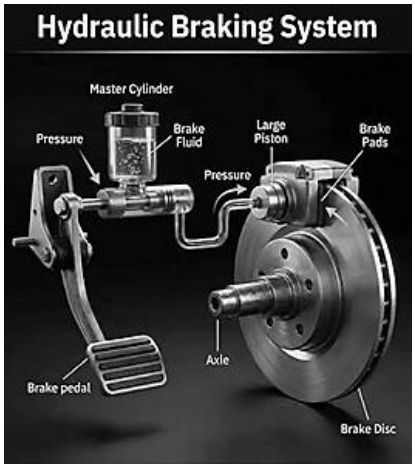
This is used in garages to lift cars so that repairs and service on them can be done easily underneath the car. A force applied to the small piston, raises the large piston, which lifts the car. One valve allows the liquid to pass from the small cylinder to the wider one. A second valve allows more liquid (usually oil) to pass from oil reservoir on the left to the small cylinder. When one valve is open, the other must be shut.



HYDRAULIC BRAKE:

A hydraulic car brake system is a mechanism that uses incompressible fluid to transmit stopping force from the driver's foot to the vehicle's wheels. It relies on the principle that pressure exerted anywhere in a confined liquid is distributed equally and undiminished in all directions. This system acts as a force multiplier, allowing a relatively light push on the pedal to generate the massive friction required to stop a moving, multi-ton vehicle.

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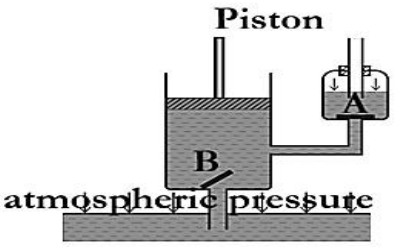


- When the driver steps on the brake pedal, sending mechanical force into the system through a pushrod. The mechanical force passes through a brake booster (servo), which uses engine vacuum or a hydraulic pump to multiply the force applied by the driver's foot.
- When force is applied to the brake pedal, the piston in the master cylinder generates hydraulic pressure.
- The pressurized brake fluid travels instantly through steel brake lines and flexible hoses to each wheel.
- At the wheel assembly, the fluid enters a caliper (for disc brakes) or a wheel cylinder (for drum brakes). The hydraulic pressure forces the internal pistons outward.
- These pistons press high-friction brake pads or shoes against the spinning brake disc (rotor) or drum. The friction converts the car's kinetic energy into heat, slowing the vehicle to a stop.

Understand: *The fluid should be incompressible, with a low freezing point, having a high boiling point, and not corrosive with the parts of the brake system.*

FORCE PUMP

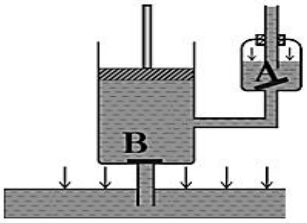
A force pump is a mechanical device designed to move liquids, particularly water, by utilizing pressure. It consists of a solid plunger and a foot valve, which work together to create a flow of liquid.



UPSTROKE:

- When the plunger / piston is pushed (pulled) up, pressure in the barrel reduces / decreases, and water pushes valve B to open, flowing past it into the chamber, while valve A is still closed.

DOWNSTROKE:



- When the plunger is pushed down, valve B closes and A opens, it forces water into the air chamber; which cushions the water out through a side valve, allowing it to be expelled from the pump.
- Water level in the barrel rises further and enters the air chamber through the outlet valve A and in the next repeated strokes; water reaches the spout and pours out.

The operation of a force pump relies on the principle of pressure. Unlike lift pumps, which depend on atmospheric pressure to draw water, force pumps can push water to greater heights without being limited by air pressure making them advantageous in scenarios where water needs to be transported over long distances or to significant elevations.

ATMOSPHERIC PRESSURE

Atmospheric pressure, the weight of the air above us, affects weather patterns and our health. Changes in barometric pressure can lead to various physical symptoms, including headaches, joint pain, and fatigue. When atmospheric pressure drops, it can cause the tissues in our bodies to expand, leading to discomfort and pain, particularly in those with pre-existing conditions like arthritis. Atmospheric pressure increases

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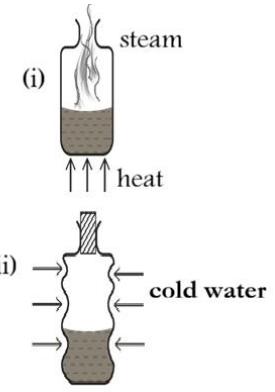
with decrease in altitude (height) and vice versa. The density of air above the earth's surface decreases as altitude increases leading to a decrease in atmospheric pressure at high altitudes. Therefore, atmospheric pressure is low at high altitudes (mountain peaks) and atmospheric pressure is high at low altitudes.

At sea level, the value of atmospheric pressure is very large though we do not normally feel it because blood pressure is slightly greater than atmospheric pressure. A person may faint if he/she experiences a loss in blood pressure. The low blood pressure decreases the rate at which blood flows to the brain thus causing an insufficient blood flow to the brain.
The earth is surrounded by a sea of air called atmosphere. Air has weight therefore; it exerts pressure at the surface of the earth. **The pressure this air exerts on the earth's surface is called atmospheric pressure.**

Atmospheric pressure is the pressure exerted by the weight of air on all objects on earth's surface.
Atmospheric pressure is measured by an instrument called Barometer
The more the air molecules around an object the more force exerted on the object hence exerting high pressure on the object. Therefore, pressure increases with increase in air molecules and pressure decreases with decrease in air molecules

Atmospheric pressure increases with decrease in altitude (height) and vice versa
The density of air above the earth's surface decreases as altitude increases leading to a decrease in atmospheric pressure at high altitudes. Therefore atmospheric pressure is low at high altitudes (mountain peaks) and atmospheric pressure is high at low altitudes.

The higher you go the less dense the atmosphere and therefore atmospheric pressure decrease at high altitude and increase at low altitude. The value of atmospheric pressure is about 101325N/m.



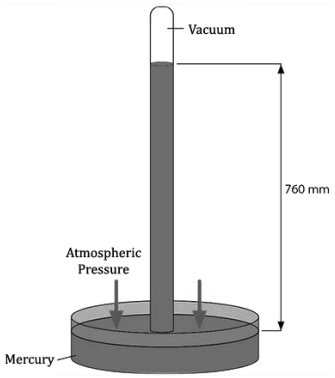
Experiment to demonstrate the existence of atmospheric pressure using crushing can.

A metal can with its tight stopper removed, is heated until the small quantity of water in boils.
When the steam has driven out all the air, the cork is tightly replaced and the heat removed at the same time.
Cold water is poured over the can. This causes the steam inside to condense reducing air pressure inside the can. The can collapses in wards. This is because the excess atmospheric pressure outweighs the reduced pressure inside the can.

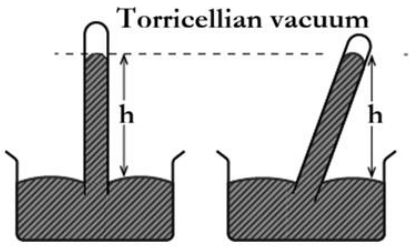
MEASUREMENT OF ATMOSPHERIC PRESSURE

Simple barometer

A simple barometer is made by completely filling a thick-walled glass tube of uniform bore about 1m long with mercury.
The tube is tapped from the open side and inverted several times to expel any air bubbles trapped in mercury.



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It is inverted over a dish containing mercury as shown in the diagram. The mercury level falls leaving a column "h" of about 76 cm. The height "h" gives the atmospheric pressure 76cmHg.
The empty space created above the mercury in the tube vacuum called **Torricellian vacuum.**
The vertical height of the mercury will remain constant if the tube is lifted provided the top of the tube is not less than 76cm above the level of mercury in the dish. If it is lifted so that "h" is less than 76cm. The mercury completely fills the tube.
Atmospheric pressure ($P_O = h\rho g$) = ***barometer height x density of liquid x gravity***

Example
The column of mercury supported by the atmospheric pressure is 76cm. Find column of water that the atmospheric pressure will support in the same place. Comment on your answer.
P = hpg= 0 .76x 13600 x 10 = 103360 Nm^{-2}. If at all in the same place, atmosphere pressure is the same as using water;
P = hpg; 103360 = h x 1000 x 10. h = 103360/ 1000 x 10.
h= 1034m, column of water exceeds 1m

This explains why water is not used in a barometer because the column will be too long.
Water is not used in barometers **due to its low density compared to mercury**. The density of water is 1,000 kg/m³, which means that a water column would need to be over 10 meters tall to balance atmospheric pressure.
Water **vaporizes under low-pressure conditions**, which can lead to inaccuracies in pressure readings. Unlike mercury, which remains liquid and stable in a vacuum, water can form vapor bubbles that disrupt the measurement process. The physical properties of water, its **exposure to temperature** changes and evaporation, further complicate its use in barometers. These factors collectively make mercury the preferred liquid for barometric instruments, ensuring accurate and reliable atmospheric pressure readings.

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The height of mercury column of the barometer supported by the atmospheric pressure is 76cm. Determine the height of the column of water supported by the same atmospheric pressure.
(Density of mercury is 13600kgm^{-3} and Density of water is 1000kgm^{-3})

For mercury, h=76cm=0.760m,
Atmospheric pressure, $H = h\rho g = hx1000x10 = 103360Pa$

For water,
Atmospheric pressure, $H = h\rho g = 0.760x13600x10 = 103360Pa$,
$h = \frac{103360}{10000} = 10.33m$

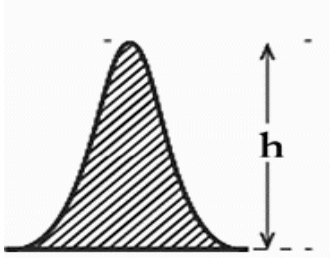
The above example explains why water is not used in barometers because it gives a high barometric height thus requiring a long glass or capillary tube.

Activity
(a).If the barometer reads 76cm$H$g, determine the atmospheric pressure.

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(b).The height of mercury column of the barometer supported by the atmospheric pressure is 0.76mHg. Determine the height of the column of water supported by the same atmospheric pressure. (Hint: Density of mercury is 13600kgm^{-3}, density of water =1000kgm^{-3})

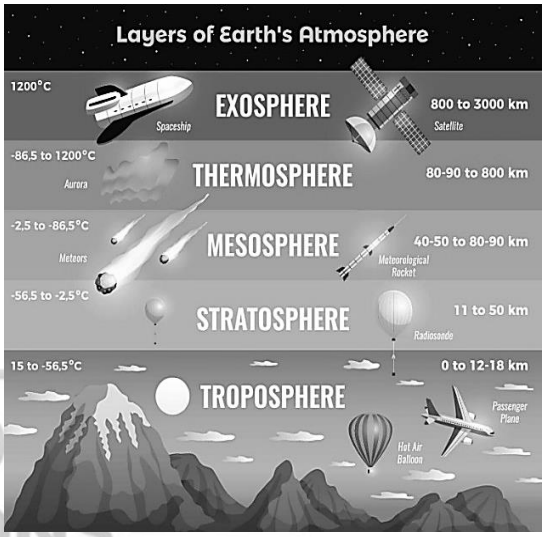
Measurement of height of a mountain



Pressure at the top P_{top} and pressure at the bottom P_{bottom} are determined using a mercury barometer. The difference between the two pressures is got $\Delta P = P_{bottom} - P_{top}$

The pressure difference is equal to the pressure of air between the bottom and the top of the mountain. The height of the air $height_{\ air}$ is calculated and it is equal to the height of the mountain.

Structure of the Atmosphere



The atmosphere is the layer of gases surrounding Earth, held in place by gravity. It helps in supporting life by providing oxygen, regulating temperature, and protecting the planet from harmful solar radiation. These layers are differentiated based on temperature gradients and extend from the Earth's surface to the outer reaches of space.

The layers of the atmosphere

Troposphere:

From the surface to about 8-15 km (5-9 miles).

Decreases with altitude (approximately 6.5°C per kilometer).

The lowest layer of the atmosphere, where all weather phenomena occur (clouds, rain, storms, and wind).It contains about 75% of the atmosphere's mass and 99% of its water vapor. Air pressure and density are highest at this level.

Significance: Supports life by containing the gases essential for breathing, especially oxygen and nitrogen. Plays a key role in the hydrological cycle, enabling weather and precipitation. Turbulent mixing of air occurs here, which helps in the redistribution of heat and moisture across the planet. Airplanes fly near the top of the troposphere (the tropopause) to avoid turbulence and storms.

Stratosphere:

About 15 to 50 km (9 to 31 miles). Increases with altitude, due to the absorption of ultraviolet (UV) radiation by the ozone layer. It is the second layer and is characterized by stable air and very little mixing of gases. It contains the ozone layer, which absorbs and scatters the sun's harmful UV radiation.

Significance: The ozone layer plays a critical role in protecting living organisms from dangerous ultraviolet radiation. Since there is very little turbulence in the stratosphere, it is a favorable region for jet aircraft and high-altitude balloon flights. The temperature increase in this layer prevents vertical mixing, separating it from the troposphere and ensuring weather stays in the lower layers.

Mesosphere: About 50 to 85 km (31 to 53 miles). Decreases with altitude; it is the coldest layer, with temperatures dropping to around -90°C (-130°F) near the mesopause (the boundary between the

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mesosphere and thermosphere). The mesosphere is where most meteoroids burn up upon entering Earth's atmosphere due to increased friction with the particles present.
Significance: The burning of meteors in this layer protects the Earth from impacts. The mesosphere is poorly understood because it is difficult to study too high for weather balloons and too low for satellites. Extremely cold temperatures play a role in the formation of noctilucent clouds, which are the highest clouds in the atmosphere, made of ice crystals.

Thermosphere: About 85 to 600 km (53 to 373 miles). Temperature increases significantly with altitude, reaching up to 2,500°C (4,500°F) or higher. Despite these high temperatures, the thermosphere would not feel hot to humans because the air density is so low. The thermosphere is where solar activity strongly influences temperature and energy. The lower part of the thermosphere contains the ionosphere; a region filled with charged particles.
Significance: The ionosphere is crucial for radio communication because it reflects radio waves back to Earth, allowing long-distance communication. This is also the region where auroras (northern and southern lights) occur, caused by the interaction between solar winds and Earth's magnetic field. The thermosphere provides protection from harmful solar and cosmic radiation. The International Space Station (ISS) and many low Earth orbit satellites operate in this region.

Exosphere: Ranges about 600 km (373 miles) up to 10,000 km (6,200 miles) or more. The temperature continues to rise, but is not easily defined due to the extremely low density of particles. The exosphere is the outermost layer of the Earth's atmosphere, where atoms and molecules can escape into space. It gradually fades into the vacuum of space.
Significance: The exosphere serves as the transition zone between Earth's atmosphere and outer space. Spacecraft and satellites orbit the Earth within this layer, as air resistance is almost nonexistent. It contains very few particles, mostly hydrogen and helium, and is where Earth's atmosphere thins out into the void of space.

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Applications of Atmospheric pressure

Used in syringes
When the piston is pulled up, the pressure inside the cylinder decreases, allowing liquid to be drawn in due to the higher atmospheric pressure outside. This principle is essential in medical and laboratory settings for administering medications and conducting experiments.

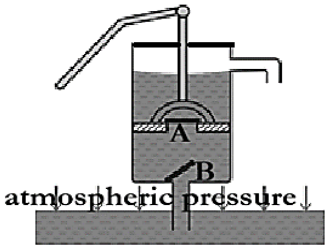
Used in straws
When a person sucks on a straw, they reduce the air pressure inside it. The higher atmospheric pressure outside pushes the liquid up into the straw, allowing for easy drinking. This simple yet effective mechanism demonstrates how atmospheric pressure can facilitate fluid movement.
Atmospheric pressure influences weather patterns. Low-pressure systems often lead to cloud formation and precipitation, while high-pressure systems typically bring clear skies.

Others uses of Atmospheric pressure include in rubber suckers, bicycle pump, lift pump, force pump, siphon, water supply system and among others.

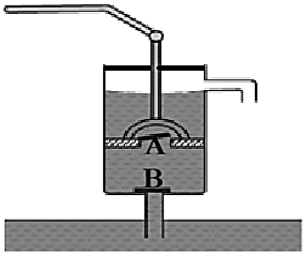
LIFT PUMP / BORE-HOLE

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During the upstroke; the plunger moves upwards, which reduces the pressure inside the barrel. Outlet valve A closes and inlet valve B opens. Water is pushed up the pipe through the inlet valve B by the atmospheric pressure acting on the surface of the water and occupies the space above the inlet valve B.



During the down stroke; the plunger moves downwards. Inlet valve B closes and outlet valve A opens. Water level in the barrel rises further through the outlet valve A and in the next repeated strokes; water reaches the spout and pours out.



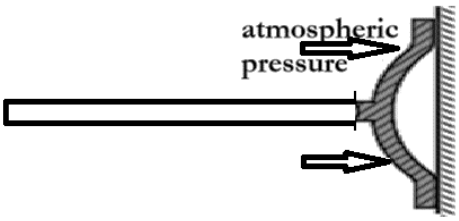
The lift pump can't raise water beyond 10m. This is because atmospheric pressure is low in high altitudes. Atmospheric pressure can only support a water column of 10m.

Drinking straw

When drinking using a straw some of the air in the straw goes into the lungs once sucked. This leaves space in the straw partially evacuated and atmospheric pressure pushing down the liquid becomes greater than the pressure of the air in the straw.

RUBBER SUCKER:

A rubber sucker is moistened with water and then pressed on a smooth surface. The air between the rubber sucker and the smooth surface is decreased thus causing a partial vacuum. The atmospheric pressure outside the rubber sucker exceeds the air pressure in between the sucker and the surface. Therefore, the atmospheric pressure pushes the rubber sucker onto the smooth surface thus holding it firmly. Suckers are used to lift papers to be fed into printers, heavy metal sheets in factories, pressing stickers on walls, cleaning toilets, etc.

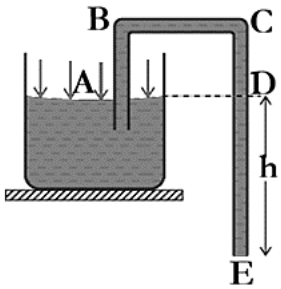


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The siphon

This is used to take the liquid out of vessels (Aquarium, petrol tank)

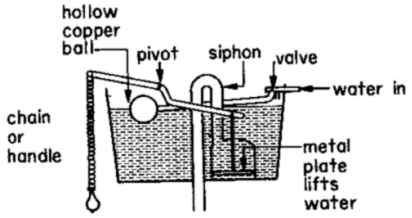
How a siphon works



- The pressure at A and D is atmospheric, therefore the pressure at E is atmospheric pressure plus pressure due to the column of water DE. Hence, the water at E can push its way out against atmospheric pressure
- To start the siphon, pipe/tube must be full of liquid and end A must be below the liquid level in the tank.
- The tube must remain at the bottom of the liquid surface of the upper container.
- Therefore, pressure at this end D is greater than the atmospheric pressure at the surface of liquid
- Since the liquid at end D has a high pressure it can easily flow out.
- The liquid will continue flowing out as long as tube end D is below the surface of the liquid.

Applications of siphon principle

Automatic flushing tank: This uses siphon principle. Water drips slowly from a tap into the tank. The water therefore rises up the tube until it reaches and fills the bend. In the pipe, the siphon action starts and the tank empties (the water level falls to the end of the tube). The action is then repeated repeatedly.



Flushing tank of water closet:

This also uses the siphon principle. When the chain or handle is pulled, water is raised to fill the bend in the tube.

The siphon action at once starts and the tank empties.

Water supply system

Water supply in towns often comes from a reservoir on a high groundwater flows from it through a pipe to any tap or storage tank that is below the water reservoir.

In very tall building, it may be necessary to first pump water to a large tank on a roof. Reservoirs of water supply in hydroelectric power stations are often made in mountainous areas.

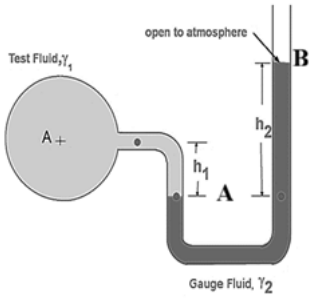
The dam must be thicker at the bottom than at the top to with stand large water pressure at the bottom.

Atmospheric pressure is 760mmHg.When you move on the top of the mountain, the pressure reduce to about 600mmHg.***This shows that pressure reduces with increase in altitude.***

Manometer

It is a U-shaped tube containing mercury. One limb is connected to the gas or air cylinder whose pressure P is required. Second limb is left open to the atmosphere.

Using a metre rule, pressure P of the gas is calculated as Pressure due to h_1 = Pressure due to h_2 = H + h_2 (B is above A) = H – h_2 (when B is below A). Where, H is the atmospheric pressure.

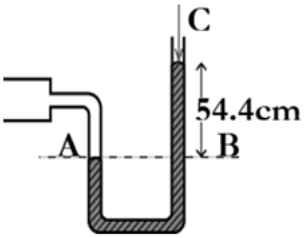


Example: 1. A man blows in one end of a water U – tube manometer until the level differs by 40. 0cm.If the atmospheric pressure is 1.0x 10^5 Nm^{-2} and density of water is 1000kgm^{-3}. Calculate his lung pressure.

Pressure of air = H + hpg = 1.01 x 10^5 + x 1000 x 10 = 105,000Nm^{-2}.

Therefore, lung pressure = 105,000Nm^{-2}

2. The manometer contains mercury, when the gas tap was opened; the difference in the level of mercury was 54.4cm. What is the pressure in cmHg at points A, B, and C.



Pressure at A = pressure B = H + h.

$\boldsymbol{P = (54.4 + 76)cmHg = 130.4cmHg.}$

Final answers can be converted into Pascal's as

$$\boldsymbol{P = \frac{130.4}{100} x13600x10 = 177,344 pascals}$$

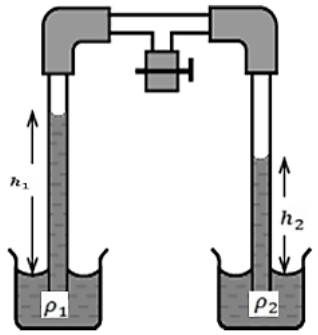
3. The difference in pressure at the peak of the mountain and the foot of the mountain is 5.0 x 10^4Pa. Given that the density of air is 1.3kgm^{-3}, calculate the height of the mountain.

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Difference of $\Delta P = hpg$ $\rightarrow 5.0 \times 10^4 = h \times 1.3 \times 10.$
h = 3846.15m or 3.85km

Comparison of densities of liquids using Hare's apparatus



Liquids of different densities are placed in glass pots as shown above. When the gas tap is opened each liquid rises to different height h_1 and h_2. Since they are subjected to the same gas supply,
Pressure on liquid 1 = Pressure on liquid 2
$h_1\rho_1 g = h_2\rho_2 g.$

$$\frac{h_1}{h_2} = \frac{\rho_2}{\rho_1}$$

Activity :

In a coastal district along Lake Victoria, a team of professional marine rescue divers is called in after a ferry transporting passengers and goods capsizes during a night storm. Several important cargo containers sink to the lakebed at a depth of about 30 meters, and the district authorities request the divers to retrieve them before they are damaged. The weather is unstable, and the rescue team constantly monitors conditions because storms in the region can build up quickly.

After completing the underwater retrieval, the containers must be airlifted to a regional emergency response center using a helicopter. During the airlift, the helicopter climbs to 5,000 meters, passing through different atmospheric layers. Before diving, the team checks the weather using a barometer at the rescue base. As the lead diver and safety coordinator, you must ensure diver safety, prevent equipment failure, and guide the helicopter crew in understanding altitude-related risks.

Hint: Density of sea water:$\rho = 1020\text{kgm}^{-3}$, acceleration due to gravity: $g = 10\text{ms}^{-2}$

Task: Using the knowledge of physics; help to

a) Determine the pressure acting on the diver.

b) Describe how pressure increases with depth in water and explain two health or safety implications for the diver during descent and ascent.

c) Explain how a barometer measures atmospheric pressure, and why this measurement is useful for predicting weather changes that might disrupt the rescue operation.

d) Name the main layers of the atmosphere encountered during this ascent and explain the significance of each layer.

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FLUID MOTION: BERNOULLI EFFECT:

The Bernoulli Effect states that as the speed of a moving fluid (liquid or gas) increases, the pressure within that fluid decreases. (An increase in the speed of a moving fluid occurs simultaneously with a decrease in fluid pressure**)**

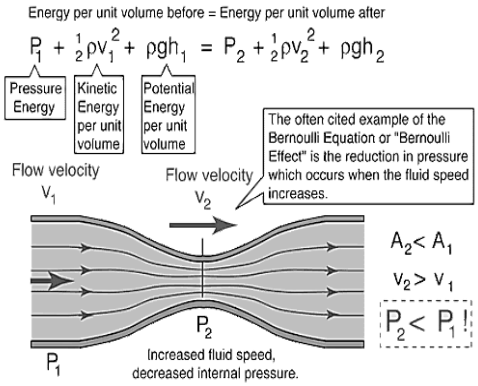
In a flowing fluid, the total mechanical energy comprising pressure energy, kinetic energy (motion), and potential energy (elevation) remains constant along a streamline.

If the fluid speeds up (gaining kinetic energy), its pressure must drop to compensate.

- ♠ As fluid flows faster through a narrow or constricted area, its internal pressure drops. Slow-moving fluid exerts higher pressure.
- ♠ The effect is based on the work-energy theorem. As energy shifts into increased kinetic energy (speed), the potential energy or static pressure component must decrease.
- ♠ The total mechanical energy per unit volume remains constant along a streamline:

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$P + \frac{1}{2}\rho v^2 + h\rho g = constant$, *(Where* p *is pressure,* ρ *is density,* v *is velocity,* g *is gravity, and* h *is height), where* $\rho = \frac{m}{v} = \frac{mass}{volume}$



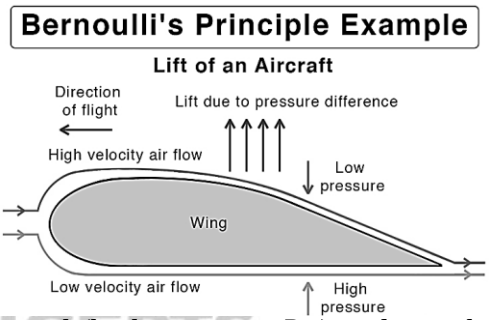
Assumptions and Limitations

- It applies best to incompressible fluids (constant density) with steady, laminar flow.
- It fails when high friction, turbulence, or significant temperature changes and machines like turbines are involved.

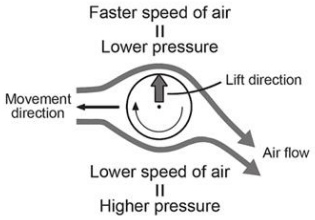
How it Works

Imagine water flowing through a pipe that suddenly narrows:
In the wide section, the water moves slowly, exerting high pressure against the pipe walls.
In the narrow section, the water must speed up to allow the same amount of fluid to pass through. As it accelerates, its pressure drops.

Applications of Bernoulli's effects



- **Aerodynamic Lift:** Airplane wings are shaped so that air travels faster over the curved top surface than under the flat bottom. The high-speed air on top creates a low-pressure zone, while the slower air underneath creates higher pressure, pushing the wing upward.
  Because the fluid flowing above the aerofoil has to travel a longer distance than that flowing below, it has to travel at a higher speed (low pressure, P_2) compared to the low speed (high pressure, P_1) underneath. The pressure difference ($P_1 - P_2$) gives rise to the lift of the aerofoil, called the dynamic lift. The force of the lift is given **by $F = (P_1 - P_2)\,A$** where A is the area of the aerofoil.
- **Venturi Tubes & Atomizers:** Perfume bottles and old car carburetors use a narrowed tube to speed up airflow. This speed creates a low-pressure vacuum that sucks liquid up from a reservoir and sprays it as a fine mist.
- **The Spinning Ball (Magnus Effect):** When a soccer ball or baseball spins through the air, it drags air faster around one side than the other. The pressure difference curves the ball's flight path.



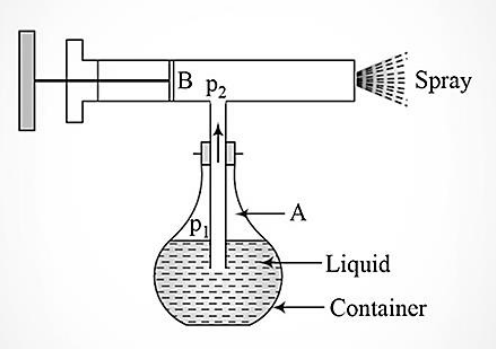
- **Shower Curtain Snugging:** When you turn on a high-speed stream of water, it drags the surrounding air with it, lowering the air pressure inside the shower. The higher air pressure outside the shower pushes the curtain inward toward your legs
- **Entrainment Devices**: Atomizers, aspirators, and Bunsen burners use fast streams of fluid to create low-pressure zones that draw in secondary fluids
  Bunsen burner: When a gas is made to flow into the Bunsen burner from the gas cylinder, its velocity is increased when it passes through the nozzle. Because of the atmospheric pressure outside the barrel, air is then drawn in. The air and the gas then mix as they rise up and when ignited, a flame is produced.

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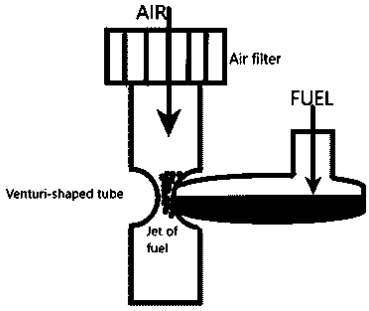
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Spray gun: When the piston is moved forward, air is made to flow through the barrel, some of it going down tube. A and the remainder blowing past the mouth of tube B, where it causes low pressure. Because of increased pressure on the surface of the liquid and reduced pressure at the mouth B, the liquid is compelled to move up tube B and blown to the nozzle by the air from the barrel.

The velocity of the liquid is increased as it passes through the nozzle because of reduced cross-section area. The liquid thus emerges as a fine spray.



The carburetor: Due to action of the engine pistons, air is drawn into the venturi. The fast moving air causes low pressure above the petrol pipe. Petrol is drawn into the venturi due to low pressure in the venturi and atmospheric pressure in the float chamber. The mixture of air petrol is thus drawn into the cylinders for combustion.



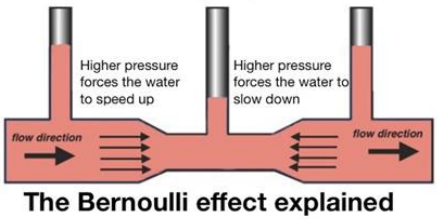
Dangers of Bernoulli's Effect

- **Blowing off of roof-tops:** The air flowing over a roof-top has a high velocity compared, to the one flowing underneath. Consequently, the pressure acting on the roof from underneath will be higher than that acting from above. Hence, the roof is blown off.
- **Road accidents:** A small car travelling at a very high velocity is likely to be dragged into a long track travelling in the opposite direction, also at high speed. This is because the air between them moves with very high speed, reducing the pressure between them. The atmospheric pressure acting from the sides of the two vehicles will push them closer together, increasing chances of an accident.
- **Roof Uplift:** High-velocity winds rushing over buildings create low-pressure zones above the roof while higher pressure remains inside the structure, potentially lifting roofs off buildings.

Limitations of Bernoulli's Principle

Viscous Fluids: Bernoulli's principle assumes an ideal, incompressible, and non-viscous fluid. In reality, viscosity (fluid friction) can affect how pressure and velocity interact.

Turbulent Flow: The principle works best for steady, laminar flow. In turbulent flow, energy is lost due to eddies and vortices, making Bernoulli's principle less applicable.



The Bernoulli effect explained

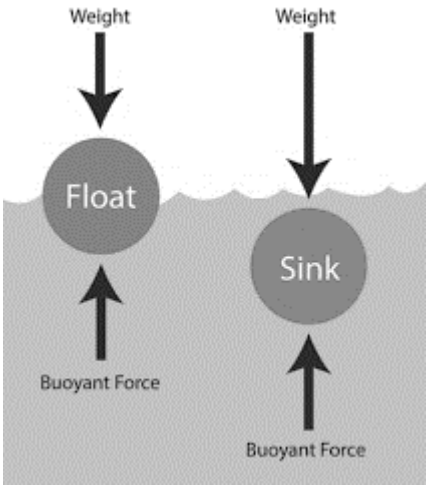
Compressibility: The principle assumes incompressibility, meaning the fluid's density remains constant. For highly compressible fluids (like gases at high velocities), corrections need to be made.

Conclusion

Bernoulli's effect is a cornerstone of fluid dynamics with wide-ranging applications in both natural phenomena and technology. It provides insights into the behavior of fluids under varying pressures and velocities, helping explain everything from airplane flight to the simple functioning of spray bottles.

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Floating and Sinking



Floating and sinking are primarily determined by buoyancy and density.

Buoyancy refers to the upward force exerted by a fluid, which counteracts the weight of an object.

Floating and Sinking

Floating and sinking are phenomena observed when objects are placed in a fluid (like water or air). Whether an object floats or sinks depends on its density relative to the fluid and the buoyant force acting on it.

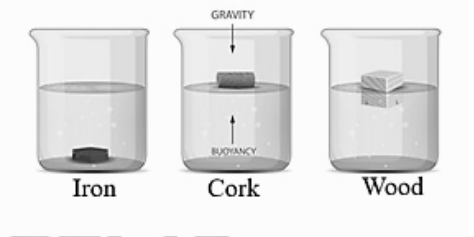
Density is mass per unit volume of a substance.

Buoyant Force is the upward force exerted by a fluid on an object immersed in it.

Archimedes' Principle: The buoyant force on an object is equal to the weight of the fluid displaced by the object.

Up-thrust: It is an upward force due to the fluid resisting being compressed. When any object is immersed or submerged into a fluid, its weight appears to have been reduced because it experiences an up thrust from the fluid.

Explanation:



Floating:

- ♠ An object floats if its density is less than the density of the fluid.
- ♠ The buoyant force equals the weight of the object.
- ♠ The object partially or fully stays on the surface without sinking.

Sinking:

- ♠ An object sinks if its density is greater than the density of the fluid.
- ♠ The buoyant force is less than the weight of the object.
- ♠ The object moves downward until it rests on the bottom or is fully submerged.

Example:

- ♠ A wooden block floats on water because wood is less dense than water.
- ♠ A metal nail sinks in water because metal is denser than water.

This explains why some objects float and others sink when placed in fluids.

Applications

- ♠ **Submarines:** Submarines use "ballast tanks" to control their buoyancy. To sink, they fill the tanks with water to increase their weight until it exceeds the upward buoyant force. To rise, they pump compressed air into the tanks, forcing the water out, reducing weight, and letting the buoyant force push them back to the surface.
- ♠ **Hot Air Balloons:** Archimedes' principle applies to all fluids, including gases like air. Hot air inside the balloon is less dense than the cold air outside. This causes the surrounding cold air to exert an upward buoyant force greater than the weight of the balloon, lifting it off the ground.
- ♠ **Hydrometers:** These tools measure the density of liquids. Because a less dense liquid provides less up-thrust, the hydrometer will sink deeper into it, allowing users to read the fluid's specific gravity on a scale.

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The Role of Density

- ♠ Density is a measure of how much mass is packed into a given volume. From $\rho = \frac{mass}{volume} = \frac{m}{v}$. An object will float if its average density is less than the density of the surrounding fluid, and it will sink if its density is greater.
- ♠ Relative density explains why an ice cube (approx. 0.9 g/cm³) floats in water (1.0 g/cm³) but sinks in kerosene (approx. 0.8 g/cm³).
- ♠ It also resolves the riddle of how massive steel ships can float. While steel itself is incredibly dense (7.8 g/cm³), a ship is shaped to enclose vast pockets of air, making the overall volume large enough that the ship's average density drops below that of water.
- ♠ In fluid mechanics, density dictates how liquids and gases behave under pressure and in motion.
- ♠ Aerodynamics: Atmospheric air density decreases at higher altitudes. This drop in density reduces aerodynamic drag force, allowing airplanes to travel faster and consume less fuel, though it also reduces the lift generated by the wings.
- ♠ Pipeline Transportation: Engineers rely heavily on density to calculate pressure drops in pipelines. Denser fluids generate more internal friction, requiring significantly more pumping energy to transport.

Example:

A wooden log floats on a lake because wood's density (around 0.4–0.8 g/cm³) is less than water's. But if you compress the wood into a denser form (like a heavy brick of sawdust), it might sink.

Buoyancy and Archimedes' Principle

Buoyancy is the net upward force exerted by a fluid on any object placed in or submerged within it. It's based on Archimedes' Principle, which states that the upward buoyant force on an object is exactly equal to the weight of the fluid that the object displaces.

Buoyancy is a direct consequence of gravity acting on a fluid. Fluid pressure increases proportionally with depth $P = h\rho$g because of the weight of the fluid pressing down from above.
When an object is immersed, its bottom face rests at a greater depth than its top face. The deeper part experiences a stronger upward pressure than the downward pressure acting on the top surface.

These pressure differential yields a net upward force the buoyant force $\boldsymbol{F_B}$. Archimedes' Principle is stated as:$F_B = \rho_{fluid}.v_{displaced.}.g$, where,

- ✓ $\boldsymbol{F_B}$ is the buoyant force measured in newtons, N
- ✓ ρ_{fluid} is the density of the fluid kgm-3
- ✓ $V_{displaced}$ is the volume of the fluid shifted by the object m3
- ✓ g is the acceleration due to gravity 10kgm-3

Effects and Equilibrium Conditions

The physical behavior of an immersed body rests on the balance between its downward weight w=mg and the upward buoyant force $\boldsymbol{F_B}$

- → Sinking: Occurs when $\boldsymbol{F_B < W}$. This happens if the average density of the object is greater than the density of the fluid $\rho_{object} > \rho_{fluid}$.
- → Floating/Rising: Occurs when $\boldsymbol{F_B > W}$ while fully submerged, causing the object to rise to the surface until a portion is exposed.
- → At equilibrium on the surface, $\boldsymbol{F_B = W}$. This occurs when $\rho_{object} = \rho_{fluid}$.

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→ Neutral Buoyancy: Occurs when $\boldsymbol{F_B = W}$ while entirely underwater. The object remains suspended at its current depth because the densities match $\rho_{object} = \rho_{fluid}$

→ Apparent Weight Loss: An immersed object feels lighter because the upward buoyant force counteracts a portion of its true weight. $\boldsymbol{Apparent\ Weight\ (W_a) = Actual\ Weight\ (W) - BuoyantForce\ (F_B)}$

Applications

- ♠ **Shipbuilding & Naval Architecture:** Huge iron ships float because their hollow shapes ensure they occupy a massive volume, displacing a volume of water whose weight matches the massive weight of the ship. This increases the volume of displaced water yielding a buoyant force equal to the ship's entire weight.
- ♠ **Submarine Ballast Control:** Submarines feature "ballast tanks". Flooding these tanks with water increases the submarine's overall weight to sink. Pumping compressed air into the tanks expels the water, making the submarine lighter so it can rise.
- ♠ **Hydrometers:** These specialized glass floats measure the specific gravity (relative density) of liquids. They sink deeper in low-density liquids and float higher in high-density liquids.
- ♠ **Aerostats and Hot Air Balloons:** Archimedes' principle extends to gases. Heating the air inside a balloon lowers its density compared to the surrounding cool air. When the weight of the air displaced by the balloon exceeds the structural weight plus the hot air inside, it ascends.

Example

1.A solid steel block of volume $0.02m^3$ is completely submerged in pure water of density $1000kgm$-3. If the density of steel is 7800 kgm-3, calculate:

a) The weight of the block in air.
b) The buoyant force acting on it.
c) Its apparent weight when submerged.

Responses :

Weight in Air,

$Mass = density\ of\ steel\ x\ volume = 7800x0.02 = 156kg$

$W_{air} = mg = 156x10 = 1560N$

Buoyant Force($\boldsymbol{F_B}$)

Since it is fully submerged, the volume of displaced water equals the block's total volume, $Volume = 0.02m^3$, $F_B = \rho vg = 1000x0.02x10 = 200N$

Apparent Weight, $\boldsymbol{W_{apparent}}$

The upward buoyant force makes the object feel lighter.

$W_{apparent} = W_{air} - F_B = 1560N - 200N = 1360N$

2.An iceberg has a density of 917kgm^{-3}. It floats in seawater, which has a density of 1025kgm^{-3}. What percentage of the iceberg stays hidden beneath the surface?

Solution:

For any floating object, its weight equals the buoyant force $W = F_B$

$\rho_{object} \cdot v_{total.} \cdot g = \rho_{fluid} \cdot v_{submerged.} \cdot g$,

→ $\rho_{object} \cdot v_{total.} = \rho_{fluid} \cdot v_{submerged.}$,

Rearrange to find the ratio of submerged volume: $\frac{v_{submerged}}{v_{total}} = \frac{\rho_{object}}{\rho_{fluid}}$

Substitute the values: $\frac{v_{submerged}}{v_{total}} = \frac{917}{1025} = 0.895$

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Converting this to a percentage gives 89.5%. Therefore, about **89.5%** of the iceberg remains underwater.

3.A solid metal sphere of volume $0.002m^3$ and mass 16kg is completely submerged in water density of water = $1000kgm^{-3}$. Calculate the buoyant force and its apparent weight. Hint: use g = $9.8ms^{-2}$

a) Calculate the actual weight of the sphere:
b) Calculate the buoyant force, and
c) the actual weight of the sphere

Responses

a) $W = mg, W = 16x9.81 = 156.8N$
b) Because it is fully submerged,$V_{displaced} = V_{object} = 0.002m^3$,
$F_B = \rho_{water} x v_{displaced} x g, F_B = 1000x0.002x9.8 = 19.6N,$
The apparent weight:
c) The buoyant force: Because it is fully submerged,$V_{displaced} = V_{object} = 0.002m3$

$F_B = \rho_{water} x v_{displaced} x g, F_B = 1000x0.002x9.8 = 19.6N,$ The apparent weight; $W_{apparent} = W - F_B = 156.8 - 19.6 = 137.2N$

Factors Influencing Sinking/Floating

- ♠ **Shape and Volume**: A flat sheet of aluminum foil sinks if crumpled (less volume displaced) but floats if spread out (more volume displaced).
- ♠ **Fluid Type:** Objects float better in denser fluids. Saltwater (density ~1.025 g/cm³) buoys more than freshwater, which is why it's easier to float in the Dead Sea (high salt, density ~1.24 g/cm³).
- ♠ **Temperature:** Fluids expand when heated, lowering density. Hot air balloons float because heated air inside is less dense than cooler outside air.
- ♠ **Air Pockets or Gases:** Life jackets trap air, reducing overall density. Helium balloons float in air because helium is less dense than nitrogen/oxygen mix.
- ♠ **Surface Tension:** Tiny objects like insects can "float" on water due to surface tension (cohesive forces at the surface), not just buoyancy.

Common Misconceptions

- *Weight alone doesn't determine sinking/floating—it's density. A massive ship floats, but a small dense pebble sinks.*
- *Not just liquids: These principles apply to gases too (why clouds "float" in the sky).*
- *In zero gravity (like space), there's no "up" or "down," so buoyancy doesn't apply the same way.*

ARCHIMEDES PRINCIPLE

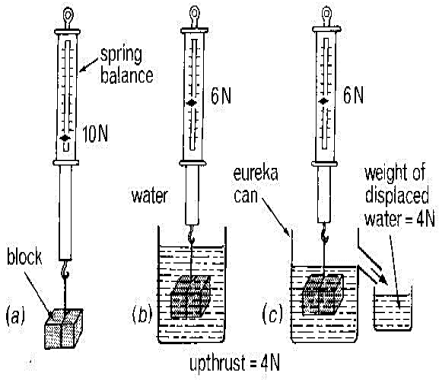
Archimedes' principle states that when a body is wholly or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid displaced. i.e. up thrust = weight of fluid displaced.

Experiment to verify Archimedes' principle

- ✓ An object is weighed in air using a spring balance to obtain its weight W_1(10N).
- ✓ The eureka can is completely filled with the liquid and a beaker is put under its spout.
- ✓ The body is then immersed in the liquid.
- ✓ The new weight W_2 is also read from the spring balance (6N).
- ✓ The liquid collected in the small beaker is weighed to determine its weight W_3(4N)
- ✓ It is obtained that $W_3 = W_1 - W_2$, i.e. $W_1 = 10N,$
- ✓ $W_2 = 6N, W_3 = 10 - 6 = 4N$

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The weight of the body when completely immersed or submerged is called the *apparent weight* (6N). The apparent weight is less than the weight of the body because when the body is immersed it experiences an up thrust force (U=4N).



Activity

1. During a practical lesson, a group of learners suspended a glass block from a spring balance. They recorded that the block weighed **25 N in air**. When the block was completely immersed in water without touching the bottom of the container, the spring balance reading reduced to **15 N**. **Task:** Using the information from the investigation, **determine the upthrust acting on the glass block.**

2. A learner carried out an experiment to investigate the effect of water on a solid object. The learner measured the weight of the object in air and obtained a reading of 1 N. When the object was completely immersed in water, the spring balance reading reduced to 0.3 N.

Task: Using the principle of flotation and upthrust, calculate the weight of water displaced by the object.

3. During a Physics practical activity, learners were given a metal object whose weight was measured using a spring balance. Its weight in air was found to be **20 N**. When the metal was completely immersed in water, its apparent weight reduced to 15 N. The learners were provided with the following information:

- Weight of metal in air = 20 N
- Apparent weight in water = 15 N
- Density of water = 1000 kg/m³
- Acceleration due to gravity, **g = 10 N/kg**

Tasks: Use the knowledge of physics to:

a) Calculate the weight of water displaced by the metal.
b) Calculate the volume of water displaced.
c) determine the volume of the metal.
d) Calculate the density of the metal.
e) Explain how the experimental results demonstrate Archimedes' principle.

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Application of Archimedes' principle

Archimedes' principle states that an object submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid it displaces.

Applications

- Ships are hollow and shaped to displace a large volume of water. This creates an upward force that matches the massive weight of the vessel, allowing it to float.
- Submarines use ballast tanks to control their depth. Filling these tanks with water increases the sub's overall weight so it sinks, while pumping compressed air in to expel the water makes it rise.
- In hot Air Balloons**,** The surrounding air acts as a fluid. Heating the air inside a balloon makes it less dense than the outside air, generating an upward lift.
- A hydrometer measures the density of liquids. It sinks to different depths depending on how dense the liquid is.
- Lactometers devices measure the purity of milk by determining its density relative to pure milk.

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Measurement of relative density of a solid

→ Weigh the object in air and note it to be W_{air}
→ Weigh the object in water and note it to be W_{water}
→ Determine the upthrust $U = W_{air} - W_{water}$

Relative density of solid $R.D = \frac{\text{Weigh the object in air}}{\text{upthrust}}$

Determination of RD of a liquid

→ Weigh the object to find its weight in air W_{air} using a spring balance
→ Weigh the object in the liquid whose RD is to be determined, label it W_{liquid}
→ Weigh the object in water, call it $Wwater$

Find the up thrust in liquid = $Wair - W_{liquid}$
Find the up thrust in water = $Wair - Wwater$
Obtain the RD of a liquid from $R.D = \frac{Wair - W_{liquid}}{Wair - Wwater}$

Example

A metal weighs 40N in air and 25N when fully immersed in water. Density of water=1000kgm^{-3} Determine the upthrust, weight of displaced water, volume of displaced water, volume of the metal, and density of the metal.

Response .

$Upthrust = W_{air} - W_{water} = 40N - 25N = 15N$
$Weight\ of\ displaced\ water = upthrust = 15N$
Volume of displaced water = upthrust
$M_w g = V_w \rho_w g, 15N = V_w x1000x10, V_w = \frac{15}{10000} = 1.5x10^{-3}m^3$
Volume of the metal; $V = 1.5x10^{-3}m^3$
From Archimedes principle, Volume of displaced water= volume of the metal in air.
$W_{air} = mg; 30 = v_a xg, 30 = v_m \rho_m g$, **30**$=1.5x10^{-3}m^3x10x\rho_m$,
$30 = 1.5x\rho_m x10, \boldsymbol{\rho_m = 600kgm^{-3}}$

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Activity

1. In a laboratory experiment, a student named Alex is investigating the properties of an unknown liquid found in a chemical storage room. Alex uses a solid metal cube that weighs 5.6 N when measured in air using a spring balance. When the cube is fully immersed in pure water, its apparent weight decreases to 4.8 N. Curious about the unknown liquid, Alex then fully immerses the same cube in the liquid and records an apparent weight of 4.6 N. Assuming the cube is fully submerged in both fluids and neglecting any other effects, determine the density of the unknown liquid. Explain with reasons, the application of Archimedes' principle.
2. An object weighs 100N in air and 20N in a liquid of RD 0.8. Determine its weight in water.

FLOATING OBJECTS

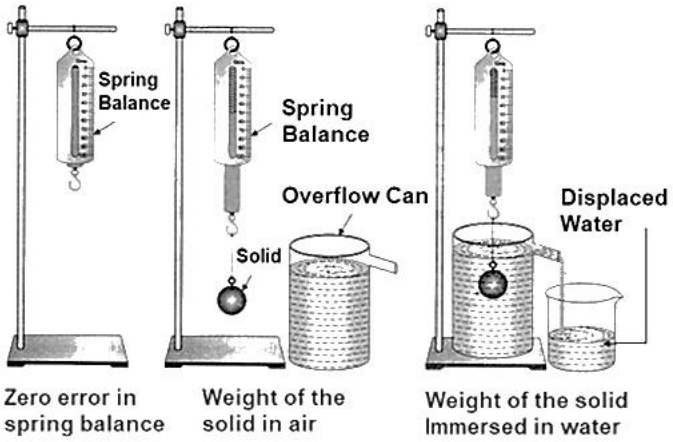
Floating objects are primarily explained by the principles of buoyancy and density. An object floats when it is positively buoyant, meaning it is less dense than the fluid it is in. According to Archimedes' Principle, when an object is submerged, it displaces a volume of fluid equal to its own weight. If the weight of the fluid displaced is greater than the weight of the object, it will float. For instance, wood floats on water because its density is lower than that of water, allowing it to displace enough water to support its weight. Objects denser than water, like stones, will sink.

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There are two vertical forces which act on an object when immersed in water, weight (W) and up thrust (U). If W is less than U the object rises, If W is equal to up thrust U object floats, and If W is greater than up thrust U object sinks. Therefore, floating objects weigh equal to up thrust. From Archimedes principal, up thrust is equal to weight of a fluid displaced. Therefore, for floating objects, weight of objects should be equal to weight of fluid displaced.

Law of floatation

The principle of floatation, rooted in Archimedes' principle, states that an object will float in a fluid if the buoyant force acting on it is equal to its weight. This buoyant force arises from the pressure difference exerted by the fluid on the object, which is greater at the bottom than at the top. Consequently, when an object is placed in a liquid, it displaces a volume of fluid equal to its own weight, allowing it to float. For an object to float, its density must be less than that of the fluid. This is why large ships, despite their heavy weight, can float; they are designed to displace enough water to counterbalance their weight. Similarly, icebergs float because they displace a volume of water equal to their weight, with a significant portion submerged. In summary, the principle of floatation explains how objects interact with fluids, emphasizing the relationship between buoyancy, weight, and density. ***Hence the law of floatation states that a floating object displaces its own weight of the fluid in which it floats.***



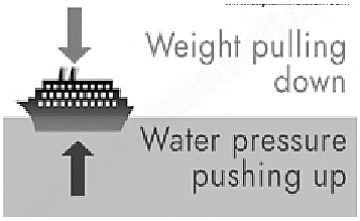
Experiment to verify law of floatation

a) A simple experiment can be conducted using a eureka can and a solid object.
b) Fill the eureka can with water up to the spout level.
c) Gently lower the object into the water until it floats. As the object displaces water, the displaced water will flow out of the spout.
d) Collect this water in a measuring container to determine the volume of water displaced.

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According to the law of flotation, an object will float if the weight of the water displaced is equal to the weight of the object.
By measuring the weight of the object and the volume of water displaced, you can confirm this principle. Weigh the displaced water.
Weight of water displaced = weight of object measured in air.
If the object's density is less than that of the fluid, it will float; if greater, it will sink. This experiment effectively demonstrates Archimedes' principle and the concepts of buoyancy and flotation.

Application of law of floatation

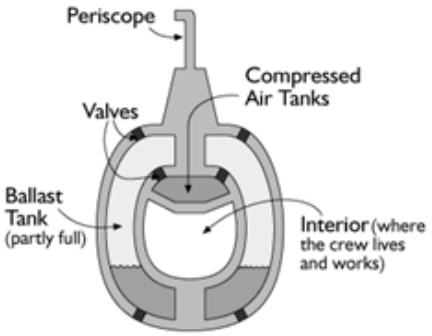


Ship: A ship floats when the up thrust of the water it displaces equals its weight**.**
$Weight\ of\ floating\ ship\ = weight\ of\ water\ displaced.$
While a ship is being loaded, it sinks lower and displaces more water to balance the extra load. While steel does not float, steel ship floats. This is because steel ship is hollow and

most of its parts contain air, hence its average density is less than the density of water. Therefore, hollow steel displaces many times its volume of water.

Submarines

A submarine has ballast tanks which can be filled with water or air. When full of water, the average density of the submarine is slightly greater than the density of sea water and it sinks. When air is pumped into the tanks, the average density of the submarine falls until it's the same or slightly less than that of water around it. The submarine therefore stays at one depth or rises to the surface.



Submarine (cross section)

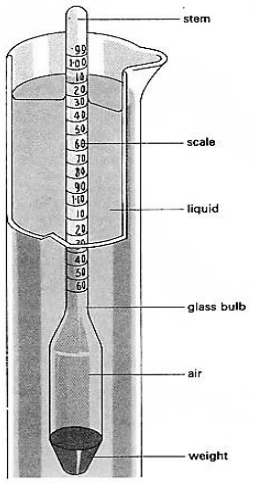
Balloons and airships

A balloon is an airtight, light bag with hydrogen or helium. These gases are less dense than air. An airship is a large balloon with a motor to move it and fins to steer it. The down ward force on the balloon equals to the weight of the bag plus the weight of gas in it. The balloon rises if the up thrust is greater than the downward force. The lifting force= up thrust –total weight. Upthrust = weight of air displaced –weight of bag + weight of gas. Balloons that carry passengers control their weight by dropping ballast to make them rise and by letting gas out of the gas bag to make them fall. As the balloon rises, the atmospheric pressure on it becomes less. The gas in the balloon tends to expand. Therefore, the gas bag must not be filled completely when the balloon is on the ground.

Hydrometers: A hydrometer is an instrument used to measure the density or relative density (specific gravity) of liquids based on the concept of buoyancy.

Operation

- It is usually a sealed glass tube with a wider, weighted bottom bulb (using lead or mercury) to make it float upright and a narrow stem with a graduated scale.
- The instrument sinks deeper in less dense liquids and floats higher in denser liquids.
- You drop it into a tall container of liquid and read the measurement where the liquid's surface touches the stem's scale.



Applications

- Brewing and Winemaking: Measures sugar content in water or juice before and after fermentation to calculate alcohol by volume (ABV).
- Aquarium Maintenance: Checks the salinity (salt level) of saltwater tank water.
- Automotive: Tests the state of charge in lead-acid car batteries by measuring electrolyte density, or checks engine coolant antifreeze concentration.

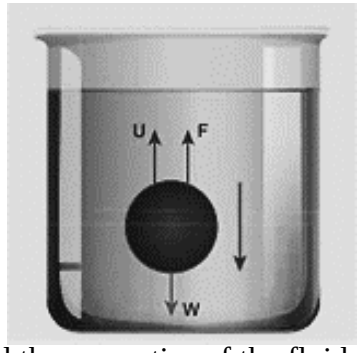
Motion of a body through fluids

The motion of a body through fluids, such as air or water, involves When a solid body moves through a fluid (either a liquid or a gas), it experiences a complex system of forces due to the interaction between its surface and the surrounding molecules. This motion is critical for engineering airplanes, submarines, cars, and even analyzing how blood flows through our bodies.

Forces Acting on the Body

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A body moving vertically or through a viscous medium experiences three primary forces:



- **Weight (W):** The downward force due to gravity acting on the mass of the body (W = mg).
- **Up-thrust (Buoyancy (U):** The upward force exerted by the fluid, equal to the weight of the fluid displaced by the body.
- **Viscous Drag Force (F_v):** The frictional resistance offered by the fluid that opposes the direction of the body's motion.

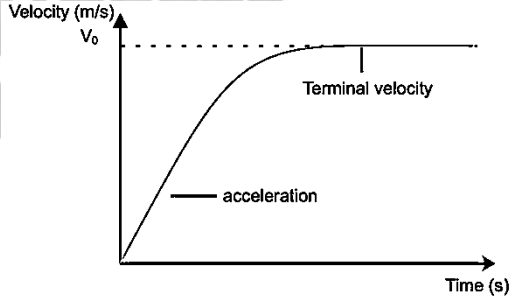
Viscous Drag and Flow Regimes

The nature of the fluid drag depends heavily on the velocity of the object and the properties of the fluid, characterized by a dimensionless value called the Reynolds number (Re).

Flow Regime	Description	Drag Force Relationship
Laminar Flow (Re < 1)	The fluid moves in smooth, parallel layers (streamlines) without mixing.	($F_v \propto V$): (Drag is directly proportional to speed).
Turbulent Wake (Re > 1)	The flow breaks apart, creating irregular eddies, swirls, and chaotic mixing behind the body.	($F_v \propto V^2$); Drag is proportional to the square of the speed.

Terminal Velocity

- When an object is dropped into a fluid, it initially accelerates downward because its weight is greater than the combined upward forces of up-thrust and drag ($W > U + F_v$).
- As the object's speed increases, the viscous drag force (F_v) also increases. Eventually, a point is reached where the upward forces perfectly balance the downward weight: ($W = U + F_v$)
- Once the forces are balanced, the object stops accelerating and continues to fall at a constant, maximum speed known as the terminal velocity.



- Terminal velocity is the steady speed achieved by an object freely falling through a gas or liquid. When an object is dropped, it accelerates due to gravity until the force of air resistance equals the gravitational pull.
- At this point, the object stops accelerating and continues to fall at a constant speed, known as terminal velocity. The terminal velocity of an object depends on its **mass, shape, and cross-sectional area**.

Terminal velocity: *This is a constant or uniform velocity with which a body falling through a fluid moves such that the upward forces acting on it are equal to its weight*. The uniform velocity attained by a body falling through a fluid when the net force on the body is zero

Applications of terminal Velocity

Aerodynamic Phenomena: When a body rotates while moving through a fluid, it can experience an asymmetric lift force perpendicular to its line of motion. This is known as the **Magnus effect**, which explains why spinning baseballs, tennis balls, or soccer balls curve significantly in mid-air.

Parachute: Objects with larger cross-sectional areas or higher drag coefficients, such as a parachute, will fall more slowly than denser, more streamlined objects like a rock.

Skydiver: A skydiver in a spread-eagle position experiences a lower terminal velocity compared to a head-down position due to increased air resistance. It illustrates the balance between gravitational force and air resistance, providing insight into the dynamics of free fall.

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Activity:
A skydiver with a mass of 70 kg jumps from a malfunctioning small airplane flying at an altitude of 3000 meters above sea level over a coastal region. The airplane has lost engine power, forcing the pilot to glide using the aerodynamic design of the wings. During descent, the skydiver deploys a parachute, but strong winds push them toward a nearby saltwater lake (density =1025 kg/m³). The skydiver safely lands in the water and stays afloat using a flotation device until rescue arrives.
Task: Using your understanding of physics, answer the following:

(a) Explain how the airplane's wings generate lift during a glide.
(b) Describe the forces acting on the skydiver during free fall.
(c) Explain why opening the parachute reduces the skydiver's terminal velocity.
(d) Explain why massive cargo ships float on ocean water despite being made of dense steel.

S2.4 MECHANICAL PROPERTIES OF MATERIALS AND HOOKE'S LAW

Learning Outcomes

a) Understand how the mechanical properties of common materials can be utilised in physical structures (u, s, v/a)
b) Understand that the tensile strength of materials is determined by the properties of the substances they are composed of (u)
c) Understand that heating changes the structure and properties of some materials(u)

Mechanical properties of matter refer to the behaviors and characteristics of materials when they are subjected to mechanical forces.
Mechanical properties define how a material behaves when subjected to external forces, dictating its strength, durability, and suitability for engineering applications. Under small loads, many materials exhibit elastic behavior, where they return to their original shape once the load is removed a relationship fundamentally governed by Hooke's Law.

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Mechanical Properties of Materials

- **Elasticity:** The ability of a material to return to its original shape and size after the deforming force is removed.
- **Plasticity:** The property by which a material undergoes permanent deformation without breaking when loaded past its elastic limit.
- **Strength**: The ability of a material to withstand large forces or loads without breaking or suffering permanent structural failure.
- **Ductility:** The capacity of a material to stretch or deform plastically under tensile stress without fracturing (drawing copper into wires).
- **Brittleness:** The tendency of a material to fracture or break with little to no prior plastic deformation when subjected to stress (glass, ceramics).
- **Malleability:** The ability of a material to be flattened or rolled into thin sheets under compressive stress (gold foil).
- **Toughness or Stiffness:** The capability of a material to absorb energy and deform plastically before fracturing. Stiffness measures resistance to bending or changing shape (requiring large forces), while toughness measures energy absorption before fracturing.

Stress and Strain
To analyze how materials handle forces, engineers standardize force and deformation using two terms:

Stress: The internal restoring force per unit cross-sectional area. $Stress\ (\delta) = \frac{Force\ (F)}{Area\ (A)}$, $\delta = \frac{F(N)}{A(m^2)}$

Unit: pascals (Pa) or Nm^2

Strain: The extension per unit original length or relative deformation caused by stress.

$\varepsilon = \frac{\Delta l}{L_0} = \frac{L - L_o}{L_o}$ Unit: Dimensionless (ratio of lengths)

Hooke's Law: Hooke's Law states that the extension or deformation of a material is directly proportional to the applied force (load), provided the elastic limit is not exceeded, or within the proportional limit of a material, the strain produced is directly proportional to the stress causing it.

Stress and Strain Form: For continuous solid materials, it states that normal stress is directly proportional to normal strain within the elastic region: i.e. $stress \propto strain, \sigma \propto \varepsilon.\ \sigma = E\varepsilon.\ E = \frac{\sigma}{\varepsilon}$, where E is a constant known as the Young's Modulus (or Modulus of Elasticity).

Young's Modulus (E): The constant of proportionality representing the slope of the linear elastic portion of a stress-strain curve, measuring the stiffness of the material. It measures a material's stiffness. A higher Young's Modulus means the material is stiffer and harder to stretch.

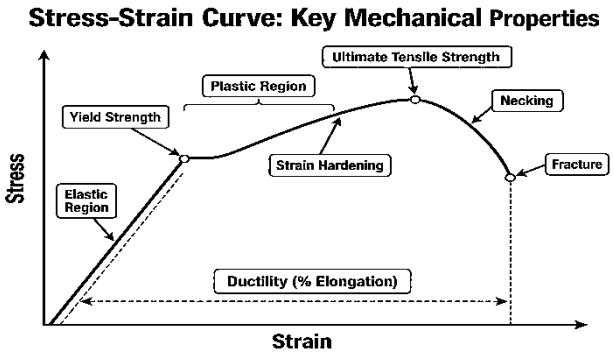
The Spring Constant. $(\boldsymbol{K})$**:** For macroscopic objects like springs, Hooke's Law is commonly written as; $F = kx$, (or $F = -kx$, for restoring force),where F= Applied force (N), k= Spring constant or stiffness (N/m), x= Extension or compression distance (m).

The Stress-Strain relationship

When a ductile material (like structural steel) is pulled until it breaks, it goes through several distinct regions on a stress-strain diagram:

Proportional Limit: The point up to which stress is directly proportional to strain (Hooke's Law applies perfectly).

Elastic Limit: The maximum stress a material can withstand without undergoing permanent plastic deformation.



Yield Point: The stress level at which the material begins to deform plastically. Beyond this point, removing the load will leave a permanent set.

Ultimate Tensile Strength (UTS): The maximum stress the material can withstand. This is the peak of the curve.

Fracture/Breaking Point: The point at which the material physically separates or snaps.

Applications and Importance

- **Vehicle Suspensions:** Springs use Hooke's law principles to absorb shocks and smooth out rough rides.
- **Measuring Instruments: Spring** balances rely on proportional extension to accurately measure weight and force magnitudes.
- **Structural Engineering:** Engineers use these concepts to calculate load-bearing limits, deflections, and stresses in steel beams and concrete columns.
- **Material Testing:** Researchers test new alloys and composites to determine safety factors, Young's modulus, and failure thresholds before mass production.

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Bricks and blocks as building materials

Bricks and blocks are rigid masonry units used to build durable walls, foundations, and structures.

Mechanical Properties

- Bricks and blocks resist heavy crushing forces pushing down on them, making them ideal for load-bearing walls.
- They resist forces that try to slide one layer sideways over another.
- They have very low resistance to pulling or stretching forces, so builders add steel or mortar reinforcement to prevent cracking.
- They deform very little under high loads, maintaining structural shape under pressure.
- Denser units block water and offer higher strength, while porous units provide better thermal insulation but less strength.

Applications

- They supporting the weight of roofs and upper floors in buildings.
- They divide interior spaces where structural support is not needed.
- Used in providing a solid base layer below ground level to distribute a building's weight.
- In paving and retaining Structures creating durable outdoor pathways or retaining earth on slopes.

Importance

- They safely transfer building weight down into the ground.
- High compressive strength keeps multi-story buildings upright and secure.
- Mechanical toughness protects buildings from physical wear, wind loads, and impacts

Disadvantages

They are brittle, they need firing, and it turn out to be expensive, and not suitable under wet conditions i.e. can soften and weaken.

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Glass as a building material

Glass as a building material is a solid, amorphous (non-crystalline) inorganic substance produced by fusing silica (sand) with soda and lime at high temperatures, then cooling it rapidly to prevent crystallization. In modern construction, it is engineered into a rigid, transparent, or translucent structural element capable of enclosing spaces, transmitting light, and bearing structural loads.

Mechanical Properties of Glass

- Glass resists crushing forces exceptionally well, boasting a compressive strength of 700 to 1,000 MPa (roughly ten times its tensile strength).
- Standard glass has a low tensile strength (~40 MPa). It is highly vulnerable to pulling or bending forces because tiny, microscopic surface flaws quickly spread into major fractures when stretched.
- Glass has zero plasticity. It does not warp, bend, or give any visual warning before failure; it breaks instantly and catastrophically once its elastic limit is exceeded.
- With a Young's Modulus of roughly 70 GPa (comparable to aluminum), glass is highly stiff and resists bending out of shape under normal atmospheric pressures.
- Rating 5.5 to 6.5 on the Mohs scale, its surface resists abrasion from windblown dust, cleaning tools, and everyday physical contact.

Uses and Applications

- To use glass safely in structures, it is treated mechanically toughened (tempered) by rapid heating and either cooling to create built-in surface compression, or laminated by sandwiching a plastic interlayer between sheets.

- ♠ Building Facades and Curtain Walls: Large exterior sheets enclose skyscrapers, using high stiffness to resist intense lateral wind loads while supporting their own weight.
- ♠ Structural Fins and Beams: Heavy, multi-layered vertical glass fins are used as columns to support massive glass walls without relying on metal framing.
- ♠ Flooring, Walkways, and Staircases: Thick, laminated glass panels are engineered to bear the live loads of pedestrian traffic safely.
- ♠ Balustrades and Overhead Glazing: Used as protective barriers and skylights where the material must resist sudden impacts (like falling objects or human collision).

Importance (Mechanical & Architectural Benefits)

- ♠ High Strength-to-Thickness Ratio: Because of its immense compressive strength, thin panes of engineered glass can replace thick masonry walls, shedding significant dead load (weight) from a building's superstructure.
- ♠ Elastic Recovery: Because it is perfectly elastic right up to its breaking point, glass can repeatedly flex under wind pressure and snap back to its exact original shape without suffering permanent deformation or fatigue.
- ♠ Safety Control via Engineering: Manufacturing modifications alter its breaking mechanics. Tempered glass breaks into small, dull granules rather than dangerous shards, while laminated glass holds shattered pieces firmly in place to prevent structural collapse.

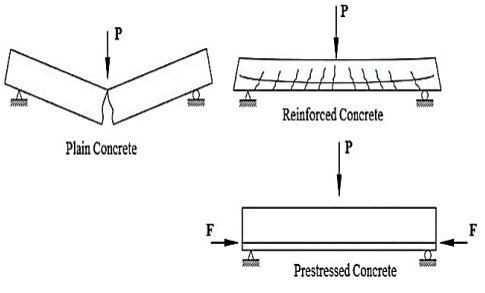
Disadvantages & Mechanical Limitations

Mechanical Cause / Impact
♠ Being highly brittle, glass yields no structural warning signs (like stretching or cracking slowly) before completely shattering.
♠ Small surface scratches, edge chips, or internal impurities drastically lower its real-world tensile strength, acting as weak points where cracks instantly trigger.
♠ Glass expands when heated. If one part of a glass pane is in hot sunlight and the edge is cool inside a frame, the uneven expansion creates internal tensile stress that can crack the pane.
♠ Because glass structural components (like fins) are thin and rigid, they are highly prone to buckling under vertical compressive loads if they are not perfectly aligned.

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Concrete

Concrete is a composite building material formed by mixing a binding agent (usually Portland cement), water, and aggregates (sand and crushed stone or gravel). When mixed, the water activates the cement through a chemical process called hydration, causing it to harden into a rock-like mass over time.



From the perspective of mechanical properties of materials, concrete is categorized as a brittle, non-homogeneous, and anisotropic material.

Mechanical Properties of Concrete

- ♠ Concrete is exceptionally strong under loads that crush or compress it. Its ultimate compressive strength typically ranges from 20 MPa to over 80 MPa depending on the mix design.
- ♠ Concrete is weak when pulled apart. Its tensile strength is remarkably low only about 10% to 15% of its compressive strength.

- Under heavy tension or excessive compression, concrete exhibits brittleness. It fails suddenly with very little plastic deformation (yielding) or warning signs, unlike ductile materials like steel.
- Concrete has a moderately high modulus of elasticity (generally between 20 to 40 GPa), meaning it is quite stiff under working loads but undergoes sudden micro-cracking once its elastic limit is crossed.
- Because shear stresses generate diagonal tension within a material, concrete's weak tensile capacity makes it highly susceptible to diagonal shear failure.

Importance of Concrete (Based on Mechanical Properties)

- Because structural elements like foundations, columns, and arches primarily experience compression, concrete's excellent compressive load capacity makes it the ideal material for transferring immense building weights to the ground.
- Its high stiffness reduces the deflection and deformation of structures under heavy dead loads (permanent structure weight) and live loads (people, furniture, traffic).
- Concrete shares an almost identical thermal expansion coefficient with structural steel. By embedding steel rebar into concrete zones facing tension, engineers create Reinforced Concrete (RC). This marries concrete's compressive strength with steel's high tensile strength and ductility, preventing sudden, catastrophic failure.

Disadvantages of Concrete (Based on Mechanical Properties)

Disadvantage	Mechanical Explanation	Engineering Impact
Susceptibility to Tensile Cracking	Extremely low tensile strength.	Any bending (flexure) generates tension at the bottom of a beam, causing concrete to crack immediately if not heavily reinforced with steel.
Sudden, Catastrophic Failure	Low fracture toughness and lack of ductility (brittleness).	Instead of bending or stretching to give warnings, pure concrete snaps or crushes violently when its ultimate strength limit is breached.
Creep Deflection	Time-dependent plastic deformation under sustained compressive loads.	Even under constant, unchanging structural weight, concrete will slowly and permanently deform (sag) over months and years.
Drying Shrinkage & Thermal Cracking	Volume change during hydration and moisture loss creates internal tensile stress.	As water evaporates, the material shrinks. Because the outer shell shrinks faster than the core, internal tensile stresses develop, causing the material to crack before external loads are even applied.

Uses and Applications

- Mass concrete blocks utilize superior compressive strength to anchor high-rise buildings and bridges safely into the earth.
- Vertical members utilize its compressive rigidity to support multi-story slabs.
- Heavy gravity structures rely on concrete's weight and compressive resistance to hold back immense water and soil pressure.
- When combined with steel, it is used in bridges, highways, and high-rise floors to withstand complex bending and shear stresses safely.

REINFORCED CONCRETE

Reinforced Concrete (RC) is a composite building material engineered by embedding a high-tensile material, universally structural steel rebar, inside fresh concrete before it sets. This combination creates a symbiotic material system where the two components work together to resist external loads.

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From the perspective of mechanical properties of materials, plain concrete is highly non-homogeneous and asymmetrical it features an excellent compressive strength but a critically deficient tensile strength. Reinforced concrete is designed to correct this fundamental flaw. By placing ductile steel reinforcement in zones subject to tension, the composite material transforms from a brittle, tension-weak material into a highly ductile, structurally reliable macro-composite.

Mechanical Properties of Reinforced Concrete

- Plain concrete fails instantly and explosively under critical tensile or compressive limits. Reinforced concrete introduces ductility, allowing the composite system to undergo significant plastic (permanent) deformation, visible cracking, and deflection before total structural collapse occurs.
- Under structural bending (flexure), a beam deflects downward, creating a compression zone at the top and a tension zone at the bottom. In RC, the concrete matrix absorbs the compressive stresses at the top, while the embedded steel rebar intercepts and carries 100% of the tensile stresses at the bottom once the concrete cracks.
- The mechanical performance relies heavily on the bond stress between the steel and hardened concrete. Ribbed profiles on modern rebar provide mechanical interlocking, ensuring no slippage occurs and that strain remains continuous across the concrete-steel interface (\(\epsilon_{concrete} = \epsilon_{steel}\)).
- Structural steel and concrete share nearly identical thermal expansion coefficients. This prevents internal thermal shear stresses and bond delamination when temperature fluctuations occur.

Importance of Reinforced Concrete (Mechanical Advantages)

- Elimination of Catastrophic Brittle Failure: The integration of ductile steel ensures that buildings give ample physical warning (sagging, visible cracks) long before a structural failure occurs, saving human lives during overloading or seismic activity.
- High Modulus of Rupture and Flexural Rigidity: RC dramatically increases a structure's flexural capacity compared to plain concrete, allowing engineers to design long-span beams and thin slabs without structural splitting.
- High Shear and Torsional Resistance: Diagonal tension caused by shear forces leads to brittle diagonal cracking. RC utilizes vertical and inclined steel loops called stirrups to mechanically clamp these cracks together, providing shear toughness.

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Direct Mechanical Comparison: Plain vs. Reinforced Concrete

Plain Concrete	Reinforced Concrete (RC)
Pure compression zones only.	Combined flexure, tension, shear, and compression.
Brittle (Sudden, explosive splitting).	Ductile (Yielding, warning cracks, progressive bending).
Extremely low (10% of compressive strength).	Very high (Governed by steel yield strength.
Negligible; low fracture toughness.	High; absorbs considerable kinetic energy before failure.

Disadvantages of Reinforced Concrete (Based on Mechanical Properties)

- Under sustained permanent dead loads, the concrete portion continues to experience creep (time-dependent plastic deformation). This gradually increases structural sag over years, requiring engineers to over-design the steel content to control long-term deflections.
- While concrete protects steel from rust via its alkaline environment, carbonation or chloride ingress breaks down this protection. When steel corrodes, it expands up to 600% of its original

volume. This internal volumetric expansion creates immense tensile stresses within the concrete shell, causing it to crack, split, and break away (spalling), entirely destroying the composite bond.

- ♠ By mechanical design, the steel cannot take significant tensile loads until the surrounding concrete cracks first. Therefore, RC structures inherently possess micro-cracks under normal service loads. If these cracks grow too wide, they expose the internal steel to ambient moisture and chemicals.
- ♠ RC has a high density (~2400-2500 kg/m³). A substantial portion of its mechanical compressive capacity is expended simply supporting its own immense weight rather than carrying external live loads.

Uses and Applications

- ♠ Columns, beams, and shear walls in modern skyscrapers rely on RC to handle extreme wind, gravity, and lateral earthquake loads.
- ♠ Bridge decks and multi-story floors use RC to span long horizontal distances while resisting heavy dynamic traffic and moving loads.
- ♠ RC raft and pile foundations anchor massive structures, safely resisting uplift and lateral bending stresses during earthquakes.
- ♠ Tunnels, retaining walls, and deep bunkers utilize RC to counter intense bending pressures from surrounding soil and groundwater forces.
- ♠ Reinforced concrete is a composite building material made by combining concrete and steel reinforcement bars (rebar's) to work together under loads.

Properties (Mechanical)

- ♠ High Compressive Strength resists heavy squeezing forces very well.
- ♠ Steel bars inside resist pulling and stretching forces that would normally crack plain concrete.
- ♠ The steel addition allows the material to bend slightly and warn before breaking under extreme loads.
- ♠ It withstands weather, fire, and long-term wear when built correctly.

Uses and Applications

- ♠ Used for strong foundations, columns, beams, and floor slabs in high-rise structures.
- ♠ Used to build highway bridges, retaining walls, and tunnels.
- ♠ Used for large water tanks, dams, and underground drainage pipes.

Importance

- ♠ It can be molded into almost any shape or size while wet.
- ♠ It pairs the cheap compressive strength of concrete with the high tensile strength of steel.
- ♠ It resists fire and wind loads better than wood or plain steel alone.

Disadvantages (Mechanical)

- ♠ It is very heavy, which increases the load on foundations and requires heavy machinery to lift.
- ♠ Concrete naturally shrinks slightly as it dries, which can cause minor surface cracks.
- ♠ It requires temporary wooden or metal molds (formwork) to hold the wet mixture until it hardens.

BEAMS

A beam is a long, horizontal structural element designed to carry loads that push down on it from above. A beam connects supports like columns or walls. When a weight sits on a beam, the beam bends slightly. It moves the weight sideways and down into the supports. This stops the building from breaking or sinking in the middle.

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Mechanical Properties

Beams depend on specific mechanical properties to handle heavy loads safely:



- ♠ The ability to resist breaking when forced to bend.
- ♠ The ability to resist pulling apart. When a beam bends, the bottom part stretches under tension.
- ♠ The ability to resist crushing. When a beam bends, the top part squeezes together under compression.
- ♠ The ability to resist sagging or deflection (bending out of shape) under everyday loads.
- ♠ The ability to resist internal sliding forces that try to cut or shear the beam in half vertically.
- ♠ The ability to bend without suddenly snapping. Ductile beams give a visual warning by sagging before they fail completely.

Uses and Applications

- ♠ Supporting floorboards and ceiling panels in houses and offices.
- ♠ Holding up roof tiles, rafters, and flat roof decks.
- ♠ Placing small beams (headers) over doors and windows to hold the wall brickwork above the opening.
- ♠ Carrying cars and trains across wide gaps like rivers or valleys.

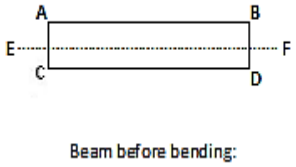
Importance

- ♠ Moving heavy overhead loads safely down to the ground.
- ♠ Allowing builders to create wide, open rooms without needing walls everywhere for support.
- ♠ Keeping structures stable against everyday weight, wind, and even earthquakes.

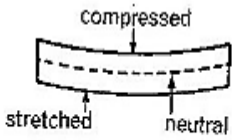
Disadvantages

- ♠ Bending too much over time if the load is too heavy or the material is too weak.
- ♠ Needing extra mid-supports if the space is too wide for a single beam length.
- ♠ Hanging down from the ceiling and taking up vertical space in a room.
- ♠ Brittle materials (like concrete or cast iron) can snap without warning if overloaded.

When a force is applied on a beam it bends on one side of the beam in compressed (under compression), the other side is stretched (under tension) and its centre is un-stretched (neutral).



Beam before bending:



Beam after bending

AB – Under compression

DC – Under tension

EF – un-stretched i.e. it neither under tension nor under compression.

The neutral axis of beam does not resist any forces and can therefore be removed without weakening the stretch of the beam.

GIRDERS

A girder is a large, deep horizontal beam designed to support heavy concentrated loads or smaller beams (joists). It acts as the primary horizontal backbone of a structure.

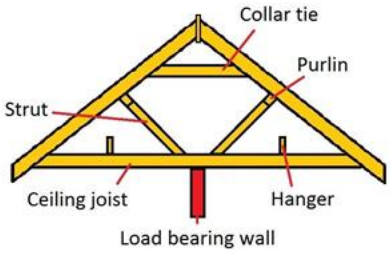
A structure consists of pieces of materials joined together in a particular way. The pieces of materials used to strengthen structures are called ***girders.*** Both the upper and lower parts of the buildings are under compression. The bridge is weak under tension

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Primary Function: Resists bending forces and shear stresses from vertical loads.

Uses & Applications:

- Supporting bridges to span long distances between piers.
- Acting as the main load-bearing beam in high-rise buildings.
- Supporting floors and roofs in large warehouses.



Examples:

- Steel I-beams used in highway overpasses.
- Box girders used in modern concrete segmental bridges.
- Plate girders (welded steel plates) used in heavy industrial structures.

Ties

A tie is a structural member designed to resist longitudinal tension (pulling forces). It keeps other components from spreading or pulling apart.

Primary Function: Resists tensile forces (stretching).

Uses & Applications:

- Holding the bottom ends of roof rafters together so the walls don't push outward.
- Suspending bridge decks in suspension or arch bridges.
- Bracing trusses against wind and lateral loads.

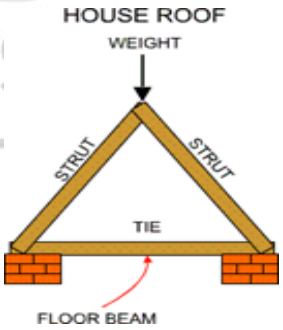
Examples:

- The bottom chord of a triangular roof truss.
- Steel cables or hangers on a suspension bridge.
- Tie rods used to reinforce masonry walls in old buildings.

Struts

A strut is a structural component designed to resist longitudinal compression (pushing forces). It keeps other components from collapsing inward.

Primary Function: Resists compressive forces (squeezing/buckling).



Uses & Applications:

- Providing diagonal bracing in scaffolding and crane booms.
- Supporting wings on aircraft or chassis components in vehicles.
- Transferring loads down to foundations in roof and bridge trusses.

Examples:

- The diagonal web members inside a bridge truss.
- Concrete columns or raked props used to support temporary formwork.
- The strut assembly in a car's suspension system (MacPherson strut).

Direct Comparison

Component	Primary Force	Orientation	Common Material
Girder	Bending & Shear	Horizontal	Steel, Reinforced Concrete, Timber
Tie	Tension (Pulling)	Any (often Horizontal/Diagonal)	Steel cables, Rods, Timber
Strut	Compression (Pushing)	Any (often Vertical/Diagonal)	Steel pipes, Heavy Timber, Concrete

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NOTCH AND NOTCH EFFECTS

What is a notch?

A notch is a small cut, groove, indentation, hole, or sharp change in the shape of a material that causes the cross-sectional area to change suddenly. Notches may occur intentionally during design or accidentally because of scratches, cracks, corrosion, machining marks, or other damage.

Examples include a V-shaped groove cut into a metal rod, a hole drilled through a machine component, a sharp corner in a beam, and a scratch or crack on a structural component.

What is the notch effect?

The notch effect is the concentration of stress around a notch or other sudden change in the shape of a material when the material is subjected to a load. In a uniform component, stress is distributed relatively evenly. A notch causes the stress lines to become crowded around the notch.

Therefore, a notch causes the local stress near it to become much greater than the average stress in the rest of the material. This phenomenon is called stress concentration.

Why are notches dangerous?

A notch reduces the effective cross-sectional area and creates a region where stress becomes concentrated. If the local stress exceeds the strength of the material, a crack can start and grow from the notch.

Effects of notches

- Stress becomes concentrated around the notch.
- A crack can begin at the tip of a sharp notch.
- The component may carry a smaller load than an identical component without a notch.
- In some materials, particularly under impact or severe loading, failure can occur suddenly.
- Repeated loading can cause cracks to develop and grow from a notch.
- Components containing severe notches may fail earlier than expected.

Sharp versus rounded notches

The sharper the notch, the greater the stress concentration. A sharp V-shaped notch is generally more dangerous than a smooth, rounded groove of similar depth because the sharp tip concentrates stress in a very small region.

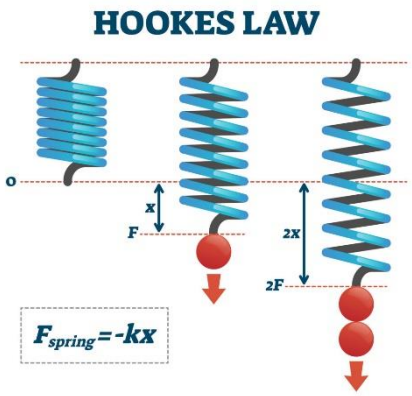
Ways of reducing notch effects

- Replace sharp corners with smooth curves or fillets. The rounded shape allows the stress to spread over a larger region.
- Where a groove or change in cross-section is necessary, use a larger radius rather than a very small radius. A larger radius reduces stress concentration.
- Use a gradual transition from a thick section to a thin section instead of changing the cross-section suddenly. This distributes the load more smoothly.
- Scratches, dents, corrosion pits and machining marks can act as tiny notches. Proper machining, polishing and surface finishing can reduce stress concentration.
- Reinforcing plates, collars, washers or fillets may be used around regions where high stress concentration is expected.
- Holes and grooves should only be introduced where necessary. If a hole is required, its shape and position should be carefully designed to minimise stress concentration.
- Materials with suitable strength, toughness and fatigue resistance can reduce the likelihood of failure caused by notches.

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HOOKE'S LAW OF ELASTICITY



Hooke's Law of elasticity states that the extension or compression of a spring (or any elastic material) is directly proportional to the force applied, as long as the material remains within its elastic limit.

Hooke's law states that ***the strain of the material is proportional to the applied stress within the elastic limit of that material****.*

Elasticity is the ability of a material to regain its original shape and size when the deforming force is removed, provided the material has not been stretched or deformed beyond its elastic limit.

For example, when a spring is pulled and then released, it returns to its original length if it has not been overstretched.

Hooke's Law states, "**Within the elastic limit, the extension of an elastic material is directly proportional to the applied force".**

$F \propto e, F = ke$, Where, F = applied force in newtons (N), e = extension in metres (m), k = spring constant in N/m.

Spring Constant: The spring constant k measures the stiffness of a spring. $k = F/e$

A large k means the spring is stiff and requires a large force to produce a given extension.

A small k means the spring is less stiff and stretches more easily.

It helps in designing structures and mechanical systems that can withstand forces without permanent deformation.

Meaning of 'Within the Elastic Limit': Hooke's Law does not apply indefinitely. When a force is gradually increased, a material passes through a proportional region, elastic limit, and plastic deformation region and eventually may reach breaking point.

Within the proportional region, doubling the force doubles the extension. Once the material passes its elastic limit, it may not return to its original length when the force is removed.

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Important Terms

- **Original length:** The length of the spring or wire before a force is applied (L_0).
- **Final length:** The length after the force has been applied (L).
- **Extension:** The increase in length: $e = L - L_0$.
- **Elastic limit:** The greatest deformation a material can undergo and still completely regain its original dimensions when the force is removed.
- **Proportional limit:** The point up to which force and extension remain directly proportional.
- **Elastic deformation:** Temporary deformation that disappears when the force is removed.
- **Plastic deformation:** Permanent deformation that remains after the force is removed.

Elastic Potential Energy

When a spring is stretched or compressed, work is done on it. This work is stored as elastic potential energy. $E = \frac{1}{2}ke^2$, $E = \frac{1}{2}Fe$, E = elastic potential energy in joules (J), k = spring constant in N/m, e = extension in metres (m), F = force in newtons (N).

Examples

1: A spring has a spring constant of 200 N/m. A force of 10 N is applied. Find its extension.

$F = ke, e = \frac{F}{k}, e = \frac{10}{200} = 0.05\,m. Therefore, e = 5\,cm.$

2:A force of 15 N produces an extension of 3 cm in a spring. Find the spring constant.

$3\,cm = 0.03\,m, k = F/e, k = 15/0.03 = 500\,N/m. Therefore, k = 500\,N/m.$

3: A spring has a spring constant of 400 N/m. Calculate the force required to produce an extension of 2.5 cm. $2.5\,cm = 0.025\,m, F = ke, F = 400 \times 0.025 = 10\,N. Therefore, F = 10\,N.$

4: A spring is initially 20 cm long. A force of 12 N produces an extension of 6 cm. Find the final length.

$L = L_o + e, L = 20 + 6 = 26\,cm, Therefore, final\ length = 26\,cm.$

5: A 2 kg mass is suspended from a spring of spring constant 500 N/m. Take g = 10 N/kg. Find the extension.

$F = mg = 2 \times 10 = 20\,N, e = \frac{F}{k} = \frac{20}{500} = 0.04\,m. Therefore, e = 4\,cm.$

6: A spring of spring constant 200 N/m is stretched by 0.10 m. Calculate the elastic potential energy stored.

$E = ½ke^2, E = ½ \times 200 \times (0.10)^2, E = 100 \times 0.01 = 1\,J. Therefore, E = 1\,J.$

Springs in Combination

For springs in parallel: $k = k_1 + k_2$. Parallel springs are effectively stiffer.

For springs in series: $\frac{1}{k} = \frac{1}{k^1} + \frac{1}{k^2}$. Series springs are effectively less stiff.

For two identical springs, each with spring constant k: Parallel: $k_{eff} = 2k$, and Series: $k_{eff} = \frac{k}{2}$

Hooke's Law Applications

Hooke's Law states that **the strain in a solid is directly proportional to the applied stress, provided the material remains within its elastic limit.**

Applications and Uses of Hooke's Law

- **Spring balances:** Measure force or weight from the extension of a calibrated spring.
- **Vehicle suspension systems:** Springs absorb shocks caused by bumps and uneven roads, improving comfort and helping tyres maintain contact with the road.
- **Weighing machines:** Some mechanical weighing devices use calibrated springs whose extension is related to the applied load.
- **Shock absorbers:** Springs work with damping systems to reduce the effects of sudden impacts.
- **Dynamometers**: Measure force using the extension of a calibrated spring.
- **Door mechanisms:** Springs provide restoring force that returns doors or mechanisms to their original position.
- **Mechanical toys:** Spring mechanisms store and release elastic energy.
- **Engineering structures**: Engineers consider elastic deformation when designing bridges, buildings, cranes, machines and lifting equipment.

Limitations and Disadvantages Hooke's Law

- The principle does not apply to all materials or conditions, making it an incomplete rule for general physics.
- The rule breaks down completely once the Elastic Limit is crossed and permanent plastic deformation occurs.
- It only works for solid bodies experiencing very small changes in shape or low amounts of stress.
- The formula does not account for how heat or cold alters material stiffness and elasticity.

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- ♠ It assumes materials are uniform and isotropic (the same in all directions), which is rare in real-world structures.
- ♠ It fails to measure delayed material responses like creep or stress relaxation over time.

Example

1. An elastic wire of length 10cm has force applied on it of 3N. Find its extension and elastic constant k. Extension $e = l - l_0 = 12 - 10 = 2cm = 0.02m$, Using $F = ke$, $3 = k \times 0.02$ $K = 150Nm^{-1}$
2. A spring extends by 0.5 cm when a load of 0.4N hangs on it. Find the load required to cause an extension of 1.5cm, and what additional load causes the extension of 1.5cm?

Method 1: Using $F = ke, 0.4 = k\,x0.5, k = 0.8N/cm, F_2 = ke_2$ $F = 0.8\,x\,1.5 = 1.2N$.
Method 2: F_2 = 1.2N**.** Extra load required = (1.2 – 0.4) = 0.8N

Activity

A mechanic was testing a new coil spring to be used in a small machine. The spring was found to have an unstretched (natural) length of 12 cm when no force is applied to it. The mechanic hanged a weight that exerted a downward force of 8 N on the spring, he measured its new length and found it had stretched to only 6 cm.

Task: Using the knowledge of physics;

(i) Calculate the extension produced in the spring under this 8 N force.
(ii) Determine the spring constant (k) of this spring (N/m — show units clearly).
(iii) Using the same spring, predict the extension that would be produced if a larger force of 12 N is applied instead.

Experiment to verify Hooke's law

Aim / Objective

To investigate the relationship between the extension of a spring and the force applied to it, and to determine the spring constant (k).

Variables

Independent variable: The force applied to the spring (F, in newtons, N). This is varied by adding known masses.

Dependent variable: The extension of the spring (e or x, in metres or millimetres). This is measured as the change in length.

Control variables (kept constant):

- ♠ The same spring is used throughout (same material, length, and spring constant).
- ♠ The same ruler / metre rule for all measurements.
- ♠ Room temperature (to avoid thermal expansion effects on the spring).
- ♠ The spring hangs vertically under gravity with no additional sideways forces.

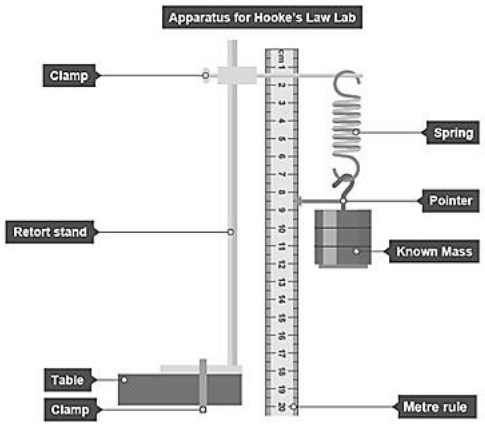
Apparatus

Clamp stand (retort stand) with boss and clamp
Helical coil spring
Metre rule or ruler (attached vertically, parallel to the spring)
Mass hanger (to hold slotted masses)
Slotted masses (e.g., 100 g each, providing approximately 0.98 N per 100 g)
Pointer or fiduciary marker (a thin pointer or pin attached to the bottom of the spring for precise reading)
Electronic balance (for accurate mass measurement)

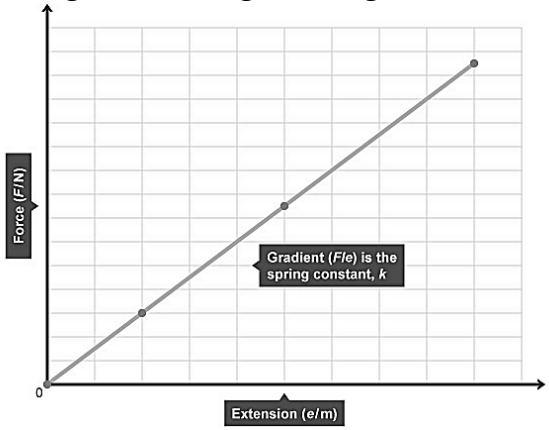
Method

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1. Set up the apparatus as shown in the diagram: Clamp the metre rule vertically to the stand. Hang the spring from the clamp so it hangs freely next to the ruler.
2. Attach a pointer (or fiduciary marker with a fine point) to the bottom of the spring to make the position easier to read accurately against the ruler.
3. With no masses attached (force = 0 N), measure and record the original/unloaded length of the spring (L_0) using the ruler. Ensure your eye is level with the pointer to avoid parallax error.
4. Place the mass hanger on the spring (record its mass if not zero) and allow the spring to come to rest (no oscillations).
5. Measure the new loaded length (L) of the spring using the pointer position.
6. Calculate the extension: extension = L - L_0.
7. Calculate the force applied: Use an electronic balance to measure the total mass (hanger + added slotted masses) in kg, then F = m × g where g = 9.8 m/s² (or 10 m/s² for approximation if specified).
8. Add more masses incrementally (e.g., 100 g steps, up to about 600 g or 6 N, ensuring the spring does not exceed its elastic limit).
9. For each added force, wait for the spring to stop moving, then repeat steps 5–6 to record the new extension.
10. Repeat measurements for reliability (e.g., unload and reload at least once per mass to check consistency).
11. Plot a scatter graph of force (F) on the y-axis against extension (e) on the x-axis.
12. Draw a line of best fit through the points (it should be a straight line through the origin if within the elastic limit).
13. The gradient (slope) of the line of best fit gives the spring constant k (in N/m), since $F = k\,e$ (Hooke's Law), so $k = \frac{\Delta F}{\Delta e}$



Safety Precautions

Ensure the clamp stand is stable and on a flat surface to prevent tipping.

Do not overload the spring beyond its elastic limit (avoid permanent deformation).

Handle masses carefully to avoid dropping them.

Improving Accuracy

- Measure the mass of each weight (or combination) using an electronic balance on a level surface each time, then calculate force using W = mg with g = 9.8 m/s².
- Use a fiduciary marker (pointer with a fine sharp edge) attached to the bottom of the spring to reduce parallax error — always read the ruler at eye level.
- Ensure the spring is stationary (not oscillating) when taking length measurements.
- Take repeat readings and calculate averages to reduce random errors.
- Use smaller mass increments if needed for more data points in the linear region.

Improving Precision

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- ♠ Attach a fiduciary marker with a fine point to the bottom of the spring. This provides a precise reference line against the ruler scale, reducing random errors from parallax or difficulty in judging the exact position of the coils.
- ♠ Use a ruler or metre rule with 1 mm resolution, and estimate to the nearest 0.5 mm if possible.
- ♠ Perform measurements in a draft-free area to avoid unwanted movement of the spring.

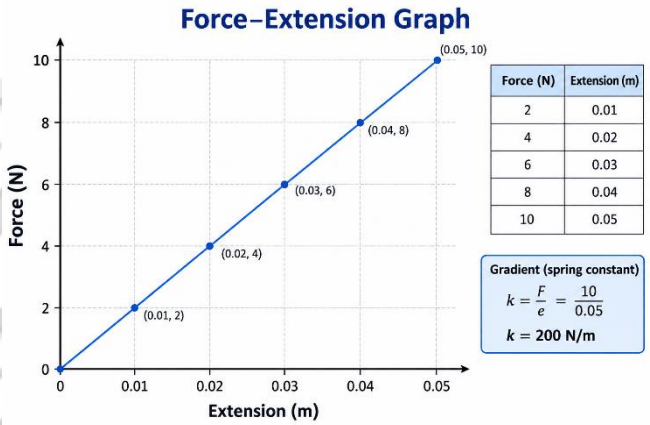
Conclusion and recommendation

- ♠ The experiment demonstrates Hooke's Law: F = k e (force is directly proportional to extension within the elastic limit).
- ♠ The graph is linear, and k is the constant of proportionality (spring constant), confirming that the extension is proportional to the force applied, as long as the elastic limit is not exceeded.
- ♠ This simple experiment demonstrates the fundamental principles of elasticity and the validity of Hooke's Law.

Force-Extension

A student obtains the following results:

Force (N)	Extension (m)
2	0.01
4	0.02
6	0.03
8	0.04
10	0.05



Using F = 10 N and e = 0.05 m:

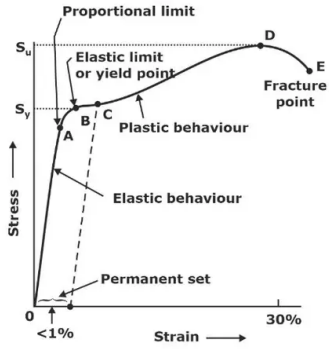
k = F/e = 10/0.05 = 200 N/m

The constant ratio shows that the spring obeys Hooke's Law over this range.

Plastic deformation: Deformation often referred to strain, is the change in the size and shape of an object due to the change in temperature or an applied force. Depending on the size, material and the force applied, various forms of deformation may occur.

Based on these factors, deformation is classified into the following:

Elastic deformation: This is the deformation, which occurs before the elastic limit. The wire regains its shape and size after deformation. Energy is stored as potential energy.



Elastic deformation refers to a temporary deformation of a material's shape that is self-reversing after removing the force or load. Elastic deformation alters the shape of a material upon the application of a force within its elastic limit.

This physical property ensures that elastic materials will regain their original dimensions following the release of the applied load. Here deformation is **reversible and non-permanent**.

Elastic deformation of metals and ceramics is commonly seen at low strains; their elastic behavior is generally linear. The mechanisms that cause plastic deformation differ widely. Plasticity in metals is a consequence of dislocations while in brittle materials such as concrete, rock and bone, plasticity occurs due to the slippage of micro cracks.

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STRESS, STRAIN AND YOUNG'S MODULUS

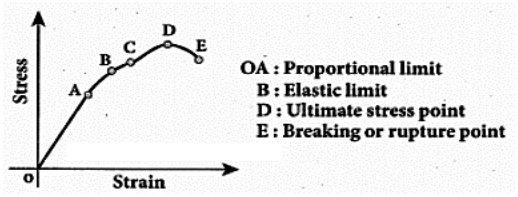
Stress is defined as **the force applied per unit area of a material, leading to internal forces between atoms.**

When a material is subjected to stress, it undergoes strain, which is the measure of deformation resulting from that stress. Strain can be tensile (stretching) or compressive (squeezing), depending on the nature of the applied force.

Young's modulus also the **modulus of elasticity**, quantifies a material's stiffness and is **the ratio of stress to strain in the elastic region of the material's deformation**.

Stress-strain profile curve: The stress versus strain profile is a plot in which stress and strain are noted for each load and a graph is drawn taking strain along the X-axis and stress along the Y-axis.

The elastic characteristics of the materials can be analyzed from the stress-strain profile.



(a) **Portion OA:** In this region, stress is very small such that stress is proportional to strain, which means Hooke's law is valid. The point A is called limit of proportionality because above this point Hooke's law is not valid. The slope of the line OA gives the Young's modulus of the wire. (

b) **Portion AB**: This region is reached if the stress is increased by a very small amount. In this region, stress is not proportional to the strain. But once the stretching force is removed, the wire will regain its original length. This behaviour ends at point B and hence, the point B is known as yield point (elastic limit). The elastic behaviour of the material (here wire) in stress-strain curve is OAB.

(c) **Portion BC**: If the wire is stretched beyond the point B (elastic limit), stress increases and the wire will not regain its original length after the removal of stretching force.

(d) **Portion CD**: With further increase in stress (beyond the point C), the strain increases rapidly and reaches the point D. Beyond D, the strain increases even when the load is removed and breaks (ruptures) at the point E. Therefore, the maximum stress (D) beyond which the wire breaks is called breaking stress or tensile strength. The corresponding point D is known as fracture point. The region BCDE represents the plastic behaviour of the material of the wire.

Consider a force F acting on a material e.g. a wire of length l and cross section area A so that it extends by length e.

Stress for the wire is defined as the ratio of applied force on a material to its cross section area.

$\textbf{stress} = \frac{\textbf{Force}}{\textbf{area}}$**. SI unit: N/m^2**

Strain is a ratio of extension of a material to its original length. $\text{strain} = \frac{\text{extension}}{\text{original length}}$

Strain has no units.

Young's modulus is defined as the ratio of stress to strain. $E = \frac{\text{stress}}{\text{strain}}$. SI unit = N/m^2

Young's modulus is determined when the elastic limit is not exceeded and its value is constant

Example

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A sample of steel alloy wire has a cross-sectional area of **10 cm²** and an original length of **3 m**. When a tensile force of **20 N** is applied (representing a scaled load from bridge components), the length increases to **5 m**. At the same time, a thinner copper wire sample, is intended for secondary support or tensioning, picked for testing has an original length of **10 cm** and a cross-sectional area of **5 cm²**. A tensile force of **2 N** is applied, producing an extension of **0.2 cm**.
Task: use the knowledge of physics;
For this copper wire, determine:
a) The **tensile stress**
b) The **tensile strain**
c) The **Young's modulus** of the copper wire
For the steel alloy sample, determine the Young's modulus in the wire. Explain which of the wires is capable of supporting big loads for a long period of time.

Tensile Stress, Strain and Young's Modulus Analysis

1. Copper Wire

a) Tensile Stress

Tensile stress(σ) $= \frac{Force}{Area}$, Force = 2 N, Area = 5 cm² = 5×10^{-4} m²

$\sigma = 2 / (5 \times 10^{-4})$, σ = 4000 Pa = 4×10^3 Pa

b) Tensile Strain

Tensile strain=$\frac{Extension}{original\ length}$,

Original length = 10 cm = 0.1 m, Extension = 0.2 cm = 0.002 m

ε = 0.002 / 0.1 ε = 0.02 (dimensionless)

c) Young's Modulus

Young's modulus (Y) = $\frac{Stress}{strain} = \frac{4000}{0.02} = 200{,}000Pa = 2 \times 10^5$ Pa

2. Steel Alloy Wire

a) Tensile Stress

Area = 10 cm² = 10×10^{-4} m² = 0.001 m²

Force = 20 N; $\sigma = \frac{20}{0.002} = 20{,}000Pa$

b) Tensile Strain

Original length = 3 m

Final length = 5 m, Extension = 5 − 3 = 2 m; $\varepsilon = \frac{2}{3} = 0.667$

c) Young's Modulus

$$Y = \frac{20000}{0.667} = 30{,}000Pa = 3 \times 10^4\ Pa$$

3. Interpretation and Conclusion

Based on the calculated values:
Copper: 2×10^5 Pa
Steel alloy: 3×10^4 Pa
From these results, copper appears to have a higher Young's modulus in this numerical example. However, in real physical situations, steel has a much higher Young's modulus than copper. Therefore, in practical engineering applications, steel alloy would support larger loads for longer periods within elastic limits.

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You are a materials engineer at a civil engineering firm in Kampala, Uganda, working on reinforcement and safety upgrades for pedestrian footbridges and suspended walkways in rural and peri-urban areas (similar to projects like the Nyakabugha-Bikone bridge or trail suspension bridges in western Uganda). These structures often use steel wires or cables to support hanging loads from platforms, walkways, or even maintenance loads.

To verify the material properties and ensure the wires can safely handle real-world loads without permanent deformation, you are performing tensile tests in the lab on sample wire sections.

A test wire (high-strength steel alloy, suitable for load-bearing cables) has:

- Original length = **15 cm** (0.15 m)
- Cross-sectional area = **0.2 cm²** (0.00002 m²)
- A heavy mass of **200 kg** is suspended from the end, simulating a significant load (equivalent to multiple people or structural components on a small bridge section).
- The wire extends by **1.5 cm** (0.015 m) under this load.

Calculate for this wire determine the **tensile stress** and the **tensile strain**

Later, lighter second test using the **same wire dimensions** of length 15 cm and cross-sectional area 0.2 cm² but with a much smaller mass of **200 g** was hung from the end. This represented a scaled-down or auxiliary load test. The wire extends by the **same 1.5 cm** under this smaller force.

For this second test, calculate:

a) the **tensile stress**

b) the **tensile strain**

c) the **Young's modulus** of the material

Compare the two stress values and explain why using a very heavy mass (200 kg) in a real bridge cable test would be impractical or risky in the lab, and why engineers often start with smaller loads for initial Young's modulus determination.

(Hint: Young's modulus for steel wires is around 190–210GPa, gravitational acceleration, g = 10m/s²)

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Response

Original Length (L) = 15 cm = 0.15 m

Cross-sectional Area (A) = 0.2 cm² = 0.00002 m²

Extension (ΔL) = 1.5 cm = 0.015 m

Acceleration due to gravity (g) = 9.81 m/s²

First Test (Heavy Load = 200 kg)

Mass = 200 kg

Force (F = mg) = 200 × 9.81 = 1962 N

$Tensile\ Stress\ \left(\sigma = \frac{F}{A}\right);\ \sigma\ = \frac{1962}{0.00002} = 98{,}100{,}000Pa$ = 98.1 MPa

Tensile Strain ($\frac{\varepsilon = \Delta L}{L} = \frac{0.015}{0.15} = 0.10$)

Second Test (Small Load = 200 g)

Mass = 200 g = 0.2 kg

Force (F = mg) = 0.2 × 9.81 = 1.962 N

a) Tensile Stress (σ = F/A); σ = 1.962 / 0.00002; σ = 98,100 Pa = 98.1 kPa

b) Tensile Strain (ε = ΔL/L), ε = 0.015 / 0.15 = 0.1

c) Young's Modulus (Y = σ/ε); Y = 98,100 / 0.1, Y = 981,000 Pa = 0.98 MPa

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Engineering Interpretation

Expected Young's Modulus for structural steel ≈ 190–210 GPa (≈ 2×10^{11} Pa). The calculated modulus (0.98 MPa) is far below the expected value. This indicates that the extension value (1.5 cm) is unrealistic for steel under these loads. A strain of 0.1 (10%) is extremely large and would normally indicate plastic deformation.

The heavy 200 kg load produces stress of 98.1 MPa, while the small 200 g load produces 98.1 kPa — a difference of 1000 times.

In laboratory practice, engineers begin with smaller loads to remain within the elastic region of the material, prevent permanent deformation, ensure safety, and obtain accurate Young's modulus values from the linear portion of the stress-strain curve.

Examination

In a construction project for a new pedestrian bridge, engineers are evaluating materials for the suspension cables and support beams. The cables exhibited elastic behavior under varying loads from pedestrians, while the beams were made of reinforced concrete for durability. During testing, a steel rod was used to model the cable, and a springboard setup simulates dynamic loading. A boy of mass 50 kg stands at the end of the springboard, depressing it by 15 cm. Later, an adult man of mass 80 kg stands at the same position. A steel rod of cross-sectional area 32 mm^2 and length 4 m extends by 1 mm under a force of 1.6×10^5 N. The engineers used tea cups made of clay while other preferred using plastic ones, also considered ductile materials for certain components and compared them to brittle ones like clay used in everyday items. To verify material properties, lab experiments are conducted using springs and wires.

Hint: Assume gravitational acceleration, g = 10m/s²

Using the knowledge of physics to,

a) State the factors on which the strength of a material depends.

b) Describe an experiment to verify Hooke's law, and explain the precautions taken to ensure accurate results.

c) Sketch a labeled graph of extension against weight, and describe the features of the graph, including the elastic limit and any non-linear behavior.

d) For the springboard, determine the depression when the man of 80 kg stands at the end.

e) Determine the Young modulus for the steel rod modeling the cable:

f) i) Explain the effect of a shear force on a body.

(ii) Explain why tea cups are usually made of clay materials and not metals.

(iii) State any three characteristics of concrete that make it a desirable building material for the bridge beams.

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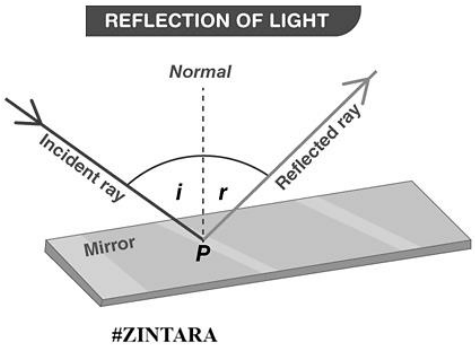
S2.5 REFLECTION OF LIGHT AT CURVED SURFACES

Learning Outcomes

a) Understand reflection of light and the formation of images by curved mirrors(u)
b) Use ray diagrams to show how images are formed by curved mirrors and the nature of the images(s)
c) Determine the focal length of concave mirrors using a variety of methods. (s,gs)

Reflection of Light by Curved Surfaces

- ♠ **Reflection of light is the bouncing back of lights rays into the same medium where it was originally coming from after striking a reflecting surface.**
- ♠ A mirror is a surface that reflects almost all incidents light.
- ♠ Mirrors come in two types: those with a **flat surface**, known as **plane mirrors**, and those with a **curved surface, called spherical mirrors**.
- ♠ The reflection of light by curved surfaces primarily involving **concave and convex mirrors**.
- ♠ Concave mirrors, which **curve inward**, focus parallel rays of light to a single point known as the focal point. This property makes them useful in applications like **telescopes and shaving mirrors**, where magnified images are desired.
- ♠ Convex mirrors **bulge outward** and cause light rays to **diverge**. This results in a **wider field of view**, making them ideal for use in **vehicle side mirrors and security applications**. The images formed by convex mirrors are **smaller and appear farther away** than they actually are.
- ♠ Both types of mirrors adhere to the law of reflection, where the angle of incidence equals the angle of reflection.



Mirrors

A mirror is a smooth surface that reflects light and forms images of objects placed in front of it.

→ Incident rays travel from the object towards the mirror.
→ Reflected rays bounce off the mirror and form or appear to form an image.

Images formed by mirrors are of two types:

→ **Real image:** formed when reflected light rays actually meet (intersect).
→ **Virtual image:** formed when reflected rays only appear to come from a point (apparent intersection of rays).

Ray diagrams use lines and arrows to show the paths of incident and reflected rays and help explain image formation.

Plane Mirror against Spherical Mirror

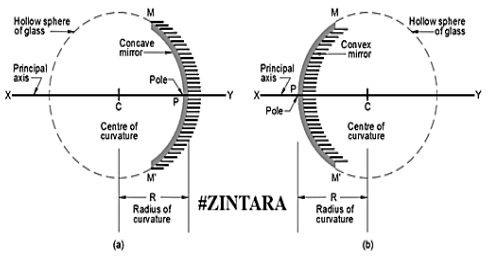
A plane mirror is a flat, smooth reflective surface with a clear, undistorted reflection. When an object is reflected in a plane mirror, it always forms a virtual image that is upright, of the same shape and size as the object.

A spherical mirror exhibits a consistent curvature. It possesses a constant radius of curvature.

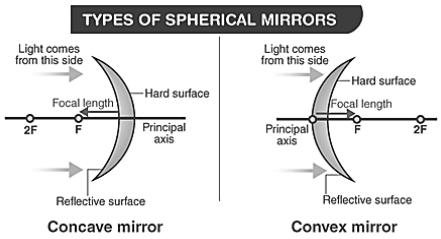
Spherical mirrors can create both **real and virtual images**, depending on the position of the object and the mirror. Spherical mirrors are further categorized into **concave** and **convex mirrors**, each with distinct properties and image formation characteristics.

Core terms and definitions used in spherical mirrors

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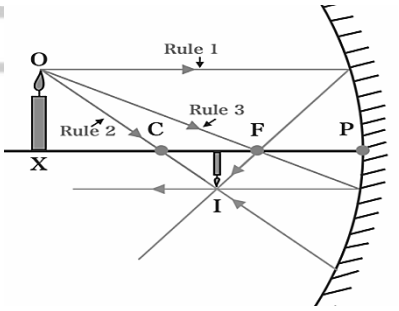
1) **Pole (P):** The geometric center of the reflecting surface of a spherical mirror, lying directly on the mirror.
2) **Center of Curvature (C):** The center of the imaginary hollow glass sphere of which the spherical mirror is a piece. It lies in front of a concave mirror and behind a convex mirror.
3) **Radius of Curvature (R):** The radius of the imaginary sphere that the mirror is a part of, or the straight-line distance from the pole to the center of curvature (R = 2f=PC).
4) **Principal Axis:** An imaginary straight line passing through both the pole and the center of curvature, extending on either side. It is normal (perpendicular) to the mirror at the pole.
5) **Principal Focus (F):** The point on the principal axis where light rays parallel to the axis actually converge (for a concave mirror) or appear to diverge from (for a convex mirror) after reflection.
6) **Focal Length (f):** The distance measured along the principal axis between the pole and the principal focus (f = r/2). **Aperture:** The effective diameter or width of the reflecting surface of the spherical mirror, which dictates how much light it can gather.
7) **Focal Plane:** A plane that passes through the principal focus and is perpendicular (at a right angle) to the principal axis.



Characteristics of Concave and Convex Mirrors

Concave Mirror

A concave mirror is a curved mirror that bends inward in the middle like a cave, and it reflects light to a single central point called the focus.



How It Works

→ Light rays bounce off the shiny inner surface of the mirror.
→ Parallel rays of light hit the mirror and bounce back to cross at one spot.
→ This spot is the focus or focal point.
→ Because it pulls light together, a concave mirror is also called a converging mirror.

Characteristics of Images

The image you see in a concave mirror depends on how close the object is to the mirror:

→ **Far away:** The image is real, upside down (inverted), and smaller than the object.
→ **Close up (inside the focal point):** The image is virtual (appears behind the mirror), right side up (erect), and magnified (larger than the object).
→ **At the focus:** The image becomes extremely large and forms far away.

Applications and Uses of concave mirrors

→ **Shaving and makeup mirrors:** They make your face look bigger and clearer when you stand close.
→ **Car Headlights:** Car lights place a bulb at the focus to throw a strong, straight beam of light down the road.

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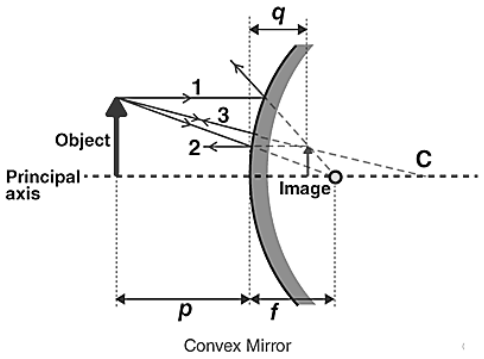
→ **Telescopes:** Large reflecting telescopes use concave mirrors to gather faint light from distant stars and focus it to see deep space.
→ **Solar cookers:** They collect sunlight into one small spot to heat up and cook food.
→ **Dentist mirrors**: Dentists use small concave mirrors to see a magnified, clear view of your teeth.

Convex Mirror

A convex mirror is a curved mirror where the reflective surface bulges outward toward the light source. Convex mirrors always form virtual, erect, and diminished images, regardless of the object's position. Commonly used in applications requiring a wide field of view, such as rear-view mirrors and security mirrors.

How It Works

→ It bends parallel light rays outward (diverges them) when they hit the surface.
→ The reflected rays spread apart, but if you trace them backward behind the mirror, they meet at a point called the principal focus.
→ Because the rays only appear to come from behind the mirror, it forms a virtual image that you cannot project onto a screen.



Convex Mirror

Characteristics of Images

→ **Always upright (erect):** The image is never upside down.
→ **Diminished (smaller):** The image appears smaller than the actual object, which helps fit a large area into a small view.
→ **Widened field of view:** It covers a much wider area than a flat mirror of the same size.
→ **Closer appearance:** Objects appear closer than they actually are.

Applications and Uses of convex mirrors

→ **Vehicles:** Used as passenger-side car mirrors and motorcycle rearview mirrors to see blind spots and nearby traffic.
→ **Road safety:** Placed at dangerous blind corners, Sharp Mountain turns, and underground parking exits to help drivers see oncoming cars.
→ **Security:** Mounted in hallways of shops, hospitals, and office buildings so staff can monitor large areas and prevent theft.
→ **Automated teller machines (ATMs):** Placed near the screen so users can see if anyone is standing behind them.

Image Formation by Spherical Mirrors

Guidelines for ray incidence on concave and convex mirrors, constructing accurate ray diagrams and comprehending image formation processes.

Guidelines for rays falling on the concave mirrors/ Rules of Reflection for Concave Mirrors

1) A ray traveling parallel to the principal axis reflects through the principal focus (F) of the mirror.
2) A ray passing through the principal focus (F) before hitting the mirror reflects parallel to the principal axis.
3) A ray passing through the center of curvature (C) reflects back along the exact same path because it hits the mirror perpendicularly to the surface.

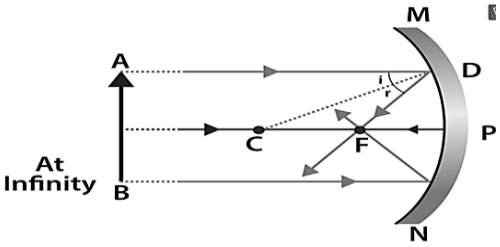
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4) A ray striking the pole (P) of the mirror reflects obliquely, making equal angles with the principal axis according to the standard laws of reflection.

OBJECT AT INFINITY

→ A real and inverted image is formed at the focus when the object is placed at infinity.

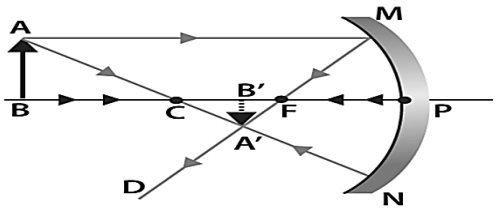
→ The size of the image is significantly smaller than that of the object.



OBJECT BEYOND THE CENTRE OF CURVATURE

→ When the object is positioned beyond the centre of curvature, a real image is formed between the centre of curvature and the focus.

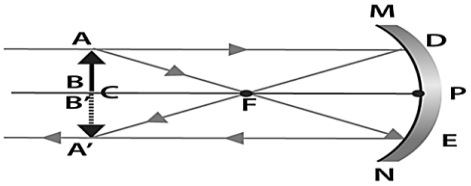
→ The size of the image is smaller compared to that of the object.



Object at the Centre of Curvature or Focus

→ When the object is placed at the centre of curvature, or the focus, a real image is formed at the centre of curvature.

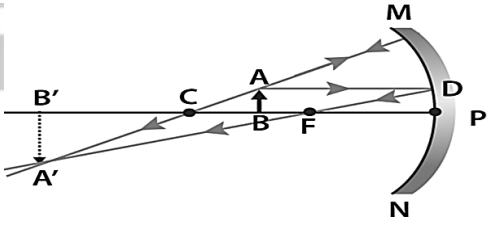
→ The size of the image remains the same as that of the object.



OBJECT BETWEEN THE CENTRE OF CURVATURE AND FOCUS

→ If the object is located between the centre of curvature and the focus, a real image is formed behind the centre of curvature.

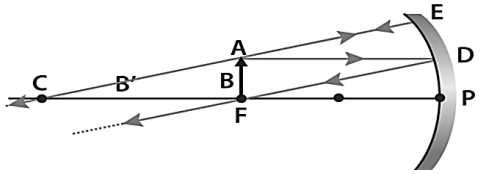
→ The size of the image is larger compared to that of the object.



OBJECT AT THE FOCUS

→ When the object is positioned exactly at the focus, a real image is formed at infinity.

→ The size of the image is much larger than that of the object.



Object between the Focus and the Pole

→ Placing the object between the focus and the pole results in the formation of a virtual and erect image.

→ The size of the image is larger compared to that of the object.

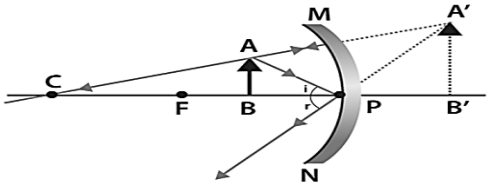


IMAGE FORMATION BY CONVEX MIRROR

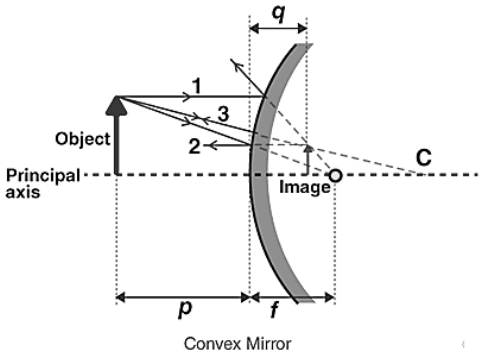
A convex mirror always forms a **virtual, upright (erect), and smaller image behind the mirror**, no matter where the object stands.

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Rules for Drawing Ray Diagrams

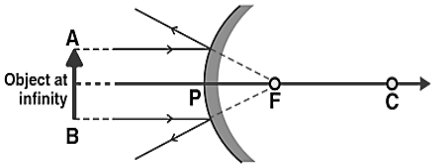
To find where the image forms, trace any two of these four special light rays:

1. A light ray moving parallel to the middle line (principal axis) reflects outward as if it comes straight from the focus point behind the mirror.
2. A light ray heading directly toward the focus point behind the mirror reflects back running parallel to the middle line.
3. A light ray heading directly toward the center point of the sphere (center of curvature) hits the mirror and bounces straight back along that exact same path.
4. A light ray hitting the exact center of the mirror's surface (the pole) bounces off at an equal angle on the opposite side of the middle line



Convex Mirror

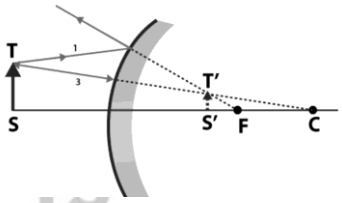
OBJECT AT INFINITY



→ When the object is positioned at infinity, a virtual image is formed at the focus of the convex mirror.

→ The size of the image is significantly smaller than that of the object.

OBJECT AT A FINITE DISTANCE



→ When an object is placed at a finite distance from the mirror, a virtual image is formed between the pole and the focus of the convex mirror.

→ The size of the image is smaller than compared to that of the object.

REFLECTION LAWS FOR CURVED SURFACES

Reflection from curved surfaces still obeys the laws of reflection:

Law 1: The angle of incidence (angle between the incident ray and the normal) equals the angle of reflection (angle between the reflected ray and the normal).

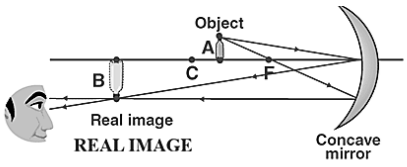
Law 2: The incident ray, the normal to the surface at the point of incidence, and the reflected ray all lie in the same plane.

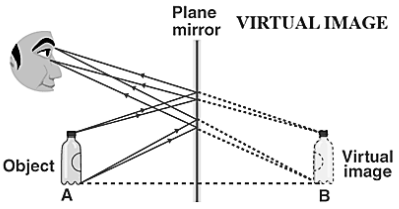
Real Image and Virtual Image

Real Image: Formed when reflected **rays converge** and meet at a point; can be projected on a screen (seen with concave mirrors).

Virtual Image: Formed when reflected **rays diverge** and appear to originate from a point behind the mirror; cannot be projected on a screen (seen with both concave and convex mirrors).

A virtual image is found by tracing real rays that emerge from an optical device backwards to perceived or apparent origins of ray divergences. Because the rays never really converge, a virtual image cannot be projected onto a screen.

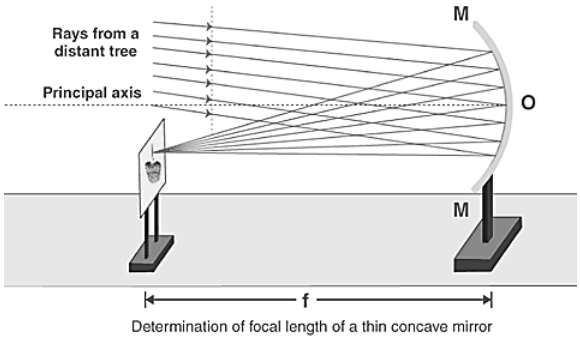




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Determining the Focal Length of Concave Mirrors

The focal length (f) of a concave mirror is the distance from the mirror's surface to its focal point, where parallel light rays converge after reflection. Several methods can be used to determine the focal length of concave mirrors, including direct experimentation with light sources, practical observation of image formation, and mathematical calculations.



Determination of focal length of a thin concave mirror

Using a Distant Object (Sunlight or Distant Light Source)

Method Overview: This is one of the simplest methods and relies on the fact that light rays from distant objects (such as the sun) are nearly parallel when they reach the mirror. These parallel rays converge at the focal point after reflection.

Procedures:

a) Take the concave mirror outside on a sunny day or use a distant artificial light source.
b) Position a screen or white paper in front of the mirror.
c) Adjust the position of the screen until a sharp, bright spot of light (the focused rays) appears on the screen. This point is where the parallel rays converge.
d) Measure the distance from the mirror's surface to the screen. This distance is the focal length (f).

Notes: This method works well for objects far away because the incoming rays are nearly parallel.
The sharpness of the focused spot helps in accurately determining the focal length.
Typically used to determine the focal length of mirrors used in telescopes or headlights.

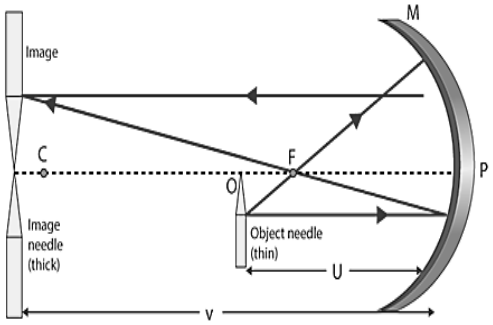
Using the Image of a Nearby Object (Object-Image Distance Method)

Method Overview: This method uses an object at a finite distance from the mirror and applies the mirror formula to calculate the focal length based on the object distance and image distance.

Mirror Formula: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$**.** Where: f is the focal length, u is the object distance (distance from the object to the mirror), and v is the image distance (distance from the image to the mirror).

Procedures:

a) Place the lamp-box well outside the approximate focal length
b) Move the screen until a clear inverted image of the crosswire is obtained.
c) Measure the distance u from the crosswire to the mirror, using the metre rule.
d) Measure the distance v from the screen to the mirror.
e) Calculate the focal length of the mirror using $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
f) Repeat this procedure for different values of u.
g) Calculate f each time and then find an average value.



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Using the Focal Length Formula and Parallax Method

Understand: This method works well for concave mirrors with shorter focal lengths. Parallax refers to the apparent shift in the position of an object when viewed from different angles. When parallax is zero, the object is located at the focal point.

Using Ray Diagrams and Graphical Methods

Aim/Purpose: An experiment to determine the focal length of a concave mirror by measuring different object distances (u) and corresponding image distances (v) to determine its suitability for use as solar concentrator.

Apparatus: Concave mirror**,** Illuminated object**,** Screen**,** Metre rule**,** Mirror holder**,** Stand**, and** Optical bench

Procedure

a) The concave mirror was placed vertically on a stand.
b) The illuminated object was placed in front of the mirror.
c) The screen was placed between the object and the mirror.
d) The screen was moved until a sharp and well-defined image was =obtained.
e) The distance between the object and the pole of the mirror was measured using a metre rule and recorded as (u).
f) The distance between the screen and the pole of the mirror was measured using a metre rule and recorded as (v).
g) The position of the object was changed, and the procedure was repeated for several different positions.
h) The values of $(u + v)$ and (uv) were calculated for each observation.
i) A graph of (uv) against $(u + v)$ was plotted.
j) A best-fit straight line was drawn through the plotted points.
k) The gradient of the graph was determined using two well-separated points on the line.
l) The gradient was taken as the focal length of the concave mirror.

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Table of results

$(\boldsymbol{u})$ $(\boldsymbol{cm})$	$(\boldsymbol{v})$ $(\boldsymbol{cm})$	$(\boldsymbol{u+v})$ $(\boldsymbol{cm})$	$(\boldsymbol{uv})$ $(\boldsymbol{cm^2})$
30	30.0	60.0	900
35	26.3	61.3	921
40	24.0	64.0	960
50	21.4	71.4	1070
60	20.0	80.0	1200
70	19.1	89.1	1337

Graphical Analysis

→ A graph of (uv) against ((u+v)) was plotted.
→ The horizontal axis represented ((u+v)) in cm.
→ The vertical axis represented= (uv) in cm².
→ A straight line was obtained.
→ The gradient was calculated from $f = \frac{\Delta(uv)}{\Delta(u+v)}$

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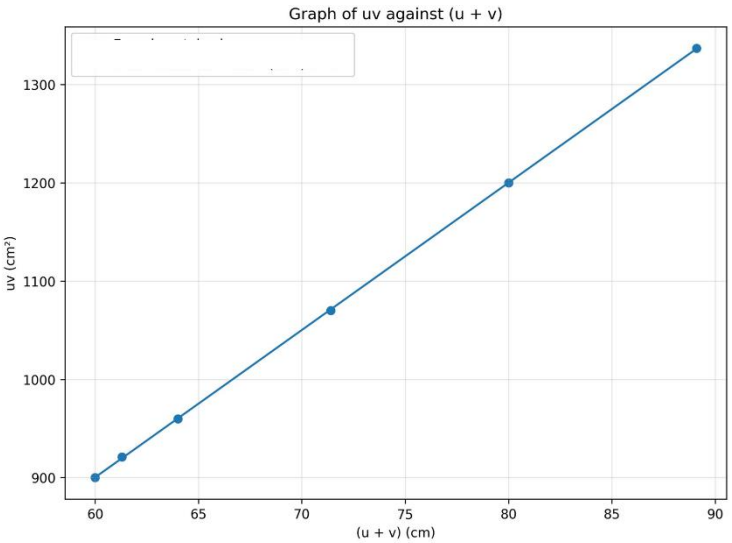
→ The gradient was approximately f=15.0cm

Conclusion

→ The focal length of the concave mirror was determined graphically.

→ A graph of (uv) against ((u+v)) produced a straight line, and the gradient of the line gave the focal length of the mirror.

→ The focal length obtained from the illustrative results was approximately 15 cm.



Precautions

→ The mirror was kept vertical throughout the experiment.

→ The object, mirror and screen were kept at approximately the same height.

→ Distances were measured from the pole of the mirror.

→ The screen was adjusted until a sharp image was obtained.

→ Parallax errors were avoided when readings were taken.

→ Several readings were taken to improve the reliability of the results.

Construction of ray diagrams to scale.

Example

An object 4cm high is placed 30cm from a concave mirror of focal length 10cm. by construction, find the position, nature and size of the image (scale, 1:5)

Graph

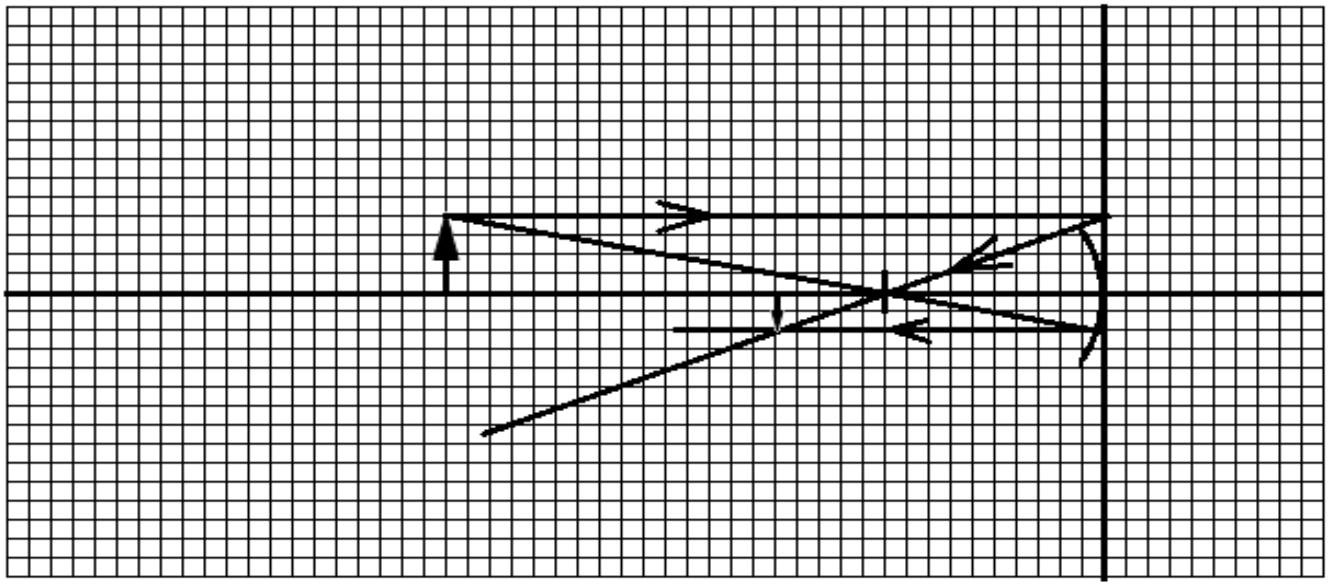


Image: Real; inverted, diminished; between C and F

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Activity

1. An object 4cm high is placed 2.4cm from concave mirror of focal length 8cm. draw a ray diagram to find the position size and nature of image**. Scale 1cm = 2cm**

2. An object of height 10cm is placed at a distance 60cm from a convex mirror of focal length 20cm. By scale find the image position, height, nature and magnification (scale 1cm: 5cm).

MAGNIFICATION

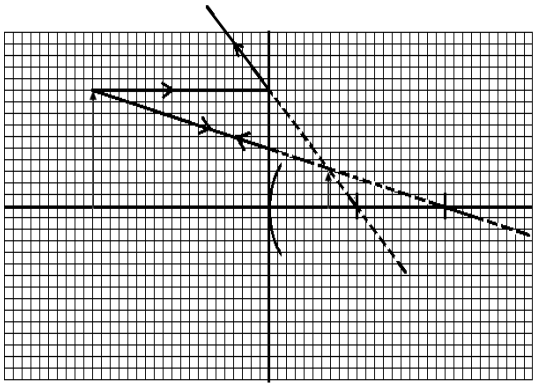
This is the ratio of image height to the object height. M = where h_I – image height, ho – object height

OR

This is the ratio of image distance from distance from the mirror to the object distance from the mirror $M = \frac{v}{u}$, Where v – image distance, u – object distance

Example 1

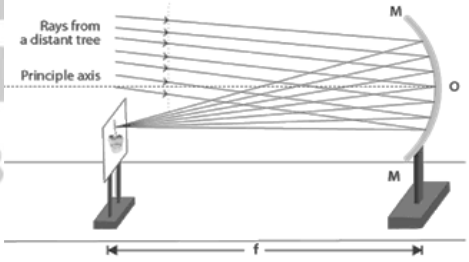
An object 10cm high is placed at distance of 20cm from a convex mirror of focal length 10cm. Draw a ray diagram, locate the position of the image, and the magnification (Using Scale of 1cm: 5cm)



MEASURING FOCAL LENGTH OF A CONCAVE MIRROR

METHOD 1: **Distant object method**

a) Hold a concave mirror at one end focusing the distant object.
b) Hold a white screen in front of the mirror so that it receives rays reflected from it to reach the mirror from the object.
c) Move the screen at different distances from the mirror until a sharp image is formed on the screen.
d) Measure the distance from the screen to the mirror using a metre rule.
e) Repeat the experiment several times and find the average value of the distance between the screen and the mirror. This is the focal length (f) of the mirror



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By scale drawing (using graph paper)

1. Find the focal length of a concave mirror from the following results
   a) Object distance u = 30cm, Image distance v = 20cm
   b) Object distance u = 8cm, Image distance v = 24cm
2. Find the image distance when an object is placed 12cm from the concave mirror of focal length 8cm and 10cm from a convex mirror of focal length 10cm.

Examination item

A learner is observing their image in a **convex safety mirror** fixed along a school corridor to help monitor movement. The mirror has a focal length of **20 cm**. An object of height **10 cm** is placed **60 cm** in front of the mirror. Using a **ray diagram drawn to scale**; Locate the position of the image, nature of the image, and its magnification.

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S2.6 MAGNETS AND MAGNETIC FIELDS

Learning outcomes

a) Know that a small number of materials are magnetic, but most are not (k)
b) Know how magnets can be made and destroyed (k, s)
c) Understand the behaviour of magnets and magnetic fields(u)
d) Know that the earth is a magnet and how a compass is used to determine direction (k, s)

Introduction

The force which causes attraction or repulsion by a magnet is called magnetic force. A magnet has two types of poles, a north pole and a south pole. Like poles repel while unlike poles attract. Some materials are attracted by a magnet while others are not. Those which are attracted are called magnetic materials while those not attracted are called non-magnetic materials. Magnetic and non-magnetic materials are classified based on their interaction with a magnetic field. Magnetic materials are those that can be attracted to a magnet, while non-magnetic materials do not exhibit this property. The distinction between these two types is due to the atomic structure and the alignment of electrons within the material, which determines whether or not it responds to a magnetic field.

Magnetic Materials

Magnetic materials are primarily composed of metals that have magnetic properties. These materials contain regions called magnetic domains, which are groups of atoms with aligned magnetic moments. In the presence of a magnetic field, these domains align themselves in the direction of the field, allowing the material to be attracted to the magnet. Common magnetic materials are iron, nickel, and cobalt. Magnetic materials are often used in applications that require the manipulation of magnetic fields, such as in electromagnets, motors, and electronic devices. Magnetic materials are essential components in various technologies, ranging from electronics to renewable energy systems. These materials can be classified into three main categories: ferromagnetic, paramagnetic, and diamagnetic.

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Ferromagnetic materials, such as iron, cobalt, and nickel, exhibit strong magnetic properties and can be permanently magnetized. They are commonly used in the production of permanent magnets and magnetic storage media. Paramagnetic materials, on the other hand, have unpaired electrons that create a weak magnetic moment. They are attracted to magnetic fields but do not retain magnetization once the external field is removed. Diamagnetic materials, in contrast, are characterized by their weak repulsion to magnetic fields, resulting from the paired electrons that create no net magnetic moment.

Introduction to Magnets and Magnetic Fields

Magnets and magnetic fields are fundamental concepts in physics, deeply connected to the force of magnetism, one of the four fundamental forces in nature. Magnets are objects that produce a magnetic field, an invisible area of influence that exerts forces on certain materials like iron, nickel, cobalt, and other magnets. Magnetic fields are essential in understanding how magnets interact with their environment and are responsible for many technological applications, such as electric motors, magnetic resonance imaging (MRI), and data storage devices.

Magnets are fascinating objects that produce invisible magnetic fields, which can attract ferromagnetic materials like iron, nickel, and cobalt. These magnetic fields arise whenever electric charges are in motion. The strength of a magnetic field increases with the amount of charge in motion, demonstrating a direct relationship between electric currents and magnetism.

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Magnetic fields exert forces on other magnetic materials without requiring physical contact, allowing magnets to attract or repel each other. This phenomenon is not magic; it is a fundamental aspect of physics that governs how magnets interact. The lines of force in a magnetic field exit from one pole of the magnet and enter through the other, creating a continuous loop.
The Earth's magnetic field, generated in its outer core, also protects our planet from solar radiation, highlighting the importance of magnetism in both technology and nature.

Properties of Magnets
Magnetic materials
Some materials, known as ferromagnets, can be magnetised to form a magnet. In their unmagnetised form they are attracted to a magnet.

Magnetic poles
The *poles* are the places in a magnet to which magnetic materials, such as iron filings, are attracted. They are near the ends of a bar magnet and occur in pairs of equal strength.

North and south poles
A magnet has two poles; a north pole (N pole) and a south pole (S pole). If a magnet is supported so that it can swing in a horizontal plane it comes to rest with one pole, the N pole, always pointing roughly towards the Earth's North Pole. A magnet can therefore be used as a *compass*.
Law of magnetic poles
If the N pole of a magnet is brought near the N pole of another magnet, repulsion occurs. Two S (south-seeking) poles also repel. By contrast, N and S poles always attract. The law of magnetic poles summarises these facts and states: *Like poles repel, unlike poles attract.*
The force between magnetic poles decreases as their separation increases.

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Induced magnetism
When a piece of unmagnetised magnetic material touches or is brought near to the pole of a permanent magnet, it becomes a magnet itself.
The material is said to have magnetism induced in it. When a N pole in the permanent magnet induces a N pole in the right-hand end of the magnetic material.
This can be checked by hanging two iron nails from the N pole of a magnet. Their lower ends repel each other and both are repelled further from each other when the N pole of another magnet is brought close.

Magnetisation of iron and steel

Chains of small iron nails and steel paper clips can be hung from a magnet. Each nail or clip magnetises the one below it and the unlike poles so formed attract.
If the iron chain is removed by pulling the top nail away from the magnet, the chain collapses, showing that magnetism induced in iron is *temporary*. When the same is done with the steel chain, it does not collapse; magnetism induced in steel is *permanent*.

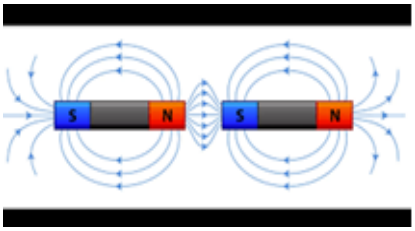
Key definitions
Temporary magnets made of soft iron, lose their magnetism easily
Permanent magnets made of steel, retain their magnetism
Magnetic materials; materials that can be magnetised by a magnet; in their unmagnetised state they are attracted by a magnet

Non-magnetic materials; materials that cannot be magnetised and are not attracted by a magnet.

Magnetic materials such as iron that magnetise easily but readily lose their magnetism (are easily demagnetised) are said to be **soft**. Those such as steel are harder to magnetise than iron but stay magnetised are **hard**. Both types have their uses; very hard ones are used to make permanent magnets.

The Nature of Magnetic Fields

A magnetic field is the region around a magnet where its magnetic forces can be felt. This field is represented visually by magnetic field lines, which depict the direction and strength of the field. These lines emerge from the north pole of a magnet and curve around to enter the South Pole, forming continuous loops. The density of these lines indicates the strength of the magnetic field: the closer the lines, the stronger the field. The lines are most concentrated near the poles, where the magnetic forces are strongest, and they spread out as they move farther away from the magnet.



Magnets possess distinct properties that define their behavior and applications.

The primary property of magnets is attraction; they can attract ferromagnetic materials such as iron and nickel. Additionally, magnets exhibit repulsion, where like poles (north-north or south-south) push each other away, while opposite poles (north-south) attract. This duality is crucial in various applications, from simple toys to complex machinery.

When suspended freely, a magnet aligns itself along the Earth's magnetic field, with its North Pole pointing towards the magnetic north. This property is utilized in compasses, aiding navigation. Magnets are widely used in everyday life, including in electric motors, generators, and magnetic storage devices. Their unique properties not only enhance technology but also open avenues for innovative applications, such as in renewable energy solutions.

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How Magnetic fields are produced

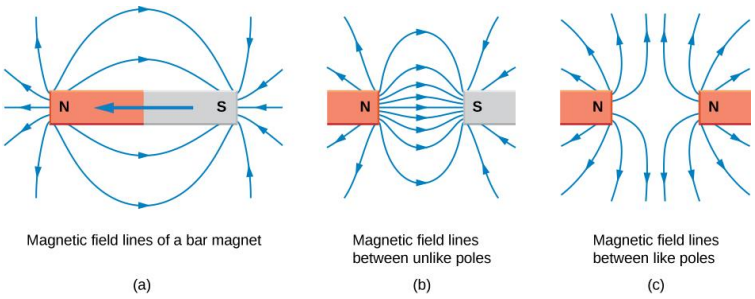
Magnetic fields are generated by moving electric charges, which is why they are closely associated with electricity. In a magnet, the movement of electrons within the atoms, particularly their spin and orbital motion, creates the magnetic field. In larger-scale systems, such as electromagnets, magnetic fields are produced when an electric current flows through a conductor, such as a coil of wire. The strength of this field can be increased by increasing the current or by using a ferromagnetic material like iron as a core.

Magnetic fields are generated whenever electric charges are in motion. This phenomenon occurs at both macroscopic and microscopic levels. For instance, the movement of electrons around an atomic nucleus creates a magnetic field, while larger currents flowing through wires also produce magnetic fields.

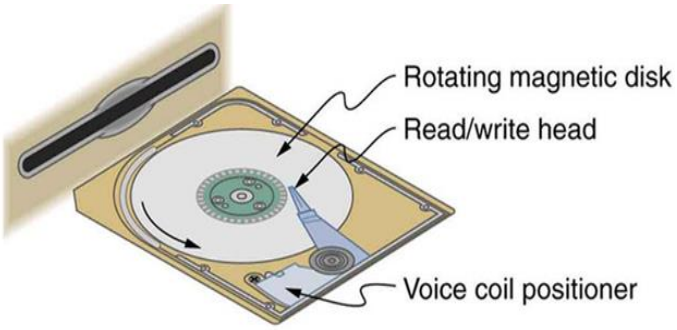
When electric current flows through a conductor, such as a wire, it generates a magnetic field that encircles the wire. This effect can be amplified by coiling the wire into loops or coils, which concentrates the magnetic field lines and enhances the overall strength of the magnetic field produced.

Intrinsic magnetic moments of elementary particles, such as electrons, contribute to the creation of magnetic fields. These moments arise from the particles' spin and charge, further illustrating the fundamental relationship between electricity and magnetism. Thus, magnetic fields are a direct result of moving charges and the properties of particles at the quantum level.

Types of Magnetic Materials



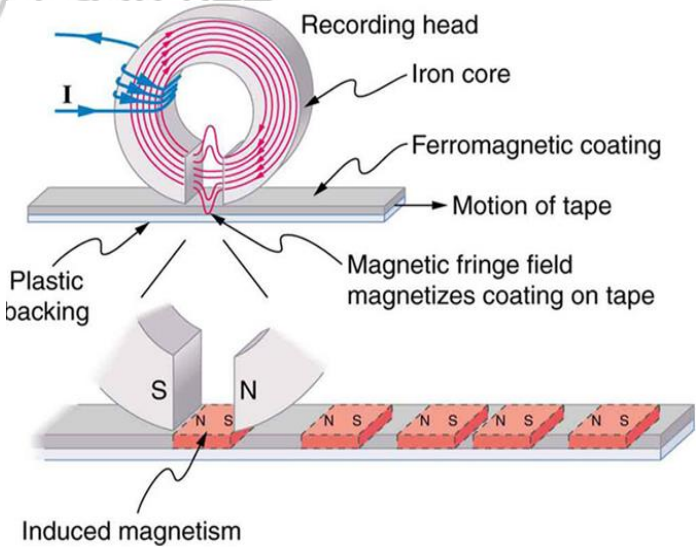
Magnetic materials can be classified into several categories based on their magnetic properties. The primary types include diamagnetic, paramagnetic, ferromagnetic, and ferromagnetic materials. Ferromagnetic materials, such as iron, cobalt, and nickel, have strong magnetic properties because their atomic magnetic moments align to form magnetic domains. When exposed to an external magnetic field, these domains align in the same direction, creating a strong overall magnetic field. Paramagnetic materials, such as aluminum and platinum, have weak and temporary alignment with the magnetic field, while diamagnetic materials, like copper and bismuth, are repelled by the field due to induced opposing magnetic moments.



Diamagnetic materials, such as copper and bismuth, exhibit a weak repulsion to magnetic fields, making them the least magnetic. In contrast, paramagnetic materials, like aluminum and platinum, are weakly attracted to magnetic fields and only exhibit magnetism in the presence of an external field. Ferromagnetic materials, including iron, cobalt, and nickel, display strong magnetic properties and can retain magnetization even after the external field is removed. Ferromagnetic materials, found in compounds like magnetite, have opposing magnetic moments that result in a net magnetization. Understanding these types of magnetic materials is crucial for various applications, from electronics to data storage technologies.

Magnetic Fields in Everyday Life

From the simple fridge magnets that hold cherished photos to the powerful magnets used in MRI machines, their utility is both diverse and essential. These magnetic forces are generated by moving electric charges and magnetic materials, impacting objects around them.



The most familiar uses of magnets is in compasses, which rely on Earth's geomagnetic field to guide navigation. This natural magnetic force allows us to orient ourselves and find our way, demonstrating the importance of magnetism in daily activities. Various household items, such as magnetic locks and hangers, utilize these forces for convenience and security. The Earth itself acts like a giant magnet, with a magnetic field generated by the motion of molten iron in its outer core. This magnetic field protects the planet from harmful solar winds and enables navigation using compasses. Magnetic fields are also utilized in technology, such as in electric motors, which

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convert electrical energy into mechanical energy, and in magnetic storage devices, where data is stored by aligning tiny magnetic domains.

Applications of Magnets and Magnetic Fields

From small toys to heavy machinery, magnets are integral in devices such as refrigerators, speakers, and magnetic locks. Their ability to attract or repel materials without direct contact makes them invaluable in numerous sectors, including healthcare, where magnetic resonance imaging (MRI) utilizes strong magnetic fields to create detailed images of the body.

In engineering, solenoids and electromagnets are essential for controlling magnetic fields, enabling their use in transformers and electric motors.

In transportation, magnetic levitation (maglev) trains use magnets to lift and propel the train, reducing friction and allowing for high speeds. Magnets are also essential in renewable energy technologies, such as wind turbines, where they are used to generate electricity.

Magnetization

Magnetization in magnetism represents the density of magnetic dipole moments within a magnetic material. It is quantified as the ratio of the magnetic moment to the volume of the material, indicating how strongly a material can be magnetized. This property can arise from either permanent magnetic dipoles or induced dipoles when exposed to an external magnetic field. Different materials exhibit varying responses to magnetization, categorized as diamagnetic, paramagnetic, and ferromagnetic.

Diamagnetic materials are weakly repelled by magnetic fields, while paramagnetic materials are weakly attracted.

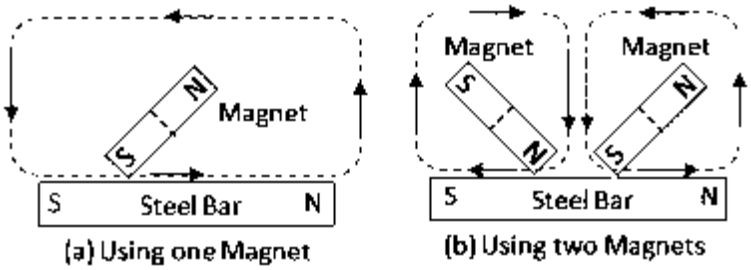
Ferromagnetic materials can retain magnetization even after the external field is removed, making them essential in various applications, from electric motors to data storage. Magnets can be created through several methods that align the magnetic domains in a material, which are small regions where magnetic fields from individual atoms are aligned. When these domains are organized in the same direction, the material becomes magnetized.

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The common ways magnets are made:

Magnetizing by Stroking

This involves taking a strong magnet and repeatedly stroking it along the surface of a ferromagnetic material (like iron or steel). The repeated stroking aligns the magnetic domains in the material in the direction of the stroking motion. The strength of the resulting magnet depends on the material's properties and the consistency of the stroking motion.



This technique involves stroking a steel bar with a permanent magnet, which causes the magnetic domains within the steel to align. As these domains align, a north (N) pole and a south (S) pole are induced in the steel bar, effectively turning it into a magnet.

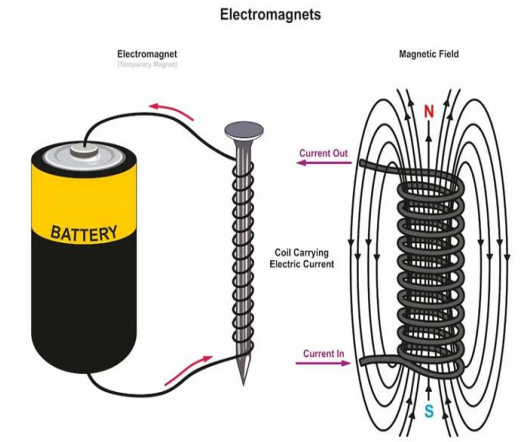
Increasing the number of strokes or using a stronger permanent magnet can lead to a more powerful magnet. Stroking in one direction consistently ensures that the external magnetic field is effectively applied, further promoting alignment of the magnetic domains.

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Magnetizing by Electrical Current

Electromagnets are created by passing an electric current through a coil of wire wound around a ferromagnetic core. The electric current generates a magnetic field that aligns the domains in the core material. This method is widely used in industries because it allows for control over the strength of the magnet by adjusting the current.

Electromagnets are commonly used in electric motors, generators, and lifting equipment.

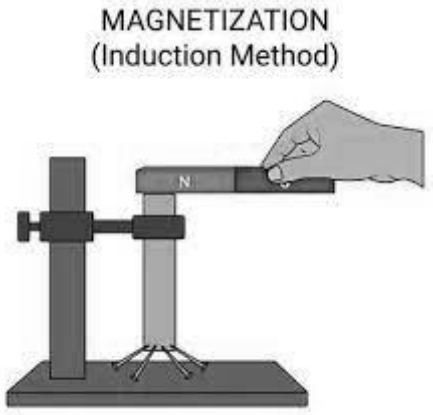


Action: When an electric current flows through a conductor, it generates a magnetic field around it. This phenomenon can be observed by placing a magnetic compass near a current-carrying wire, which will deflect due to the magnetic field produced. When an electric current passes through the coil, it induces a magnetic field, effectively turning the coil into an electromagnet. The magnetic field aligns the material's internal dipoles, enhancing its magnetic properties.

The electrical method of magnetization also allows for the creation of stronger magnets, making it a preferred choice in various applications, from industrial uses to everyday electronics.

Magnetizing by Induction

When a ferromagnetic material is placed in a strong magnetic field, it can become magnetized through induction. The external magnetic field forces the domains in the material to align in the same direction. This process can occur naturally, such as when a piece of iron comes into contact with a strong magnet, or artificially in controlled environments.



Action: Magnetizing by induction is a process that transforms magnetic materials, such as iron and steel, into magnets without direct contact with a magnetic source. This phenomenon occurs when a ferromagnetic material is exposed to a magnetic field, causing its magnetic domains small regions within the material that act like tiny magnets to align in the direction of the external field. For example, when a magnet is brought close to a nail, the magnetic field induces magnetism in the nail, resulting in the attraction of small metal pins to it. This method is widely used in creating artificial magnets and is fundamental in various applications, from household items to advanced technologies. Induction magnetization is not limited to physical contact; even a strong magnetic field can induce magnetism in materials at a distance.

Magnetizing by Heating and Cooling

Certain materials can be magnetized by heating them above their Curie temperature (the temperature at which their magnetic properties are lost) and then cooling them in the presence of a magnetic field. This method realigns the domains during the cooling process, resulting in a permanent magnet.

Action

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Magnetizing by heating and cooling is a fascinating process that significantly affects the strength and behavior of magnets. When a neodymium magnet is heated above its Curie point, it loses its magnetism due to increased thermal agitation, which disrupts the alignment of its magnetic domains. Upon cooling, these domains can realign, allowing the magnet to regain some of its magnetic proper ties. Temperature plays a crucial role in the performance of permanent magnets. Heating a magnet can weaken its magnetic field, as the increased kinetic energy causes the molecules to move more rapidly, disrupting their alignment. If the temperature exceeds the magnet's maximum operating limit but remains below the Curie temperature, irreversible performance losses may occur.

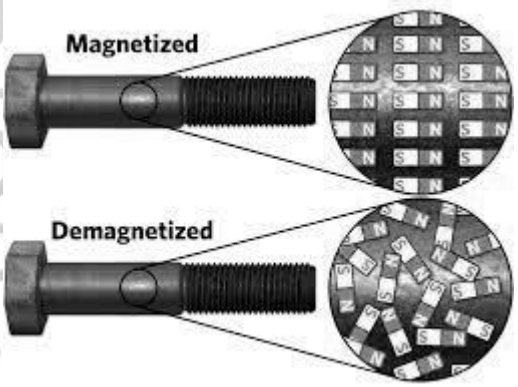
Demagnetisation

Magnets can lose their magnetism or become demagnetized through processes that disrupt the alignment of their magnetic domains.

Heating beyond the Curie temperature

Magnets can be significantly affected by temperature, particularly when heated beyond their Curie temperature. The Curie temperature is the point at which a magnet's magnetic domains become disordered due to increased thermal energy. As the temperature rises, the kinetic energy of the magnet's molecules increases, causing them to vibrate more vigorously. This disruption leads to a weakening of the magnet's strength and magnetic field.

When a magnet is heated above its Curie temperature, it undergoes irreversible changes. The magnetic domains, which are responsible for the magnet's alignment and strength, become misaligned and lose their ability to maintain a magnetic field. Even if the magnet is cooled back down, it may not regain its original magnetic properties, as the domains may not realign properly.



Mechanical Shock

Striking a magnet repeatedly or subjecting it to strong mechanical vibrations can disorient the aligned magnetic domains. This process diminishes the magnet’s strength over time, and with enough shocks, the magnet can become fully demagnetized. Dropping a magnet onto a hard surface is a common example of how mechanical shock can destroy a magnet. Magnets, particularly permanent magnets, can be surprisingly vulnerable to mechanical shock, which can lead to demagnetization. One of the primary causes of this phenomenon is the physical impact from dropping or striking the magnet. Such shocks can disrupt the alignment of the magnetic domains within the material, leading to a loss of magnetism. Additionally, exposure to strong external magnetic fields can also demagnetize a magnet. When a magnet is subjected to another magnetic field, it can interfere with its own magnetic alignment, causing a reduction in strength. Moreover, temperature fluctuations can exacerbate the effects of mechanical shock. High temperatures can weaken the magnet's structure, making it more susceptible to damage from physical impacts.

Exposure to a Strong Opposing Magnetic Field

When a magnet is exposed to a strong external magnetic field that opposes its own field, the domains can become misaligned, leading to partial or complete demagnetization. This principle is used in demagnetization processes, such as in degaussing coils. Magnets can be destroyed or demagnetized when exposed to a strong opposing magnetic field. This phenomenon occurs because the external magnetic field

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can disrupt the alignment of the magnetic domains within the magnet. When these domains, which are responsible for the magnet's magnetic properties, become misaligned, the magnet loses its ability to attract or repel other magnetic materials.

Several factors contribute to the demagnetization of permanent magnets. Besides exposure to strong magnetic fields, heat can also play a significant role. When a magnet is heated above its Curie temperature, the thermal energy can cause the magnetic domains to become disordered, leading to a loss of magnetism. Additionally, physical shocks or vibrations can further exacerbate this process by causing misalignment of the magnetic domains.

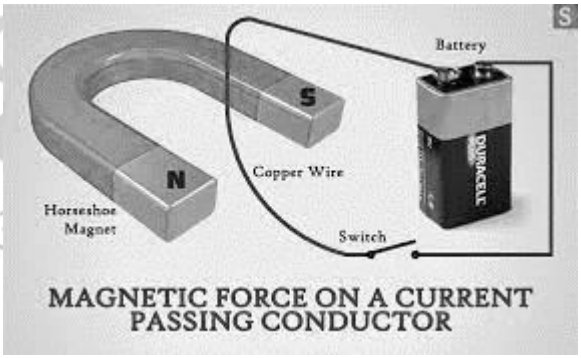
Corrosion or Oxidation

Magnets can be significantly weakened by corrosion and oxidation, particularly when they are made from ferromagnetic materials like iron. When exposed to moisture, these magnets undergo oxidation, resulting in the formation of iron oxide, commonly known as rust. This rust is non-magnetic, which means that as the magnet rusts, it loses its attractive power and overall functionality.

Corrosion not only diminishes the magnetic strength but also affects the durability of the magnet. Rusty magnets are more susceptible to further damage, which can lead to complete demagnetization over time. Factors such as temperature fluctuations and physical shocks can exacerbate this process, making it crucial to protect magnets from harsh environments. To prevent corrosion, it is advisable to apply protective coatings or use coverings like rubber. Corrosion alters the material's structure and disrupts the alignment of magnetic domains. Protective coatings, such as nickel plating, are often applied to prevent this. Proper storage and maintenance can significantly extend the life of magnets, ensuring they retain their magnetic properties for longer periods.

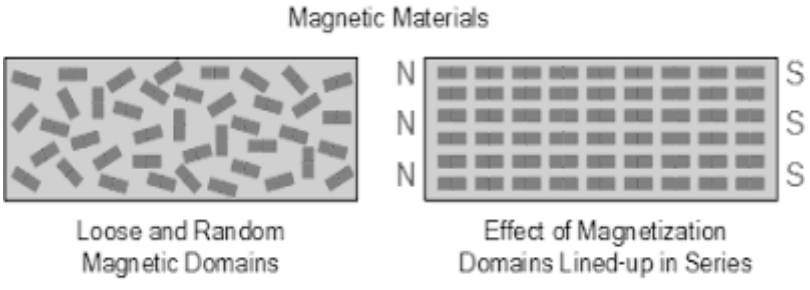
Passing Electrical Current

If a magnet is placed in the vicinity of an alternating current (AC) circuit or subjected to high-frequency electromagnetic waves, the domains can become disoriented due to the rapidly changing magnetic field. This process is a common cause of demagnetization in magnets used near electrical devices. Magnets can be demagnetized through various methods, one of which involves passing an electrical current through them. When current flows through a wire, it generates a magnetic field that can interfere with the existing magnetic field of the magnet, potentially leading to its demagnetization.



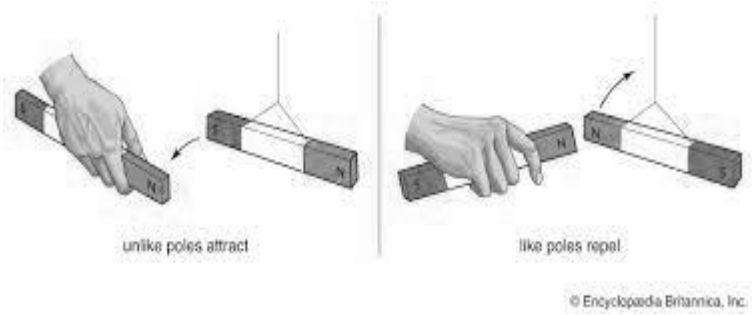
Time and Natural Decay

Over long periods, magnets naturally lose their magnetism due to the gradual randomization of magnetic domains. This process is called magnetic decay and is accelerated in unstable materials or in environments with fluctuating temperatures or external magnetic fields. Magnets can indeed lose their strength over time due to a process known as



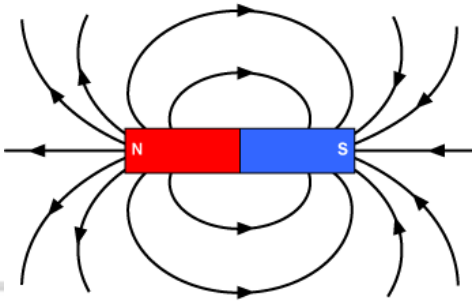
demagnetization. This gradual decline in magnetic power is primarily influenced by environmental factors, particularly temperature. When exposed to elevated temperatures, the thermal energy can disrupt the alignment of magnetic domains within the material, leading to a permanent loss of magnetism.

In addition to heat, physical impacts can also contribute to a magnet's decay. Striking a magnet with a hammer or subjecting it to mechanical stress can misalign its internal structure, further diminishing its magnetic strength. Unlike radioactive decay, which follows a predictable half-life, the loss of magnetism in permanent magnets occurs at an unpredictable rate, making it difficult to determine exactly when a magnet will lose its effectiveness.



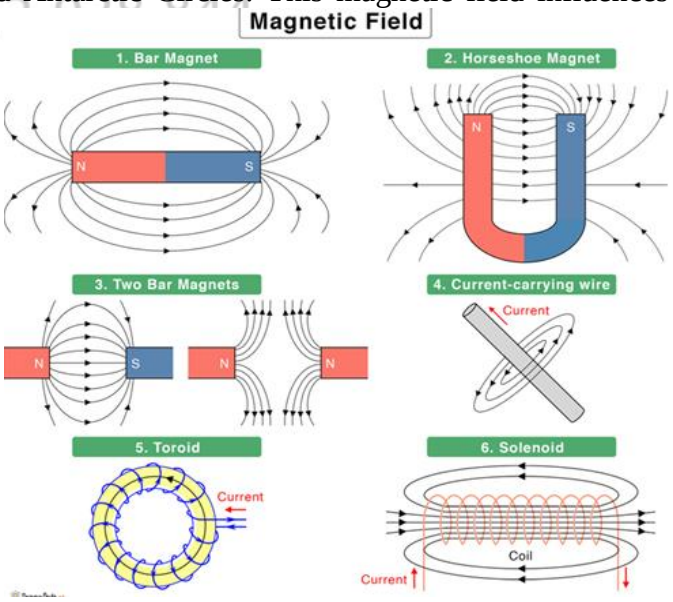
Magnetism and Magnetic Poles

Magnets are objects that produce a magnetic field, an invisible force that exerts attraction or repulsion on other materials. The magnetic field is generated by the movement of electric charges within the material, particularly the alignment of electron spins. Every magnet has two poles, called the North Pole and the South Pole. These poles are the regions where the magnetic force is strongest. Opposite poles (north and south) attract each other, while like poles (north and north or south and south) repel. This behavior is summarized in the basic rule of magnetism: like poles repel, and unlike poles attract. The magnetic poles always exist in pairs; even if a magnet is broken into smaller pieces, each piece will still have a north and a south pole. Every magnet has two distinct regions known as magnetic poles: the North Pole and the South Pole. These poles are where the magnetic field is strongest, and they dictate how magnets interact with each other. A north pole will attract a south pole, while two north poles or two south poles will repel each other. The Earth itself acts as a giant magnet, with its magnetic poles located near the Arctic and Antarctic Circles. This magnetic field influences various natural processes, including the orientation of compasses and the behavior of charged particles in the atmosphere. Interestingly, Earth's magnetic poles are not fixed; they can shift over time due to changes in the planet's core dynamics.



The Magnetic Field

The magnetic field is the region around a magnet where its magnetic forces can be detected. This field is represented by magnetic field lines, which visually map the direction and strength of the field. Magnetic field lines emerge from the North Pole and loop around to enter the South Pole, forming closed loops. The density of these lines indicates the strength of the field; they are closer together near the poles, where the field is strongest, and spread



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out as they move farther away. The field lines never cross, as each line represents a distinct direction of force at any point.

A magnetic field is a physical field that exerts a magnetic influence on moving electric charges, electric currents, and magnetic materials. This invisible field surrounds magnets and can exert forces on other magnetic materials without direct contact. Magnetic fields are vector fields, meaning they have both direction and magnitude. They are observable in the vicinity of magnets, electric currents, or changing electric fields. The Earth itself has a magnetic field, which plays a crucial role in influencing various geological and atmospheric processes.

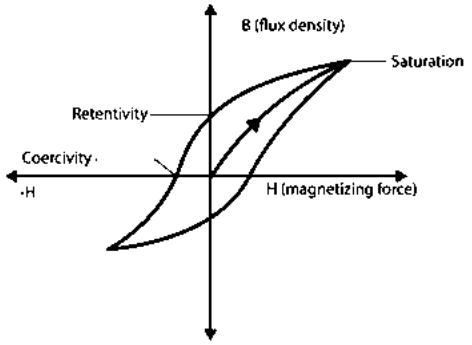
Behavior of Magnets in a Magnetic Field

When a magnet is placed in a magnetic field, it experiences forces that depend on the orientation of its poles relative to the field. If the magnet's North Pole is near the north pole of another magnet, they will repel each other, causing the magnet to move away. If the north pole of one magnet is near the south pole of another, they will attract and move closer. These interactions demonstrate the alignment tendencies of magnetic dipoles in external magnetic fields. The strength of the magnetic interaction diminishes with distance, following an inverse square law.

Magnets exhibit fascinating behavior when placed in a magnetic field, which can be categorized into permanent and temporary types.

Permanent magnets retain their magnetic properties indefinitely, while temporary magnets, such as electromagnets, only exhibit magnetism when an electric current is applied.

The strength and direction of a magnet's influence are quantified by its magnetic moment, which is determined by the alignment of electron spins within the material. When magnets interact with a magnetic field, they can attract or repel other magnetic materials, such as iron, nickel, and cobalt. This interaction is governed by the orientation of the magnetic field lines, which emerge from the magnet's North Pole and re-enter at the South Pole. The behavior of magnets is not only limited to solid materials; researchers have even discovered ways to manipulate the movement of bacteria using magnetic fields, showcasing the diverse applications of magnetism in science.



Magnetic Materials and Magnetization

Magnetic materials are characterized by the presence of atomic magnetic dipoles, which can align to produce a net magnetism that is observable on a macroscopic scale. The origin of magnetism is rooted in the orbital and spin motions of electrons, as well as their interactions. This alignment of dipoles is crucial for the material to exhibit magnetic properties. There are several classes of magnetic materials, including ferromagnetic, paramagnetic, and diamagnetic substances.

Magnetisation and Demagnetisation

A ferromagnetic material can be magnetised by placing it inside a solenoid and gradually increasing the direct current (d.c.). This increases the magnetic field strength in the solenoid (the density of the field lines increases), and the material becomes magnetised. Reversing the direction of current flow reverses the direction of the magnetic field and reverses the polarity of the Magnetisation. A magnet can be demagnetised by placing it inside a solenoid through which an alternating current (a.c.) is passed and gradually reduced.

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Solenoids can be used to magnetise and demagnetise magnetic materials; dropping or heating a magnet also causes demagnetisation.
Hammering a magnetic material in a magnetic field causes magnetisation but in the absence of a field it causes demagnetisation. 'Stroking' a magnetic material several times in the same direction with one pole of a magnet will also cause it to become magnetised.

Magnetic Materials
Ferromagnetic: Strongly attracted, can become permanent magnets (iron, cobalt, nickel). Atomic moments align strongly due to exchange forces.
Paramagnetic: Weakly attracted, temporary magnetization disappears when the field is removed (aluminum, oxygen).
Diamagnetic: Weakly repelled by a magnetic field (copper, water).

Electromagnetism
Electromagnetism is a branch of Physics, which deals with the electromagnetic force that occurs between electrically charged particles. The electromagnetic force is one of the four fundamental forces and exhibits electromagnetic fields such as **magnetic fields,** electric fields, and light. It is the basic reason electrons are bound to the nucleus and are responsible for the complete structure of the nucleus.

Electromagnets
An electromagnet is formed from a coil of wire through which an electrical current is passed that allows the strength of the magnet to be varied.
The magnetism of an electromagnet is *temporary* and can be switched on and off, unlike that of a permanent magnet. It has a core of soft iron, which is magnetized only when there is current in the surrounding coil.
The strength of an electromagnet increases if
(i) the current in the coil increases
(ii) the number of turns on the coil increases
(iii) the poles are moved closer together.

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In C-core (or horseshoe) electromagnets, condition (iii) is achieved. Note that the coil on each limb of the core is wound in *opposite* directions.

Uses of permanent magnets and electromagnets
Permanent magnets made from magnetic materials such as steel retain their magnetism, so can be used in applications where the magnetic field does not need to be varied. These include a compass, computer hard disk, electric motor, electricity generator, microphone, loudspeaker and many more everyday devices such as credit and debit cards.

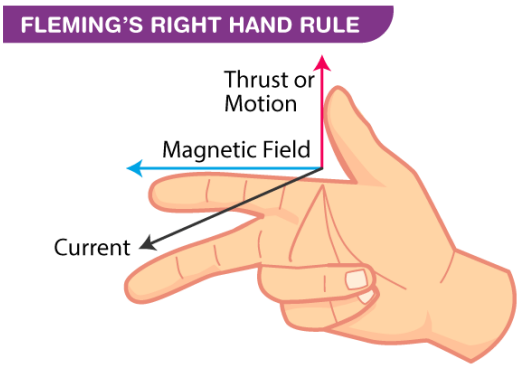
An advantage over an electromagnet is that it does not require a current to maintain its magnetism.
Electromagnets are temporary and are used where one wants to be able to vary the strength of the magnetic field (by varying the current) and switch it on and off. As well as being used in cranes to lift iron objects, scrap iron, etc. Electromagnets are an essential part of many electrical devices such as electric bells, magnetic locks, relays and practical motors and generators.

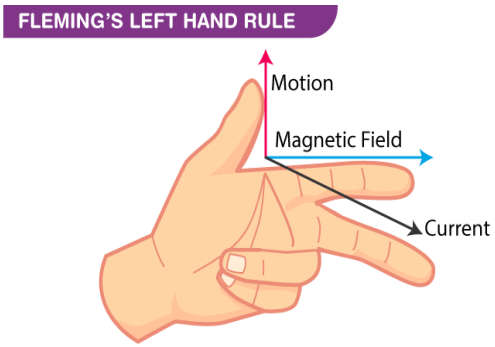
Electromagnetic Force

The electromagnetic force is a type of physical interaction that occurs between electrically charged particles. It acts between charged particles and is the combination of all magnetic and electrical forces. The electromagnetic force can be attractive or repulsive.

Electromagnetism

Electromagnetism is a process where a magnetic field is created by introducing the current in the conductor. When a conductor is electrically charged it generates magnetic lines. For example, if current i.e., positive charges move in a wire, it produces the magnetic field along the wire, and the direction of magnetic lines and force can be determined using **Right-hand Rule.**



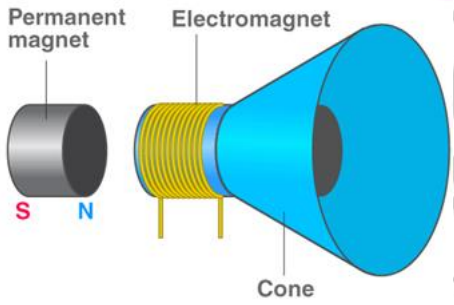


Refer to the image for a detailed explanation

Explanation of Electromagnetism with an Example

Permanent Magnetic speakers commonly used in TV's and Radios are perfect examples of Electromagnetic devices.

In order to convert electrical waves into audible sound, the speakers are designed.



A metal coil is attached to a permanent magnet and when current passes through the coil it generates a magnetic field. The newly formed magnetic field is repelled by the permanent magnetic field resulting in the vibrations. These vibrations are amplified by the cone-like structure causing the sound. This is how speakers work based on electromagnetism.

Electromagnetic Induction

When a conductor is placed or moved through the magnetic field it generates voltage i.e., electricity. This principle is called **Electromagnetic Induction.** The voltages generated will be based on the speed of the conductor moving through the magnetic field. The faster the speed of the conductor, the greater the induced electricity or voltage.

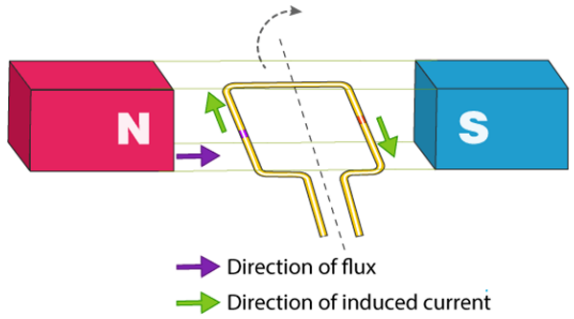
Faraday's Law

According to **Faraday's Law,** the relative motion between the magnetic field and conductor, the flux linkage changes and this change in flux induces a voltage across the coil.

Explanation with an example

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DC Generator works on the principle of Faraday's Law of Electromagnetic Induction. It is a system that converts mechanical energy into electrical energy.



In the above figure, a rectangular conductor width sides are placed in between a magnetic field. When the rectangular conductor rotates in between magnetic, it cuts the magnetic field thereby causing the Electromagnetic field (e m f).

Properties of the Electromagnetic Wave

A few properties of electromagnetic waves are:

Electromagnetic waves are propagated by oscillating electric and magnetic waves at right angles to each other.

They exhibit the properties of interference and diffraction.

They travel at a speed of 3×10^8m/s in a vacuum.

They are transverse waves.

The relationship between the wavelength (λ) and frequency (c) of an electromagnetic wave is given as follows: $c = v \lambda$

Applications of Electromagnetism

Electromagnetism serves as a fundamental working principle for many of the home appliances in household applications.

The Maglev trains or high-speed trains work on the principle of electromagnetism.

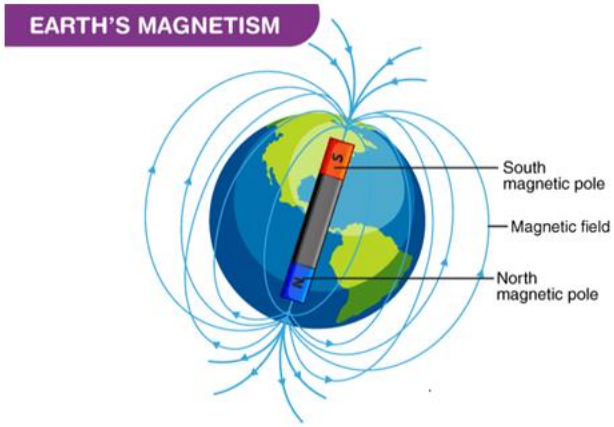
Electromagnetic radiations are used in the communication system to transfer data from the source to the receiver.

In industries, starting from small instruments to large power equipment, electromagnetism is used at least at one stage of their work.

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Earth's Magnetic Field

Earth's magnetic field is also referred to as the geomagnetic field. The earth's magnetic field extends millions of kilometers into outer space and looks very much like a bar magnet. The earth's south magnetic pole is actually near the North Pole and the magnetic north pole is in Antarctica! This is why a compass magnet's North Pole actually points north (north and south poles attract). The Earth's magnetic field extends far and wide but is very weak in terms of field strength.



Theory of Earth's Magnetism

Dynamo effect: The earth gets its own magnetic field lines because of the presence of the metallic fluids that are present at the outer core as well as in the inner core. The outer core consists of molten iron, while the inner core has the solidified elements.

Earth's Magnetism

Earth's Magnetism is generated by convection currents of molten iron and nickel in the earth's core. These currents carry streams of charged particles and generate magnetic fields.

This magnetic field deflects ionizing charged particles coming from the sun (called solar wind) and prevents them from entering our atmosphere.

Without this magnetic shield, the solar wind could have slowly destroyed our atmosphere preventing life on earth to exist. Mars does not have a strong atmosphere that can sustain life because it does not have a magnetic field protecting it.

Earth's magnetic field

If lines of force are plotted on a sheet of paper with no magnets nearby, a set of parallel straight lines is obtained. They run roughly from S to N geographically, and represent a small part of the Earth's magnetic field in a horizontal plane.

Lines of force due to the Earth's field

At most places on the Earth's surface a magnetic compass points slightly east or west of true north, i.e. the Earth's geographical and magnetic north poles do not coincide. The angle between magnetic north and true north is called the declination. In Hong Kong in 2020 it was about 3º W of N and changing slowly.

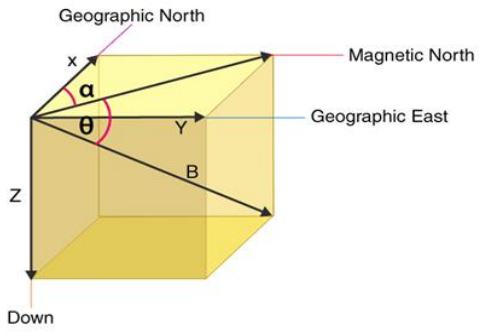
The earth's magnetic poles are not aligned to the actual geographic north and south poles. Instead, the magnetic South Pole is in Canada while the magnetic north pole lies in Antarctica. The magnetic poles are inclined by about 10 degrees to the earth's rotational axis. So, all this time your compass was really pointing to Canada, not the true North!

The magnetic North pole is located to the south in Northern Canada; the geographic South Pole is at the centre of the Antarctic continent, but the magnetic pole is hundreds of miles away, near the coast. In regions near the magnetic poles, compasses are virtually useless.

Components of Earth's Magnetic Field

There are three components that are responsible for the magnitude as well as the direction of the earth's magnetic field:

- Magnetic declination
- Magnetic inclination or the angle of dip
- Horizontal component of the earth's magnetic field



Magnetic Declination

The magnetic declination is defined as the angle between the true north and the magnetic north. On the horizontal plane, the true north is never at a constant position and keeps varying depending upon the position on the earth's surface and time.

Magnetic Inclination

The magnetic inclination is also known as the **angle of dip.**

It is the angle made by the horizontal plane on the earth's surface. At the magnetic equator, the angle of dip is 0°, and at the magnetic poles, the angle of dip is 90°.

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Non-Magnetic Materials

Non-magnetic materials are substances not attracted to magnets, like wood, plastic, copper, and aluminum, due to their balanced electron spins canceling out magnetic fields, unlike magnetic materials (iron, nickel, cobalt) that have aligned electrons and are strongly attracted.

These materials are vital in electronics, medicine (MRI), and aerospace because they avoid magnetic interference, offering properties like corrosion resistance and conductivity, with examples including gold, silver, titanium, glass, rubber, and most non-ferrous metals.

Characteristics

No Attraction: They show little to no pull towards magnets.

Electron Balance: Their electrons' magnetic spins pair up and cancel each other out, or interact weakly.

Non-Ferrous: Most common non-magnetic metals lack significant iron content.

Examples include;

Metals: Aluminum, Copper, Brass, Gold, Silver, Titanium, Lead, Zinc. **Other Materials:** Wood, Plastic, Glass, Rubber, Paper, Water.

Examples of Non-Magnetic Materials explained:

Copper: A non-magnetic metal commonly used in electrical wiring due to its excellent conductivity and lack of magnetic interference.

Aluminium: Another non-magnetic metal that is lightweight and often used in manufacturing and packaging.

Zinc: A non-magnetic metal used for galvanization to prevent rusting in steel and iron.

Wood: An organic, non-metallic material that is non-magnetic and often used in construction and manufacturing.

Rubber: A flexible, non-magnetic material often used for insulation and protective coverings.

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Applications

Electronics: Used for casings and components where magnetic fields can interfere.

Medical: Essential in MRI rooms and for surgical tools to avoid magnetic interference.

Aerospace: Lightweight and non-magnetic properties are crucial for aircraft parts.

Everyday Items: Coins (modern ones), jewelry, and construction materials.

Why they're Important

They provide alternatives to magnetic metals in sensitive applications, ensuring devices function correctly without magnetic interference.

Many non-magnetic metals offer excellent corrosion resistance and electrical conductivity.

In everyday life, non-magnetic materials are prevalent and essential. For instance, kitchen utensils made of plastic or aluminum, furniture made of wood and packaging materials like paper all fall into this category.

How to Identify Magnetic and Non-Magnetic Materials

The classification of materials into magnetic and non-magnetic can be done using a simple experiment with a magnet. By bringing a magnet close to various materials, learners can observe whether the material is attracted to the magnet (indicating it is magnetic) or not (indicating it is non-magnetic).

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Get a Magnet: Use a refrigerator magnet or another known magnet.
Bring Near: Hold the magnet close to the object you want to test.
Observe:
Attraction: If the object moves towards the magnet, it's **magnetic** (steel paperclip, iron nail).
No Attraction: If the object doesn't move, it's **non-magnetic** (wood, plastic, glass).
Repulsion (Bonus Test): If the object pushes away from the magnet, it's not just magnetic, it's another magnet! Repulsion is a strong indicator of true magnetism.

Conclusion
Magnetic materials, such as iron, nickel, and cobalt, are attracted to magnets due to their atomic structure, which allows their electrons to align in a way that creates a magnetic field. Examples include steel and certain rare earth metals.
Non-magnetic materials, such as aluminum, copper, and plastic, do not exhibit this attraction and cannot be magnetized

Magnetic properties of Steel and Iron
The magnetic properties of iron and steel differ significantly due to their composition. Iron, a pure element, is easily magnetized and exhibits strong ferromagnetic properties. However, it tends to lose its magnetism relatively quickly when the external magnetic field is removed. This characteristic makes iron suitable for applications requiring temporary magnetism. In contrast, steel, an alloy primarily composed of iron and carbon, demonstrates a unique magnetic behavior. While it retains a strong magnetic field, its retention is lower than that of pure iron. The presence of carbon and other alloying elements in steel enhances its structural integrity, making it more durable while still maintaining magnetic properties. When bars of Iron and steel of the same size are placed in contact with a pole of a permanent magnet as shown below and placed in Iron filings. More Iron filings are attracted to the Iron than those on steel. When the Iron and steel bars are removed from the magnet, all Iron filings fall off and little if any falls off the steel bar. It can be concluded that, the induced magnetism of Iron is stronger than that of steel. From the above experiment, Iron can be regarded as a soft magnetic material and steel a hard magnetic material.
Magnetic materials are classified into two main categories: hard and soft magnetic materials, each with distinct properties and applications. Hard magnetic materials, such as neodymium and ferrite, exhibit permanent magnetism, meaning they retain their magnetization even in the absence of an external magnetic field. This characteristic makes them ideal for applications like permanent magnets in motors and generators. In contrast, soft magnetic materials, such as iron and silicon steel, possess temporary magnetism. They can be easily magnetized and demagnetized, which allows them to respond quickly to changing magnetic fields. This property is crucial in applications like transformers and inductors, where efficient magnetic flux management is essential. The key difference lies in their coercivity: hard materials have high coercivity, while soft materials have low coercivity.

Differences between Temporary and Permanent Magnets
Magnets are materials that produce a magnetic field, attracting certain materials such as iron, nickel, and cobalt. They are broadly classified into temporary magnets and permanent magnets based on their ability to retain magnetic properties.
Retention of Magnetism
The primary distinction between temporary and permanent magnets lies in their ability to retain magnetism. Permanent magnets are materials that retain their magnetic properties even after the external

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magnetizing force is removed. They are inherently magnetic due to their atomic structure, where magnetic domains are aligned and remain fixed. Examples include neodymium, alnico, and ferrite magnets. In contrast, temporary magnets exhibit magnetism only when exposed to an external magnetic field. Once the external field is removed, their magnetic properties quickly diminish or disappear entirely. Soft iron is a common example of a temporary magnet.

Material Composition

The composition of the material plays a critical role in determining whether a magnet is temporary or permanent. Permanent magnets are typically made from hard magnetic materials, such as steel, cobalt, and certain alloys, which have a high resistance to demagnetization. These materials require a significant amount of energy to align their magnetic domains, making them stable over time. On the other hand, temporary magnets are made from soft magnetic materials like soft iron. These materials have low resistance to demagnetization, allowing their magnetic domains to realign easily under an external field but revert to a random state when the field is removed.

Strength and Stability

Permanent magnets generally provide consistent and stable magnetic fields over time, making them suitable for applications where a constant magnetic force is required, such as in electric motors, generators, and loudspeakers. Their strength is a result of the permanent alignment of magnetic domains. Temporary magnets, however, exhibit varying magnetic strength depending on the intensity of the external field. Their magnetic properties are transient, which makes them ideal for applications like electromagnetic cranes, which require controlled magnetism.

Cost and Durability

Permanent magnets tend to be more expensive to produce due to the use of rare-earth elements or specialized alloys. However, they offer durability and long-term performance, making them cost-effective in the long run for certain applications. Temporary magnets are usually less expensive, as they are made from readily available materials. However, their limited use in retaining magnetism and susceptibility to external conditions like temperature make them less durable for applications requiring sustained magnetic properties.

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Applications

The differences in magnetic retention and material properties lead to distinct applications for each type of magnet. Permanent magnets are used in devices requiring a stable magnetic field, such as compasses, electric motors, and magnetic storage media. They are also found in everyday objects like refrigerator magnets and magnetic locks. Conversely, temporary magnets are used in applications where the magnetic field needs to be easily turned on and off, such as in electromagnets used in electric bells, maglev trains, and scrapyard cranes. Their ability to lose magnetism quickly when the external field is removed is advantageous in such contexts.

Dependence on External Factors

Temporary magnets are highly dependent on external factors such as the presence of an external magnetic field or electric current. Without these factors, they cannot maintain their magnetic properties. In contrast, permanent magnets are less influenced by external conditions. However, their performance can be slightly affected by extreme temperatures or physical damage, which may cause partial demagnetization.

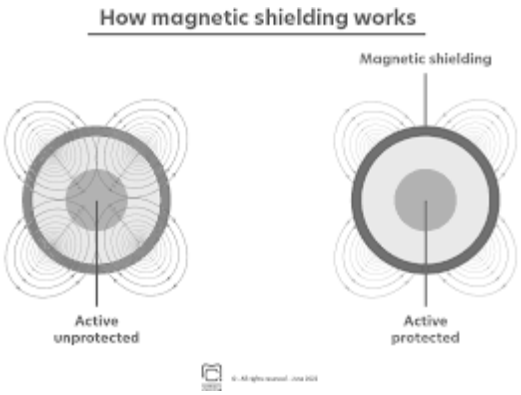
Magnetic Domain Alignment

In permanent magnets, the alignment of magnetic domains is fixed and remains consistent without external influence. This alignment is achieved during manufacturing through processes like heating the material above its Curie temperature and exposing it to a strong magnetic field. In temporary magnets, the magnetic domains are randomly aligned in the absence of an external field and only temporarily align when subjected to magnetizing forces.

Magnetic screening (shielding)

Magnetic shielding

Any ferromagnetic material can be used for magnetic screening of sensitive electronic equipment. Steel is often used as it is cheap, readily available and works well in strong magnetic fields. Mu-metal, a nickel iron soft ferromagnetic material is more effective for weaker magnetic fields but is more expensive.



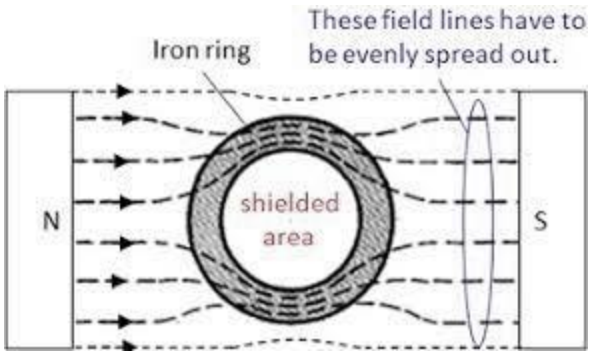
Magnetic shielding, also known as magnetic screening, is a technique used to exclude magnetic fields from specific areas by redirecting their field lines. This process is essential in protecting sensitive electronic devices, such as alternating-current measuring instruments, from stray external magnetic fields that could interfere with their operation. By utilizing materials with high magnetic permeability, like steel or iron, magnetic shielding effectively reroutes the magnetic field, preventing it from penetrating the shielded area. There are two primary types of magnetic shielding: **passive and active.** Passive shielding involves using materials to absorb and redirect magnetic fields, while active shielding employs controlled currents to neutralize magnetic fields. Although static magnetic fields cannot be completely blocked, they can be significantly reduced through these methods, enhancing the performance and longevity of devices like Hall thrusters in aerospace applications.

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Magnetic screening, also known as magnetic shielding, is the process of reducing or blocking the influence of a magnetic field in a specific area by redirecting or absorbing the magnetic field lines. This technique is used to protect sensitive equipment, devices, or spaces from unwanted magnetic interference, which can cause functional disruptions or inaccuracies. Magnetic shielding is achieved by using materials that have high magnetic permeability, such as soft iron, mu-metal, or certain ferromagnetic alloys, which attract and channel magnetic field lines away from the protected area.

The principle of magnetic shielding lies in the ability of high-permeability materials to provide a low-resistance path for magnetic field lines. When a magnetic field encounters a shielding material, the field lines are concentrated within the material instead of passing through the shielded region. This occurs because the shielding material has a higher capacity to "conduct" magnetic flux compared to air or non-magnetic materials. As a result, the field intensity inside the shielded area is significantly reduced or eliminated, depending on the effectiveness of the shielding material and its configuration.

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For instance, in medical imaging technologies like Magnetic Resonance Imaging (MRI) machines, magnetic shielding ensures that external magnetic fields do not distort the images or compromise the machine's performance. Similarly, in scientific laboratories, sensitive equipment such as electron microscopes and superconducting quantum interference devices (SQUIDs) require shielding to maintain accurate measurements in environments exposed to fluctuating magnetic fields. The design of magnetic shielding depends on factors such as the strength and frequency of the magnetic field, the level of shielding required, and the size and shape of the area to be protected. Common shielding configurations include enclosures, sheets, or layers of high-permeability materials placed around the object or space. For low-frequency magnetic fields, materials like mu-metal are often used because of their excellent shielding properties, while for high-frequency fields, conductive materials like copper or aluminum are more effective due to their ability to reflect electromagnetic waves.

Electrical Quantities

ELECTROSTATICS

Learning Outcomes

a) *Understand everyday effects of static electricity and explain them in terms of the build-up and transfer of electrical charge (u,s)*
b) *Apply knowledge of electrostatic charge to explain the operation of devices like lightening conductors (u, s,v/a)*

Introduction

Electrostatic charges arise when electrons are transferred between objects by rubbing. Sparks can fly after you comb your hair or walk across a synthetic carpet when you touch an earthed object, through which the charge can be neutralised; the discharge can lead you to feel a small electric shock. A flash of lightning is nature's most spectacular static electricity effect. There are two types of electrostatic charge. Like charges repel while opposite charges attract. Charges build up on an insulator such as plastic and remain static, but for conductors like metals, charges flow away to try to neutralise charge. Both electrical conductors and insulators have their uses.

Electric charges are surrounded by an electric field which exerts a force on a nearby charge.

This effect is made use of in applications from ink-jet printers to crop sprayers. As with a magnetic field, an electric field exerts an action-at-a-distance force.

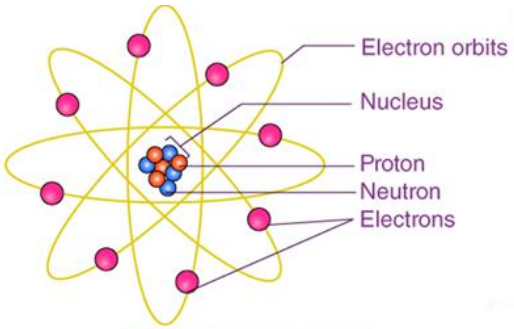
Clothes containing nylon often crackle when they are taken off. We say they are charged with static electricity; the crackles are caused by tiny electric sparks which can be seen in the dark. Pens and combs made of certain plastics become charged when rubbed on your sleeve and can then attract scraps of paper.

Electrostatics is a branch of physics that focuses on the study of electric charges at rest. It examines the forces and interactions between stationary electric charges, which can either attract or repel each other. This phenomenon occurs when there are no moving charges, establishing a static equilibrium. The most common examples of electrostatics are the behavior of materials when rubbed together, such as a plastic

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rod rubbed with fur or a glass rod with silk. This friction generates static electricity, leading to observable effects like the attraction of small particles or the discharge of sparks. The fundamental principle governing electrostatics is Coulomb's Law, which quantifies the electrostatic force between two charges. Hence, this refers to the study of charge at rest.



The Structure of Atom

Structure of an atom

An atom has a dense, central nucleus containing positively charged protons and neutral neutrons, surrounded by a cloud of much lighter, negatively charged electrons orbiting in distinct energy levels or shells; the number of protons defines the element, while the equal number of protons and electrons in a neutral atom balances their charges.

Positive and negative charges

When a strip of polythene is rubbed with a cloth it becomes charged. If it is hung up and another rubbed polythene strip is brought near, repulsion occurs. Attraction occurs when a rubbed strip of cellulose acetate is brought near.

These shows there are two kinds of electric charge.

That on cellulose acetate is taken as **positive** (+) and that on polythene is **negative** (–). It also shows that: Like charges (+ and +, or – and –) repel, while unlike charges (+ and –) attract.

The force between electric charges decreases as their separation increases.

Components of an Atom

Positive charges repel other positive charges, but positive charges attract negative charges

Negative charges repel other negative charges, but negative charges attract positive charges

Charges, atoms and electrons

There is evidence that we can picture an atom as being made up of a small central nucleus containing positively charged particles called **protons**, surrounded by an equal number of negatively charged **electrons**. The charges on a proton and an electron are equal and opposite so an atom as a whole is normally electrically neutral, i.e. has no net charge.

Hydrogen is the simplest atom with one proton and one electron. A copper atom has 29 protons in the nucleus and 29 surrounding electrons. Every nucleus except hydrogen also contains uncharged particles called **neutrons**

The production of charges by rubbing can be explained by supposing that friction causes electrons to be transferred from one material to the other. For example, when cellulose acetate is rubbed with a cloth, electrons go from the acetate to the cloth, leaving the acetate short of electrons, i.e. positively charged. The cloth now has more electrons than protons and becomes negatively charged. Note that it is only electrons which move; the protons remain fixed in the nucleus.

Key Principles

Atomic Number (Z): The number of protons in the nucleus, which determines the element (8 protons = Oxygen).

Mass Number (A): The total count of protons and neutrons (A = Z + N).

Neutral Atom: Has an equal number of protons and electrons, resulting in no net electrical charge.

Isotopes: Atoms of the same element (same protons) with different numbers of neutrons.

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Static electricity is a common phenomenon resulting from an imbalance of electric charges on the surface of materials. When two objects come into contact and are then separated, electrons may transfer from one to the other, leading to one object becoming positively charged and the other negatively charged. This charge buildup can create noticeable effects, such as the familiar shock felt when touching a doorknob after walking on a carpet. The effects of static electricity can be both beneficial and hazardous. It can be harnessed in applications like photocopiers and air purifiers. Static discharges can damage sensitive electronic components, ignite flammable materials, and disrupt industrial processes. Static electricity can lead to physical phenomena, such as electrostatic attraction or repulsion, causing materials to stick together or repel each other.

Effects of Static Electricity

Static electricity is the buildup of electric charges on the surface of materials, typically resulting from friction, separation, or induction. When two objects come into contact and then separate, electrons can transfer from one surface to another, creating an imbalance in electric charge. This imbalance often results in various observable and measurable effects, which can be categorized as beneficial, disruptive, or even hazardous, depending on the context.

Attraction and Repulsion of Objects

One of the most noticeable effects of static electricity is the attraction or repulsion of objects. When an object becomes statically charged, it can attract neutral objects or repel other charged objects with like charges. For instance, a statically charged balloon can stick to a wall or attract small pieces of paper. This phenomenon occurs because the electric field created by the charged object induces opposite charges on nearby neutral objects, leading to an attractive force. Similarly, objects with similar charges repel each other due to electrostatic forces. This effect is commonly observed in everyday life, such as when combing hair on a dry day, where strands of hair repel each other and stand up due to static charge buildup. While often harmless, such effects can also cause challenges in industrial processes, where unwanted static attraction can interfere with material handling and packaging.

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Static Electricity Discharges

The sudden release of static electricity, known as an electrostatic discharge (ESD), is another significant effect. When a charged object comes into proximity with a conductor or another object with a different charge, the electric field can cause electrons to jump across the gap, resulting in a discharge. This is often experienced as a small shock when touching a doorknob after walking on a carpeted floor. While such discharges are usually harmless to humans, they can have serious implications in certain environments. In industrial and technological settings, ESD can damage sensitive electronic components, such as semiconductors, integrated circuits, and microchips. These devices are vulnerable because the high voltage associated with ESD can cause permanent damage to their intricate structures. Consequently, static electricity control measures, such as grounding, ionization, and antistatic materials, are widely used to prevent such effects.

Hazards in Flammable Environments

Static electricity can pose significant safety risks in environments containing flammable gases, vapors, or dust. A static discharge in such settings can ignite combustible materials, leading to fires or explosions. For example, in oil and gas facilities, the movement of fluids through pipes can generate static charges, and if these charges accumulate and discharge near flammable substances, they can trigger catastrophic accidents. Similarly, static electricity is a concern in industries such as grain handling and chemical

manufacturing, where combustible dust or volatile chemicals are present. To mitigate these risks, industries implement strict safety measures, including proper grounding, bonding of equipment, and the use of antistatic clothing and tools. These measures help dissipate static charges before they can accumulate to dangerous levels.

Disruption in Everyday Activities

Static electricity can also interfere with routine activities and the performance of certain technologies. For instance, in the printing and textile industries, static charges can cause materials to stick together, leading to production inefficiencies and defects. Similarly, in photography or electronics manufacturing, dust particles attracted by static electricity can compromise product quality. In addition, static electricity can affect consumer electronics, such as touch screens, where it may cause erratic behavior or temporary malfunctions. Although these effects are typically minor, they highlight the need for effective static control in modern technology.

Positive Applications of Static Electricity

Despite its potential hazards, static electricity also has numerous beneficial applications. For example, it is used in electrostatic precipitators to control air pollution. In these devices, static charges are applied to particulate matter in exhaust gases, causing the particles to be attracted to oppositely charged plates, effectively removing them from the air stream. This technology is widely used in industries to reduce emissions. Static electricity is also used in photocopiers and laser printers, where it plays a key role in transferring toner to paper to create printed images and text. Additionally, it is employed in electrostatic painting, where charged paint particles are sprayed onto objects, ensuring an even and efficient coating.

Biological Effects

Static electricity can affect living organisms, including humans. Low-level discharges, such as those experienced when touching a charged object, are generally harmless but can be startling or uncomfortable. Prolonged exposure to strong static electric fields, however, may cause mild discomfort or physiological effects, such as tingling sensations. In rare cases, static electricity can interfere with medical devices like pacemakers, emphasizing the need for precautions in healthcare settings.

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Environmental Impact

In natural phenomena, static electricity contributes to significant events such as lightning. Lightning occurs when charges build up in clouds due to friction between air molecules and water droplets. When the charge difference between the cloud and the ground becomes too great, a massive discharge occurs, releasing energy in the form of light, heat, and sound. While awe-inspiring, lightning can cause severe damage to property, ecosystems, and human life.

Insulators and Conductors:

Insulators and conductors are two fundamental classifications of materials based on their ability to transmit electrical current or heat. Understanding these materials and their properties is critical in science, engineering, and daily life, as they form the foundation of numerous applications in technology, safety, and energy management.

Properties and Effects

Insulators are materials that do not allow the free flow of electric current or heat. This resistance to conduction occurs because their atomic structure does not have free electrons available to move easily

between atoms. Instead, electrons in insulators are tightly bound to their atoms, which inhibits the transmission of electrical energy. Common examples of insulators include rubber, glass, plastic, wood, and ceramics. In daily life, insulators play a crucial role in ensuring safety and efficiency in electrical and thermal systems. For instance, electrical wires are coated with insulating materials such as plastic or rubber to prevent accidental electric shocks and to ensure that electricity flows only through the conductor inside. Similarly, insulators are used in home appliances, such as oven handles or electrical outlets, to prevent the transfer of heat or electricity to unintended areas. Insulators are also significant in reducing energy loss. For example, insulating materials such as fiberglass or foam are used in building construction to minimize heat transfer, keeping indoor spaces warm in winter and cool in summer. This reduces energy consumption for heating and cooling, making buildings more energy-efficient and environmentally friendly.

Properties and Effects

Conductors are materials that allow the free flow of electric current or heat due to the presence of free electrons in their atomic structure. These electrons can move easily between atoms, facilitating the transfer of energy. Metals such as copper, aluminum, silver, and gold are excellent electrical conductors, while materials like iron and steel are good conductors of both heat and electricity. Conductors are indispensable in daily life, particularly in electrical and electronic systems. Copper, for example, is widely used in electrical wiring due to its excellent conductivity, affordability, and flexibility. Aluminum is another common conductor, often used in high-voltage power lines because it is lightweight and relatively inexpensive. The ability of conductors to efficiently transmit electricity ensures the operation of household appliances, lighting, communication devices, and industrial equipment.

In addition to electricity, conductors play a vital role in heat transfer. For instance, metals like aluminum and stainless steel are used in cookware because they efficiently conduct heat, ensuring that food cooks evenly. Heat conductors are also employed in radiators, heat exchangers, and engines, where rapid and effective heat dissipation is necessary to maintain performance and safety.

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Combined Use of Insulators and Conductors

The combined use of insulators and conductors is central to the design of most electrical and electronic systems. For example, electrical circuits require conductive materials to allow current flow, but they also need insulating materials to protect users and to prevent short circuits. A typical example is a power cord, where copper wires conduct electricity while the plastic coating serves as an insulator to prevent accidental shocks. Similarly, in thermal applications, the strategic use of conductors and insulators enhances energy efficiency and functionality. For example, a thermos flask uses insulating materials to keep beverages hot or cold by minimizing heat transfer, while the metallic interior ensures even temperature distribution.

Daily Challenges and Solutions

While insulators and conductors are essential, they also present challenges in everyday life. Poor insulation in electrical systems can lead to energy loss, higher electricity bills, and even fire hazards. Similarly, improper use of conductors can result in accidental electric shocks or equipment damage. To address these challenges, manufacturers and engineers have developed advanced materials and technologies. For instance, improved insulating materials, such as polymer composites, are now used in high-voltage transmission systems to enhance safety and efficiency. Innovations in conductive materials, such as superconductors, offer the potential for more efficient energy transmission with minimal resistance.

Environmental and Industrial Implications

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The choice of conductors and insulators also has significant environmental and industrial implications. Metals like copper and aluminum require energy-intensive mining and manufacturing processes, which contribute to environmental degradation. Recycling these materials, however, reduces the environmental impact and conserves resources. Similarly, insulating materials, particularly plastics, can pose environmental challenges due to their non-biodegradable nature. The development of biodegradable or recyclable insulators is an area of ongoing research to address these concerns.

Examples in Nature and Everyday Life

Nature provides its own examples of insulators and conductors. For instance, air is a natural insulator, preventing the easy transfer of electricity and heat. This property is harnessed in power lines, where air serves as an insulating medium between live wires and the ground. In contrast, water, particularly saltwater, acts as a conductor due to the presence of dissolved ions. This principle is critical in understanding lightning strikes, where the conductive properties of water in the atmosphere and the ground facilitate the discharge of electricity.

In daily life, the principles of conductors and insulators are evident in activities as simple as cooking, where metal pots conduct heat while plastic or wooden handles prevent burns. Similarly, the clothes we wear, often made of insulating materials like wool or synthetic fibers, help regulate body temperature by trapping heat.

Everyday Examples of Static Electricity

Static electricity is a common phenomenon that we encounter in our daily lives, often without realizing it. It occurs when there is an imbalance of electric charges on the surface of materials, typically resulting from friction or the movement of electrons between objects. While it is a natural occurrence, static electricity can manifest in a variety of ways, some of which are harmless and even useful, while others can be inconvenient or potentially hazardous.

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Shocks from Door Handles or Metal Objects

One of the most common and familiar experiences with static electricity occurs when a person touches a metal doorknob or any other conductive surface after walking on a carpet or rubbing against a synthetic fabric. This sudden shock is the result of an electrostatic discharge (ESD), where electrons rapidly flow from the person to the metal object, neutralizing the charge imbalance. The shock itself is typically harmless but can be startling or uncomfortable. This phenomenon occurs more frequently in dry weather, as low humidity levels prevent the dissipation of charge, leading to an accumulation of static electricity on the body.

Hair Standing on End

Another well-known example of static electricity is when a person's hair stands up after brushing or combing it, especially during dry weather. This effect occurs because combing or brushing the hair causes the transfer of electrons between the hair and the comb, creating an imbalance of electric charges. The individual strands of hair become charged with the same type of charge (either positive or negative), and because like charges repel each other, the hair fibers push away from each other, causing the hair to stand upright. This can be a temporary effect, but it is often most noticeable when the environment is dry, which is conducive to the buildup of static charges.

Static Cling in Clothing

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Static electricity is the main cause of the frustrating problem of static cling in clothing, particularly when wearing synthetic fabrics like polyester. When clothes made of synthetic materials rub against each other in the dryer or during wear, electrons are transferred between them, causing one item to become negatively charged and the other positively charged. As a result, the clothes attract each other, causing them to cling together. This effect can be especially troublesome when clothing sticks to the skin or other garments. To mitigate static cling, fabric softeners or dryer sheets are often used, as they help neutralize the static charge by adding a conductive layer to the fabric.

Sparks from Touching Electronics

Another common example of static electricity in daily life occurs when individuals touch sensitive electronic devices, such as computers, televisions, or cell phones, and experience a brief spark or discharge. This occurs when a person has accumulated a significant static charge by walking on a carpet, rubbing clothing, or moving through an area with low humidity. The charged person then touches an electronic device, and the charge flows into the device, causing a visible spark. While this is often harmless to the person, it can be damaging to sensitive electronic components, leading to malfunctions or, in extreme cases, complete failure of the device. Therefore, electronic manufacturers take Procedures to design equipment with grounding systems to minimize the effects of static electricity.

The Attraction of Dust and Small Debris

Static electricity also causes dust and small particles to be attracted to certain surfaces. This effect can be seen when cleaning televisions, computer screens, or even plastic items like packaging materials. The buildup of static charge on a surface can attract dust particles from the air, causing them to stick to the surface. This is particularly evident when cleaning electronics, where small particles may cling to the screen or keyboard despite efforts to wipe them away. The effect is most noticeable in environments with low humidity, as moisture in the air typically helps to reduce static charge accumulation.

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Use of Electrostatic Precipitators

In some households or industries, static electricity is intentionally used for practical purposes, such as in electrostatic precipitators. These devices are designed to remove dust and particulate matter from the air by charging the particles and then using an oppositely charged collector plate to attract and capture them. This process is commonly used in air purifiers, where static electricity is harnessed to remove allergens, smoke, and other pollutants from the air. Similarly, industrial electrostatic precipitators are employed to reduce air pollution from smokestacks by capturing harmful particulates before they are released into the atmosphere.

The Functioning of Copy Machines and Printers

Static electricity also plays a critical role in the operation of photocopiers and laser printers. These machines rely on the principle of electrostatic charge to transfer toner onto paper. In a photocopier or laser printer, a drum or belt is charged with static electricity, and a laser or light source selectively discharges areas of the drum, forming an image. The toner, which is charged with the opposite type of charge, is then attracted to the discharged areas, and the image is transferred to the paper. This process, known as xerography, is efficient and widely used in modern printing technology.

Spark Discharge When Fueling Vehicles

When fueling a vehicle at a gas station, static electricity can build up on the body of the car or on the person's clothes, especially when moving in and out of the vehicle. If this static charge discharges when

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coming into contact with the gas nozzle, it can cause a small spark. Although rare, this spark could ignite flammable vapors, leading to a fire or explosion. To prevent this, it is important to touch a metal surface away from the fuel nozzle to discharge any built-up static before refueling, ensuring a safe fueling process.



Charging by friction: When two different materials are rubbed together, electrons are transferred from one material to the other. Charging by friction, also known as turboelectric charging, occurs when two insulating materials are rubbed together, resulting in the transfer of electrons from one object to another. This process leads to one object becoming positively charged and the other negatively charged. The material losing electrons becomes positively charged, while the material gaining electrons becomes negatively charged. The phenomenon is commonly observed in everyday situations, such as when a plastic comb is rubbed through hair, causing the comb to attract hair strands due to the opposite charges. The effectiveness of charging by friction depends on the materials involved.

Different insulating materials have varying tendencies to gain or lose electrons, which is described by the turboelectric series. When two materials from this series are rubbed together, the one higher on the list will typically lose electrons, while the one lower will gain them.

This method of charging is significant in understanding static electricity and has practical applications in various fields, including electronics and material science.

Friction Generates Electric Charge

When two materials rub against each other, electrons are transferred from one material to another. The material that gains electrons becomes negatively charged, while the material that loses electrons becomes positively charged. On insulators, electric charge can build up because these materials do not allow electrons to move freely. For example, when rubbing a balloon, the balloon (an insulator) can retain the charge.

Charging by Induction

Charging by induction involves bringing a charged object close to a neutral object without direct contact. The presence of the charged object causes a redistribution of charges within the neutral object. This results in the neutral object acquiring a charge opposite to that of the charged object.

Example: If a negatively charged rod is brought near a neutral metal sphere, electrons in the sphere will be repelled, causing a positive charge to appear on the side closest to the rod.

Principle of Charging by Induction

The fundamental principle behind induction is the ability of a charged object to influence the distribution of charges within a nearby neutral object. When a charged object (either positively or negatively) is brought close to a neutral object, the electric field from the charged object exerts a force on the electrons within the neutral object. If the charged object is positively charged, it will attract electrons from the neutral object, causing them to accumulate on the side of the object closest to the charged object, creating a negative charge on that side. Conversely, the side of the neutral object farthest from the charged object will have a deficit of electrons, resulting in a positive charge. This separation of charges creates a dipole within the neutral object, with the side nearest to the charged object becoming negatively charged and the far side becoming positively charged. This redistribution of charges within the object does not involve

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any physical transfer of electrons from the charged object but rather a rearrangement of electrons within the neutral object.

Procedures Involved in Charging by Induction

The process begins when a charged object, such as a charged rod (either positively or negatively charged), is brought near a neutral conducting object, such as a metal sphere or a metal plate.

The electric field from the charged object causes the electrons in the neutral object to move. If the charged object is negatively charged, it repels the electrons in the neutral object, pushing them away, which leaves a positive charge near the charged object. If the charged object is positively charged, it attracts the electrons of the neutral object, causing them to move toward the region near the charged object, creating a negative charge.

As a result of the redistribution of electrons, the neutral object develops two regions: a region of negative charge (closer to the charged object) and a region of positive charge (further from the charged object). This is known as electrostatic induction.

If the neutral object is connected to the ground during induction, the object will lose or gain electrons through the ground, depending on the type of charge of the external object. For example, if a negatively charged object is brought near the neutral object, the neutral object's electrons will be repelled to the ground, leaving behind a positively charged object. If the object is then disconnected from the ground while the external charge is still nearby, the object will retain a net positive charge.

After the charged object is removed, the redistributed charges within the neutral object remain in their new positions. If the object has been grounded, the flow of charge will stop once the grounding is removed. If the object has not been grounded, the redistribution of charges results in a net charge on the object.

Types of Induction

There are two main types of induction:

Electrostatic Induction (**Conduction without touching**): This occurs when a charged object induces a charge separation within a nearby object, leading to an induced charge. In this case, the object does not physically touch the charged body, but the redistribution of charges creates a net charge on the object.

Induced Charge Separation: This involves the temporary rearrangement of charges within an object. When a charged body is brought near a neutral object, it causes the electrons within the neutral object to shift. However, once the charged object is removed, the induced charges disappear, and the object returns to its original state.

Applications of Charging by Induction

Capacitors use the principle of charging by induction to store energy. When two conductive plates are placed close together and connected to a power source, the electric field from the power source induces charges on the plates. The positive plate attracts electrons, and the negative plate repels them, creating a potential difference between the plates. The energy is stored as electrostatic energy in the form of a charge imbalance.

The electrophorus is a device used to generate static electricity by induction. It consists of a charged plate and a metal disc. By touching the disc to the charged plate, charge is induced on the metal disc. This induced charge can then be transferred to other objects.

A lightning rod works on the principle of induction. It is designed to provide a safe path for the discharge of electricity from a storm cloud to the ground. The charged cloud induces charges on the lightning rod, causing the rod to become oppositely charged. This attracts the lightning strike to the rod, where it is then conducted safely to the ground.

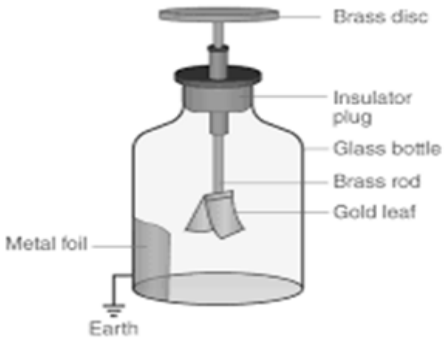
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The concept of inductive charging, which is commonly used in wireless charging devices, is based on induction. In these systems, an alternating current (AC) in the charging pad creates a changing magnetic field that induces a current in a coil within the device, thus charging it without the need for physical connections.
Induction is used in devices like electrostatic precipitators, which remove particulate matter from the air in industrial settings. These devices induce charges on particles, causing them to move toward oppositely charged plates where they are collected and removed from the air.

Charge Transfer
Charges can be transferred between objects through direct contact or by induction. When two objects come into contact, electrons can move from one to the other, transferring the charge.
Electrons: The primary particles responsible for electric charge are electrons. Electrons carry a negative charge. The movement of electrons from one object to another creates static electricity.

Gold Leaf Electroscope
A gold-leaf electroscope consists of a metal cap on a metal rod at the foot of which is a metal plate with a leaf of gold foil attached. The rod is held by an insulating plastic plug in a case with glass sides to protect the leaf from draughts.



Detecting a charge
Bring a charged polythene strip towards the cap: the leaf rises away from the plate. When you remove the charged strip, the leaf falls again. Repeat with a charged acetate strip.

Charging by contact
Draw a charged polythene strip firmly across the edge of the cap. The leaf should rise and stay up when the strip is removed. If it does not, repeat the process but press harder. The electroscope has now become negatively charged by contact with the polythene strip, from which electrons have been transferred.

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Insulators and conductors
Touch the cap of the charged electroscope with different things, such as a piece of paper, a wire, your finger, a comb, a cotton handkerchief, a piece of wood, a glass rod, a plastic pen, rubber tubing. Record your results.
When the leaf falls, charge is passing to or from the ground through you and the material touching the cap. If the fall is rapid the material is a **good conductor**; if the leaf falls slowly, the material is a poor conductor. If the leaf does not alter, the material is a **good insulator**.
The gold-leaf electroscope used in this experiment could be replaced by an electronic instrument capable of measuring electric charge – an electrometer.

Electrons, insulators and conductors
In an insulator all electrons are bound firmly to their atoms; in a conductor some electrons can move freely from atom to atom. An insulator can be charged by rubbing because the charge produced cannot move from where the rubbing occurs, i.e. the electric charge is static. A conductor will become charged only if it is held with an insulating handle; otherwise electrons are transferred between the conductor and the ground via the person's body.

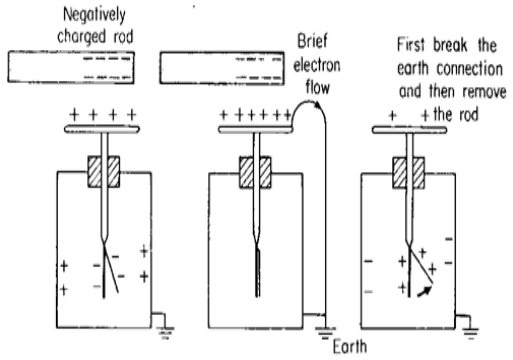
Good insulators include plastics such as polythene, cellulose acetate, Perspex and nylon. All metals and carbon are good conductors. In between are materials that are both poor conductors and (because they conduct to some extent) poor insulators. Examples are wood, paper, cotton, the human body and the Earth. Water conducts and if it were not present in materials such as wood and on the surface of, for example, glass, these would be good insulators. Dry air insulates well.

Function of a Gold Leaf Electroscope:

The gold leaf electroscope is a sensitive device used to detect, measure, and observe electric charges. It consists of a metal rod with a metal cap at one end and thin gold leaves at the other, housed in a transparent insulating case to protect the leaves from disturbances.

When a charged object is brought near the cap, charges in the electroscope redistribute, causing the gold leaves to repel each other. This divergence indicates the presence and magnitude of the charge. The electroscope can also determine the type of charge on an object by observing the behavior of the leaves when a charged object is brought close.

In addition to detecting charges, the electroscope is used to compare the relative magnitude of charges and distinguish between conductors and insulators. A conductor transfers charge to the electroscope, causing the leaves to diverge, while an insulator does not affect the leaves. Furthermore, the electroscope has been historically used to detect ionizing radiation, as radiation neutralizes its charge, causing the leaves to collapse.



CHARGING A GOLD LEAF ELECTROSCOPE BY INDUCTION

Charging it positively

Bring a negatively charged rod near the cap of the gold leaf electroscope. Positive charges are attracted to the cap and negative charges are repelled to the plate and gold leaf.

The leaf diverges due to repulsion of the same number of charges on the plates and the leaf. Earth the gold leaf electroscope in presence of a negatively charged rod. Electrons on the plate and leaf flow to the earth. The leaf collapses.

Remove the negatively charged rod. Positive charges on the cap spread out to the plate and leaf therefore the leaf diverges, hence the gold leaf is positively charged.

Charging it negatively

Get an uncharged gold leaf electroscope.

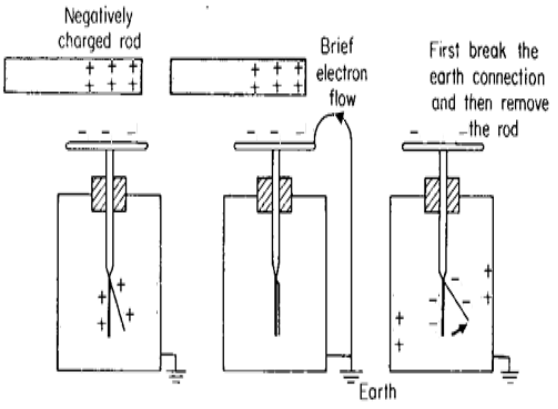
Bring a positively charged rod near its cap.

Negative charges are attracted to the cap and positive charges are repelled to leaf and brass plate.

Earth the gold leaf electroscope in presence of a positively charged rod.

Negative charges flow from the earth to neutralize positive charges on plate and leaf. The leaf collapses.

Remove the positively charged rod, negative charges on the cap spread out on the leaf and plate, hence charged negatively



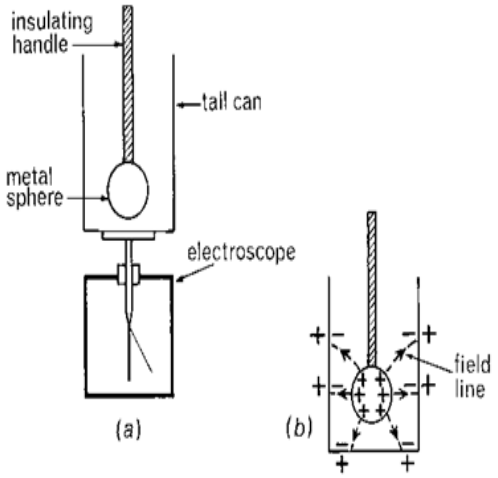
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Testing for presence of charge

A negatively charged rod is brought near the cap of a negatively charged gold leaf electroscope, the leaf increases in divergence as the charged rod is lowered on to the cap.

Distribution of charge on a conductor on Hollow conductor

When the proof plane is placed on the outside surface of a charged hollow conductor (a) and charge is transferred to the uncharged G.L.E, the leaf diverges. This proves that charge was present on the outside of the surface. When the proof plane is placed on the inside of a charged hollow conductor and transferred to the uncharged G.L.E, the leaf does not diverge. Therefore, charge resides on the outside surface of the hollow charged conductor.



Curved bodies

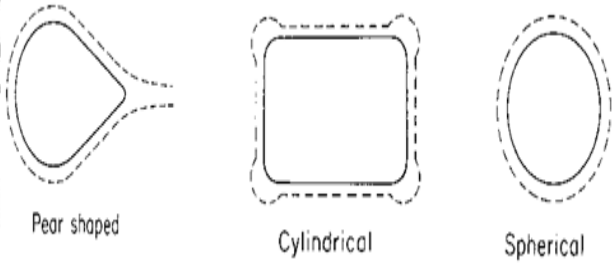
A curve with a big curvature has a small radius and a curve with small curvature has big radius therefore, curvature is inversely proportional to radius. A straight line has no curvature.

Surface charged density is directly proportional to the curvature. Therefore, a small curvature has small charge density.

Note. Surface charge density is the charge per unit area of the surface

Action of points

Charge concentrates at sharp points. This creates a very strong electrostatic field at charged points which ionizes the surrounding air molecules producing positive and negative ions. Ions which are of the same charge as that on the sharp points are repelled away forming an electric wind which may blow a candle flame as shown in the diagram below and ions of opposite charge are collected to the points



Therefore, a charged sharp point acts as; Spray off' of its own charge in form of electric wind. Collector of unlike charges.

The spray off and collecting of charges by the sharp points is known as **corona discharge**.

Application of action of points (corona discharge)

Used in a lightening conductor**,**

Used in electrostatics generators,

Electrostatic photocopying machines,

Aircrafts are discharged after landing before passengers are allowed to board. Aircrafts get electrified but charge remains on the outer surface.

Lightning

One of the most dramatic and powerful examples of static electricity is lightning, a natural phenomenon that occurs when static electricity builds up in the atmosphere. During thunderstorms, the movement of

air and water droplets causes friction, resulting in a build-up of static charges in the clouds. Once the charges reach a critical level, the electric field becomes strong enough to overcome the insulating properties of the air, causing a discharge in the form of a lightning strike. This discharge is a massive release of energy, producing a bright flash of light, a loud thunderclap, and significant heat. While lightning is awe-inspiring, it is also extremely dangerous and can cause fires, injuries, and even fatalities. Safety precautions, such as staying indoors during a storm, are essential to minimize the risks associated with lightning.

Occurrences of Lightning in Uganda

Uganda experiences frequent and intense lightning due to its equatorial location, high temperatures, and proximity to Lake Victoria, which create ideal conditions for storm formation. The country's rainy seasons and mountainous regions, such as the Rwenzori and Elgon areas, further contribute to the development of thunderstorms and lightning. Charged cumulonimbus clouds generate lightning through static electricity created by the collision of ice particles and water droplets. Lightning frequently strikes populated areas, schools, and farmlands, causing fatalities, injuries, and damage to property and infrastructure. Rural areas are particularly vulnerable due to a lack of lightning protection systems and proper grounding in buildings. Efforts to reduce the impact of lightning include awareness campaigns, installation of lightning arrestors, and enforcement of safety measures, although significant challenges remain in improving protection, especially in resource-limited regions.

Uganda experiences frequent thunderstorms, especially during the rainy seasons (March to May and September to November). Lightning is common in areas with high humidity and warm temperatures. Lightning strikes can cause fires, damage to buildings, and even fatalities. Understanding the patterns and frequency of lightning can help in disaster preparedness and safety.

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Causes of Lightning

Lightning is a form of static discharge that occurs when electric charges build up in clouds and the atmosphere. This buildup is caused by friction between different layers of air masses. As air currents cause collisions between ice crystals and water droplets in thunderstorms, static electricity accumulates. When the charge becomes strong enough, it is released as lightning. Lightning is a spectacular natural phenomenon caused by the buildup of static electricity within thunderstorm clouds. As turbulent winds move water droplets, ice crystals, and graupel (a type of soft hail) within the cloud, they collide and create an imbalance of electrical charges. This process leads to the accumulation of negative charges at the cloud's base and positive charges at the top. When the difference in charge becomes significant, a discharge occurs, resulting in lightning. This discharge can happen within the cloud (intra-cloud lightning) or between the cloud and the ground. The rapid expansion of heated air from the lightning bolt creates a shockwave, which we hear as thunder.

Lightning Conductors

Lightning conductors are metal rods placed on buildings and structures to safely conduct lightning strikes into the ground. They provide a path of low resistance for the electrical charge, preventing damage to the structure. Lightning conductors are installed at the highest points of a building and connected to a grounding system that disperses the charge safely into the earth. A lightning conductor, commonly known as a lightning rod, is a metal rod installed at the highest point of a building to protect it from lightning strikes. It is typically made of copper or aluminum and is connected to the ground through a thick wire. This system is crucial for safeguarding structures from the destructive power of lightning. The operation of a lightning conductor is based on the principle of induction. When a charged cloud passes overhead,

the conductor acquires an opposite charge, which helps to attract the lightning bolt. Upon striking the rod, the electrical energy is safely channeled down the conductor and into the ground, preventing damage to the building and its occupants. In addition to protecting buildings, lightning conductors are essential for safeguarding lives and reducing the risk of fire.

Factors Influencing Lightning Occurrence

Elevated regions and mountainous areas are more prone to thunderstorms and lightning.

High humidity levels, common in tropical climates, contribute to the formation of thunderstorms and lightning.

Warm temperatures increase the likelihood of convection currents, which can lead to thunderstorm development.

Causes of Lightning in Uganda

Lightning in Uganda is influenced by several environmental factors, including ground elevation, latitude, prevailing wind currents, and relative humidity. The country's unique geography, characterized by its proximity to both warm and cold bodies of water, contributes to the frequency of thunderstorms, which are the primary conditions for lightning strikes. Recent studies indicate that climate change is exacerbating extreme weather patterns in Uganda, leading to an increase in lightning occurrences.

Meteorologists have noted that as weather conditions become more unpredictable, the risk of deadly lightning strikes rises, posing a significant threat to communities. Additionally, traditional beliefs in Uganda often attribute lightning to supernatural forces, reflecting cultural interpretations of natural phenomena.

Impact of Lightning in Uganda

Lightning significantly impacts Uganda, causing fatalities, injuries, and extensive damage to infrastructure, agriculture, and the economy. Schools and rural areas are particularly vulnerable, with poorly grounded buildings and open spaces increasing the risk. Fatalities and injuries often occur, while property damage includes fires, destroyed electronics, and disrupted communication networks. Agriculture suffers from crop loss, livestock deaths, and risks to farmers working in fields, leading to food insecurity and economic setbacks.

The psychological effects of lightning, such as fear and trauma, affect communities, while educational disruptions occur when schools are struck. Environmentally, lightning can ignite fires, leading to habitat destruction and contributing to climate change. Efforts to mitigate these effects include installing lightning arrestors, raising awareness, and enforcing safety standards, though more resources are needed to reduce the ongoing risks.

Lightning Safety and Preparedness

Lightning safety and preparedness involve several key measures to minimize the risk of injury and damage during storms. Seeking shelter indoors or in a car is the safest option, avoiding open fields and tall trees. It's important to wait at least 30 minutes after the last thunderclap before leaving shelter. Installing lightning rods and grounding systems in buildings, along with regular maintenance, can prevent structural damage. Creating emergency plans, educating the public, and monitoring weather reports can further enhance safety. Outdoor equipment should be lightning-resistant, and first aid knowledge, such as performing CPR, is essential in the event of a lightning strike. Community and government efforts should focus on improving infrastructure and spreading awareness to ensure widespread preparedness.

Components of a Lightning Conductor System

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The lightning rod is a metal rod, usually made of copper or aluminum, mounted at the highest point of a building or structure. It serves as the point where lightning is most likely to strike. The rod is designed to attract and intercept lightning strikes. Metal conductors (usually copper or aluminum) connect the lightning rod to the ground. These conductors create a low-resistance path for the electrical charge to travel from the lightning rod to the ground. The grounding system consists of metal rods or plates buried in the ground. It disperses the electrical charge safely into the earth. The grounding system must be in good contact with the soil to effectively conduct the charge. Bonding refers to the connection of the lightning conductor system to other conductive parts of the building, such as metal plumbing or electrical systems. This ensures that all conductive parts of the building are at the same electrical potential, reducing the risk of side flashes or damage.

How Lightning Conductors Work

The lightning rod is designed to attract lightning because it is the highest point of the structure. While lightning rods do not prevent lightning from striking, they provide a controlled point of entry. When lightning strikes, the rod intercept the electrical discharge and prevent it from hitting other parts of the building. The metal conductors create a direct path for the electrical energy to travel from the lightning rod to the ground. This pathway is designed to be low in electrical resistance. The electrical energy travels along the conductors, bypassing sensitive parts of the building and avoiding potential damage. Once the electrical energy reaches the ground, the grounding system disperses it safely into the earth. The metal rods or plates in the ground conduct the charge into the soil, where it is absorbed and neutralized. Proper grounding ensures that the electrical energy does not cause harm to the building's structure, electrical systems, or occupants.

By directing lightning safely into the ground, lightning conductors prevent lightning from causing fires by striking flammable materials or electrical systems. The system also reduces the risk of secondary fires caused by electrical surges or damage to wiring. Lightning conductors help prevent power surges and electrical damage by directing lightning away from electrical components and wiring. They protect sensitive equipment and electronics from potential damage due to lightning-induced electrical surges. By preventing lightning strikes from entering the building, lightning conductors reduce the risk of injuries or fatalities caused by electrical discharge. The system helps maintain a safe environment for occupants during thunderstorms.

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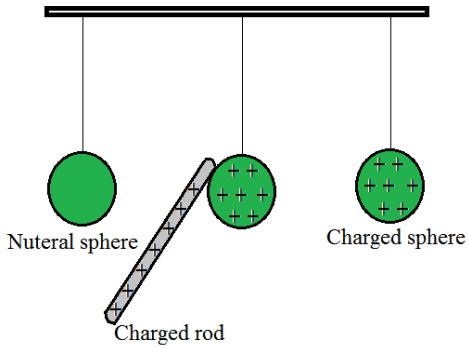
ELECTRIFICATION

Electrification is the process of transforming a neutral body into a charged one, a phenomenon that occurs universally. This process involves the transfer of electric charge, typically through the movement of electrons. When an object gains or losses electrons, it becomes electrically charged, resulting in an imbalance of charges. This imbalance can lead to static electricity, where charges remain on the surface of materials until they find a path to neutralize. Static electricity arises from the interaction between negatively charged objects and positively charged ones, often through friction. For instance, rubbing materials together can cause electrons to transfer, creating a charge imbalance. This principle is illustrated in the turboelectric series, which ranks materials based on their tendency to gain or lose electrons.

Methods of producing Electric charges

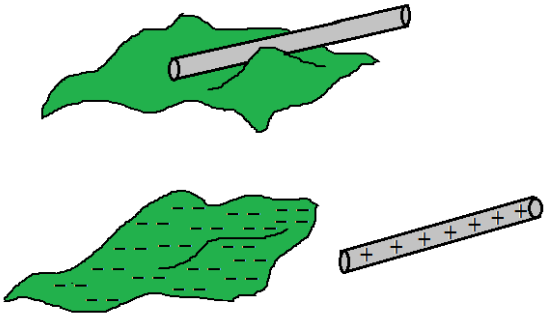
Charging by Induction- A spark or crackling sound emerges when our synthetic garments or sweaters are removed from our bodies, especially in dry weather. Lightning, in the sky during thunderstorms, is another case of electric discharge. It is an electric shock always felt while opening a car door or grabbing the iron bar of a bus after sliding out of our seats.

Induction



The cause of these sensations is the discharge of electric charges that have collected as a result of rubbing insulating surfaces. This is due to static electricity generation. Anything that does not have movement or change with time is referred to as static. The study of forces, fields, and potentials coming from static charges is known as Electrostatics.

Electrical neutrality refers to the presence of an equal amount of positive and negative charges in most bodies. To charge a neutral body, the balance of positive and negative charges has to be changed.



Charging by Friction

The charging by friction method includes rubbing one particle against another, causing electrons to move from one surface to the next. This procedure can be used to charge insulators.

Charging by friction

Different types of atoms and atom combinations in material objects give rise to various electrical characteristics.

Electron affinity is a property that describes a substance's affinity for electrons.

Materials with high electron affinity strongly attract electrons.

Turboelectric charging, or charging by friction, relies on electron affinity.

For example, rubbing a rubber balloon with animal fur brings their atoms close together, causing their electron clouds to interact.

Rubber atoms, with a stronger affinity for electrons, steal them from the fur, leading to both materials becoming charged.

Similarly, when two glass rods rubbed with wool or silk cloth are brought together, they repel each other, along with the strands of cloth.

However, the glass rod and the cloth are attracted to each other due to their differing electron affinities.

Charging by Conduction

Charging by conduction occurs when a charged particle comes into contact with a neutral conductive medium. Charges are transmitted from the charged substance to the neutral conductor. This approach can be used to charge conductors.

Charging by Conduction

Conduction charging happens when a charged object touches a neutral object.

For instance, if a positively charged aluminum plate contacts a neutral metal sphere, the sphere becomes charged.

Electrons from the neutral sphere move towards the positively charged plate.

This movement causes the sphere to acquire a positive charge.

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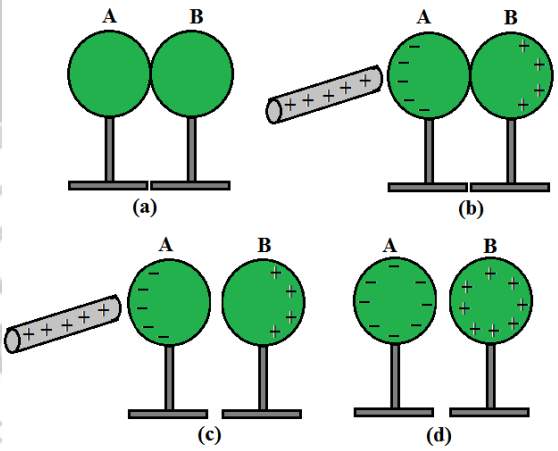
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Consider the case of a negatively charged metal spherical being pressed against the top plate of a neutral needle electroscope. When the metal sphere makes contact with the neutral electroscope, it charges it.
Finally, imagine that an uncharged physics scholar is standing on an insulating platform when a scholar comes into contact with a negatively charged Van de Graff generator causes the neutral physics scholar to become charged.
Each of these cases includes a charged object making contact with a neutral object. In contrast to induction charging, which involves bringing the charged object close to but never touching the object being charged, conduction charging entails physically connecting the charged object to the neutral object. Charging by conduction is sometimes known as charging by touch since it involves contact.

Charging by Induction
Induction charging is a charging method in which a neutral object is charged without actually touching another charged object. The charged particle is held near a neutral or uncharged conductive material that is grounded on a neutrally charged material. When a charge flows between two objects, the uncharged conductive material develops a charge with the polarity opposite that of the charged object.

Charging by induction using a positively charged rod:

Charging by induction using a positively charged rod
Place two metal spheres, A and B, on insulating platforms and bring them together.
Bring a positively charged rod close to one of the spheres, say A, but don't let it touch it. The rod attracts the free electrons in the spheres. The rear surface of sphere B now has an excess of positive charge. Both types of charges are encased in metal spheres and are unable to escape. As a result, they live on the surfaces. The left surface of sphere A has a negative charge surplus, while the right surface of sphere B has a positive charge excess. On the left surface of A, not all the electron particles in the spheres have collected. Other electron particles are repelled by the negative charge that is building upon A's left surface. Under the operation of the rod's attraction force and the force of repulsion caused by the accumulated charges, equilibrium is achieved in a short period. The equilibrium situation is depicted in Fig. (b).



Induction of charge is the name for the process, which occurs nearly quickly. The collected charges remain visible on the surface until the glass rod is held close to the sphere, as shown. When the rod is withdrawn, the charges are no longer affected by external forces and revert to their original neutral condition.
As indicated in Figure separates the spheres by a modest distance while holding the glass rod near sphere A. (c).
The two spheres are found to be charged in opposite directions and are attracted to each other.
Take out the rod. As demonstrated in Figure the charges on spheres rearrange themselves (d). Separate the spheres completely now. As illustrated in Figure the charges on them are uniformly spread over them (e).
The metal spheres will be equal and oppositely charged in this operation.

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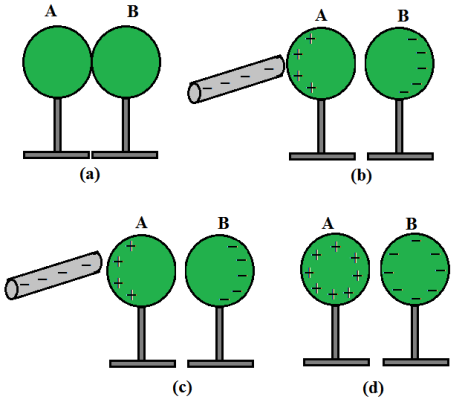
This is known as induction charging. In contrast to charging through contact, the positively charged glass rod does not lose any of its charges.

Charging by induction using a negatively charged rod

Consider two metal spheres A and B, which are touching in the illustration. Take a charged rod that is negatively charged. When a charged rod is kept close to the spheres, the repulsion between the charged rod's electrons and the spheres causes electrons in the two-sphere system to move away.

The electrons from sphere A are transported to sphere B as a result. Sphere A becomes positively charged and sphere B becomes negatively charged due to electron migration.

As a result, the entire two-sphere system is electrically neutral. As illustrated, the spheres are then separated (avoiding direct contact with the metal). When the charged rod is removed, the charge is redistributed throughout the spheres, as indicated in the diagram.



Law of Conservation of Charge

A charge is a characteristic of matter that causes it to create and experience electrical and magnetic effects.

According to the rule of conservation of charge, the total charge of an isolated system will always remain constant. At any two time intervals, any system that is not exchanging mass or energy with its surroundings will have the same total charge.

When two objects in an isolated system each have a net charge of zero and one of the body transfer one million electrons with the other, the object with the surplus electrons will be negatively charged, while the object with the fewer electrons will have a positive charge of the same magnitude. The total charge of the system has never changed and will never change.

Properties of Electric Charges

Additivity of Charges: In a system with two point charges q1 and q2 the total charge is determined by algebraically adding q_1 and q_2 similar to how real numbers are added.

For a system with n charges; $Q_1, Q_2, Q_3, Q_4, \dots, Q_n$, the total charge is calculated as $Q_1 + Q_2 + Q_3 + Q_4 + Q_n$. Charge, like mass, possesses magnitude but lacks direction.

Unlike mass, which is always positive, charge can be positive or negative.

When adding charges to a system, specific conventions must be followed to indicate the sign of each charge.

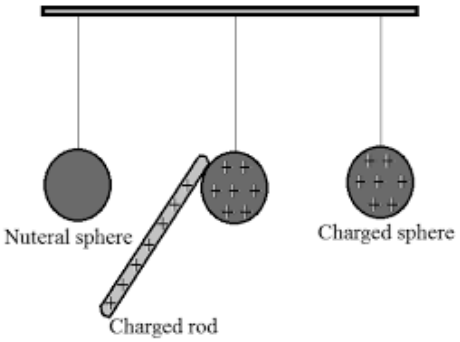
Conservation of Charge:

The rule of conservation of charge states that the total charge of an isolated system remains constant over time.

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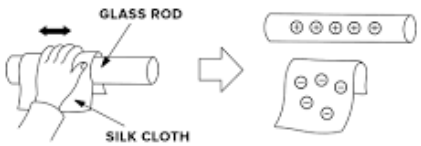
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In an isolated system not exchanging mass or energy with its surroundings, the total charge remains the same at any two time intervals.
For example, if two objects in an isolated system each have a net charge of zero and one transfers one million electrons to the other, the object gaining electrons becomes negatively charged, while the one losing electrons becomes positively charged.
However, the total charge of the system remains unchanged throughout the process.
This demonstrates the principle of charge conservation, where the total charge of an isolated system is constant and does not change over time.



Quantization of Electric Charge:
All available charges are integral multiples of a basic unit of charge designated by e. As a result, the charge q on a body is always given by $q = ne$, where n is any positive or negative integer.
The charge that an electron or proton carries is the basic unit of charge. The charge on an electron is assumed to be negative; the charge on an electron is written as –e, while the charge on a proton is written as +e.

Electrification by friction
Electrification by friction is a fundamental process in physics where two bodies, when rubbed together, exchange electrons. This interaction results in one body acquiring a negative charge and the other a positive charge, with both charges being equal in magnitude. During this process, the body that loses electrons becomes positively charged, while the one that gains electrons becomes negatively charged. When rubber is rubbed against fur, electrons move from the fur to the rubber, charging them oppositely. The resulting static electricity can lead to various effects, such as attracting light objects or causing small shocks. The body which loses electrons becomes positively charged and that which gains electrons becomes negatively charged.

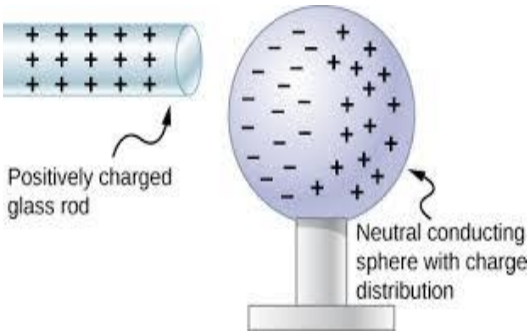


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Electrification by conduction
Electrification by conduction is a process that occurs when a charged object comes into direct contact with a neutral object. This contact allows for the transfer of electrons between the two objects. If the charged object is negatively charged, electrons will flow from it to the neutral object, imparting a negative charge to the latter. Alternatively, the charged object is positively charged, electrons will move from the neutral object to the charged one, leaving the neutral object positively charged. This method of charging is straightforward and relies on the principle that like charges repels and opposite charges attract. The result is that the neutral object acquires the same type of charge as the charged object it contacted. This phenomenon is fundamental in electrostatics and has practical applications in various fields, including electronics and materials science.

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Note: The insulated stand prevents flow of charge away from the conductor. To charge the conductor negatively, a negative rod is produced.



Electrification by induction

Charging the body positively

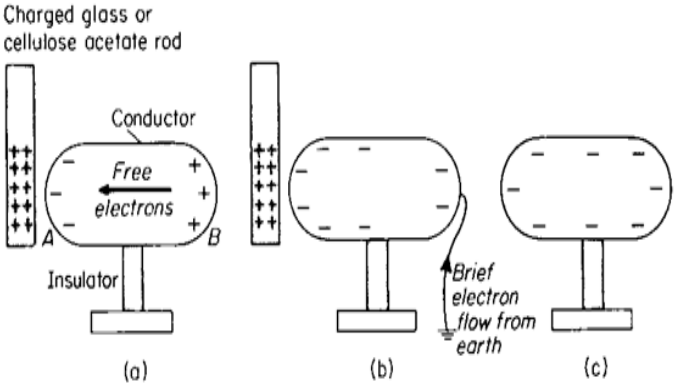
Procedure

Put the conductor on an insulated stand as in (a)
Bring a negatively charged rod near the conductor.
The positive and negative charges separate as shown in (a)
Earth the conductor by momentarily touching it with a finger and electrons flow from it to the earth as in (b) in presence of the charged rod.
Removing the charged rod. The conductor is obtained to be positively charged.

Charging the body negatively by induction

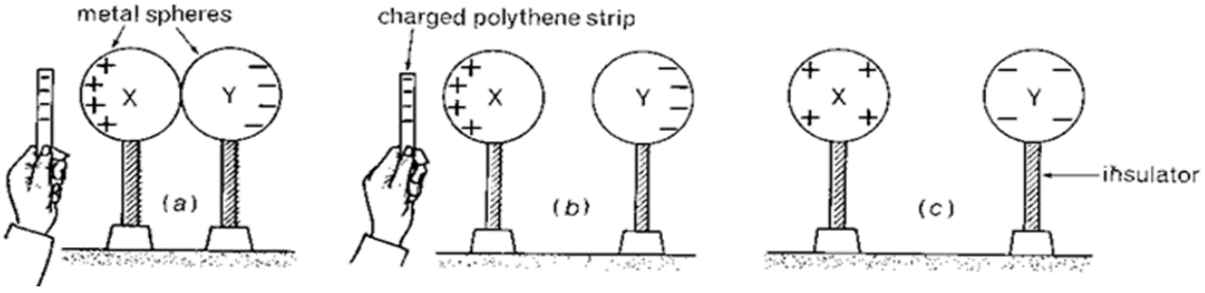
Procedure

Put the conductor on an insulated stand as in (a).
Bring a positively charged rod near the conductor.
The positive and negative charges separate as shown in (a)
Earth the conductor by momentarily touching it with a finger and electrons flow from it to the earth as in (b) in presence of the charged rod.
Remove the charged rod. The conductor is obtained to be negatively charged.



Charging two bodies simultaneously with opposite charges

Support two uncharged bodies in contact on an insulated stand as shown in (a)



Bring a positively charged rod near the two bodies
Positive and negative charges separate as in (b).
Separate (X) from (Y) in presence of the inducing charge.
Remove the inducing charge
Body (X) will be positively charged and (Y) will be negatively charged.

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Conductors and Insulators

Conductors and insulators are two categories of materials that differ in their ability to allow the flow of electric charges (electrons) or heat. Understanding the distinction between them is essential in fields such as electricity, electronics, and thermodynamics.

Conductors are materials that allow the flow of electric charges (usually electrons) or heat through them easily. They have free-moving charge carriers, which can be electrons or ions that enable electricity or heat to pass through.

Characteristics of Conductors:

Conductors have many free electrons (delocalized electrons) in their atomic structure. These electrons are loosely bound to their atoms and can move freely when an electric field is applied.

Conductors offer very little resistance to the flow of electric current because the free electrons can move with minimal hindrance. This makes them highly efficient at transmitting electricity.

In addition to conducting electricity, conductors can also efficiently transfer heat. Metals, for instance, can quickly transfer thermal energy from one part of the material to another.

Examples:

Copper, aluminum, gold, and silver are excellent electrical conductors because they have free-moving electrons. While non-metallic, graphite is a good conductor due to the presence of free electrons in its structure. Ionized gases in the plasma state (e.g., in stars or neon signs) can conduct electricity due to the presence of free-moving ions and electrons.

Applications of Conductors:

Copper and aluminum are commonly used in electrical wiring and power lines because of their excellent conductivity. Conductors are used in circuit boards, connectors, and various electrical components. Metal conductors like aluminum are used in heat sinks to dissipate heat from electronics like CPUs and GPUs.

Insulators are materials that resist the flow of electric charges or heat. They do not allow electrons or ions to move freely, which makes them poor conductors of electricity or heat.

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Characteristics of Insulators

In insulators, the electrons are tightly bound to their respective atoms and cannot move freely. This prevents the movement of electric charges and stops the flow of current. Insulators have very high resistance to electric current. This makes them effective at blocking or containing electrical charges. Insulators are also poor conductors of heat. They resist the transfer of thermal energy, making them good for thermal insulation.

Examples:

Materials such as rubber, glass, wood, plastic, and ceramics are excellent insulators of electricity and heat. Although technically a gas, air acts as an insulator, preventing the free flow of electricity (which is why air gaps are used in electrical insulators).

Dry paper is a good insulator and is used in various applications where electrical insulation is necessary.

Applications of Insulators:

Plastic and rubber are often used to coat electrical wires to prevent accidental contact with live conductors and to contain electrical energy within the system. Insulators such as fiberglass, foam, and wool are used in building construction to prevent the loss of heat in homes and offices.
Insulators are used in capacitors as dielectric materials, which can store electrical energy.

Comparison between Conductors and Insulators

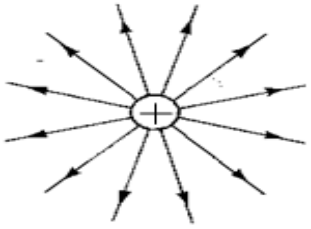
Property	**Conductors**	**Insulators**
Electrical Conductivity	High (due to free electrons)	Low (due to tightly bound electrons)
Resistance	Low (minimal resistance to current flow)	High (resist the flow of current)
Heat Conductivity	Good (thermal energy transfers easily)	Poor (resist the transfer of heat)
Examples	Copper, aluminum, gold, silver	Rubber, glass, plastic, wood
Electron Movement	Free electrons move easily	Electrons are tightly bound and immobile

Semiconductors:
In addition to conductors and insulators, semiconductors represent a special class of materials that have properties between conductors and insulators. Their conductivity can be controlled or modified by adding impurities (a process called doping), applying voltage, or changing temperature. Semiconductors are the foundation of modern electronics, used in devices like transistors and diodes.
Examples of Semiconductors: Silicon and germanium.
Applications: Semiconductors are the building blocks of computer chips, solar cells, and other electronic devices.

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ELECTRIC FIELDS
Electric fields
When an electric charge is placed near to another electric charge it experiences a force. The electric force does not require contact between the two charges so we call it an 'action-at-a-distance force' – it acts through space. The region of space where an electric charge experiences a force due to other charges is called an *electric field*. If the electric force felt by a charge is the same everywhere in a region, the field is uniform; a uniform electric field is produced between two oppositely charged parallel metal plates. It can be represented by evenly spaced parallel lines drawn perpendicular to the metal surfaces. The *direction of an electric field at a point*, denoted by arrows, is the direction of the force on a small *positive* charge placed in the field (negative charges experience a force in the opposite direction to the field). An electric field is a vector quantity as it has both magnitude (strength) and direction. Moving charges are deflected by an electric field due to the electric force exerted on them.

This is a region around a charged body where electric forces are experienced. Electric fields may be represented by field lines. Field lines are lines drawn in an electric field such that their directions at any point give a direction of electric field at that point. The direction of any field at any given point is the direction of the forces on a small positive charge placed at that point.



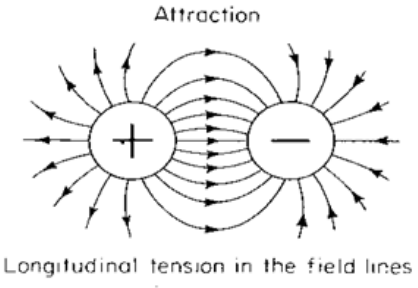
Properties of electric field lines
They begin and end on equal quantities of charge.
They are in a state of tension which causes them to shorten.

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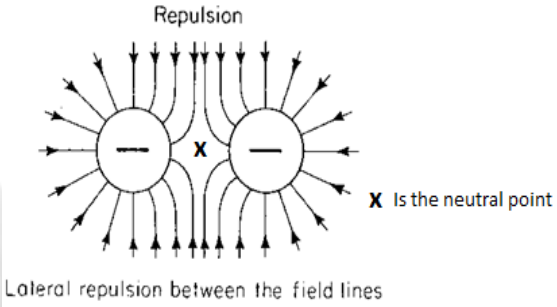
They repel one another side ways.

Field patterns

(a) Isolated charge
(b) Unlike charges close together
(c) Like charges close together



A neutral point is a region where the resultant electric field is zero i.e. field lines cancel each other and therefore no resultant electrostatic forces exists.



Uses of static electricity

There are many uses of static electricity in applications from flue-ash precipitation in coal-burning power stations, paint and crop spraying to photocopiers and ink-jet printers.

In an ink-jet printer tiny drops of ink are forced out of a fine nozzle, charged electrostatically and then passed between two oppositely charged plates; a negatively charged drop will be attracted towards the positive plate causing it to be deflected.

The amount of deflection and hence the position at which the ink strikes the page is determined by the charge on the drop and the p.d. between the plates; both of these are controlled by a computer. About 100 precisely located drops are needed to make up an individual letter but very fast printing speeds can be achieved

Dangers of static electricity

Sparks occur between electrostatic charges when the electric field is strong enough. Damage can be reduced by providing an easy path for electrons to flow safely to and from the earth.

For example, a tall building is protected by a lightning conductor consisting of a thick copper strip fixed on the outside of the building connecting metal spikes at the top to a metal plate in the ground.

Thunderclouds carry charges: a negatively charged cloud passing overhead repels electrons from the spikes to the Earth. The points of the spikes are left with a large positive charge (charge concentrates on sharp points) which removes electrons from nearby air molecules, so charging them positively and causing them to be repelled from the spike.

This effect, called action at points, results in an 'electric wind' of positive air molecules streaming upwards which can neutralise electrons discharging from the thundercloud in a lightning flash. If a flash occurs it is now less violent and the conductor gives it an easy path to ground.

Sparks from static electricity can be particularly dangerous when flammable vapour is present.

Fuel flowing in a pipeline (particularly a plastic pipe) experiences friction, which may lead to a build-up of static charge. During refueling, aircraft, fuel tanker and pipeline hoses are all earthed to avoid sparks which could ignite the fuel and cause an explosion.

Computers and sensitive electronic equipment should also be earthed to avoid electrostatic damage.

THEME: SPACE PHYSICS: Earth and the Space System

2.1 THE SOLAR SYSTEM

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Learning Outcomes

a) Know the relative sizes, positions, and motions of the earth, sun and moon (k, u)
b) Understand how day and night occur and demonstrate the phases of the moon (u, s)
c) Understand the roles of the sun, earth and moon in explaining time, seasons, eclipses, and ocean tides (k, u,gs)
d) Know the components of the solar system and their positions(k)
e) Know the main characteristics of the inner and outer planets in the solar system(k)
f) Understand the various views about the origin and structure of the universe (k, v/a)

Introduction

Day and night and the rising and setting of the Sun can be explained by the rotation of the Earth on its axis. In this section you will learn more about these natural occurrences. The Earth is the third planet from the Sun and travels in a nearly circular orbit controlled by the large gravitational attraction exerted by the Sun. The Earth takes one year to travel around the orbit. The Moon orbits the Earth under the influence of the Earth's gravitational attraction and always has the same area of its surface facing towards the Earth. You will learn how to calculate the average orbital speed of an object such as the Moon or a planet.

The Earth is a planet of the Sun travelling in a nearly circular orbit around the Sun, and the Moon orbits the Earth as a satellite. The motion of the Earth, and Moon account for the occurrence of a number of natural -events.

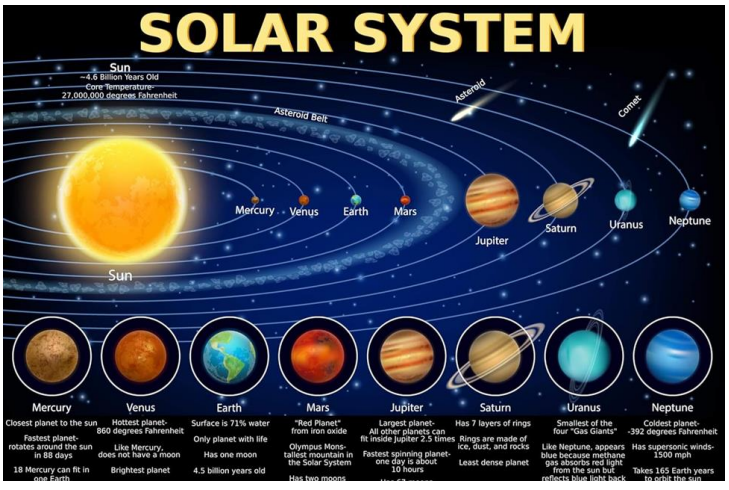
The solar system

The solar system is a vast and intricate collection of celestial bodies, primarily centered on the Sun, a G-type main-sequence star that contains 99.86% of the system's mass. The Sun's gravitational pull governs the orbits of various components, including eight planets, which are categorized into terrestrial (Mercury, Venus, Earth, and Mars) and gas giants (Jupiter, Saturn, Uranus, and Neptune).In addition to the planets, the solar system is home to five officially recognized dwarf planets, such as Pluto and Eris, along with hundreds of moons that orbit these planets. Furthermore, countless asteroids and comets populate the space between the planets, contributing to the dynamic nature of our solar system. Together, these components create a complex and fascinating environment, showcasing the diversity and beauty of the cosmos.

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The planets in the solar system

The solar system consists of eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. These planets can be categorized into two groups: **terrestrial** and **gas giants**. The **four inner planets**: Mercury, Venus, Earth, and Mars are t**errestrial**, characterized by their rocky surfaces.



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In contrast, **the outer planets**: Jupiter, Saturn, Uranus, and Neptune are **gas giants**, composed mainly of gases and lacking solid surfaces. Mercury, the closest planet to the Sun, experiences extreme temperature fluctuations, while Venus, often called Earth's twin, has a thick atmosphere that traps heat. Earth is unique for its liquid water and life, and Mars is known for its red surface and potential for past life. The gas giants, particularly Jupiter, are massive and have numerous moons, with Saturn famous for its stunning rings. In addition to these eight planets, the solar system contains five officially recognized **dwarf planets**, hundreds of moons, and countless asteroids and comets, showcasing the vast diversity of celestial bodies orbiting our Sun.

THE BRIGHT PLANETS IN THE SKY

In January, the night sky offers a spectacular view of several bright planets, with Venus shining as the most brilliant. Known as the "Evening Star," Venus reflects about 70% of the sunlight that reaches it, making it a dazzling sight in the western sky after sunset. Its steady golden light is complemented by the nearby presence of Saturn, which also adds to the celestial display. Jupiter and Mars are other notable planets visible this month. Jupiter, the largest planet in our solar system, reflects around 34% of sunlight, making it a prominent feature in the night sky. Mars, while not as bright as Venus or Jupiter, can still be spotted with relative ease. For stargazers, January is an excellent time to observe these planets. With clear skies, the combination of Venus, Saturn, Jupiter, and Mars creates a stunning panorama that captivates both amateur and seasoned astronomers alike.





Motion of planets around the sun

Orbital motion refers to the movement of an object in space as it travels forward while being pulled by gravity toward another object. The motion of planets around the Sun is governed by gravitational forces and follows specific patterns described by Kepler's Laws. Each planet orbits the Sun in a counterclockwise direction when viewed from above the Sun's North Pole. These orbits are elliptical, with the Sun located at one of the foci, which means that the distance between a planet and the Sun varies throughout its orbit. Kepler's **First Law** states **that planets move in elliptical orbits**, while the **Second Law** indicates that a line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time. This means that **planets move faster when they are closer to the Sun and slower when they are farther away**.

The **Third Law** relates the time a planet takes to orbit the Sun to its average distance from the Sun, establishing a predictable relationship between these two factors. Kepler's findings by explaining that the gravitational force between two objects depends on their masses and the distance between them. This interplay of forward motion and gravitational pull keeps planets in stable orbits.

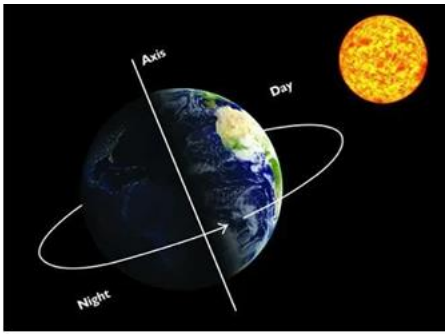
The Earths' orbit about the sun & Moons' orbit about the earth.

The Earth revolves in an orbit around the Sun in **365.25 days,** with reference to the stars, at a speed ranging from 29.29 to 30.29 kms^{-1}. The 6 hours, 9 minutes (0.25 days) adds up to about an extra day every fourth year, which is designated in a leap year, an extra day added as February 29th. The Moon takes **about one month** to orbit the Earth (27.3 days to complete a revolution, but 29.5 days to

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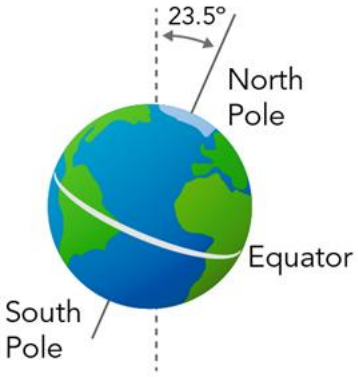
change from the present Moon to New Moon). As the Moon completes each 27.3-day orbit around Earth, both Earth and the Moon are moving around the Sun. A gravitational force that attracts and keeps them in the orbit maintains the Earth and the Moon's orbits.

Day and night



The formation of day and night on Earth is a result of its **rotation** on an imaginary line known as the **axis**. As the **Earth spins**, different parts of the planet are exposed to sunlight, creating the cycle of day and night. When a specific area faces the Sun, it experiences daylight, while the opposite side remains in darkness, resulting in nighttime. This rotation occurs about every 24 hours, which is why we have a consistent cycle of day and night. The spherical shape of the Earth ensures that only half of it can receive sunlight at any given moment. As the Earth continues to rotate, the areas that were once in darkness gradually move into the light, transitioning from night to day. Daytime is when you can see the sun from where you are, and its light and heat can reach you. Nighttime is when the sun is on the other side of the Earth from you, and its light and heat do not get to you. Over a year, the length of the daytime in the part of the Earth where you live changes. Days are longer in the summer and shorter in the winter.

Seasons in some parts of the earth



The formation of seasons on Earth is primarily due to the planet's axial tilt of approximately 23.5 degrees. This tilt causes different parts of the Earth to receive varying amounts of sunlight throughout the year. As Earth orbits the Sun, the angle at which sunlight strikes the surface changes, leading to the distinct seasons we experience: spring, summer, autumn, and winter. During summer, the hemisphere tilted towards the Sun receives more direct sunlight, resulting in warmer temperatures. During winter, the same hemisphere is tilted away from the Sun, leading to cooler temperatures and shorter days. The transition periods of spring and autumn occur as the Earth moves between these extremes, with varying sunlight and temperatures. This consistent pattern of changing seasons is a result of Earth's revolution around the Sun combined with its axial tilt, creating a dynamic and ever-changing climate that influences ecosystems and human activities alike.

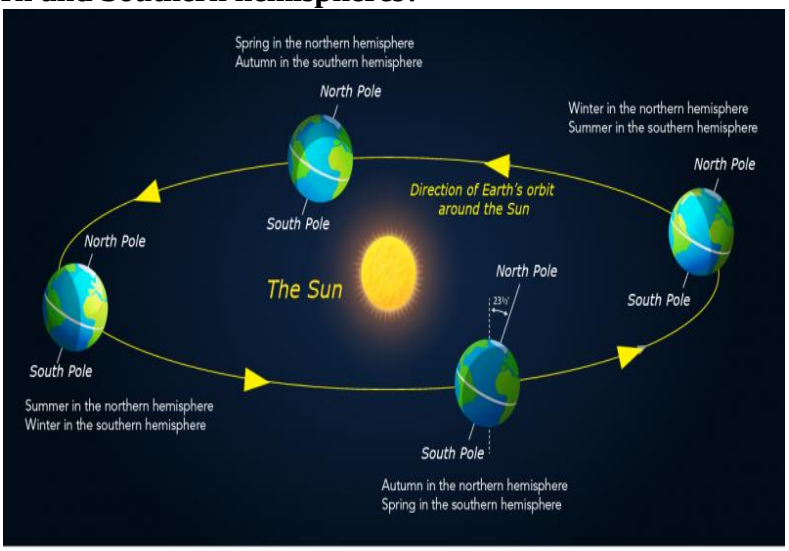
Why do the seasons change on earth?

Two things cause the **seasons** to change. First, the Earth moves around the Sun. Second, the Earth has a **tilted** axis of rotation. The Earth spins around an **axis**. This imaginary line extends from the South Pole to the North Pole. But the Earth's axis is not vertical. It's actually tilted at an angle of 23.5°. The planet is always tilted in the same direction as it **orbits** the Sun. The Earth spins around its axis. The planet's rotational axis is tilted at 23.5 degrees from perpendicular. It means that different parts of the planet are tilted toward the Sun at different times of the year. It's also why the seasons are different in different parts of the world. Not all parts of the Earth have four distinct seasons. But they all experience **seasonal variation**. Closer to the North Pole and the South Pole, daylight and temperatures change with the seasons. Days are longer and temperatures are colder in summer than in winter. Near the **Equator**, days are always about 12 hours long. But these areas usually have a wet season and a dry season.

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How are seasons different in the Northern and Southern hemispheres?

Seasons happen at different times in different parts of the world. The tilt of the Earth doesn't change as it rotates around the Sun. But the part of the planet that gets the most direct sunlight does change. The Northern Hemisphere is tilted away from the Sun from September to March. That means the northern half of the planet doesn't get as lighter and heat from the Sun. This causes autumn and winter. During the same months, the Southern Hemisphere is tilted towards the Sun. That means the southern half of the planet gets spring and summer.



From March to September, the Northern Hemisphere is tilted towards the Sun. So that's when the northern half of the Earth experiences spring and summer. During the same months, the Southern Hemisphere experiences autumn and winter.

Other planets also have seasons. But the length and intensity of each season varies from planet to planet. On Earth, seasons last between 90 and 93 days. On Venus, seasons last between 55 and 58 days. On Mars, seasons change about once every six months. Summer lasts 199 days and winter lasts 146 days. On Saturn, seasons last about seven years. And if you lived on Neptune, you would have to wait more than 40 years for the seasons to change!

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Implication of season on activities on earth

The Earth's seasons are a direct result of its axial tilt as it orbits the Sun. This tilt causes variations in sunlight distribution, leading to distinct seasonal changes. When the Northern Hemisphere tilts towards the Sun, it experiences summer, while the Southern Hemisphere endures winter, and vice versa. This phenomenon not only affects temperature but also influences the length of daylight, impacting various ecosystems and human activities. Seasonal changes significantly affect environmental conditions, including precipitation, soil moisture, and river flows. For instance, spring brings increased rainfall, promoting plant growth, while autumn leads to leaf fall and preparation for winter dormancy. These changes are crucial for agriculture, as farmers plan planting and harvesting schedules based on seasonal patterns. Moreover, climate change is altering traditional seasonal behaviors, leading to unpredictable weather patterns. Understanding these implications is vital for adapting agricultural practices and managing natural resources effectively.

Relative Motion of the Sun, Moon and Eclipse

The Sun is the largest of the sun, Earth and Moon. The earth rotates about the sun and revolves about its own axis. The moon rotates about the Earth and the sun concurrently. When the Sun, Earth and the Moon are in a straight line, the shadow of the sun is cast either on the Earth or on the Moon. This is referred to as an eclipse. During a solar eclipse, the moon moves between the Earth and the sun and blocks the sunlight. The shadow is formed on Earth. During a lunar eclipse, the Earth blocks the sun's light from reaching the moon. The shadow is formed on the moon as the Earth blocks light from reaching the moon. Since we are standing on Earth, what we see is that the moon gets dark. Other kinds

of eclipses happen too.

Characteristics of Inner and Outer Planets

The solar system is divided into two distinct groups of planets: the inner and outer planets. The four inner planets; Mercury, Venus, Earth, and Mars are characterized by their rocky composition and metallic surfaces. They have shorter orbits around the Sun, slower rotation speeds, and lack ring systems. Their proximity to the Sun results in higher temperatures and a more solid structure compared to their outer counterparts. In contrast, the outer planets; Jupiter, Saturn, Uranus, and Neptune; are significantly larger and primarily composed of gases like hydrogen and helium. These gas giants have longer orbits and faster rotation rates, which contribute to their dynamic atmospheres. Unlike the inner planets, the outer planets possess extensive ring systems and numerous moons, showcasing their complex gravitational interactions. **Hence (i) Inner planets are denser than outer planets, (ii) Outer planets are made of gas, ice, and rocks, whereas the inner planets are made of iron, nickel, and silicates, (iii) Inner planets have very few to no moons around them, whereas the outer planets have dozens of moons orbiting them.**

Explain why Earth is the only planet that supports life

Earth is the only planet known to support life, primarily due to its unique combination of factors. First, Earth is situated in the habitable zone, where temperatures allow for liquid water to exist. This is crucial, as water is a fundamental requirement for all known life forms. Additionally, Earth has a diverse ecosystem that provides various habitats and resources necessary for survival. The planet's atmosphere is rich in oxygen, which is essential for the respiration of most living organisms. This atmosphere also protects life from harmful solar radiation and helps regulate temperature. Earth's geological activity, driven by plate tectonics, contributes to a dynamic environment that fosters biodiversity. While scientists continue to search for life beyond Earth, no other planet in our solar system has demonstrated the same capacity to support life, making Earth truly unique in the cosmos. Earth is the third planet from the Sun. It is one of the inner planets. As far as we know, Earth is also the only planet that has liquid water. Earth's atmosphere has oxygen. The water and oxygen are crucial to life, as we know it. Therefore, the Earth is able to support life in it.

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FORMATION OF OCEAN TIDES

Ocean currents are driven by wind, water density differences, and tides. Oceanic currents describe the movement of water from one location to another. Ocean tides are primarily caused by the gravitational pull of the Moon and, to a lesser extent, the Sun. This gravitational attraction generates a tidal force that results in the regular rise and fall of ocean waters, known as tides.

What is the tide?

Tides can be defined as the alternate rise and fall of the ocean water. It is caused by the combined effects of:

1. The gravitational force exerted on Earth by the Sun
2. The gravitational force exerted on Earth by the Moon

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3. Rotation of the Earth

How do tides work?

The mechanism of tides could be understood by understanding the gravitational force of the Sun and the Moon. These bodies experience the gravitational pull over each other depending upon their mass and the distance between them. Since the Sun is far away from the Earth as compared to the Moon. Hence, the Sun's gravitational pull is lesser over the Earth than the moon. Thus, the moon determines the magnitude of the tide. It is supposed that only the water bodies are pulled by the gravitational pull, however, it is not the fact. It is both the land and water bodies that get pulled by the gravitation. Since the relative pull of the land is less in comparison to that of water, the effect of gravitation on the water bodies is more. It should be noted that the magnitude of ant tide is determined by the relative position of the Moon, the Sun, and the Earth.

Impact of Tides

Tides raise the level of seawater and hence exposes a large part of the ocean for erosion

It is helpful for the tidal ports that have shallow water which is a constraint for the big ships to enter. Tidal currents are a very potential source of tidal energy which is harnessed by many developed countries on a very large scale and to some extent in India as well. It can be devastating in cases where the tide gets too huge and results in the flooding of the nearby coastal regions. Tides are very helpful for ecosystems such as the mangrove forests and coral reefs to grow and sustain.

Characteristics of Tides

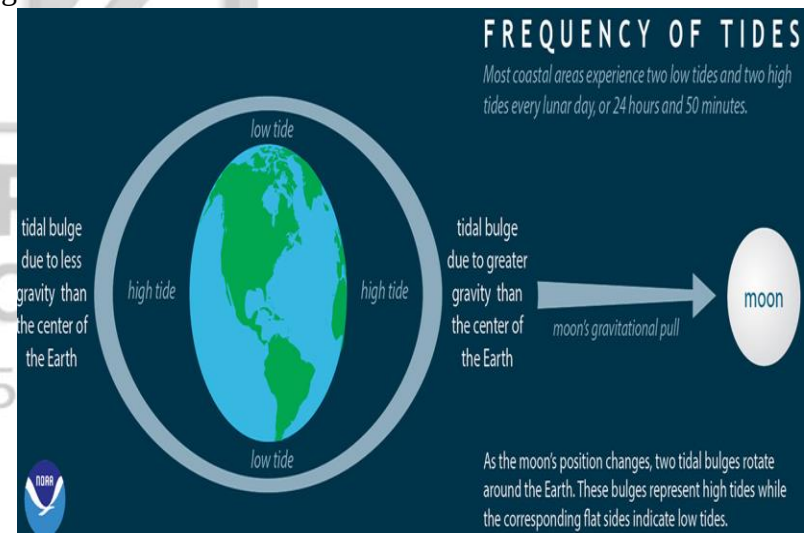
Tide changes as per the 4 stages given below.

Flood Tide – Over a period of several hours there will be a rise in sea level.

High Tide – This is a stage where the water reaches its maximum level.

Ebb Tide – This is a stage where sea level keeps receding over several hours.

Low Tide – The Level of Seawater stops receding.



What is a tidal bulge?

The side of the earth that is nearest to the moon witnesses one tidal bulge. The other side of the earth that is farthest to the moon witnesses the second tidal bulge. These tidal bulges are high tides. The water in the ocean is pulled towards the moon under the impact of the gravitational pull. That creates a **tidal bulge.**

Gravitational Pull of the Moon and Sun

According to Newton, tides result from the gravitational attraction exerted by these celestial bodies. The Moon, being closer to Earth, has a more significant impact, causing the oceans to bulge on both the side facing the Moon and the opposite side. As the Earth rotates, these bulges (***direct tidal bulge***) create high and low tides. The Sun also exerts a gravitational force, but its effect is less pronounced due to its greater distance. When the Sun and Moon align during full and new moons, their combined gravitational pull results in higher high tides, known as **spring tides**. Equally, when they are at right angles, the Sun's pull counteracts the Moon's, leading to lower high tides, known as **neap tides**. When they are at right angles (first and third quarters of the moon), neap tides occur, with less extreme tidal ranges.

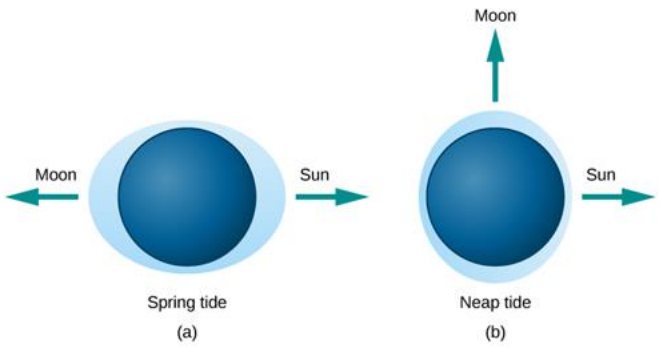


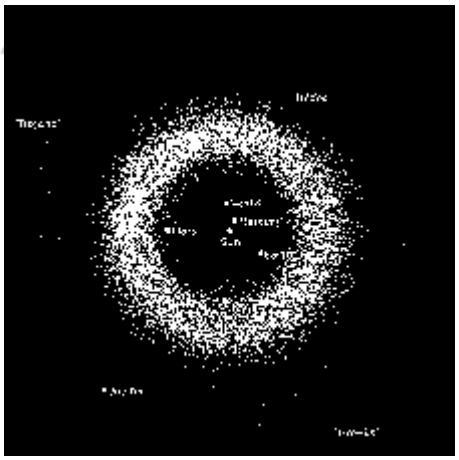
Figure: (a) In spring tides, the Sun's and Moon's pulls reinforce each other. (b) In neap tides, the Sun and the Moon pull at right angles to each other and the resulting tides are lower than usual.

Centrifugal Force from Earth's Rotation

Centrifugal force, Latin term meaning "center fleeing," describes the apparent force that pushes objects outward when they follow a curved path. This phenomenon is particularly evident due to Earth's rotation. As the planet spins, objects on its surface experience a force directed away from the axis of rotation, which is most pronounced at the equator and diminishes towards the poles. This force is often referred to as a "fictitious" force in Newtonian mechanics, as it arises from the perspective of a rotating frame of reference. While gravity pulls objects toward the Earth's center, centrifugal force acts outward, creating a balance that affects everything from the shape of the Earth to the behavior of objects in motion. Thus, tides form two bulges on opposite sides of the planet: one caused by the Moon's gravity and the other by centrifugal force.

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CORIOLIS EFFECT

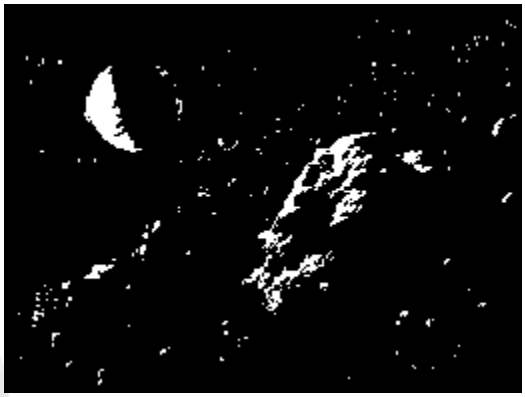


The Coriolis Effect is a phenomenon that causes moving objects, such as air currents and planes, to appear to curve rather than travel in a straight line. This effect arises from the rotation of the Earth on its axis. In the Northern Hemisphere, moving objects are deflected to the right, while in the Southern Hemisphere, they are deflected to the left. This deflection influences weather patterns and ocean currents, playing a crucial role in the dynamics of our atmosphere. Without the Coriolis Effect, air would flow directly from high-pressure areas to low-pressure areas, leading to a very different weather system. Instead, the curved paths created by this effect contribute to the formation of cyclones and anticyclones, which are essential for understanding global weather patterns. The rotation of Earth causes the Coriolis Effect, which deflects the movement of water. This affects the direction and flow of tidal currents, especially in large ocean basins.

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The Asteroid Belt

Asteroids are numerous tiny bodies that also move around the Sun apart from the stars, planets, and satellites. The asteroid belt is a vast region of space located between the orbits of Mars and Jupiter, containing the majority of asteroids in our Solar System. This belt is estimated to harbor between 1.1 and 1.9 million asteroids larger than 1 kilometer (0.6 miles) in diameter, along with millions of smaller fragments. These celestial bodies are remnants from the early solar system, composed of materials that never coalesced into a planet due to the gravitational influence of nearby Jupiter. The asteroid belt serves as a boundary between the inner rocky planets and the outer gas giants, marking a significant transition in the solar system's structure. Its formation is still a subject of research, with theories suggesting it began as an empty space that later filled with debris from the solar system's formation.



The asteroid belt is a region within the solar system occupied by asteroids that are sparsely held together by gravity and occupying a region taking the shape of a gradient ring orbiting the Sun. Asteroids are small rocky bodies sometimes composed of iron and nickel, which orbit the Sun. The asteroid belt exists between the orbits of Mars and Jupiter, between 330 million and 480 million kilometers from the Sun.

The asteroid belt a failed planet

The asteroid belt, located between Mars and Jupiter, is often described as the remnants of a failed planet. This theory suggests that the gravitational influence of Jupiter prevented the coalescence of planetesimals, which are the building blocks of planets. Instead of forming a single, large body, these fragments remain scattered in a vast region of space. The belt contains millions of asteroids, varying in size from small rocks to dwarf planet-sized objects like Ceres. Despite its vastness, the total mass of the asteroid belt is insufficient to form a planet. The gravitational forces exerted by Jupiter disrupt the orbits of these celestial bodies, maintaining their status as a collection of debris rather than a cohesive planet. While the asteroid belt may be seen as a failed planet, it also serves as a crucial area for understanding the early solar system's formation and evolution, offering insights into the processes that shaped our planetary neighborhood. Astronomers now believe the asteroid belt never gravitationally accreted into a planet, but was kept from doing so because of the massive gravity from Jupiter's mass.

Origin and structure universe

The origin and structure of the universe are primarily explained by the Big Bang theory, which posits that the universe began approximately 13.7 billion years ago from an infinitely dense and hot core. This initial explosion led to the rapid expansion of space, cooling the universe and allowing matter to form. As the universe expanded, it transitioned from a hot, formless state into a structured cosmos filled with galaxies, stars, and planets. They explore concepts such as dark matter, which constitutes about 80% of the universe's mass, and its role in shaping cosmic structures.

The big-bang theory proposes the universe was formed from an infinitely dense and hot core of the material. The bang suggests there was an explosive, outward expansion of all matter and space that created atoms. Spectroscopy confirms that hydrogen makes up about 74% of all matter in the universe. Since its creation, the universe has been expanding for 13.8 billion years and recent observations suggest the rate of this expansion is increasing.

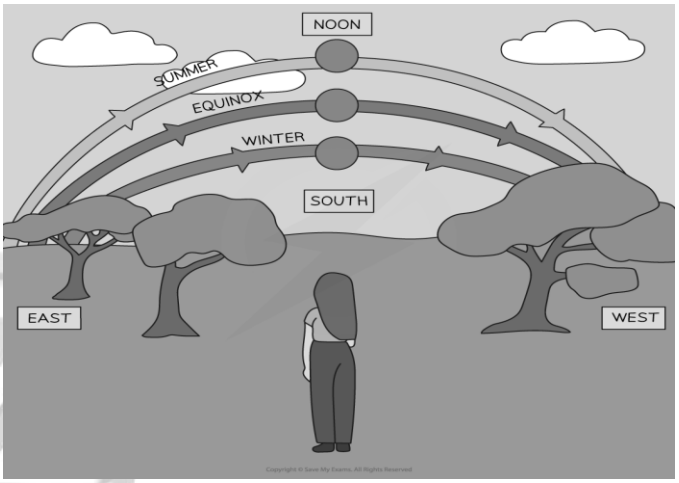
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The Earth's Axis

The Earth is a rocky planet that rotates in a near circular orbit around the Sun. It rotates on its axis, which is a line through the north and south poles. The axis is tilted at an angle of approximately 23.5° from the vertical. The Earth completes one full rotation (revolution) in approximately 24 hours (1 day). This rotation creates the apparent daily motion of the Sun rising and setting. Rotation of the Earth on its axis is therefore responsible for the periodic cycle of day and night.

Rising and Setting of the Sun

The Earth's rotation on its axis makes the Sun looks like it moves from east to west. At the equinoxes, the Sun rises exactly in the east and sets exactly in the west. Equinox (**meaning 'equal night'**) is when day and nights are approximately of equal length. However, the exact locations of where the Sun rises and sets change throughout the seasons.

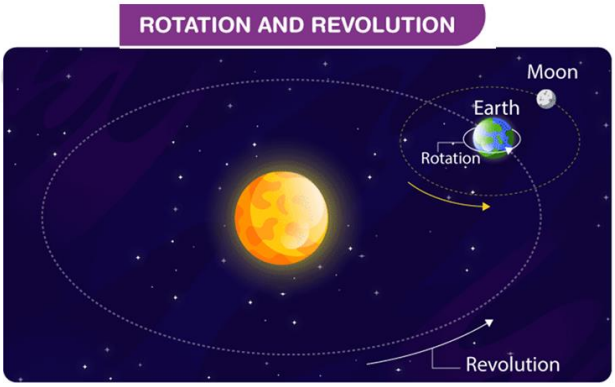


In the northern hemisphere (above the equator): In summer, the sun rises north of east and sets north of west. In winter, the sun rises south of east and sets south of west. The Sun rises in the east and sets in the west. Its approximate area changes throughout the year. The Sun is highest above the horizon at noon (12 pm).

In the northern hemisphere, the daylight hours are longest up until roughly 21st June. This day is known as the **Summer Solstice** and is where the Sun is at its highest point in the sky all year. The daylight hours then decrease to their lowest around 21st December. This is known the **Winter Solstice** and is where the Sun is at its lowest point in the sky all year.

Moon & Earth

Motion of the Earth



What is Rotation?

A rotation is a circular movement of an object around a centre of rotation. If three-dimensional objects like the earth, moon and other planets always rotate around an imaginary line, it is called a rotation axis. If the axis passes through the body's centre of mass, the body is said to rotate upon itself or spin.

What is Revolution?

Revolution is often used as a synonym for rotation. However, in many fields like astronomy and its related subjects, revolution is referred to as an orbital revolution. It is used when one body moves around another, while rotation means moving around the axis. For example, the Moon revolves around the Earth, and the Earth revolves around the Sun.

Rotation of the Earth

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Earth rotates on its axis from west to east, and the Sun and the Moon appear to move from east to west across the sky. The spinning of the Earth around its axis is called 'rotation'. The axis has an angle of 23.5º and is perpendicular to the plane of Earth's orbit. This means the Earth is tilted on its axis, and because of this tilt, the northern and southern hemispheres lean in a direction away from the Sun. The rotation of the Earth divides it into a lit-up half and a dark half, which gives rise to day and night. The direction of the Earth's rotation depends on the direction of viewing. When viewed looking down from the North Pole, Earth spins counterclockwise. On the contrary, when viewed looking down from the South Pole, the earth spins in the clockwise direction.

Importance of Earth Rotation

Some of the importance of the rotation of the Earth are listed below:

The Earth's rotation creates the diurnal cycle of lightness and darkness, temperature and humidity changes.

The Earth's rotation causes tides in the oceans and seas.

Revolution of the Earth

The movement of the Earth around the Sun in a fixed path is called a revolution. The Earth revolves from west to east, i.e., in the anticlockwise direction. The one revolution of the Earth around the Sun takes around one year or precisely 365.242 days. The revolution speed of the earth is 30 km/s^{-1}.

Importance of Revolution

- Revolution causes seasons.
- Revolution creates perihelion and aphelion. Perihelion occurs when the Earth is closest to the Sun. Aphelion occurs when the Earth is far from the Sun.
- Revolution has a direct influence on the varied length of day and night time. The duration of days and nights are the same at the equator. This is known as the equinox. The duration of days and nights vary in the Northern and Southern hemispheres. This is known as solstices.

Day and night

The Earth is always spinning on an imaginary line called an axis. This line goes through the **North** and **South poles**. We call this spinning, rotation, and it takes about **24 hours** for the Earth to make one full turn. As the Earth rotates on its axis, it is also orbiting the Sun. As it rotates on its axis, different parts of the Earth face the Sun, which does not move. When a part of the Earth is facing the Sun, it's daytime and you can see the Sun in the sky. As the Earth keeps spinning, that same part of the Earth starts to turn away from the Sun and it begins to get dark. This is called night-time. During the summer, the day is longer than the night and during the winter, the day is shorter than the night. This is because the Earth's axis is actually **tilted**. This is what causes the Earth to have seasons.

The Earth's rotation is what also gives us **time zones**. In one part of the world it will be night-time while at the same point in time in another part of the world it will be daytime!

During certain months of the year at the **North** and **South Poles**, there can be **24 hours of daylight** or **24 hours of darkness**. This is due to the tilt of the Earth's axis. At any moment, half of the world is in **daylight**, with the other half in **darkness**.

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In the UK, during the summer there is around **16 and a half hours** whereas during the winter there is only around **7 hours and 45 minutes**. The Earth's rotation makes it seem like the Sun **rises in the East** and **sets in the West**. The shortest day of the year is called the **winter solstice** in the UK, and the longest is called the **summer solstice**. We can only see the **Moon** because it is lit up by the Sun; the moon does not make its own light. A day on Earth is **24 hours** long because that is how long it takes for the Earth to rotate once on its axis. Other planets in our Solar System have longer or shorter days because they take more or less time to rotate once.

Rising and setting of the Sun

The Earth's rotation on its axis causes the Sun to have an apparent daily journey from east to west. It rises exactly in the east and sets exactly in the west only at the equinoxes (around 21 March and 23 September). In the northern hemisphere in summer it rises north of east and sets north of west. In winter it rises and sets south of these points. Each day the Sun is highest above the horizon at noon and directly due south in the northern hemisphere; this height itself is greatest and the daylight hours longest about 21 June. After that the Sun's height slowly decreases and near 21 December it is lowest and the number of daylight hours is smallest.

Rising and setting of the Sun (in the Northern hemisphere)

Orbit of the Earth e r m s u m t e n r i w The Earth orbits the Sun once in approximately 365 days (i.e. in one year). The path of the Earth around the Sun is not quite circular but takes the form of an ellipse with the Sun at one focus.

The Earth is in four different positions in its orbit. Note that the Earth's axis is tilted (at 23.5°) to the plane of its path around the Sun. Day and night are of equal length only when the Earth is at points A and B of its orbit; these are the equinoxes, which often fall on 20 March and 23rd September. Earth tilted on axis 21 Jun A 20 Mar Sun 23 Sept B

Orbit of the Earth around the Sun

Motion of the Moon

The moon is a satellite of the Earth and travels round it in an approximately circular orbit approximately once a month at an average distance away of about 400 000 km. It also revolves on its own axis in a month and so always has the same side facing the Earth, so that we never see the 'dark side of the Moon'. We see the Moon by reflected sunlight since it does not produce its own light. It does not have an atmosphere. It does have a gravitational field due to its mass, but the field strength is only one-sixth of that on Earth. Hence the astronauts who walked on the Moon moved in a 'springy' fashion but did not fly off into space.

Rising and setting of the Moon

Like the Sun, the Moon appears to have a daily trip across the sky from the east, where it rises, to the west, where it sets; again, this is due to the Earth's rotation on its axis.

Scientists believe that the Earth formed from a rotating disk of dust and gas surrounding the early Sun. This process led to the creation of the Moon, which is unique in its size relative to Earth, being about 27% of Earth's diameter. This significant ratio is unlike any other moon-planet relationship in our solar system. The Moon plays a crucial role in making Earth more habitable. It influences ocean tides, stabilizes Earth's axial tilt, and serves as a historical record of our solar system's evolution. The Moon orbits Earth approximately every 27.3 days, creating a rhythmic cycle that affects various natural phenomena.

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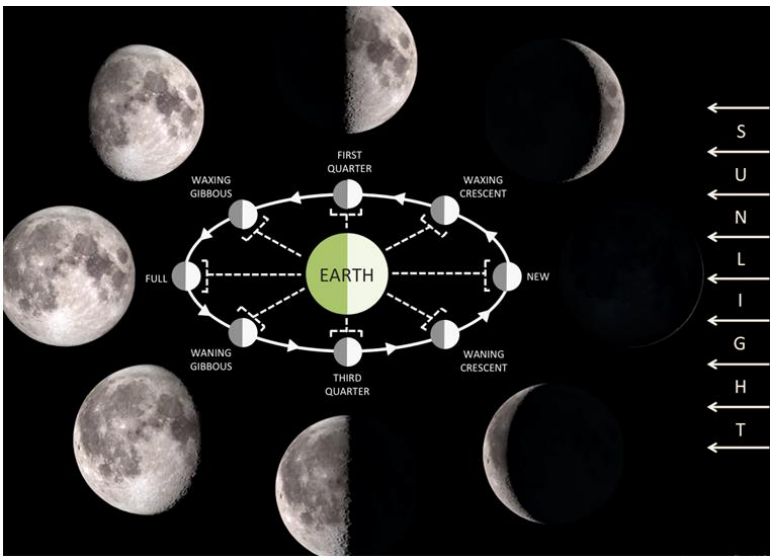
The Moon, Earth's only natural satellite, plays a crucial role in our planet's ecosystem. With a mass of 1.2% that of Earth and a diameter of 3,474 km (2,159 mi), it orbits at an average distance of about 239,000 miles (385,000 kilometers). This proximity influences various natural phenomena, including ocean tides, which are essential for marine life and coastal ecosystems. The Moon is not just a beautiful sight in the night sky; it also serves as a historical record of our solar system. Its surface, marked by craters and Maria, provides insights into the early solar system's conditions. The Moon's phases, from new to full, have guided human calendars and cultural practices for centuries. Upcoming lunar events, such as the Full Sturgeon Moon on August 19, 2025, continue to captivate sky watchers.

The Moon travels around the Earth in roughly a circular orbit once a month. This takes 27-29 days. The Moon revolves around its own axis in a month so always has the same side facing the Earth. We never see the hemisphere that is always facing away from Earth, although astronauts have orbited the Moon and satellites have photographed it. The Moon shines with **reflected light from the Sun**; **it does not produce its own light.**

Phases of the Moon

New Moon

This is the invisible phase of the Moon, with the illuminated side of the Moon facing the Sun and the night side facing Earth. In this phase, the Moon is in the same part of the sky as the Sun and rises and sets with the Sun. Not only is the illuminated side facing away from the Earth, it's also up during the day! Remember, in this phase, the Moon doesn't usually pass directly between Earth and the Sun, due to the inclination of the Moon's orbit. It only passes near the Sun from our perspective on Earth.



Waxing Crescent

This silver sliver of a Moon occurs when the illuminated half of the Moon faces mostly away from Earth, with only a tiny portion visible to us from our planet. It grows daily as the Moon's orbit carries the Moon's dayside farther into view. Every day, the Moon rises a little bit later.

First Quarter

The Moon is now a quarter of the way through its monthly journey and you see half of its illuminated side. People may casually call this a half Moon, but remember, that's not really what you're witnessing in the sky. You're seeing just a slice of the entire Moon — half of the illuminated half. A first quarter Moon rises around noon and sets around midnight. It's high in the sky in the evening and makes for excellent viewing.

Waxing Gibbous

Now most of the Moon's dayside has come into view, and the Moon appears brighter in the sky.

Full Moon

This is as close as we come to seeing the Sun's illumination of the entire day side of the Moon (so, technically, this would be the real half-moon). The Moon is opposite the Sun, as viewed from Earth, revealing the Moon's dayside. A full Moon rises around sunset and sets around sunrise. The Moon will appear full for a couple of days before it moves into…

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Waning Gibbous
As the Moon begins its journey back toward the Sun, the opposite side of the Moon now reflects the Moon's light. The lighted side appears to shrink, but the Moon's orbit is simply carrying it out of view from our perspective. The Moon rises later and later each night.
Last Quarter
The Moon looks like it's half illuminated from the perspective of Earth, but really you're seeing half of the half of the Moon that's illuminated by the Sun — or a quarter. A last quarter Moon, also known as a third quarter Moon, rises around midnight and sets around noon.
Waning Crescent
The Moon is nearly back to the point in its orbit where its dayside directly faces the Sun, and all that we see from our perspective is a thin curve.

Gravitational Field Strength
The strength of gravity on different planets affects an object's weight on that planet. **Weight is defined as the force acting on an object due to gravitational attraction.**
Planets have strong gravitational fields. Hence, they attract nearby masses with a strong gravitational force. Because of weight: Objects stay firmly on the ground, Objects will always fall to the ground, and Satellites are kept in orbit. Objects are attracted towards the centre of the Earth due to its gravitational field strength.
Both the weight of any body and the value of the gravitational field strength, g, differs between the surface of the Earth and the surface of other bodies in space, including the Moon because of the planet or moon's mass. The greater the mass of the planet then the greater its gravitational field strength. Higher gravitational field strength means a larger attractive force towards the centre of that planet or moon, g varies with the distance from a planet, but on the surface of the planet, it is roughly the same.
The strength of the field around the planet decreases as the distance from the planet increases. However, the value of g on the surface varies dramatically for different planets and moons. The gravitational field strength (g) on the Earth is approximately 10 N/kg. The gravitational field strength on the surface of the Moon is less than on the Earth. This means it would be easier to lift a mass on the surface of the Moon than on the Earth. The gravitational field strength on the surface of the gas giants (Jupiter and Saturn) is more than on the Earth. This means it would be harder to lift a mass on the gas giants than on the Earth.

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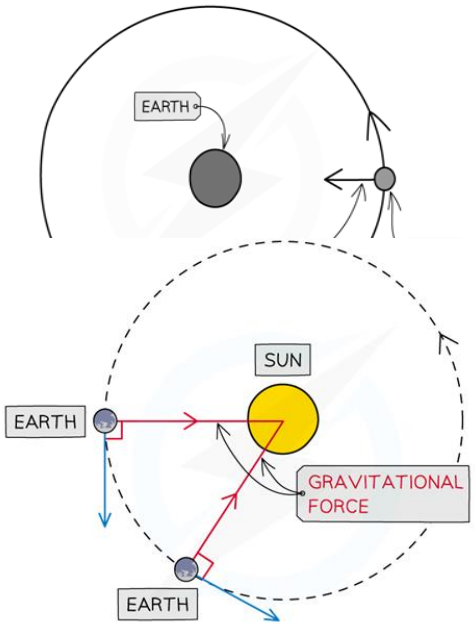
Value for g on the different objects in the Solar System
On such planets such as Jupiter, an object's mass remains the same at all points in space.
However, their weight will be a lot greater meaning for example; a human will be unable to fully stand up. A person's weight on Jupiter would be so large a human would be unable to fully stand up.

Gravitational Attraction of the Sun
There are many orbiting objects in our solar system and they each orbit a different type of planetary body.

Orbiting Objects or Bodies in Our Solar System Table
In our Solar System, the term "**orbit**" refers to the gravitational path that various celestial bodies follow around the Sun. This includes not only the eight major planets; Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune; but also, a multitude of smaller objects such as asteroids, comets, and moons. Each of these bodies has a unique orbital trajectory influenced by gravitational forces. Beyond the main planets, the Solar System is populated with millions of asteroids, primarily located in the "**main-**

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belt" between Mars and Jupiter. There are thousands of smaller bodies, particularly in the **Kuiper Belt** and **Oort Cloud**, which exhibit eccentric orbits. These irregular paths can sometimes be attributed to past stellar flybys that have altered their trajectories. For example, a planet orbiting the Sun; In order to orbit a body such as a star or a planet, there has to be a force pulling the object towards that body. Gravity provides this force. Therefore, it is said that the force that keeps a planet in orbit around the Sun is the gravitational attraction of the Sun. The gravitational force exerted by the larger body on the orbiting object is always attractive. Therefore, the gravitational force always acts towards the centre of the larger body. Therefore, the force that keeps an object in orbit around the Sun is the gravitational attraction of the Sun and is always directed from the orbiting object to the centre of the Sun. The gravitational force will cause the body to move and maintain in a circular path. Gravitational attraction causes the Moon to orbit around the Earth.



Sun's Gravitational Field & Distance

As the distance from the Sun increases; the strength of the Sun's gravitational field on the planet decreases. Their orbital speed of the planet decreases. To keep an object in a circular path, it must have a centripetal force. For planets orbiting the Sun, this force is gravity.

Therefore, the strength of the Sun's gravitational field in the planet affects how much centripetal force is on the planet. This strength decreases the further away the planet is from the Sun, and the weaker the centripetal force. The centripetal force is proportional to the orbital speed. Therefore, the planets further away from the Sun have a smaller orbital speed. This also equates to a longer orbital duration

Earth and the Solar system

Orbital speed

Orbit speed defined $average\ speed = \frac{total\ distance}{total\ time}$.

So, for the Moon, moving in a circular orbit around the Earth with average orbital speed, $v = \frac{\text{circumference of orbit}}{T} = \frac{2\pi r}{T}$, where r is the average radius of the orbit, and T is the orbital period (the time for one orbit). Average orbital speed, $v = \frac{2\pi r}{T}$, where r is the average radius of the orbit and T is the orbital period.

Table of Orbital Distance, Speed and Duration

Planet	**Orbital distance (million km)**	**Orbital Speed (km/s)**	**Orbital duration (days or years)**
Mercury	57.9	47.9	88 days
Venus	108.2	35.0	225 days
Earth	149.6	29.8	365 days
Mars	227.9	24.1	687 days

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Jupiter	778.6	13.1	11.9 years
Saturn	1433.5	9.7	29.5 years
Uranus	2872.5	6.8	75 years
Neptune	4495.1	5.4	165 years

It is important to refer to the force of gravity as 'gravitational attraction', ' strength of the Sun's gravitational field' or 'the force due to gravity'. Avoid terms such as 'the Sun's gravity' or even more vague, 'the force from the Sun'.

Orbits & Conservation of Energy

An object in an elliptical orbit around the Sun travels at a different speed depending on its distance from the Sun. Although these orbits are not circular, they are still stable. For a stable orbit, the radius must change if the comet orbital speed changes.

As the comet approaches the Sun: The radius of the orbit decreases, the orbital speed increases due to the Sun's strong gravitational pull. **As the comet travels, further away from the Sun:** The radius of the orbit increases, and the orbital speed decreases due to a weaker gravitational pull from the Sun. Comets travel in highly elliptical orbits, speeding up as they approach the Sun.

Conservation of Energy

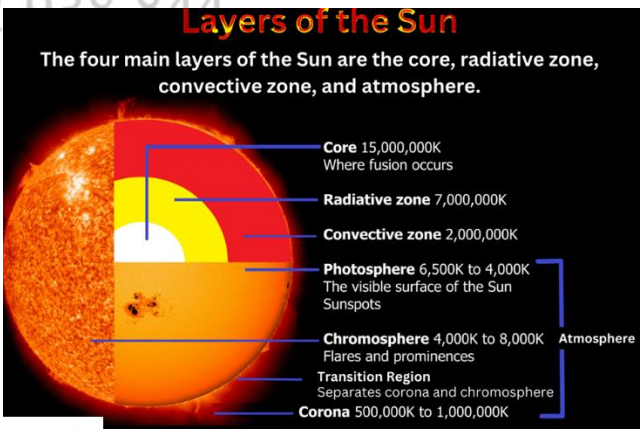
Although an object in an elliptical orbit, such as a comet, continually changes its speed, its energy must still be conserved. Throughout the orbit, the gravitational potential energy and kinetic energy of the comet changes.

As the comet approaches the Sun:

It loses gravitational potential energy and gains kinetic energy; this causes the comet to speed up. This increase in speed causes a slingshot effect, and the body will be flung back out into space again, having passed around the Sun. **As the comet moves away from the Sun:** It gains gravitational potential energy and loses kinetic energy; this causes it to slow down. Eventually, it falls back towards the Sun once more. In this way, a stable orbit is formed.

Remember that an object's kinetic energy is defined by: $E = \frac{1}{2}mv^2$; *where m is the mass of the object and v is its speed.* Therefore, if the speed of an object increases, so does its kinetic energy. Its gravitational potential energy therefore must decrease for energy to be conserved.

The Sun



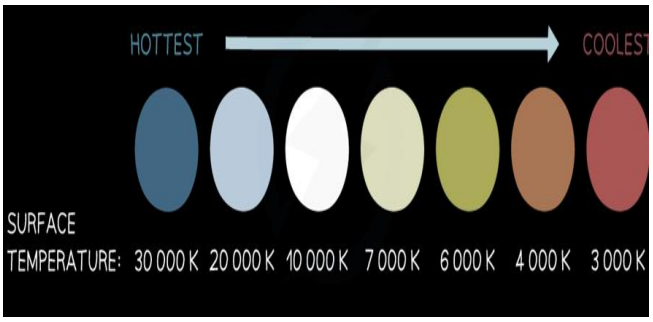
The Sun is the star at the center of our Solar System, a massive sphere of hot plasma that generates energy through nuclear fusion. Part of this energy is emitted from its surface as visible light, ultraviolet, and infrared radiation, providing most of the energy for life on Earth. This process heats the Sun to incandescence, producing the light and warmth essential for life on Earth. Comprising over 99% of the Solar System's mass, the Sun's gravitational pull keeps planets, moons, and other celestial bodies in orbit. As the closest star to Earth, the Sun plays a crucial role in sustaining life. It provides the energy necessary for photosynthesis, allowing plants to grow and, in turn, supporting the entire food chain. The Sun's energy also influences Earth's climate and weather patterns, making it a vital component of our ecosystem. The Sun is a medium sized star consisting of mainly hydrogen and helium. It radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.

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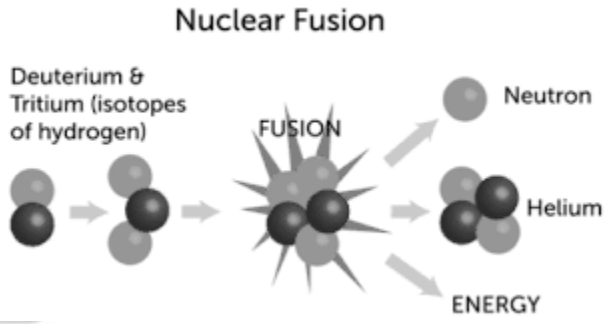
Our Sun

Stars come in a wide range of sizes and colours, from yellow stars to red dwarfs, from blue giants to red supergiant. These can be classified according to their colour. Warm objects emit infrared and extremely hot objects emit visible light as well. Therefore, the colour they emit depends on how hot they are. A star's colour is related to its surface temperature. A red star is the coolest (at around 3000 K). A blue star is the hottest (at around 30 000 K). The colour of a star correlate to its temperature.



Nuclear Fusion in Stars

Nuclear fusion is the fundamental process that powers stars, including our Sun. It occurs when two light atomic nuclei, typically hydrogen, collide and merge to form a heavier nucleus, such as helium. This reaction releases vast amounts of energy in the form of light and heat, which is essential for maintaining the star's temperature and preventing gravitational collapse. In the core of stars, extreme temperatures and pressures facilitate these fusion reactions. The energy produced not only sustains the star's brightness but also contributes to the creation of heavier elements through a process known as stellar nucleosynthesis. As stars evolve, they can fuse heavier elements, enriching the universe with diverse chemical elements.

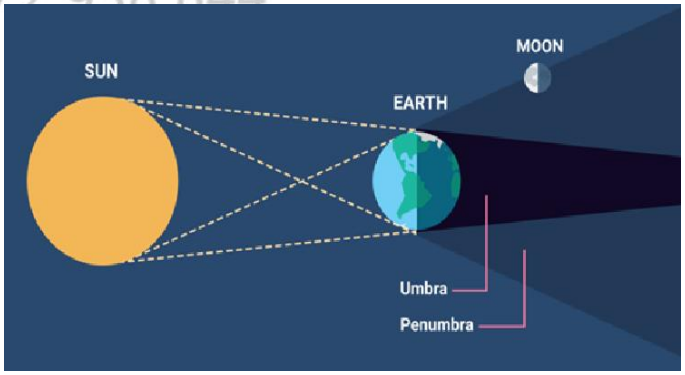


In the centre of a stable star, hydrogen nuclei undergo nuclear fusion to form helium. The equation for the reaction is shown here: **Deuterium and tritium are both isotopes of hydrogen.** $_1^2H + _1^3H \rightarrow _2^4He + _0^1n$ They can be formed through other fusion reactions in the star. A huge amount of energy is released in the reaction. This provides a pressure that prevents the star from collapsing under its gravity. The fusion of deuterium and tritium to form helium with the release of energy.

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ECLIPSES

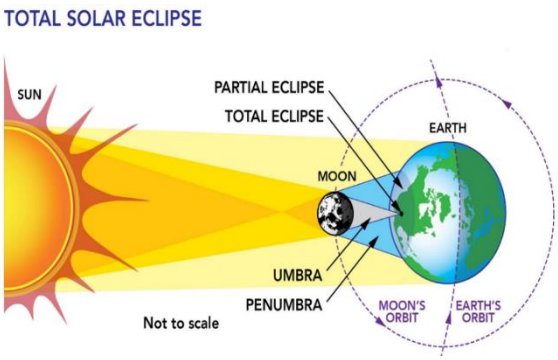
Eclipses are fascinating astronomical events that occur when one celestial body moves into the shadow of another, temporarily obscuring it. On Earth, we primarily experience two types of eclipses: solar and lunar. A solar eclipse happens when the Moon passes directly between the Sun and Earth, blocking the Sun's light and casting a shadow on Earth. This alignment can result in a total, partial, or annular eclipse, depending on the positions of the Sun, Moon, and Earth. Conversely, a lunar eclipse occurs when the Earth comes between the Sun and the Moon, causing the Earth's shadow to fall on the Moon. This can only happen during a full moon and can also be total or partial.



SOLAR ECLIPSE

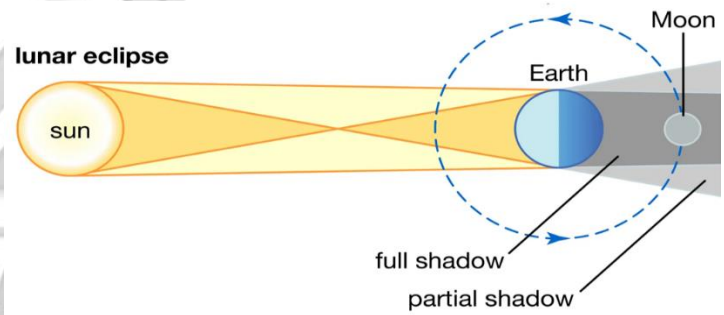
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A solar eclipse is a fascinating celestial event that occurs when the Moon passes directly between the Earth and the Sun, temporarily obscuring the Sun's light. This alignment causes the Moon to cast a shadow on specific areas of the Earth, resulting in a partial or total blockage of sunlight for observers in those regions. There are three main types of solar eclipses: total, partial, and annular. A total solar eclipse occurs when the Moon completely covers the Sun, allowing viewers in the path of totality to experience darkness during the day. A partial eclipse happens when only a portion of the Sun is obscured, while an annular eclipse occurs when the Moon is too far from Earth to completely cover the Sun, resulting in a "ring of fire" effect. Solar eclipses are relatively rare events, with total eclipses visible from only a limited area on Earth. They offer a unique opportunity for scientific observation and public engagement with astronomy.



LUNAR ECLIPSE

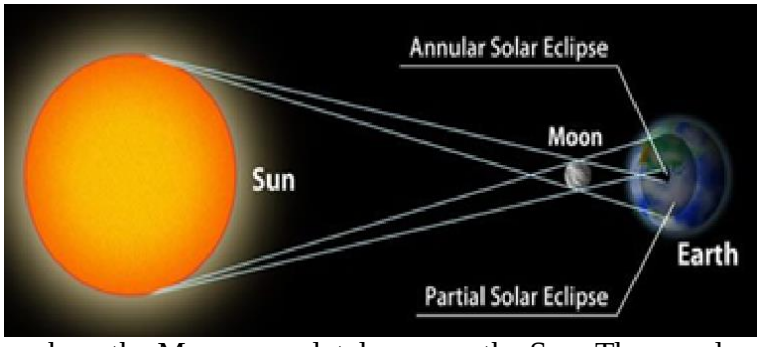
A lunar eclipse is a fascinating astronomical event that occurs when the Earth positions itself directly between the Sun and the Moon. This alignment causes the Earth to cast a shadow on the Moon, resulting in a temporary darkening of its surface. Unlike solar eclipses, which can only be viewed from specific locations on Earth, lunar eclipses are visible from anywhere on the night side of the planet.



During a lunar eclipse, the Moon can take on a striking reddish hue, often referred to as a "blood moon." This phenomenon occurs due to Rayleigh scattering, where sunlight passes through the Earth's atmosphere and bends, allowing some light to reach the Moon while filtering out other colors. The result is a captivating display that has intrigued humanity for centuries. Lunar eclipses can occur several times a year, but total eclipses, where the Moon is completely covered by Earth's shadow, are less frequent.

ANNULAR ECLIPSE

An annular solar eclipse is a fascinating celestial event that occurs when the Moon passes between the Earth and the Sun, but is at or near its farthest point from Earth. During this type of eclipse, the Moon appears smaller than the Sun, resulting in a striking "ring of fire" effect, where the outer edges of the Sun remain visible around the Moon. This phenomenon contrasts with a total solar eclipse, where the Moon completely covers the Sun. The annular eclipse is a unique spectacle, as it allows observers in specific regions to witness this stunning visual display. The next notable annular solar eclipse will occur on October 14, 2023, crossing parts of North, Central, and South America. Observers in the path of annularity will experience the full effect of the ring of fire, while those outside this path will see a partial eclipse.



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ACTIVITY

A group of tourists visited temporal Nasa station organized for public viewing of solar eclipse in different parts of North America that happened recently. They wondered how people at NASA use satellites to study weather patterns and such events are predicted to occur. They were cautioned to use solar glasses to be able to view the eclipse safely since it shinning bright. At night, they were happy to see a number of stars in the sky that appeared with different colours and shone differently. Given the high temperatures of the sun during the day, one of the young tourists was curious to know how the sun produced such energy and why stars have different colours and appear to twinkle.

Task: Use your knowledge of Physics to:

a) Explain how this particular type of eclipse occurs.
b) Explain what determines the colour and brightness of the star and why they appear to twinkle.
c) Explain the source of energy of the stars such as the sun and explain why solar glasses were necessary.
d) Explain how people around the world are able to view eclipse in real time.

SENIOR THREE

3.1 LINEAR AND NON-LINEAR MOTION

Learning Outcomes

a) Understand and apply the relationship between speed, distance, and time (u, s)
b) Understand the terms: linear motion, speed, average speed, acceleration, and be able to investigate resistance to motion (u,s)
c) Know and use the equations of motion (u,s)
d) Understand the acceleration of bodies moving in a circle and the effect of gravity and air resistance on moving bodies (u,s)
e) Understand linear momentum and that it is conserved during collisions (u,s)
f) Understand that momentum is conserved during a collision and the implication of this (u, s,v/a)
g) Understand and apply Newton's laws of motion (u,s,v/a)
h) Understand the differences between vector and scalar quantities, and give examples of each(u)
i) Understand that a number of forces acting on a body can be represented by a sign.

Introduction

Linear motion, also known as rectilinear motion, refers to the movement of an object along a straight line in one dimension.

In linear motion, the velocity of the object remains constant unless acted upon by an external force, as stated in Newton's First Law of Motion. In practical terms, linear motion can be observed in various everyday scenarios, such as a car driving down a straight road or a ball rolling along a flat surface.

The key characteristics of linear motion include position, displacement, velocity, and acceleration, all of which can be graphically represented to illustrate the object's movement over time.

It is the simplest type of motion, involving objects moving in a straight line, either at a constant speed or accelerating. Linear motion can be described using concepts such as velocity, acceleration, displacement, and time.

Quantities in Linear Motion

In linear motion, the relationship between speed, distance, and time is fundamental.

Speed is defined as the ratio of distance traveled to the time taken, expressed mathematically as $speed = \frac{distance}{time}$.

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For instance, if a person travels at a speed of 30 km/h, we can determine how far they will go in a specific time frame by rearranging the formula to distance = speed × time. When analyzing motion, it's essential to distinguish between **constant speed and accelerated motion.**
Constant speed indicates that the distance covered over time remains uniform, while accelerated motion involves changes in speed, either increasing or decreasing. This can be visualized using **distance-time** and **speed-time** graphs, where **straight lines represent constant speed, and curves indicate acceleration.**

Speed, a **scalar quantity**, measures how fast an object covers distance, while **average speed is calculated as the total distance traveled divided by the total time taken**.
Acceleration is the rate of change of velocity with time. It indicates how quickly an object speeds up, slows down, or changes direction. In scenarios where velocity remains constant, acceleration is zero. Investigating resistance to motion involves understanding the forces that oppose an object's movement, such as **friction and air resistance**. These forces can significantly affect an object's speed and acceleration, making it essential to consider them in any analysis of linear motion.

Used Terms
Displacement (s): *Displacement is the change in position of an object along a straight line.* It is a **vector quantity,** meaning it has both magnitude (distance) and direction. Example: If a car moves 5 km east, its displacement is 5 km to the east, regardless of the path taken. The SI unit of displacement is the meter (m).
Distance: *Distance is the total length of the path traveled by an object, irrespective of direction.* Unlike displacement, distance is a **scalar quantity**; it only has magnitude, not direction. Example: If a person walks 5 meters forward and then 5 meters back, the total distance is 10 meters, but the displacement is 0 meters.

Velocity (v): *Velocity is the rate of change of displacement with respect to time*. It is a **vector quantity,** meaning it describes both speed and direction. Average velocity (V_{avg}) is calculated as: $V_{avg} = \frac{\Delta s}{\Delta t}$, *where*
Δs = change in displacement, Δt = change in time. Instantaneous velocity is the velocity of an object at a particular moment in time. The SI unit of velocity is the meter per second (m/s).
Speed: *Speed is the rate at which an object covers distance.* It is a *scalar quantity and only has magnitude.* Speed is the total distance traveled divided by the time taken**.** The SI unit of speed is also meters per second (m/s).
Acceleration (a): *Acceleration is the rate of change of velocity with respect to time.* It is a vector quantity and can describe changes in speed or direction. Uniform acceleration occurs when the velocity of an object changes by the same amount each second. Average acceleration is given by: $a = \frac{\Delta v}{\Delta t}$, *where:* Δv = change in velocity, Δt = time interval. The SI unit of acceleration is meters per second squared (m/s^2).

Time (t): *Time measures the duration of motion.* It is a **scalar quantity** and is usually measured in seconds (s).

Linear motion (rectilinear motion) refers to the movement of an object along a straight line. This type of motion can be categorized into three primary types: **constant velocity motion, uniformly accelerated motion,** and **free fall.**

Uniform motion refers to the movement of an object traveling in a straight line at a constant speed. In this type of motion, the object covers equal distances in equal intervals of time, meaning its velocity remains unchanged. This can be represented graphically as a straight line on a distance-time graph, indicating that the object is not accelerating or decelerating. For example, a car moving at a steady speed of 60 km/h on a straight highway exemplifies uniform motion.

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N**on-uniform motion** occurs when an object's speed or direction changes, resulting in varying distances covered in equal time intervals.

Constant velocity motion occurs when an object moves at a steady speed in a straight line, while uniformly accelerated motion involves a consistent change in velocity over time. Free fall describes the motion of an object under the influence of gravity alone. Linear motion systems are essential in various technologies, including automation and robotics. These systems often incorporate components like linear bearings, actuators, and slides, which facilitate smooth and precise movement. Examples include screw drives and linear motors, which are crucial for tasks requiring accurate positioning.

Non-uniform motion refers to the movement of an object that changes its speed or direction over time. Unlike uniform motion, where an object travels equal distances in equal intervals, non-uniform motion involves varying distances covered in the same time frame. This can occur due to acceleration or deceleration, resulting in a change in velocity. For example, consider a car navigating through city traffic. It may speed up on a clear road and slow down at traffic lights, demonstrating non-uniform motion. The velocity of the car is not constant, as it fluctuates based on external conditions. Non-uniform motion can be represented by a curve on a distance-time graph, indicating the changes in speed.

Uniform Linear Motion: This occurs when an object moves along a straight path at a constant velocity, meaning it covers equal distances in equal time intervals. In this type of motion, acceleration is zero because the velocity does not change.

Equations: Displacement: s=vt, where v is constant velocity, and t is the time.

Non-Uniform Linear Motion: This type of motion occurs when an object moves along a straight path but with changing velocity. It experiences acceleration or deceleration. The velocity changes with time due to the influence of forces such as gravity, friction, or external applied forces.

Equations of Motion for Uniformly Accelerated Linear Motion:

These equations are crucial for solving problems involving linear motion with constant acceleration. They relate displacement, velocity, acceleration, and time:

1st Equation (velocity-time relationship):

$V = \boldsymbol{u + at}$; Where: v = final velocity, u = initial velocity, a = acceleration and t = time

2nd Equation (Displacement-Time Relationship): $\boldsymbol{s = ut + \frac{1}{2}at^2}$**,** where: s = displacement, u= initial velocity, t = time, and a = acceleration

3rd Equation (velocity-displacement Relationship): $\boldsymbol{v^2 = u^2 + 2as}$***, where: v = final velocity, u = initial velocity, a = acceleration and s = displacement***

These equations assume that acceleration is constant and the motion occurs in a straight line.

Examples of Linear Motion in Real Life:

Free Fall: When an object falls under the influence of gravity, it experiences linear motion with constant acceleration (due to gravity, $g \approx 9.8\ m/s^2$. The motion of the object can be described using the equations of motion, where: u=0, (when starting from rest), a=g, t = time taken to fall.

1. If a car is moving at a constant speed along a straight road, it is in uniform linear motion. If the car accelerates or decelerates (e.g., during braking), it is in non-uniform linear motion.

2. A train moving between stations experiences both uniform and non-uniform linear motion. It accelerates when leaving the station, travels at constant speed, and decelerates when approaching the next station.

3. In projectile motion, the horizontal component of motion (if air resistance is neglected) is uniform linear motion, as no force acts horizontally after the object is launched. The area under the velocity-time graph represents the displacement.

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ACTIVITY

A driver is testing a new sports car on both city roads and a highway section. The car is stationary at a red light. When the light turns green, the driver accelerates uniformly at 1 m/s² for 20 seconds until they reach the speed limit of the city road.

Later, while already moving at 20 m/s in the city, the driver notices a slow vehicle ahead. They decide to overtake by over pressing the accelerator hard, producing a uniform acceleration of 2 m/s² for exactly 4 seconds.

After reaching the highway, the car is traveling at 20 m/s when the driver begins to accelerate to merge into faster traffic. In exactly 5 seconds, the speed increases steadily to 40 m/s.

Task: Use the knowledge of physics to determine;

(a) the distance travelled and the average speed.
(b) the uniform acceleration during the 5 seconds
(c) The distance covered while accelerating from 20 m/s to 40 m/s

Responses:

a*). *distance travelled and average speed (from rest)

$initial\ velocity\ (u) = 0\frac{m}{s}, acceleration\ (a) = 1\frac{m}{s^2}, time\ (t) = 20\ s$

$final\ velocity: v = u + at;\ v = 0 + (1 \times 20) = 20\ m/s$

$distance\ travelled: s = ut + ½at^2 s = 0 + ½(1)(20^2)s = 200\ m$

$average\ speed = \frac{total\ distance}{total\ time};\ average\ speed = 200 / 20 = 10\ m/s$

b*). *uniform acceleration during 5 seconds

$given$:

$initial\ velocity\ (u) = 20\frac{m}{s};\ final\ velocity\ (v) = 40\frac{m}{s};\ time\ (t) = 5\ s$

$acceleration$:

$a = \frac{(v - u)}{t};\ a = \frac{(40 - 20)}{5};\ a = 4\ m/s^2$

c*) . *distance covered from 20 m/s to 40 m/s

$using: s = ut + ½at^2;\ s = (20 \times 5) + ½(4)(5^2);\ s = 100 + 50\ ;\ s = 150\ m$

d*). *free fall from height of 20 m

$initial\ velocity\ (u) = 0\frac{m}{s}, height\ (h) = 20\ m, acceleration\ due\ to\ gravity\ (g) = 10\ m/s^2$

$velocity\ on\ impact: v^2 = u^2 + 2gh;\ v^2 = 0 + 2(10)(20);\ v = 20\ m/s$

$time\ before\ striking\ the\ ground: v = u + gt;\ 20 = 0 + 10t;\ t = 2\ s$

Activity:

A body at rest at height of 20m falls freely to the ground. Calculate the velocity with which it hits the ground and the time before striking the ground.

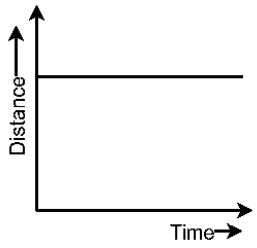
Distance – time graphs

i) For a body at rest If a body is at rest its distance from a certain point does not change as time passes
ii) For a body moving with uniform velocity

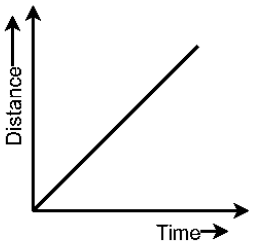
If a body is moving with the same velocity, it travels equal distance in equal intervals of time i.e. the object distance increases by equal increase in time.

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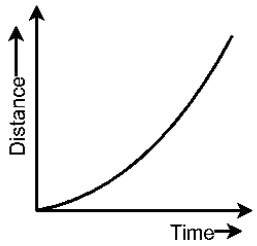
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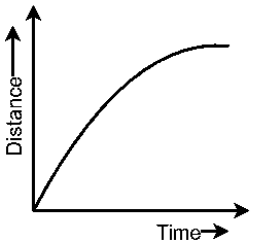
For Stationary body



(For uniform motion)



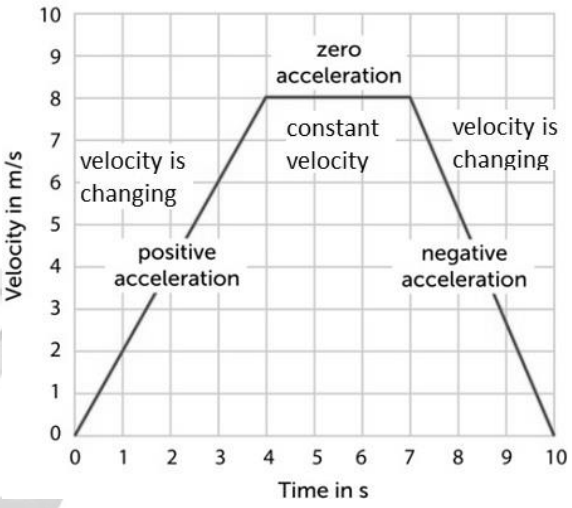
(For non-uniform motion when speed increases)



(For non-uniform motion when speed decreases)

iii) Body moving with non-uniform velocity; varying distances are moved in equal intervals of time

iv) Body moving with decreasing acceleration (retardation); for a body whose velocity is decreasing the graph bends towards the horizontal.
Velocity decreasing (retardation)



Velocity time graphs

a) Body moving with uniform velocity
b) Body moving with uniform acceleration
c) Body moving with uniform deceleration.

The area under a velocity time graph gives the distance covered by the body.
The slope of a uniform velocity time graph gives the uniform acceleration.
A velocity-time graph illustrates how an object's velocity changes over time.

Acceleration-Time Graph:

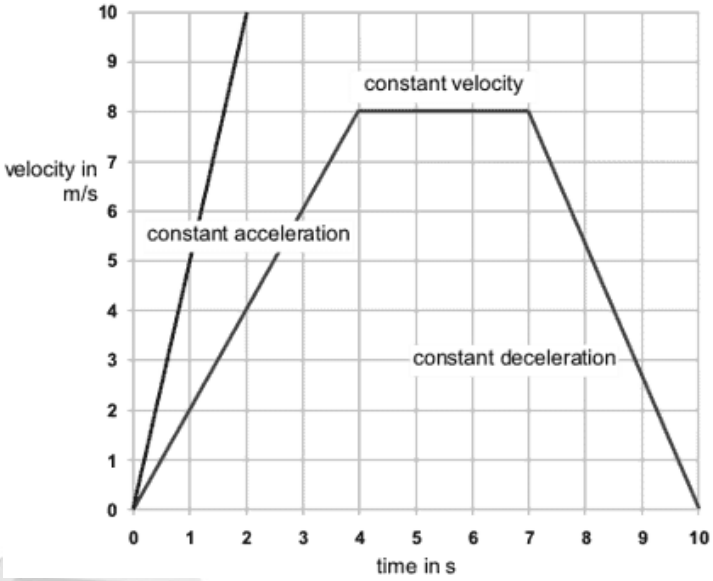
For constant acceleration, the acceleration-time graph is a horizontal line.
If acceleration is zero, the graph lies on the time axis.
For instance, a horizontal line indicates constant velocity, meaning the object is moving at a steady speed without acceleration.

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A straight diagonal line signifies uniform acceleration, where the object's velocity increases or decreases at a constant rate. The slope of the line on a velocity-time graph is particularly significant, as it represents the object's acceleration.

A steeper slope indicates greater acceleration, while a flatter slope suggests less acceleration. If the graph curves, it indicates that the acceleration is changing over time, which can occur in various real-world scenarios.

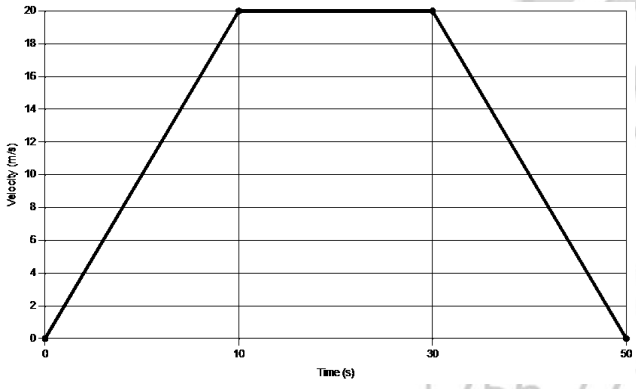


Example

1). A car starts from rest and steadily accelerates for 10s to a velocity of 20m/s. It continues with this velocity for a further 20s before it is brought to rest in 20s.

a) Draw a velocity time graph to represent this motion.

b) Calculate (i) acceleration, (ii) deceleration, (iii) distance travelled, (iv) average speed



b) **Calculations**

Acceleration:

The car accelerates from rest ($0ms^{-1}$) to $20ms^{-1}$ in 10 s.

Acceleration = $\frac{change\ in\ velocity}{time} = \frac{20-0}{10} = 2ms^{-1}$

Deceleration:

The car decelerates from $20ms^{-1}$ to rest ($0ms^{-1}$) in 20 s.

Deceleration = change in velocity / time = ($0ms^{-1}$ -$20ms^{-1}$) / 20 s = -$1ms^{-2}$1 (magnitude 1 m/s²).

(iii) Distance travelled: **The total distance is the area under the velocity-time graph**.

- Accelerating phase: $\Delta\frac{1}{2}bh = \frac{1}{2}x10sx20ms^{-1} = 100m$
- Constant velocity phase (**square**): $lw = 20sx20ms^{-1} = 400m$
- Decelerating phase: $\Delta\frac{1}{2}bh = \frac{1}{2}x20sx20ms^{-1} = 200m$

Total distance $s =$ Accelerating phase + Constant velocity phase + Decelerating phase

$s = 100m + 400m + 200m = 700m$.

iv) Average speed: $\boldsymbol{v = \frac{total\ distance}{total\ time\ taken} = \frac{700m}{50s} = 14ms^{-1}}$

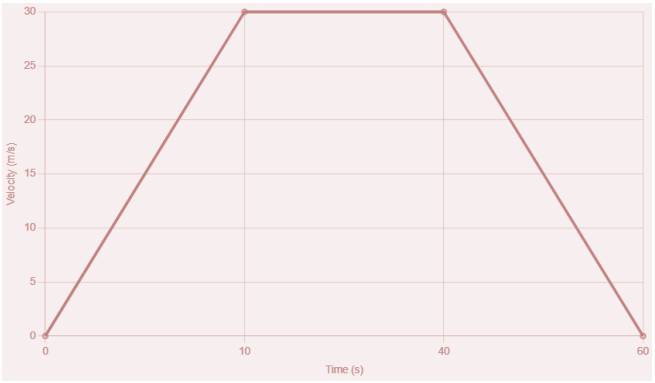
2). A car from rest accelerates to velocity 30m/s in 10s. It continues at constant velocity for 30s and then decelerates so that it stops in 20s. Task

(a). Draw a velocity time graph to represent its motion

(b). Calculate the acceleration, deceleration, distance travelled and average speed.

Velocity-Time Graph

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Calculations

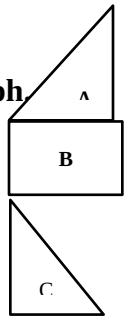
Acceleration: The car accelerates from 0 m/s to 30 m/s in 10 s.

$$Accelaration = \frac{30ms^{-1} - 0ms^{-1}}{10s} = 3ms^{-2}$$

Deceleration: The car decelerates from 30 m/s to 0 m/s in 20 s.

$$Decelaration = \frac{0ms^{-1} - 30ms^{-1}}{20s} = -1.5ms^{-2}$$

(Magnitude $1.5ms^{-2}$).



Distance travelled: The total distance is the area under the velocity-time graph

The total distance is the area under the velocity-time graph.

- Accelerating phase (0-10 s): $\Delta\frac{1}{2}bh = \frac{1}{2}x10sx30ms^{-1} = 150m$
- Constant velocity phase (10-40 s): $lw = 30sx30ms^{-1} = 900m$
- Decelerating phase (40-60 s): $\Delta\frac{1}{2}bh = \frac{1}{2}x20sx30ms^{-1} = 300m$

Total distance, $\boldsymbol{S}$ = Accelerating phase + Constant velocity phase + Decelerating phase

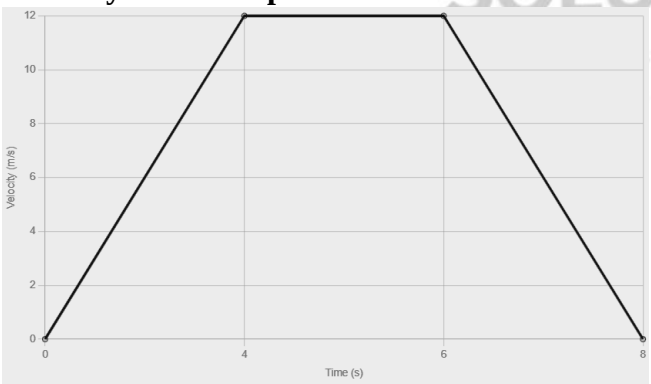
$s = 150m + 900m + 300m = 1350m$.

Average Speed: Average speed: $\boldsymbol{v = \frac{total\ distance}{total\ time\ taken} = \frac{1350m}{60s} = 22.5ms^{-1}}$

3). A racing car starts from rest and moves with uniform acceleration of $3ms^{-2}$ for 4 seconds. Then moves with constant velocity for 2 seconds. It is brought to rest after a further 2 seconds. Task:

a) Draw a velocity time graph for motion of the car
b) Find total distance travelled
c) Average speed

a) Velocity-Time Graph



b) **Total Distance Travelled**

The total distance is the area under the velocity-time graph.

- Accelerating phase (0-4 s):

$\Delta\frac{1}{2}bh = \frac{1}{2}x4sx12ms^{-1} = 12m$

- Constant velocity phase (4-6 s):

$lw = 2sx12ms^{-1} = 200m$

- Decelerating phase (6-8 s):

$\Delta\frac{1}{2}bh = \frac{1}{2}x2sx12ms^{-1} = 12m$

Total distance s = Accelerating phase + Constant velocity phase + Decelerating phase

$s = 24m + 24m + 12m = 60m$.

c) Average Speed: Average speed: $\boldsymbol{v = \frac{total\ distance}{total\ time\ taken} = \frac{60m}{8s} = 7.5ms^{-1}}$

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5). A body of mass 60 kg starts moving with an initial velocity of 15 m/s and accelerates at a rate of 4m/s^2 in 5s, then maintains a constant velocity for another 5s and brought to rest in 7s.

Task: As a physics student,

a). Draw a velocity –time graph to represent this motion,

b). Calculate the total distance travelled

c). Determine the retarding force

5. The total distance is the area under the velocity-time graph.

Accelerating phase= 125 m

Constant velocity phase 175m

Decelerating phase = 122.5m

Total distance = 422.5 m.

Retarding Force

The deceleration during the final phase is = -5 m/s^2.

Retarding force = mass × deceleration

6. A professional cyclist with a total mass of 75 kg is racing on a track. The cyclist starts from an initial speed of $10ms^{-1}$ and accelerates uniformly at $2.5ms^{-2}$ for 8 seconds while pedaling uphill. Then, the cyclist maintains a constant speed for 12 seconds on a flat section, during which he draft closely behind another rider resulting into reduced drag. Finally, the cyclist applies brakes, and comes to a stop in 10 seconds.

As a physics student analyzing this motion:

a) Draw a velocity-time graph to represent the cyclist's motion.

b) Calculate the total distance travelled by the cyclist.

c) Determine the magnitude of the average retarding force acting on the cyclist during the braking phase, assuming the deceleration is uniform.

d) Estimate the heat energy generated during braking if 60% of the kinetic energy lost is converted to thermal energy in the brake system (ignore other losses).

e) Explain qualitatively how Bernoulli's effect contributes to the reduced drag force during the constant speed phase while drafting.

Total Distance Travelled;

The total distance is the area under the velocity-time graph.

Accelerating phase = 144m, Constant velocity phase = 336 m, and Decelerating phase (20-30 s): = 140 m. Total distance = 620 m.

c) Magnitude of the Average Retarding Force

The velocity at the start of braking is$28ms^{-1}$, and it comes to rest in 10 s. Deceleration = $2.8ms^{-1}$. Retarding force = mass × deceleration magnitude = 75 kg × $2.8ms^{-1}$ = 210 N.

During Braking;

Kinetic energy lost during braking = 33750J.

Heat energy = 60% of kinetic energy lost = 0.6 × 33750 J = 20250J.

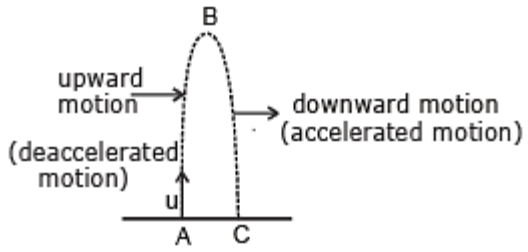
e) Bernoulli's principle states that in a fluid (like air), an increase in flow speed results in a decrease in pressure. During drafting in the constant speed phase, the lead cyclist disrupts the airflow, creating a region of faster-moving air in their wake with lower pressure. The following cyclist positions themselves in this low-pressure zone, reducing the pressure difference across their body and thus lowering the overall drag force compared to riding alone in undisturbed air. This allows the cyclist to maintain speed with less effort.

MOTION UNDER GRAVITY

Motion under gravity refers to the movement of an object influenced solely by gravitational force. This phenomenon occurs when an object is in free fall, meaning the only force acting on it is gravity, which accelerates the object towards the Earth at a constant rate, denoted as 'g' (g=9.81 m/s^2). As an object falls, its velocity increases due to this constant acceleration. For a body falling under gravity, acceleration due to gravity is positive but for a body thrown vertically upwards, acceleration due to gravity is negative. At maximum height, the body is momentarily at rest therefore final velocity is 0m/s

Equations of motion for a body falling freely under gravity, g

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$V = u - gt$
$S = ut - \frac{1}{2}gt^2$
$V^2 = u^2 - 2gs$
Vertically Upwards

Acceleration of free fall is constant for a body falling from rest

$S = ut + \frac{1}{2}gt^2$, $S = \frac{1}{2}gt^2$, when $u = 0 ms^{-1}$

ACTIVITY

1. A construction worker accidentally drops a hammer from rest at the top of a scaffolding tower 20 m above the ground during a building project. The hammer falls freely vertically downwards under gravity. As a physics student analyzing workplace safety: **Hint: g = 10 m/s²**
a) Calculate the time taken for the hammer to land on the ground.
b) Determine the velocity with which the hammer lands on the ground.
c) Explain the safety measures to prevent injuries from falling objects at construction sites.

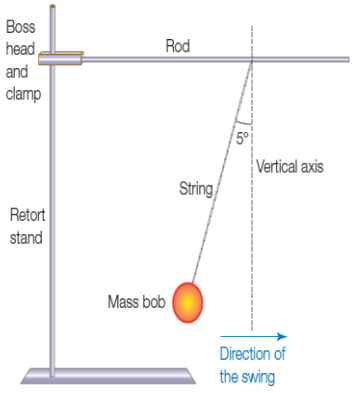
2. During a volleyball training session, a player spikes the ball vertically upwards with an initial velocity of 30 m/s to practice jump serves. As a physics student evaluating athletic performance:
a) Determine the maximum height reached by the ball.
b) Calculate the time taken to reach the maximum height.
c) Find the total time taken for the ball to return to the starting point.
d) Discuss how this can be applied to improve player coordination and reduce injury risks in team sports.

3. In a mountain rescue drill, a rescuer throws a signal flare vertically upwards with an initial velocity of 14 m/s from a cliff edge to alert a helicopter (Hint: g = 10 m/s² and neglect air resistance). As a physics student assessing emergency response:
a) Determine the maximum height reached by the flare above the throwing point.
b) Calculate the total time taken before the flare reaches the ground (assuming it falls back past the throwing point to the base of the cliff).

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An experiment to determine the acceleration due to gravity (g) can be conducted using a simple pendulum.

The experiment involves measuring the period of oscillation of the pendulum and using the formula derived from the relationship between the pendulum's length and its oscillation period.



Materials Required

1. String or thread (approximately 1 meter long)
2. Small spherical bob (a metal or wooden ball)
3. Stopwatch
4. Meter ruler
5. Stand or firm support to suspend the pendulum
6. Protractor (optional, for measuring small angular displacements)

Method I

a) Attach the bob to the end of the string, ensuring it is securely tied.
b) Fix the other end of the string to a stand or any rigid support so that the pendulum can swing freely.

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c) Measure the length (L) of the pendulum from the point of suspension to the center of mass of the bob using the meter ruler.
d) Pull the bob slightly to one side through a small angle to maintain simple harmonic motion
e) Release the bob without applying any force, allowing it to swing freely.
f) Use the stopwatch to time 20 complete oscillations (a single oscillation is the motion from one extreme point, back to the starting point).
g) Record the time, t, taken for these 20 oscillations
h) Determine the period (T) of one oscillation using $T = \frac{t}{20}$
i) Repeat the timing for 20 oscillations at least three times for the same length of the pendulum, to calculate the average period (T).
j) Adjust the string length to different values (0.5, 0.6, 0.7, 0.8 and 0.9m) and repeat the above Procedures for each length.
k) The period of a simple pendulum is given by: $T = 2\pi\sqrt{\frac{L}{g}}$
l) Using the measured length (L) and the calculated period (T), compute g for each length, and take the average of the values of $g = \frac{4\pi^2 L}{T^2}$ *ob*tained from different lengths to minimize errors.

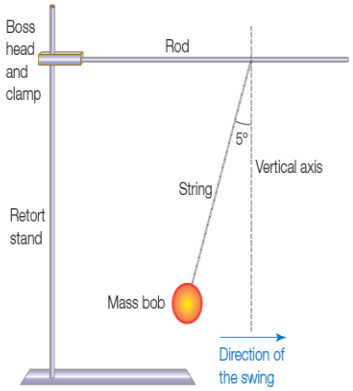
Precautions

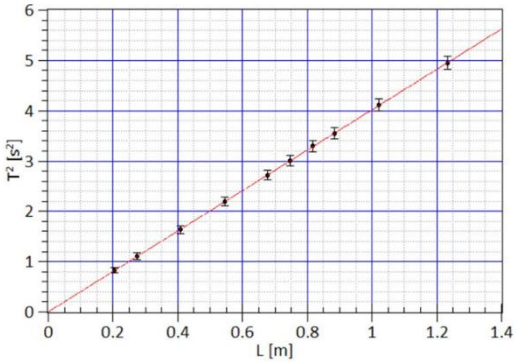
1. Ensure the pendulum swings in a single plane without any external interference.
2. Keep the amplitude of oscillation small (less than15∘) to satisfy the small-angle approximation.
3. Measure the length of the pendulum accurately from the point of suspension to the center of the bob.
4. Start timing after the pendulum has settled into a regular oscillatory motion.
5. Use a stopwatch with good precision and minimize reaction time errors.

The calculated value of g should be close to the standard value of $9.8\ ms^{-2}$*, depending on the accuracy of measurements and environmental conditions.*

<u>Method II</u>*: To determine the acceleration due to gravity (g) using simple pendulum bob*

a) Attach a small, dense bob to a string of length L and suspend it from a fixed point.
b) Measure the length of the string from the point of suspension to the center of the bob.
c) Displace the bob slightly and release it to swing back and forth as a pendulum.



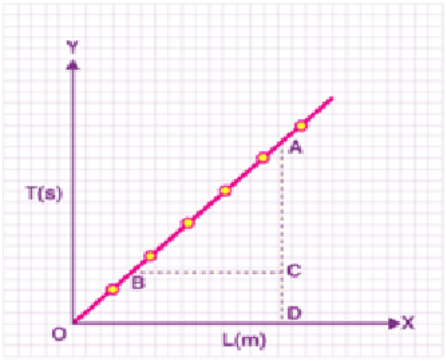


d) Using a stopwatch, measure the time (T) it takes for the pendulum to complete 10 oscillations. Divide the total time by 10 to get the period (T) for one oscillation.
e) Tabulate of results is tabulated including values of T^2
f) Plot a graph of T^2 *against* L

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g) Calculate the slope S from the graph above
h) Determine the value of acceleration due to gravity, g from $g = \frac{4\pi^2}{Slope(S)}$



Projectile motion

A projectile is any object thrown into space upon which the only acting force is gravity. The primary force acting on a projectile is gravity. This doesn't necessarily mean that other forces do not act on it, just that their effect is minimal compared to gravity. The path followed by a projectile is known as a trajectory. A baseball batted or thrown is an example of a projectile.

When a particle is thrown obliquely near the earth's surface, it moves along a curved path under constant acceleration directed towards the centre of the earth (we assume that the particle remains close to the earth's surface). The path of such a particle is called a projectile, and the motion is called **projectile motion**.

In a Projectile Motion, there are two simultaneous independent rectilinear motions:

Along the x-axis: uniform velocity, responsible for the **horizontal** (forward) **motion** of the particle.

Along the y-axis: uniform acceleration, responsible for the **vertical** (downwards) **motion** of the particle.

Acceleration in the horizontal projectile motion and vertical projectile motion of a particle: When a particle is projected in the air with some speed, the only force acting on it during its time in the air is the acceleration due to gravity (g). This acceleration acts vertically downward. There is no acceleration in the horizontal direction, which means that the velocity of the particle in the horizontal direction remains constant.

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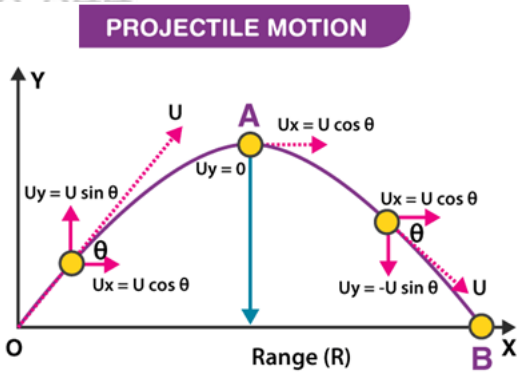
Parabolic Motion of Projectiles

Let us consider a ball projected at an angle θ with respect to the horizontal x-axis with the initial velocity u as shown below:

The **point O** is called the **point of projection**; **θ** is the **angle of projection** and **OB = Horizontal Range** or Simply Range. The total time taken by the particle from reaching O to B is called the **time of flight**.

For finding different parameters related to projectile motion, we can make use of differential **equations of motions**:

1) $v = u - gt$; 2) $h = ut - \frac{1}{2}gt^2$; 3) $v^2 = u^2 - 2gh$



Where U=initial velocity, V=final velocity, g=acceleration due to gravity, s=h=displacement and t=time.

Time of flight, $T = \frac{2usin\theta}{g}$, $h_{max} = \frac{u^2 sin^2\theta}{2g}$, **horizontal range** $R = \frac{u^2 sin2\theta}{g}$

Example

An object is dropped from a helicopter. if the object hits the ground after 2 seconds, calculate the height from which object was dropped.

The height, h, from which the object is dropped, can be calculated using the free-fall equation under constant gravity (assuming no air resistance and initial velocity of zero:

$h = \frac{1}{2}gt^2$, where, g, is the acceleration due to gravity (g= 9.8 m/s²) and t is the time (2 seconds).
Substitute the values: $h = \frac{1}{2}x9.81x2x2 = 19.6m$. Thus, the **height is 19.6 meters.**

An object is dropped from helicopter at a height of 45m above the ground.

a) If the helicopter is at rest, how long does the object take to reach the ground and what is its velocity on arrival.
b) If the helicopter falls with a velocity of 1m/s when the object is released, what would be the final velocity of the object?

(a). Helicopter at Rest
The object is dropped with initial velocity, u = 0m/s. The height is h = 45m, and acceleration due to gravity is, g = 9.8 m/s² (downward positive).
To find the time t to reach the ground, use the equation of motion: $\boldsymbol{h = u + \frac{1}{2}gt^2}$
Substitute u = 0: $45 = \frac{1}{2}x9.8t^2$, $90 = 9.8t^2$, $t = 3.03s$
To find the final velocity, v, on arrival, use: $v = u + gt$, $\boldsymbol{v = 0 + 9.8x3.03 = 29.7ms^{-1}}$
Alternatively, using $\boldsymbol{v^2 = u^2 + 2gh = 29.7ms^{-1}}$

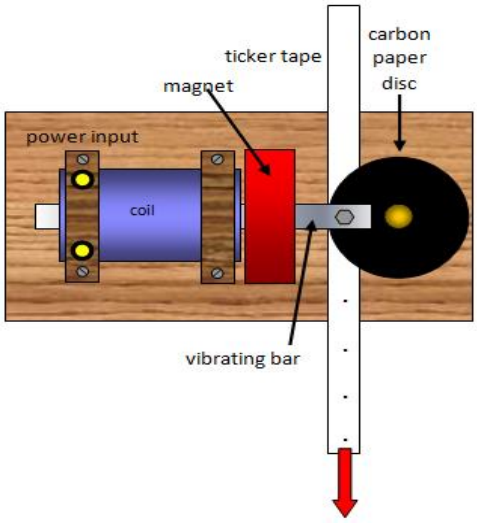
(b). Helicopter Falling with 1 m/s Downward
The object is released with initial velocity, u = 1 m/s downward (matching the helicopter's velocity). To find the final velocity, v, use: $\boldsymbol{v^2 = u^2 + 2gh,}$
$\boldsymbol{v^2 = 1^2 + 2x9.8x45 = 883 = 29.7ms^{-1}}$

Activity
An object is released from an air craft travelling horizontally with a constant velocity of 200m/s at a height of 500m. Ignoring air resistance;

a) How long does it take the object to reach the ground?
b) Find the horizontal distance covered by the object leaving the air craft and reaching the ground.

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TICKER TAPE TIMER
Motion under gravity can be effectively analyzed using a ticker tape timer, a device that records an object's movement over time. As an object falls, the ticker tape produces a series of dots at regular intervals, representing its position changes. A ticker timer is a steel strip which vibrates rapidly and print dots on a length of a paper tape pulled through it.
It prints n dots on a tape every second (frequency, = f). A ticker timer is used to measure speed or velocity and acceleration of bodies in motion. The distance between these dots indicates the object's velocity; larger gaps suggest increased speed, which is characteristic of free fall due to gravity.
To calculate the acceleration of gravity, one can use the formula $\boldsymbol{a = \frac{v-u}{t}}$, *where (a) is acceleration, (v) is the final velocity, (u) is the initial velocity, and (t) is the time taken.*

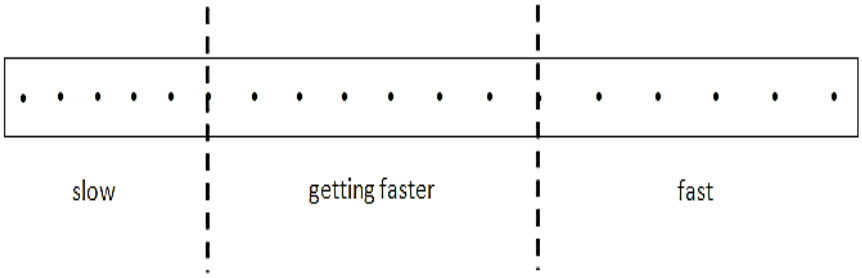


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By measuring the distance between the dots on the ticker tape and the time intervals, students can derive the acceleration due to gravity. If n dots are printed on a tape at a frequency, f, along a given length, then the time between any two successive dots is the period and it's given by $\boldsymbol{T = \frac{1}{f}}$.

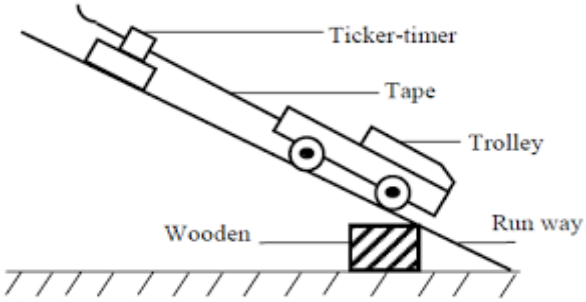
This implies, that the total time taken to print n dots is $\boldsymbol{t = (n-1)T = \frac{n-1}{f}}$

$Velocity = \frac{distance}{time} = \frac{d}{\frac{n-1}{f}} = \frac{df}{n-1}$, *where n is the number of dots, f is the frequency of the ticker timer, and d is the distance travelled.*



Experiment with a ticker timer

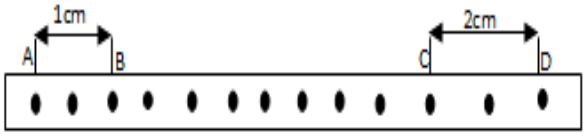
The paper tape is pulled by a trolley moving down an inclined plane as shown in the figure.
Different results are obtained on the speed of the trolley.
Trolley moving with uniform speed, spacing between successive dots is the same throughout.
The trolley is accelerating; the spacing between dots gets bigger and bigger.
Trolley decelerating, the spacing between successive dots gets smaller and smaller.



Activity

1). The paper tape shown below was made by a trolley moving with uniform acceleration. if the ticker timer operated with a frequency of 100Hz, determine

i) Initial velocity
ii) Final velocity
iii) Acceleration.



$$Initial\ velocity, u = \frac{df}{n-1} = \frac{1x100cm}{(3-1)s} = 50cms^{-1}$$

$$Final\ velocity = \frac{df}{n-1} = \frac{2x100cm}{(3-1)s} = 100cms^{-1}$$

$$acceleration = \frac{v-u}{\frac{n-1}{f}} = \frac{100-50}{\frac{13-1}{100}} = \frac{50}{0.12} = 416.7cms^{-1} = 4.167ms^{-1}$$

2). Below is a tape by a ticker – timer of frequency 50Hz



Calculate

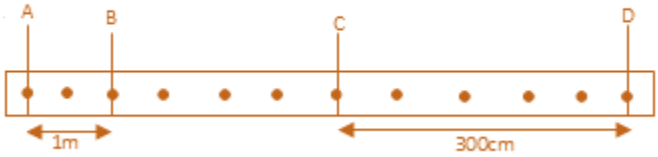
i) Initial velocity
ii) Final velocity

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iii) The acceleration of the trolley

3). The ticker timer below printed dots. Assuming it vibrates at frequency of 20Hz, calculate

i) Initial velocity
ii) Final velocity.
iii) Acceleration



COLLISION AND LINEAR MOMENTUM

Linear momentum is a fundamental concept in physics that describes the quantity of motion possessed by an object. It is defined as **the product of an object's mass and its velocity**, expressed mathematically as $p = mv$, where p is momentum, m is mass, and v is velocity. Linear momentum is a vector quantity, meaning it has both magnitude and direction, and its direction aligns with the direction of the object's velocity.

The principle of conservation of linear momentum states that the algebraic total momentum of a system remains constant if no external forces act upon it.

For example, phenomena such as collisions, rocket propulsion, and motion in closed systems, the combined momentum of all objects before the impact equals their combined momentum afterward, provided no external forces are involved. Linear momentum also helps quantify the impact force of moving objects, with higher momentum indicating a greater force needed to stop the object.

Momentum has both magnitude and direction (**Vector quantity**), which is the same as the direction of the velocity. The total linear momentum of a system remains constant if no external forces act on it (conservation of momentum). The SI unit of momentum is $kgms^{-1}$ (Ns)

Momentum and Force:

Newton's second law can be written in terms of momentum. The net force acting on an object is equal to the rate of change of its momentum: $F = \frac{\Delta p}{\Delta t}$, *where F is the net force,* $\frac{\Delta p}{\Delta t}$ is the rate of change of momentum. This indicates that force is responsible for changing an object's momentum over time.

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Collisions

Collisions refer to the sudden and forceful interaction between two or more bodies, such as balls or a golf club striking a ball. These events occur over a relatively short period, during which the bodies exert forces on each other. Collisions occur when two or more bodies interact over a short period, exerting forces on each other that significantly change their motion. Collisions can occur in everyday scenarios, such as a car crash or two balls hitting each other, and on a microscopic scale, such as in the interaction of gas molecules.

Collisions are categorized into **three main types** based on the conservation of kinetic energy.

In **elastic collisions**, both momentum and kinetic energy are conserved. Such collisions are typically observed in ideal systems, such as two billiard balls striking each other or molecules in a gas.

I**nelastic collisions** conserve momentum but not kinetic energy, as some energy is dissipated as heat, sound, or deformation. For instance, in a car crash, part of the kinetic energy is converted into the deformation of the vehicles and other forms of energy.

A subset of inelastic collisions is the **perfectly inelastic collision**, where the colliding objects stick together after impact and move as a single entity, resulting in the maximum loss of kinetic energy.

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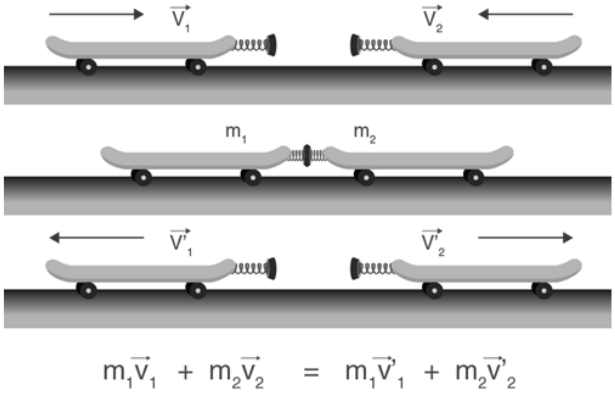
The study of collisions relies heavily on the **law of conservation of momentum**, which states that in an isolated system with no external forces, the total momentum before and after a collision remains constant. This principle can be expressed mathematically for two colliding bodies as; $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$, *where* m_1 and m_2 are the masses, u_1 and u_2 are the initial velocities, and v_1 and v_2 are the final velocities of the objects.

In elastic collisions, kinetic energy is also conserved, while in inelastic collisions, the energy lost is accounted for in other forms of **deformation or heat.**
The **coefficient of restitution (e)**, which measures the elasticity of the collision, is the ratio of the relative speed of separation to the relative speed of approach. Values of e range from 0 to 1, where e=1 represents a perfectly elastic collision, 0<e<1 represents an inelastic collision, and e=0 indicates a perfectly inelastic collision. The impulse experienced during a collision, which is the product of the force and the duration of impact, causes a change in momentum and is another important aspect of collision dynamics.

Collisions include macroscopic interactions like a bat striking a ball in sports, vehicular accidents, and even celestial events like asteroid impacts. At the microscopic level, elastic collisions are central to the behavior of gas molecules and are modeled in kinetic theory.
In traffic safety, understanding collision mechanics aids in the design of safer vehicles, airbags, and crumple zones that absorb impact forces, reducing injury.
In sports, analyzing collisions between balls, players, and equipment helps improve performance and strategies.
In astrophysics, studying celestial collisions, such as asteroid impacts or star mergers, provides insights into the evolution of the universe.

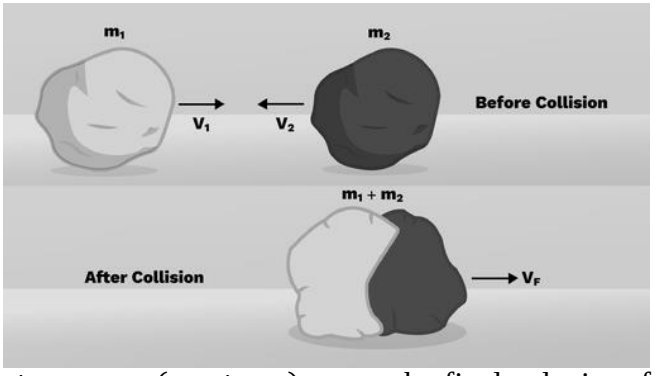
A collision occurs when two or more objects meet each other for a short period, exchanging forces and energy.
During a collision, the momentum of the involved objects changes, but the total momentum of the system (if isolated) remains conserved.
Collisions are categorized into two main types based on the conservation of kinetic energy:
a) Elastic Collision. In an elastic collision, both momentum and kinetic energy are conserved. The objects bounce off each other without any lasting deformation or generation of heat.

Examples: For two objects, 1 and 2, with masses m_1 and m_2, and initial velocities v_1 and v_2, the following conservation laws apply:
Conservation of momentum:
$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$, *Where* v_1' and v_2' are the velocities of the objects after the collision.
Conservation of kinetic energy:
$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v'^2_1 + \frac{1}{2}m_2v'^2_2$



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b) Inelastic Collision



In an inelastic collision, momentum is conserved, but kinetic energy is not. Some kinetic energy is transformed into other forms of energy, such as heat, sound, or deformation of the objects. In a perfectly inelastic collision, the colliding objects stick together after impact and move as a single object.

Examples: For two objects undergoing a perfectly inelastic collision: Conservation of momentum: $m_1v_1 + m_2v_2 = (m_1 + m_2)v_f$, v_f the final velocity of the combined mass after the collision. Unlike elastic collisions, the kinetic energy before and after the collision is different. Some of it is lost during the collision: $\Delta KE = \Delta KE_{initial} - \Delta KE_{final}$

Conservation of Momentum

The law of conservation of momentum states that in an isolated system (no external forces), the total linear momentum of the system remains constant, regardless of the interactions within the system. This is true for both elastic and inelastic collisions.

Conservation of Momentum in Collisions: For two objects 1 and 2, with initial momenta p_1 and p_2, and final momenta p_1'and p_2', the total momentum before and after the collision is conserved: $p_1+p_2=p_1'+p_2'$. In vector form: $m_1v_1+m_2v_2=m_1v_1'+m_2v_2'$

Applications of Collisions and Momentum

a) Car Crashes

Momentum conservation helps engineers understand how forces are distributed during car crashes. In inelastic collisions, energy is absorbed through vehicle deformation, minimizing the impact on passengers.

b) Sports

In sports like pool or snooker, players rely on elastic collisions to control the balls' motion. The angles and speeds are crucial to achieve the desired outcomes based on momentum transfer.

c) Space Exploration

In space, momentum conservation is key in propulsion. Rockets expel gas backward, which provides the forward momentum needed to propel them forward (action-reaction pairs from Newton's third law).

Scenario 1: During a mechanical training session at a vocational institute, two maintenance carts move along the same straight rail track. Cart A has a mass of **2 kg** and is moving at $8\boldsymbol{ms^{-1}}$ while Cart B has a mass of **3 kg** and is moving in the **same direction at** $5\boldsymbol{ms^{-1}}$. Due to worn-out couplers and friction at the point of contact, the carts **collide and stick together**. Some of the kinetic energy is converted into **heat and sound energy**, making the coupler feel warm after the collision.

Tasks:

a) Using the principle of conservation of linear momentum, determine the **common velocity** of the carts after collision.

b). Explain **why heat energy is produced** during the collision, even though momentum is conserved.

Given: Mass of Cart A, $m_1 = 2\,kg$, Velocity of Cart A, $u_1 = 8\,m/s$
Mass of Cart B, $m_2 = 3\,kg$, Velocity of Cart B, $u_2 = 5\,m/s$

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After collision, the carts stick together and move with a common velocity v.
Using the principle of conservation of linear momentum:
$m_1u_1 + m_2u_2 = (m_1 + m_2)v$, Substituting values:
$(2 \times 8) + (3 \times 5) = (2 + 3)v, 16 + 15 = 5v, 31 = 5v; v = 6.2\, m/s$
Explanation of heat production*:* During the collision, friction and deformation occur at the point of contact. Some of the kinetic energy is transformed into heat and sound energy. Momentum is conserved because there is no external force, but kinetic energy is not conserved.

Scenario 2: At a warehouse near an industrial area, a worker pushes a loaded trolley of mass **20 kg** at a speed of $\mathbf{5}\boldsymbol{ms^{-1}}$ towards an empty trolley of mass **10 kg** that is initially at rest. After collision, the trolleys **separate and continue moving in the same direction**. Due to friction between the wheels and the floor, part of the system's kinetic energy is converted into **heat energy**. The 20 kg trolley is observed to move at $\mathbf{3}\boldsymbol{ms^{-1}}$ after the collision.
Tasks:
a) Calculate the **velocity of the 10 kg trolley** immediately after the collision.
b) State **one form of energy lost** during the collision and **one physical observation** that show this energy loss.
Given: Mass of first trolley, $m_1 = 20\, kg$, Initial velocity of first trolley, $u_1 = 5\, m/s$
Mass of second trolley, $m_2 = 10\, kg$, Initial velocity of second trolley, $u_2 = 0\, m/s$
Final velocity of first trolley, $v_1 = 3\, m/s$
Using conservation of linear momentum: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
Substituting values: $(20 \times 5) + (10 \times 0) = (20 \times 3) + (10 \times v_2)$
$100 = 60 + 10v_2, 10v_2 = 40; v_2 = 4\, m/s$

Energy consideration: Some kinetic energy is converted into heat energy due to friction between the trolley wheels and the floor. This energy loss is observed as warming of the wheels and floor.

Scenario 3: During a sports science practical lesson, a learner slides a **training block** of mass **8 kg** along a smooth horizontal surface at a speed of $\mathbf{20}\boldsymbol{ms^{-1}}$. The block collides with another stationary training block. After the collision, the two blocks **move together** at a constant velocity of $\mathbf{15}\boldsymbol{ms^{-1}}$. The surface and blocks are later found to be **slightly warm**, indicating energy transformation.
Tasks:
a). Determine the **mass of the stationary training block**.
b). Explain **why the total kinetic energy of the system decreases** after the collision.
c). Identify the **form of energy gained by the surroundings**.
Given:
Mass of moving block, $m_1 = 8\, kg$ Initial velocity of moving block, $u_1 = 20\, m/s$
Mass of stationary block, $m_2 = xxx$, Initial velocity of stationary block, $u_2 = 0\, m/s$
Common velocity after collision, $v = 15\, m/s$
Using conservation of linear momentum: $m_1u_1 + m_2u_2 = (m_1 + m_2)v$
Substituting values:$(8 \times 20) + (m_2 \times 0) = (8 + m_2) \times 15; 160 = 120 + 15m_2$
$15m_2 = 40; m_2 = 2.67\, kg$

Explanation of energy change: The total kinetic energy after the collision is less than before because part of the kinetic energy is converted into heat and sound energy due to friction and deformation. The surroundings gain thermal energy, making the blocks and surface warm.

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Assessment item:
Two cargo trucks are transporting construction materials along a narrow road near a busy trading centre in Kampala.

- Truck A has a mass of **2.5 tonnes** and is moving at **0.5 m/s**.
- Truck B has a mass of **2 tonnes** and is moving at **1.2 m/s** in the opposite direction.

Due to brake failure and limited road space, the trucks collide head-on. After the collision, the trucks lock together and move as one body. As a physics student assisting a road safety team, you are required to analyze the motion of the trucks after impact.

Tasks: Using the knowledge of physics;

(a) State which physical principle you would use to determine the velocity after collision.
(b) Determine the common velocity of the trucks after the collision. Explain the sign of your answer.
(c) Suggest one reason why such low speeds might still cause significant damage in real-life road accidents.

NEWTON'S LAWS OF MOTION

Newton's First Law, or the Law of Inertia, states that an object at rest stays at rest, and an object in motion stays in motion with the same speed and in the same direction, unless acted upon by an unbalanced external force, meaning objects naturally resist changes to their state of motion, with more massive objects having greater inertia.

This principle highlights the natural tendency of objects to resist changes in their state of motion. Inertia, the property that describes this resistance, is fundamental to understanding motion. For example, a stationary ball will not roll until a force, such as a kick, is applied. Similarly, a rolling ball will not stop or change direction unless friction or another force intervenes.

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Explanation: This law explains the concept of inertia, which is the tendency of an object to resist changes in its state of motion. If no external force (like friction, air resistance, or a push/pull) acts on an object, it will either remain still or continue moving in a straight line at constant speed.
Inertia is the tendency of the body to remain at rest or if moving, to continue in its motion in a straight line with uniform velocity. The larger the mass of the body, the greater is its inertia, therefore the mass of the body is a measure of its inertia.

Examples: A book on a table will remain there unless someone pushes it. A car in motion will continue moving unless brakes (external force) are applied to slow it down or stop it.
This principle has numerous applications in everyday life.

Applications of the Law: One prominent example is the use of seatbelts and airbags in vehicles. When a car suddenly stops, the body tends to continue moving forward due to inertia. Seatbelts restrain passengers, preventing injury, while airbags provide additional protection by cushioning the impact. Another application can be observed in sports, such as baseball. A stationary baseball will not move until a player exerts force by hitting it with a bat. Similarly, when a ball is thrown, it will continue to travel in a straight line until gravity or air resistance alters its path.

Newton's Second Law of Motion (Law of Force and Acceleration)

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It states that **the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the applied force.** This relationship can be expressed with the formula F = ma, where F represents force, m is mass, and a is acceleration. For example, pushing a car requires significantly more force than pushing a bicycle due to the car's greater mass.
From the law; the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. The direction of the acceleration is in the direction of the net force. Mathematically: F=ma. Where: F = net force acting on the object (in newtons, N) m = mass of the object (in kilograms, kg), a = acceleration of the object (in meters per second squared, m/s^2)

Explanation: If a force is applied to an object, it will accelerate in the direction of the force. The larger the force, the greater the acceleration. However, if the object is more massive (heavier), the same force will result in less acceleration. Thus, heavier objects are harder to move or stop than lighter ones.

Examples: A small car requires less force to accelerate compared to a large truck. If you push a shopping cart with a strong force, it accelerates quickly; with less force, it moves slower.

Application of the law
For instance, when kicking a ball, the force exerted determines how fast and far the ball travels. Similarly, pushing a shopping cart illustrates the law; an empty cart accelerates more easily than a loaded one due to its lower mass. In automotive engineering, racing cars are designed to maximize acceleration by optimizing force and minimizing weight, displaying the law's relevance in high-performance scenarios. Engineers design vehicles based on the mass and the forces needed for efficient acceleration and braking, balancing speed and control. In aerospace, rockets utilize Newton's Second Law to propel themselves into space. The thrust generated by the engines must overcome the rocket's mass to achieve the desired acceleration.

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Newton's Third Law of Motion (Action and Reaction)
Newton's Third Law of Motion states, "**For every action, there is an equal and opposite reaction**." This means that whenever one object exerts a force on another, the second object exerts a force of equal strength in the opposite direction on the first object. This interaction highlights the symmetry present in nature. For example, when a person jumps off a small boat, they push down on the boat (action), causing the boat to move backward (reaction). Similarly, in rocket propulsion, the engines expel gas downwards, which results in the rocket being propelled upwards. It emphasizes that forces always occur in pairs, ensuring that motion and stability are maintained in our physical world.

Explanation: When one object exerts a force on a second object, the second object exerts an equal but opposite force on the first object. Forces always come in pairs. If you push on something, it pushes back with the same amount of force in the opposite direction.

Examples: When you jump off a boat onto the shore, the boat moves backward. Your feet push on the boat (action), and the boat pushes back on your feet (reaction), causing it to move. A rocket works by expelling gases downward (action), and as a result, the rocket is pushed upward (reaction).

Applications of Newtons third Law (Action-Reaction):
The most prominent examples is rocket propulsion. When a rocket expels gas downwards, the reaction force pushes the rocket upwards, allowing it to ascend into space. In everyday life, this law is evident in

activities such as walking. As a person pushes their foot backward against the ground, the ground exerts an equal and opposite force, that propels them forward. Similarly, swimming relies on this principle; when a swimmer pushes water backward, the water pushes them forward. Additionally, Newton's Third Law is crucial in sports. Athletes utilize this law to enhance their performance, whether it is a basketball player jumping or a sprinter pushing off the starting blocks. Airplanes generate lift by pushing air downward with their wings (action), and the air pushes the airplane upward (reaction), allowing it to fly.

Activity

1: A delivery truck transporting agricultural produce in Wakada District has a crate of mass 20 kg placed on a smooth platform. As the truck accelerates along a straight road, the speed of the crate increases from $5\ m/s$ to $8\ m/s$ in 10 seconds.
Tasks: Using physics knowledge;
(a) Determine the change in momentum of the crate.
(b) Determine the rate of change of momentum.
(c) Find the magnitude of the force applied on the crate.

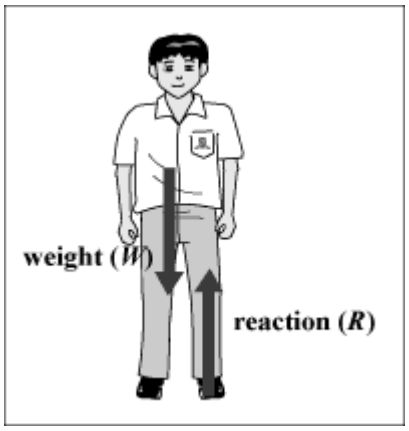
2: During athletics training at a secondary school, a student rolls a training ball of mass 600 g along a straight track. The ball is initially moving at 10 m/s and is uniformly accelerated at 2 m/s² for 4 seconds.
Tasks: Using physics knowledge;
(a) Calculate the change in momentum of the ball.
(b) Determine the rate of change of momentum.
(c) Find the force acting on the ball.

3: A one-ton car travelling along a highway is moving at a speed of 20 m/s. The driver accelerates the car uniformly at 2 m/s² for 5 seconds.
Tasks: Using physics knowledge;
(a) Determine the change in momentum of the car.
(b) Calculate the rate of change of momentum.
(c) Find the accelerating force acting on the car.

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4: In a school science workshop, a student pulls a wooden block of mass 500 g from rest along a horizontal frictionless bench. The block moves a distance of 8 m in 2 seconds under the action of a steady force F.
Tasks: Using physics knowledge;
(a) Determine the acceleration of the block.
(b) Calculate the value of the applied force F.

5: State Newton's Second Law of Motion. Using a real-life example from road transport or sports activities, explain how the law applies to everyday motion. Explain why a heavier object requires a larger force than a lighter object to achieve the same acceleration.

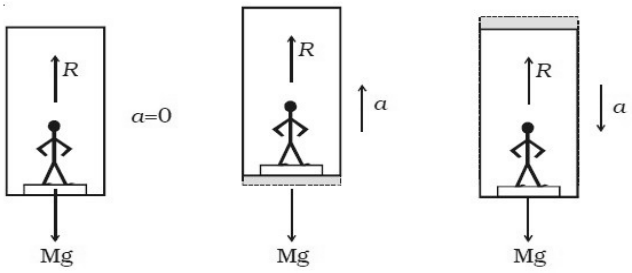


Motion of a Body in a Lift (Elevator)

When a person (or any object) is inside a lift (elevator), the motion of the lift affects the forces acting on the body. Specifically, the apparent weight of the person changes depending on the motion of the lift. Newton's second law of motion and the concepts of weight and normal

force explain this phenomenon. The real weight of a person is the force due to gravity acting on their mass, given by: $W = mg$. Where: W is the weight, m is the mass of the person, g is the acceleration due to gravity (approximately 9.8 m/s^2)

Forces Acting on the Person in the Lift:
Weight ($W = mg$): The gravitational force pulling the person downward. Normal Force (N): The force exerted by the floor of the lift on the person, which opposes the weight. You feel this force as your "**apparent weight."**



Apparent loss of weight in a lift

Situations
i). Lift at Rest or Moving with Constant Velocity
When the lift is at rest or moving at constant velocity (either upward or downward), the acceleration is zero. According to Newton's first law, there is no change in motion, so the forces are balanced. $R = W = mg$. Apparent weight (what you feel) is equal to your actual weight.
ii). Lift Accelerating Upwards
When the lift accelerates upward, there is an additional upward force due to the acceleration of the lift. The normal force (R) increases because the lift floor pushes harder against the person.
Using Newton's second law: $R = mg + ma = m(g + a)$, where: **a** is the acceleration of the lift upwards. Apparent weight increases because the normal force is greater than the gravitational force alone. You feel heavier during upward acceleration.
iii). Lift Accelerating Downwards
When the lift accelerates downward, the normal force decreases because the lift floor is not pushing as hard against the person. Again, applying Newton's second law: $R = mg - ma = m(g - a)$.
Apparent weight decreases because the normal force is less than the gravitational force. You feel lighter during downward acceleration.
4. Free Fall (Lift Cable Breaks)
If the lift were in free fall (e.g., the lift cable snaps, and the lift falls under gravity alone), the acceleration of the lift would be equal to the acceleration due to gravity g.
In this case: $R = m(g - g) = 0$. Apparent weight is zero. The person would feel weightless because there is no normal force acting on them (both the person and the lift are falling at the same rate). This is similar to the sensation astronauts experience in free fall in space.

Conclusion: The apparent weight of a person in a lift changes depending on the motion of the lift. This change is due to the varying normal force, which either increases or decreases depending on whether the lift is accelerating upwards or downwards.

Example:
A woman of mass **70 kg** is standing on a weighing scale inside a lift in a multistoried building in Kampala. The scale readings change depending on how the lift moves due to the forces acting on her body.
Hint: Take acceleration due to gravity, $g = 10ms^{-2}$.
Tasks: Use your knowledge of motion;
a) When the lift is **at rest**, determine the reaction force of the lift floor on the woman.

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b) When the lift is **ascending upwards with a uniform acceleration of** $4ms^{-2}$, calculate the reaction force acting on the woman.
c) When the lift is **moving downwards with a uniform acceleration of** $4ms^{-2}$, determine the reaction force acting on the woman.
d) Explain why the reading on the weighing scale increases when the lift accelerates upwards and decreases when it accelerates downwards.

Response
Mass of the woman, m=70kg, Acceleration due to gravity, $g = 10ms^{-2}$, Acceleration of lift, $a = 4ms^{-2}$
Reaction force (R) = reading on the weighing scale (apparent weight)
(a) Lift at rest
When the lift is at rest, acceleration (a = 0); $R = mg, R = 70x10, R = 700\ N$
(b) Lift ascending upwards with acceleration $4ms^{-2}$
When the lift accelerates upwards:$R = m\,(g + a), R = 70(10 + 4), R = 70x14\ R = 980N$
(c) Lift moving downwards with acceleration $4ms^{-2}$
When the lift accelerates downwards:$R = m(g - a), R = 70(10 - 4), R = 70x6,$
$R = 420\ N$
(d) When the lift accelerates upwards, the floor must push harder on the woman to accelerate her upward together with the lift. This increases the reaction force, so the weighing scale shows a higher reading. When the lift accelerates downwards, the floor pushes less strongly on the woman because both are accelerating downward. This reduces the reaction force, so the scale shows a lower reading. This behavior follows Newton's Second Law of Motion, which states that the force acting on a body depends on its mass and acceleration. The apparent weight therefore changes whenever the lift accelerates.

Activity
1: Sutra is standing on a spring balance inside an elevator in a multistoried building. The balance measures the reaction force between Sutra and the elevator floor. Sutra has a mass of 63 kg.
Tasks: **Use your knowledge of motion;**
a) Determine the reading of the balance when the elevator is stationary.
b) Determine the reading of the balance when the elevator is moving upward with a constant velocity of $15ms^{-1}$.
c) Calculate the reading of the balance when the elevator is moving upward with a constant acceleration of $1ms^{-2}$..
d) Determine the reading of the balance when the elevator is moving downward with a constant acceleration of $2ms^{-2}$.
2: A 54 kg boy is standing inside an elevator. The force on his feet depends on the motion of the elevator due to changes in acceleration.
Tasks: **Use your knowledge of motion;**
a) Find the force on the boy's feet when the elevator stands still.
b) Find the force on the boy's feet when the elevator moves downward with a constant velocity of $3ms^{-1}$..
c) Determine the force on the boy's feet when the elevator decelerates downward at $4ms^{-2}$..
d) Determine the force on the boy's feet when the elevator decelerates upward at $2ms^{-2}$.
e) Explain why the force on a person's feet (or the balance reading) remains the same during constant velocity motion but changes during accelerated motion.

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EXPLOSION AND RECOIL VELOCITY

Explosions can be understood through the lens of momentum changes and Newton's laws of motion. When an explosion occurs, forces are exerted, and objects are propelled in different directions, often with rapid acceleration. Key examples of these concepts include firing a gun, rocket propulsion, and a balloon releasing air. Momentum is the product of an object's mass and velocity, and it is a conserved quantity in isolated systems. In the situation of explosions, the total momentum before and after an explosion must remain constant (assuming no external forces act on the system). This principle is known as **the conservation of momentum.**

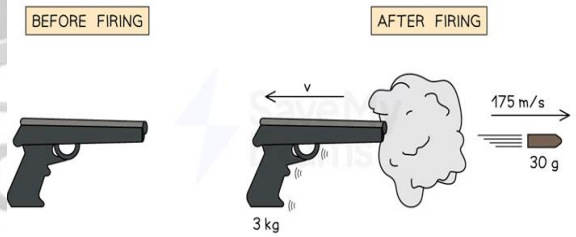
Before an explosion, the total momentum of the system is usually zero or some constant value.
During the explosion, forces act on different parts of the system, causing them to move in opposite directions. After the explosion, the sum of the momentum of all the parts must equal the total momentum before the explosion.

Example of Conservation of Momentum in an Explosion

If a firecracker explodes, the fragments move in different directions. While each fragment has its own momentum, the vector sum of the momentum of all fragments equals the momentum of the firecracker before the explosion, maintaining the system's overall momentum.

Example

A gun of mass 3 kg fires a bullet of 30 g at a speed of 175 m/s. As the bullet is fired, the gun moves back with a recoil velocity *v*. Calculate the recoil velocity of the gun *v*.



Response:

Velocity of gun-bullet system before firing = 0 m/s
Mass of gun, m_{gun} = 3 kg
Mass of bullet, m_{bullet} = 30 g = 0.03 kg
Velocity of bullet after firing , v_{bullet} = 175 m/s
Velocity of gun after firing = *v*

State the conservation of momentum equation

Momentum before firing = momentum after firing

$0 = (m_{gun}xV)+(m_{bullet}xV_{bullet})$

Substitute the known quantities into the equation

$0 = (3xV) + (0.03x175)$

Rearrange the equation to find the recoil velocity of the gun

$-3V = 5.25,\ v = \frac{5.25}{-3} = -1.75m/s$

Activity:

During a ballistics demonstration at a training range, a gun is fired while resting on a smooth horizontal surface. The gun has a mass of 10 kg and fires a bullet of mass 55 g. The bullet leaves the gun with a muzzle velocity of $400ms^{-1}$ in a straight line.
Before firing, the gun and bullet system is at rest.
Tasks: Use your knowledge of motion;
a) Using the principle of conservation of linear momentum, determine the recoil velocity of the gun.
b) State the direction of the recoil velocity relative to the motion of the bullet.
c) Explain why the gun recoils backward when the bullet is fired, even though no external horizontal force acts on the gun–bullet system.

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Newton's Laws of Motion and Explosions

a) Newton's First Law (Law of Inertia)

Newton's first law states that an object at rest will remain at rest, and an object in motion will remain in motion with a constant velocity unless acted upon by an external force.

Application to Explosions: Before an explosion, all parts of the object (e.g., gun, rocket, and balloon) are at rest or moving with constant velocity. The explosion introduces a force, overcoming the inertia of the object and causing its parts to move rapidly. Without the explosion, the object would remain at rest.

b) Newton's Second Law (Law of Force and Acceleration)

Newton's second law explains how the force applied to an object is directly proportional to the acceleration it experiences and inversely proportional to its mass: $F = ma$

In the context of explosions, the rapid release of energy exerts large forces on the object, causing a dramatic acceleration of its parts.

Application to Explosions: In a gun, the expanding gases from the explosion inside the barrel exert a force on the bullet, accelerating it out of the barrel. The greater the force applied to the bullet (which is proportional to the energy of the explosion), the greater the acceleration, and the faster the bullet will move. **In a rocket**, the combustion of fuel generates a high-pressure gas that accelerates out of the rocket's engine, pushing the rocket in the opposite direction.

c) Newton's Third Law (Action-Reaction Law)

Newton's third law states that for every action, there is an equal and opposite reaction.

Application to Explosions: This law is critical in understanding how explosions cause movement. When a force is exerted on one part of the system, an equal and opposite force is exerted on another part. These forces lead to changes in momentum, propelling objects in different directions.

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Examples of Newton's Third Law in Explosions:

Firing a Gun: The exploding gunpowder exerts a force on the bullet, propelling it forward. The gun exerts an equal and opposite force on the shooter (recoil), pushing the gun backward. Before the shot, the gun-bullet system has zero momentum (if at rest). After firing, the momentum of the bullet moving forward is equal and opposite to the momentum of the gun recoiling backward.

When the bullet leaves the barrel, the total momentum must be conserved. Therefore, the bullet moves forward, the gun jacks backwards (recoils) with a velocity called recoil velocity.

Rocket Propulsion:

The rocket engine expels gases downward at high speed due to the combustion of fuel. An equal and opposite force pushes the rocket upward. Before ignition, the rocket and gases are stationary, so the total momentum is zero. After ignition, the upward momentum of the rocket is balanced by the downward momentum of the expelled gases, conserving the total momentum of the system.

Balloon Releasing Air:

When a balloon is released, the air inside rushes out through the opening. The balloon moves in the opposite direction as a response to the force exerted by the escaping air. The total momentum before the balloon is released is zero. Once the air escapes, the momentum of the air rushing out is balanced by the momentum of the balloon moving in the opposite direction.

Conservation of Momentum in Explosions

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In all explosions, the law of conservation of momentum applies. This means that the total momentum of the system before the explosion must equal the total momentum after the explosion, provided no external forces are involved.

Before the Explosion: The system (e.g., gun and bullet, rocket and gases, balloon and air) may have zero momentum if at rest or some constant momentum if in motion.

After the Explosion: The different parts of the system move in different directions, but the vector sum of all the momenta remains equal to the initial momentum.

In an isolated system, no momentum is gained or lost during an explosion, but the energy from the explosion redistributes the momentum among the system's components.

Energy in Explosions: While momentum is conserved in explosions, kinetic energy often changes. In most explosions, energy stored in the form of chemical or nuclear potential energy is rapidly converted into kinetic energy and heat. This release of energy is responsible for the high velocities and large forces associated with explosions.

In a gun firing, the chemical energy in the gunpowder converts into the kinetic energy of the bullet.

In rocket propulsion, the chemical energy from burning fuel converts into the kinetic energy of the expelled gases and the rocket.

ACTIVITY

1: In a wildlife conservation effort in Uganda's Queen Elizabeth National Park, a ranger uses a rifle to tranquilize an elephant for medical treatment. The tranquilizer dart (considered as a bullet) has a mass of 50 g and is fired at a velocity of 400 m/s from the rifle, which has a mass of 5 kg. Assuming no external forces act on the system, determine the recoil velocity of the rifle. Explain how this demonstrates the principle of conservation of momentum in real-life wildlife management scenarios.

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2: A young fisherwoman in Lake Victoria, weighing 50 kg, is returning from a fishing trip in her wooden rowing boat that has a mass of 300 kg. To dock the boat, she jumps out onto the shore with a horizontal velocity of 3 m/s relative to the boat. Determine the velocity with which the boat begins to move backwards on the water. Relate this to how momentum conservation affects daily activities like fishing and transportation on Ugandan lakes.

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3: Fatimah, a 60 kg vendor in Owino Market, is running at 64 km/h to catch a stationary hand-pushed trolley (mass 20 kg) loaded with goods. She jumps onto it, and they move together as one after the perfectly inelastic collision. Determine the loss in kinetic energy and the final kinetic energy of the system. Discuss how understanding energy loss in such collisions can improve safety in informal transport and market activities under Uganda's competency-based curriculum.

State the similarities and differences between elastic collisions and inelastic collisions.

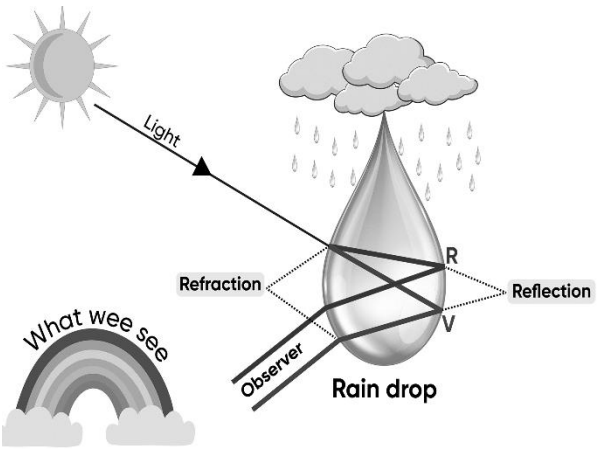
4: A construction worker at a building site in Kampala is pulling a 500 g block of cement from rest across a rough concrete floor to prepare for mixing mortar. The block moves 10 m in 4 s, and the frictional force between the block and the floor is 2 N. Determine:

(a) The acceleration of the block.

(b) The value of the applied force F.

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3.2 REFRACTION, DISPERSION, AND COLOUR



Learning Outcomes

b) Understand that light may be refracted as it passes from one medium to another and that this has both consequences and uses (u, s,v/a)
c) Understand the concept of refractive index (u,s)c. Understand the concept of total internal reflection(u)
d) Know that white light can be split into coloured light by refraction (k,s)
e) Know that white light results from the superimposition of light of all colours of the visible spectrum (u,k)
f) Determine refractive index of glass (s, gs)

Refraction of Light

Refraction is the bending or change in direction of a ray of light as it passes from one transparent medium into another medium with a different optical density. This phenomenon occurs due to the change in the speed of light when it moves from one medium to another, and is responsible for many optical phenomena and devices such as lenses, prisms, and magnifying glasses.

Concepts in Refraction

Optical Density: Optical density refers to how much a medium slows down light as it passes through. The denser the medium, the more it slows light. Light travels fastest in a vacuum and slower in materials like air, water, or glass.

Speed of Light: The speed of light in a vacuum is approximately 3×10^8 m/s[3] When light enters a denser medium (like water or glass) from a less dense medium (like air), its speed decreases, and it bends toward the normal. Conversely, when light enters a less dense medium from a denser one, its speed increases, and it bends away from the normal.

The Normal Line:

The normal is an imaginary line perpendicular to the boundary between two media at the point where the light ray strikes the surface. Refraction is measured with respect to this normal line.

Snell's Law of Refraction:

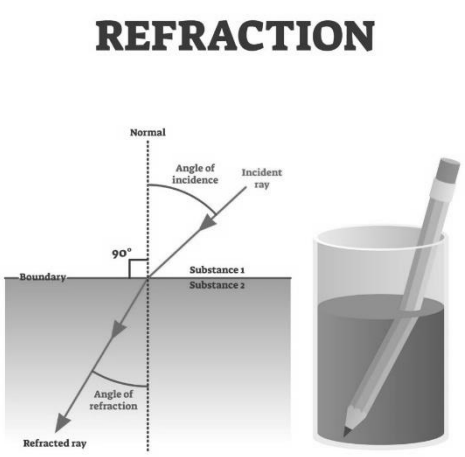
The amount of bending (refraction) of light as it passes from one medium to another is governed by Snell's Law, which is mathematically expressed as: $n_1 sin\theta_1 = n_2 sin\theta_2$. *Where*; n_1 is the refractive index of the first medium, n_2 is the refractive index of the second medium, θ_1 is the angle of incidence (the angle between the incident ray and the normal), and θ_2 is the angle of refraction (the angle between the refracted ray and the normal).

The refractive index (n) is a measure of how much light slows down in a given medium and is defined as: $n = \frac{c}{v}$; where: c is the speed of light in a vacuum, v is the speed of light in the medium. A medium with a higher refractive index has a lower light speed, causing more bending of light.

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Refraction at an Interface: When light passes through the interface of two materials, the following scenarios occur:



a) Light Passing from a Less Dense to a Denser Medium (Air to Water):

Light slows down when it enters a denser medium, causing it to bend toward the normal. Example: A pencil partially submerged in water appears bent or broken at the water's surface because the light rays refract as they move from water (denser) to air (less dense).

b) Light Passing from a Denser to a Less Dense Medium (Water to Air):

Light speeds up when it moves into a less dense medium, causing it to bend away from the normal. Example: When you look at a coin at the bottom of a pool, it appears shallower than it actually is due to the refraction of light as it exits the water.

Refraction at Plane Surfaces

This is the bending of light rays when it passes from one medium to another of different optical densities. **Refraction also defined as the change in speed of light when it moves from one medium to another of different optical densities.** When a ray of light enters an optically denser medium, it is bent towards the normal and when it enters a less dense medium, it is bent away from the normal.

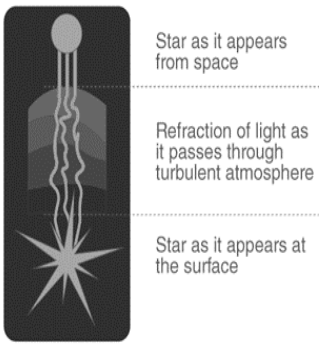
Consequences of Refraction of Light

Refraction of light is the bending of light rays as they transition between different media, resulting in a change in their path. This helps in creation of lenses, magnifying glasses, and prisms. Our eyes also rely on refraction to focus light, enabling us to see clearly. Refraction extend beyond optical devices to natural occurrences, such as the formation of rainbows and the twinkling of stars.

Optical illusions like mirages and looming effects are direct results of light refraction, highlighting its impact on our perception of reality.

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Twinkling of stars



As a star's light penetrates the Earth's atmosphere, every individual stream of starlight is refracted; caused to change direction, slightly by the various temperature and density layers in Earth's atmosphere. You might think of it as the light travelling a zigzag path to our eyes, instead of the straight path the light would travel if Earth did not have an atmosphere. The atmosphere of the earth is made of different layers.

Winds, varying temperatures, and different densities affect it as well. When light from a distant source (a star) passes through our turbulent (moving air) atmosphere, it undergoes refraction many times. When we finally perceive this light from a star, it appears to be twinkling! This is because some light rays reach us directly, and some bends away from and toward us. It happens so fast that it gives a twinkling effect.

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Laws of Refraction of Light

- ✓ *The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane*
- ✓ *The ratio sine of angle of incidence to the sine of angle of refraction is constant for any given pair of media* (Snell's law), i.e. $\frac{sini}{sinr} = n$,constant (n) where n – refractive index of the medium containing the refracted ray

Refractive index: It is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light moving from one medium to another of different optical densities.

Example

A student in a physics laboratory shines a narrow beam of light from air onto a flat glass block while investigating how light bends when it passes from one medium to another. The angle between the incident ray and the normal at the air–glass boundary is **60°**. The refractive index of the glass is **1.5**.

Task: Using the information given, determine the angle of refraction of the light ray as it enters the glass.

From Snell's law

$n_a sini_a = n_g sinr_g$, $1.0 sin60 = 1.5 sinr$, $sinr_g = \frac{sin60}{1.5} = \frac{0.866}{1.5} = 0.577$,

$r_g = \sin^{-1}(0.577) = 35.0$

Activity

1). During a classroom experiment, learners investigate how light changes direction when it passes from air into a transparent solid. A ray of light is directed from air onto a glass surface. The angle between the incident ray and the normal is 45°. The refractive index of the glass is 1.6.

Task: Using appropriate physics principles, determine the angle of refraction of the light ray as it enters the glass.

2). While swimming at a hotel pool, Amina notices that the bottom of the pool appears shallower than it actually is. Sunlight enters the water from air at an angle of 50° to the normal. The refractive index of water is 1.33. **Task: Determine the angle of refraction of the light as it enters the water.**

3). A photographer taking pictures during a school event directs light from air onto a glass camera lens. The light ray strikes the lens at an angle of 40° to the normal. The refractive index of the lens material is 1.5. **Task: Calculate the angle of refraction of the light inside the lens.**

4). During a rainy night, light from a car headlamp passes from air into the wet glass of the windscreen. The angle of incidence at the air–glass boundary is 55°. The refractive index of the windscreen glass is 1.52.

Task: Find the angle of refraction of the light inside the glass.

5). A learner places a straight drinking straw in a glass of water and observes that the straw appears bent at the water surface. A ray of light travels from air into water at an angle of 30° to the normal. The refractive index of water is 1.33. **Task: Determine the angle of refraction of the light ray in the water.**

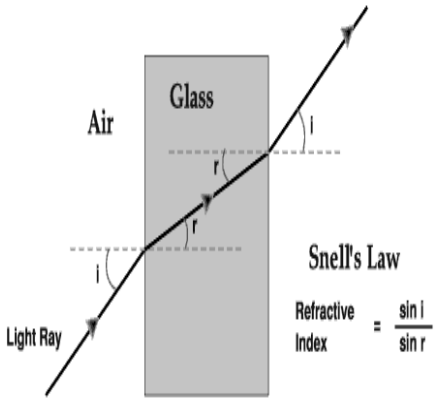
6). Sunlight enters a classroom through a clear glass window. The light strikes the glass at an angle of 65° to the normal. The refractive index of the glass is 1.5. **Task: Calculate the angle of refraction of the light as it enters the glass.**

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To determine the refractive index of a glass block by measuring the angles of incidence and refraction using Snell's Law.

Materials Required: Rectangular glass block, A4 paper, Protractor, Pencil, Ruler, Pins (4), Cork board, light source (optional for more precise light ray tracing).



Hypothesis: The refractive index of a typical crown glass block is 1.52. Values can vary slightly depending on the glass composition, ranging from about 1.5 to 1.6 for common crown glasses.

To determine it experimentally using a glass block and Snell's law ($\mathbf{n = \frac{sini}{sinr}}$), where i is the angle of incidence and r is the angle of refraction):

a) Place the glass block on a sheet of paper and trace its outline.
b) Shine a ray of light (from a laser or ray box) at an angle $i = 10^0$ into one face of the block.
c) Mark the incident ray, emergent ray, and their paths inside the block using pins or by tracing.
d) Measure, read and records the angles i and the corresponding angles r at the air-glass interface.
a) Repeat the procedures for several angles of incidence, $i = 20,30,40,50\ and\ 60^0$,and tabulate a table including values of values of $sini, and\ sinr$
e) Plot a graph of $sini\ against\ sinr$;
f) Determine the slope of the line; and it gives the refractive index n of the glass block.

$i(^0)$	$r(^0)$	Sin i	Sin r
20		0.342	
30		0.500	
35		0.574	
40		0.642	
50		0.766	
60		0.866	

Precautions:
Ensure the glass block is stable and aligned correctly over its traced outline.
Pins should be inserted vertically for accurate alignment.
Avoid parallax error when aligning the pins or measuring angles.
Repeat the experiment for accuracy and use average values.

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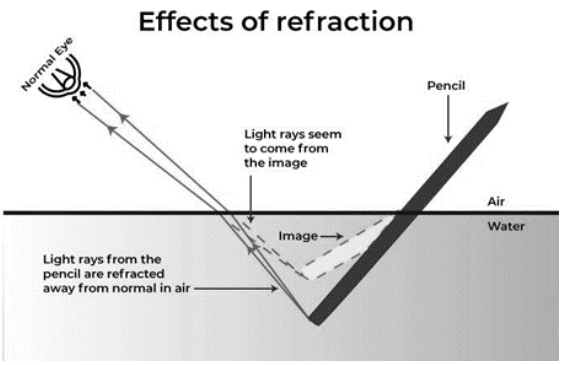
Absolute refractive index
This is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light moving from air (vacuum) to another medium of different optical density.

REFRACTION ON PLANE PARALLEL BOUNDARIES

When an electromagnetic wave encounters a boundary, part of its energy is reflected while the remainder is transmitted into the new medium. This phenomenon is governed by Snell's Law, which states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant and depends on the refractive indices of the two media. In the case of plane parallel plates, the emergent ray remains parallel to the incident ray but is laterally displaced. This displacement is proportional to the thickness of the plate and the angle of incidence.

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EFFECTS OF REFRACTION ON PLANE SURFACES

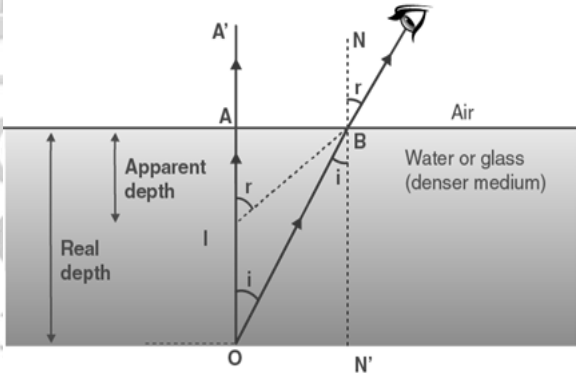


Refraction is the bending of light when it travels from one medium to another, such as from air to water or from air to glass. This bending occurs because light changes speed as it enters a medium of different optical density.

- ✓ When light enters a **denser medium**, such as water or glass, it slows down and bends **towards the normal**. The normal is an imaginary line drawn at right angles to the surface at the point where the light strikes.
- ✓ When light enters a **rarer medium**, such as from glass to air, it speeds up and bends **away from the normal**.

The bending of light is explained by **Snell's Law**: *Snell's Law* ($n_1 sini_1 = n_2 sinr_2$),
During refraction, the **frequency of light remains unchanged**, but its **speed and wavelength change** as it moves from one medium to another.
A common example of refraction is a pencil partly placed in water. The submerged part appears bent or broken because light from the part inside water changes direction as it moves from water to air. This makes the underwater part appear shifted from its actual position, producing the illusion that the pencil is bent at the water surface.

REAL AND APPARENT DEPTH



The refractive index of a glass block is determined by the ratio of its **real depth** to its **apparent depth**. When light travels from a denser medium (glass) to a less dense medium (air), it bends away from the normal, causing an object beneath the glass to appear closer to the surface than it actually is.

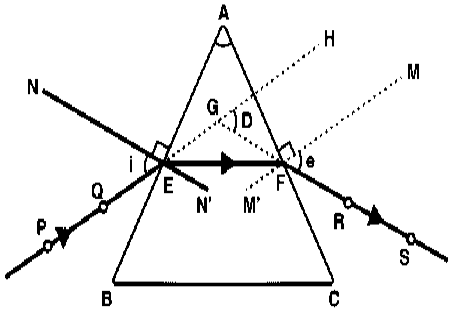
- ✓ ***Real depth $|d_r|$ refers to the actual physical distance from the surface of a medium, such as water, to an object submerged within it.***
- ✓ ***Apparent depth $|d_a|$ is the perceived distance, which is often less than the real depth due to the refraction of light.***

For example, when observing an object underwater, the light rays bend as they exit the water, causing the object to appear closer to the surface than it truly is. The refractive index of water, n=1.33, in this phenomenon, leads to the apparent depth being about 34% of the real depth. An object O placed below a water surface appears to be nearer to the top when viewed from above. The depth corresponding to apparent depth. The actual depth of an object, below the liquid surface is called **the real depth**.

$$\boldsymbol{n = \frac{real\ depth}{apparent\ depth} = \frac{d_r}{d_a}}$$

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Activity: Determination of refractive index using a triangular prism



Apparatus: Triangular prism, Drawing board, Sheet of white paper, Pins (optical pins), Protractor and ruler, Pencil and eraser, and Light source

Procedure

a) Fix the white paper on the drawing board.
b) Place the prism on the paper and trace its outline.
c) Label the two refracting faces and the angle A.
d) Choose an angle of incidence,$i = 30°, 40°, 50°, 60.$
e) Use two pins to mark a ray approaching the prism at angle i to the normal at the first face.
f) Place two more pins to mark the refracted ray inside the prism.
g) Join the incident ray to the refracted ray at the first face.
h) Measure the angle between the normal and the refracted ray at the point of incidence. This is the angle of refraction r.
i) Repeat for different values of $i = 30°, 40°, 50°, and\ 60°$, and for each value, measure the corresponding r.
j) Tabulate a table of results including values of sin i and sin r
k) Plot a graph of sin i against sin r.
l) Determine the slope of the graph as n.
m) A graph of sin i against sin r is plotted, and the slope of the graph is the refractive index of the prism.

i (°)	r (°)	Sin (i)	Sin (r)
30	19.2	0.500	0.329
40	25.4	0.643	0.429
50	31.3	0.766	0.519
60	36.4	0.866	0.593

Sources of Experimental Error

- ✓ **Measurement Precision:** Difficulty in accurately measuring angles i and r using a protractor may affect results.
- ✓ **Parallax Error:** Misalignment of pins while tracing rays can lead to inaccurate ray paths.
- ✓ **Non-ideal Prism Surfaces:** Irregularities or dirt on the prism faces may cause scattering or absorption.
- ✓ **Light Source Width:** A wide light beam might not provide a clear ray path for angle measurements.
- ✓ **Wavelength Dependence**: Refractive index depends on the wavelength of light. Using white light may cause dispersion; thus, a monochromatic source like sodium light is ideal.

TOTAL INTERNAL REFLECTION

Total internal reflection (TIR) is an optical phenomenon that occurs when light travelling from a **denser medium** to a **less dense medium** is completely reflected back into the denser medium.

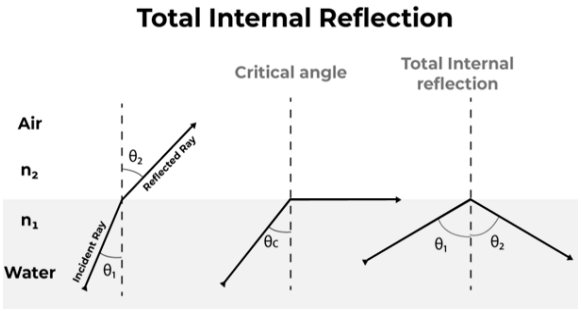
For example, it can occur when light travels from **glass to air** or from **water to air**.
Normally, when light reaches the boundary between two media, part of it is refracted into the second medium. However, in total internal reflection, **no light passes into the less dense medium**. Instead, all the light is reflected back.

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Conditions for Total Internal Reflection

For total internal reflection to occur, two important conditions must be met.



a) Light must travel from a **denser medium to a less dense medium**, such as from glass to air or water to air.

b) The **angle of incidence must be greater than the critical angle**. The critical angle is the particular angle of incidence at which the refracted ray would travel along the boundary between the two media.

c) When the angle of incidence exceeds the critical angle, the light is completely reflected back into the denser medium.

Applications of Total Internal Reflection

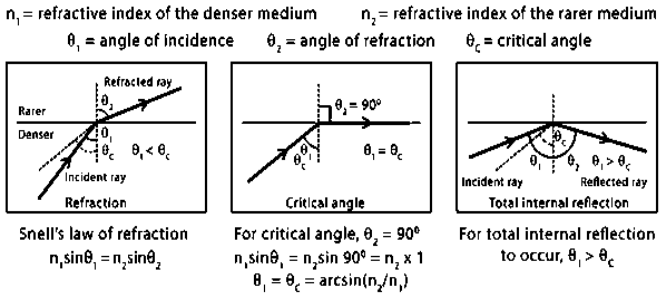
- ✓ Total internal reflection is used in many optical devices and technologies. One of its most important applications is in **optical fibres**, where light signals are repeatedly reflected inside the fibre, allowing information to be transmitted over long distances with little loss of energy.
- ✓ It is also used in **prisms, polarizing devices, binoculars, periscopes, and other optical instruments** to redirect light efficiently.
- ✓ In advanced technology, total internal reflection is applied in areas such as **radar detection, biomedical imaging, fibre optic communication, and optical sensors**.

Total internal reflection occurs when light travels from a denser medium to a less dense medium and strikes the boundary at an angle greater than the critical angle.
Under these conditions, the light is completely reflected back into the denser medium. This principle is important in fibre optics, prisms, optical instruments, sensors, and modern imaging technologies.

CRITICAL ANGLE

The **critical angle** is the angle of incidence in the denser medium at which the angle of refraction is 90 for refracted ray traveling along the boundary between the two pair of media of different optical density. This occurs when light travels from a **denser medium** to a **rarer medium**, such as from glass to air or water to air.

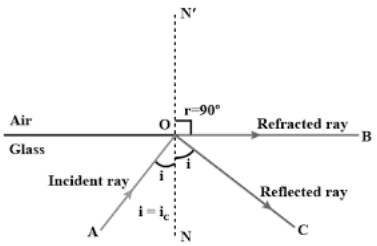
- ✓ When the angle of incidence is small, most of the light is refracted into the rarer medium, while a small part is reflected back into the denser medium. As the angle of incidence increases, the angle of refraction also increases. At a particular angle, called the **critical angle**, the refracted ray bends so much that it travels along the surface separating the two media.
- ✓ When the angle of incidence becomes greater than the critical angle, no refracted ray is formed. Instead, all the light is reflected back into the denser medium. This is called **total internal reflection**.



If the angle of incidence is greater than the critical angle, total internal reflection occurs.

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Consider a ray of light moving from glass (denser) to air (rarer).
As the angle of incidence increases, the angle of refraction also increases until it reaches 90 degrees.
At this point, the critical angle is reached, and any further increase in the angle of incidence results in total internal reflection. The critical angle is crucial in various applications, including fiber optics and optical devices, where controlling light behavior is essential for efficient transmission and imaging.



From Snell's law; $n_g sini_g = n_a sin90, n_g sinc = 1; c = \sin^{-1}\left[\frac{1}{n}\right]$

Mirage occurrence

On a hot day, the road ahead may appear to shimmer with water. The layers of air close to the surface of the road are hotter and less dense than those above and refraction of sunlight occurs. When the critical angle of incidence is reached, the light undergoes total internal reflection, resulting in a mirage, which disappears as you move towards it.

Example

1). The refractive index for a certain glass is 1.6.

Task: a) Calculate the angle of refraction for an angle of incidence of 24°.

a) Calculate the speed of light in the glass.

a). From, $n = \frac{sini}{sinr}, then\ sinr = \frac{sini}{n} = \frac{0.406}{1.6} = 0.254$, and r = 15°

b). From the refractive index, $n = \frac{\text{speed of light in air (or a vacuum).}}{\text{speed of light in medium}} =$

$$So\ speed\ of\ light\ in\ glass = \frac{speed\ of\ light\ in\ air}{n} = \frac{3.0 \times 10^8 m}{1.6}$$

$$v = 1.9 \times 10^8 m/s$$

2). If the critical angle for diamond is 24°, calculate its refractive index.

Critical angle, c=24; Sin24= 0.406, $n = \frac{sin90^0}{sinc} = \frac{1}{sin24} = 2.5$.

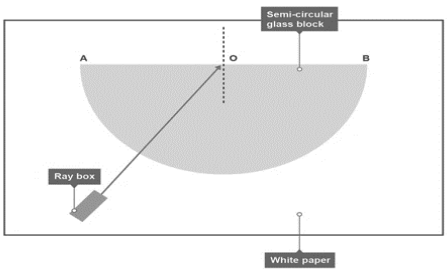
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ACTIVITY:

1. A ray of light incident on one side of an equilateral glass prism of refractive index 1.52 is critically refracted at the second surface of the prism. Determine the angle of incidence. (29.5^o)
2. Given that the critical angle for a transparent material is 32°. Calculate its refractive index.
3. The refractive index of a transparent material is 1.7. Work out its critical angle

Experiment to determine the critical angle of a glass block

The critical angle is the angle of incidence in a denser medium at which the angle of refraction in the less dense medium becomes 90°. Beyond this angle, total internal reflection occurs. The experiment described below outlines a practical procedure to determine the critical angle for a glass block.



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Materials Required: Semi-circular glass block, a ray box, a protractor, a ruler, a white sheet of paper, and a pencil. The semi-circular glass block is used to eliminate refraction at the curved surface, ensuring that light enters the block perpendicularly.

Procedure

a) Start by placing the white sheet of paper on a flat surface and tracing the outline of the semi-circular glass block. Position the glass block back on its traced outline and mark the center of the flat surface of the block.
b) Use a protractor to draw a normal line perpendicular to the flat surface of the glass at this center point.
c) Direct a thin ray of light from the ray box or laser pointer toward the flat surface of the glass block, ensuring the light ray meets the block at the center where the normal line is drawn.
d) Adjust the angle of incidence (the angle between the incident ray and the normal) starting at a small value, such as 10°, and gradually increase it. Observe the path of the refracted ray as it exits through the curved surface of the block into the air.
e) Measure the angle of incidence at which the refracted ray disappears and travels along the boundary. Record this angle as the critical angle, C.
f) Repeat the experiment several times for different angles of incidence, and take the average of the recorded angles. Ensure all angles are measured carefully with a protractor to minimize errors.
g) Using the critical angle C, the refractive index (n) of the glass can be calculated using the relationship: $n = \frac{1}{sinC}$, where n is the refractive index of the denser medium (glass) relative to air.

Precautions

To achieve reliable results, ensure the light ray is thin and precise, use a clean glass block to prevent scattering of light, and avoid parallax error while measuring angles with the protractor.

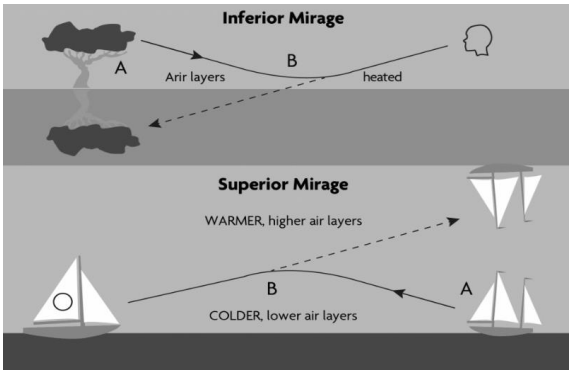
APPLICATION OF TOTAL INTERNAL REFLECTION

- ✓ Used in **optical fibres** inside a glass or plastic core to transmit information over long distances with little energy loss. This makes fibre optics useful in **telephone communication, broadband internet, cable TV, and medical endoscopes**.
- ✓ Used in **prismatic instruments** such as **binoculars and periscopes**, where prisms reflect light internally to change the direction of light and produce clear images in compact devices.
- ✓ In **road safety devices** is used in **retro reflectors**, vehicle reflectors, bicycle reflectors, and road signs. These devices reflect light back toward its source, making them visible at night or in poor lighting.
- ✓ In **lasers and optical instruments**, where it helps guide and control light in optical waveguides, ring resonators, and scientific imaging systems.
- ✓ In **optical sensors and measurement devices** in instruments such as **refractometers** to measure refractive index.
- ✓ Applied in security systems, motion detectors, food processing, pharmaceutical testing, and chemical analysis.

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EFFECTS OF TOTAL INTERNAL REFLECTION



Mirages Formation

A mirage is an optical illusion that occurs when light rays bend due to variations in air temperature. This bending, or refraction, creates the illusion of water or a distorted image of the sky on the ground.

Mirages occur on hot days when the ground heats the air just above it. This creates a temperature gradient, with hot air near the surface and cooler air above.

Light travels at different speeds through hot and cool air. When light passes from cooler to hotter air, it bends or refracts. This bending causes the light to follow a curved path. If the temperature gradient is steep enough, light rays can bend so much that they reflect off the boundary between the hot and cool air layers. This reflection can make the sky appear on the ground, creating the illusion of water.

Types of Mirages

Inferior Mirages: These are the most common and occur when the ground is much hotter than the air above. They make distant objects appear lower than they are, often creating the illusion of water on the road.

Superior Mirages: These occur when a layer of cold air lies beneath a layer of warmer air. They make objects appear higher than they are and can sometimes create multiple images of the same object.

Fata Morgana: This is a complex form of superior mirage that can create stacked images of distant objects, often seen over the horizon at sea.

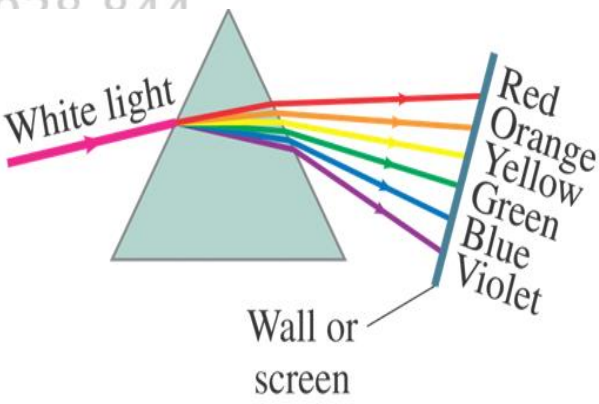
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Real-World Examples

Travelers in deserts often see what appears to be water in the distance. This is an inferior mirage caused by the hot sand heating the air above it.

On hot days, drivers may see what looks like a pool of water on the road ahead. This is also an inferior mirage.

DISPERSION OF WHITE LIGHT



When sunlight (**white light**, ***Monochromatic light; Light of one colour and so of one frequency is termed monochromatic***) falls on a triangular glass prism, a band of colours called a spectrum is obtained. The effect is termed dispersion. It arises because white light is a mixture of many colours; the prism separates the colours because the refractive index of glass is different for each colour (it is greatest for violet light).

Dispersion is the separation of white light into its constituent colours when it passes through a medium such as a glass prism.

This occurs because the different colours of light travel at different speeds in the medium and are therefore, refracted by different amounts.

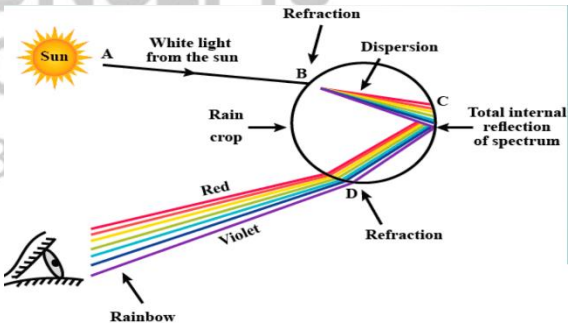
- ✓ When white light enters a prism from air, it slows down and bends because it has moved into a denser medium. Each colour bends at a different angle due to differences in wavelength and refractive index.
- ✓ Violet light bends the most because it has the shortest wavelength and highest frequency in the visible spectrum, while red light bends the least because it has a longer wavelength.

As the light passes through and leaves the prism, the colours spread out further due to another refraction at the glass-air boundary.
The separated colours form a visible spectrum arranged in the order: Red, Orange, Yellow, Green, Blue, Indigo, and Violet. Commonly called as **ROYGBIV**.
Thus, dispersion is mainly caused by the **unequal refraction of different colours of light** as they pass through a prism.

Applications of dispersion of white light are in optics, spectroscopy, medical imaging, fibre optics, sensors, cameras, and binoculars.

a) In spectroscopy, prisms and gratings separate light into its different colours or wavelengths. This helps scientists identify materials and chemical substances by studying the light they absorb or emit.
b) In medical imaging, dispersion helps improve the viewing of biological samples, especially in techniques such as quantitative phase imaging.
c) In optical technologies, dispersion is considered in the design of fibre optics and sensors to improve signal transmission and detection.
d) Dispersion is also important in camera, lenses and optical instruments, where designers try to reduce unwanted colour separation called chromatic aberration. In devices such as binoculars and prisms, the behaviour of light is carefully controlled to produce clearer images.

Examples: Formation of a Rainbow
A rainbow is formed when sunlight interacts with water droplets in the atmosphere. The main processes involved are **refraction, dispersion, and internal reflection**.



When sunlight enters a raindrop, it slows down and bends because it is moving from air into water. This bending of light is called **refraction**. As the sunlight enters the droplet, it also undergoes **dispersion**, where white light separates into its different colours because each colour bends by a different amount.

Shorter wavelengths, such as **violet and blue**, bend more than longer wavelengths, such as **red and orange**. After entering the droplet, the separated light reflects off the inner surface of the water droplet. This is called **internal reflection**.
As the light leaves the droplet, it is refracted again. This second refraction separates the colours further, producing the visible spectrum of a rainbow. The colours appear in order, with **red on the outer edge** and **violet on the inner edge**.
The spherical shape of raindrops helps light bend and reflect in a consistent way. A rainbow is usually seen when the observer has their **back to the sun** and is facing raindrops in the sky. Light from millions of droplets reaches the observer's eyes, forming the bright circular arc of colours seen as a rainbow.

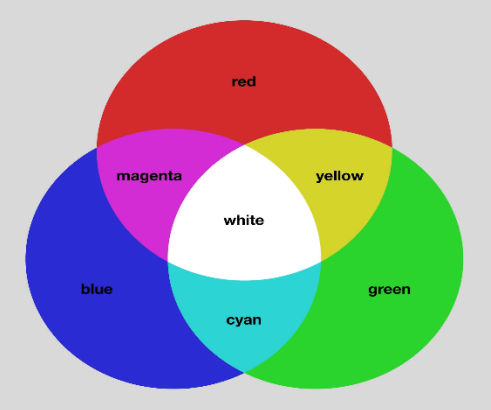
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A pure spectrum is a display of distinct and separate colors produced when white light is dispersed through a prism or diffraction grating, with each wavelength clearly visible and not overlapping. It consists of the full range of visible colors arranged in order of increasing wavelength, from violet to red, without blending between them.

The reflective surfaces of **CDs and DVDs** discs cause dispersion due to diffraction, which also separates light into its colors.
Light passing through the faceted surfaces of a crystal chandelier disperses into a colorful display.

COLORS OF OBJECTS
The color of an object is determined by the wavelengths of light it reflects, absorbs, or transmits.
When white light, which contains all colors, strikes an object, certain wavelengths are absorbed while others are reflected. For instance, a red ball appears red because it absorbs green, blue, and violet wavelengths, reflecting only the red wavelengths back to our eyes. This interaction between light and objects is fundamental to our perception of color.
The wavelengths that are reflected determine the color we see. For example, a blue object reflects blue light and absorbs other colors, while a yellow object reflects yellow light. The colour it transmits or reflects e.g. an object appears blue because it reflects blue light into the eyes and absorbs the other colours of the spectrum.

Similarly, an object appears red because it reflects red light into the eyes and absorbs all other colours. This principle applies to all colored objects, making color perception a fascinating aspect of physics and biology. A white object reflects all the colours of the spectrum into the eyes and absorbs none.



Types of colours
Primary colors are the foundation of color theory, consisting of Red, Green, and Blue. These colors cannot be created by mixing other colors together, making them unique in the color spectrum. They serve as the building blocks for all other colors, including secondary colors.
Secondary colors are formed by mixing two primary colors in equal parts. For instance, combining red and green produces YELLOW, green and blue create CYAN, and blue mixed with red results in MAGENTA. These secondary colors occupy the spaces between the primary colors on the color wheel, illustrating their relationship.

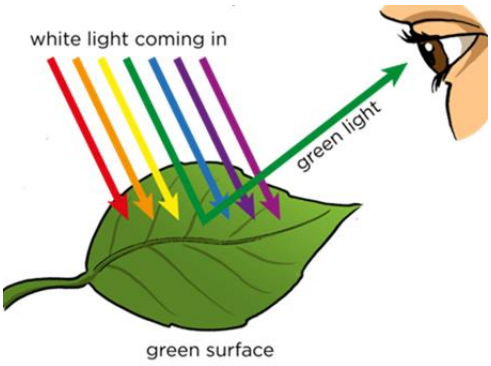
Complementally colours
Complementary colors are pairs of colors that, when combined, produce a grayscale color such as white or black. In the realm of physics, these colors are defined as those that are opposite each other on the color wheel. For instance, red pairs with cyan, magenta with green, and blue with yellow.
When two complementary colors of light are mixed in equal intensities, they create white light. This phenomenon is rooted in the additive color theory, which explains how different wavelengths of light combine to form new colors. The mixing of complementary colors results in a uniform frequency distribution, effectively canceling out the original colors.

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In practical applications, such as art and design, complementary colors are used to create contrast and visual interest.
These are two different colours which when added produce white light. One of them is a secondary colour and the other must be a primary colour. From the complementally colours, it is noted that when the three primary colours are joined, they produce white light.

Colored objects in white light

A coloured object reflects and transmits its own colour and absorbs other colour incident on it. When white light, which contains all the colors of the visible spectrum, shines on an object, the color we perceive depends on which wavelengths of light are absorbed and which does the object reflect.



How Colored Objects Appear in White Light

White light is a combination of all the colors of the rainbow, from red to violet. This means it contains all wavelengths of visible light. When white light hits an object, the object **absorbs some wavelengths and reflects others**.
The color of the object is determined by the **wavelengths of light it reflects**.

- ✓ A red object appears red because it reflects red wavelengths and absorbs other colors.
- ✓ A blue object reflects blue wavelengths and absorbs the rest.
- ✓ A green object reflects green wavelengths and absorbs other colors.
- ✓ **White objects appear white because they reflect all wavelengths of light equally.**
- ✓ **Black objects appear black because they absorb all wavelengths and reflect none.**

Examples:

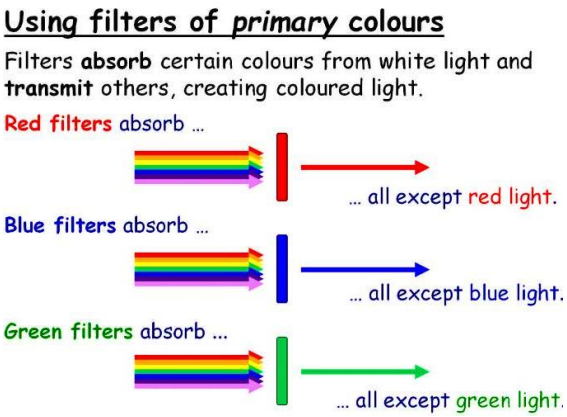
When white light shines on a red apple, the apple absorbs all colors except red, which it reflects. This is why the apple looks red to our eyes. The sky appears blue because molecules in the atmosphere scatter blue light from the sun more than they scatter red light.
If you shine colored light (blue light) on an object, the object's appearance can change. For example, a red object under blue light will appear black because it absorbs the blue light and reflects no light.

FILTERS (COLOUR)

Colour filters are essential tools in physics that manipulate light by selectively absorbing certain wavelengths while allowing others to pass through.
The primary colours of light; red, green, and blue; differ from the primary colours used in art, which are cyan, magenta, and yellow.
When light passes through a colour filter, it is subjected to a process known as colour separation by subtraction, where the filter absorbs all colours except for the one it is designed to transmit. For instance, a yellow filter allows yellow light to pass while absorbing other wavelengths, such as blue and green.

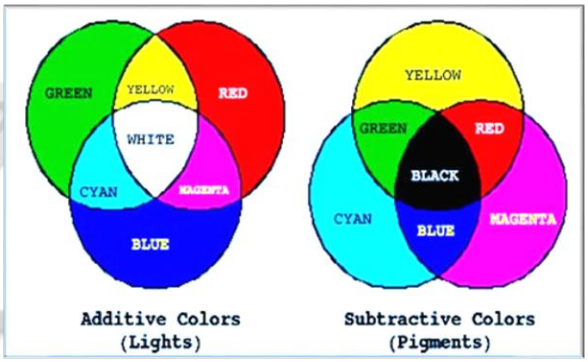
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This selective absorption is crucial in various applications, from photography to scientific experiments, where specific colours are needed for analysis or aesthetic purposes. Constructed from materials like dyed glass or plastic, colour filters are vital in optics, enhancing our understanding of light and its properties.



A filter is a coloured sheet of plastic or glass material, which allows light of its own type to pass through it and absorbs the rest of the coloured lights i.e. a green filter transmits only green, a blue transmits only blue, a yellow filter transmits red, green and yellow lights.

MIXING OF COLOURED PIGMENTS

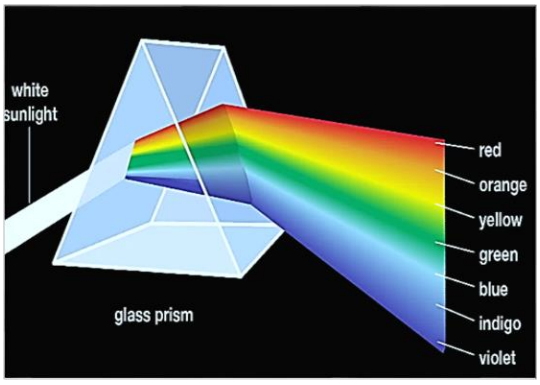


Mixing colored pigments involves the principles of subtractive color mixing, where pigments absorb certain wavelengths of light and reflect others.
When pigments are combined, they absorb more wavelengths, resulting in a new color. For instance, mixing yellow and blue pigments produces green because yellow absorbs blue light while blue absorbs yellow light, leaving only green to be reflected.
In contrast, additive color mixing occurs with light, where different wavelengths are combined to create new colors.

For example, mixing red and green light results in yellow. This distinction is crucial in various applications, such as painting, printing, and photography, where understanding how colors interact can lead to desired outcomes. The rarity of certain colors in nature, like blue, can also be explained through physics. Blue pigments are less common because they require specific structural properties to reflect blue light, making them a unique phenomenon in the natural world.

A pigment is a substance, which gives its colour to another substance. A pigment absorbs all the colours except its own, which it reflects. Mixing coloured pigments is called colour mixing by subtraction. Pigments appear black because none of the colours is reflected.

APPEARANCE OF COLOUR PIGMENT IN THE WHITE LIGHT



The appearance of color pigments in white light is due to reflection and absorption. White light, which consists of all visible wavelengths, appears white because it reflects all colors equally. When an object is white, it reflects the entire spectrum of light, allowing us to perceive it as such.
In contrast, colored pigments work by selectively absorbing certain wavelengths of light while reflecting others. For

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instance, a red pigment absorbs blue and green wavelengths but reflects red light. This selective absorption is what gives the pigment its color.

When white light hits a red object, the red wavelengths are reflected back to our eyes, making the object appear red.

This principle of color subtraction explains why objects appear colored under white light.

The appearance of a pigment in white light is determined by the specific wavelengths it reflects. When illuminated with white light, a pigment absorbs certain colours and reflects others, creating the perception of its colour. This interaction between the pigment and the various wavelengths in white light allows us to see the pigment in its characteristic hue. A colour pigment reflects only one colour

COLOURS ON A TELEVISION

Televisions produce color images through a combination of light-emitting units and the RGB (red, green, blue) color model.

In traditional CRT (cathode ray tube) televisions, three electron guns shoot beams of electrons onto a phosphorescent screen coated with red, green, and blue phosphors.

By varying the intensity of each beam, the television can create a wide spectrum of colors through additive color mixing. Modern flat-screen TVs, such as LCDs and OLEDs, utilize a different technology. LCDs use liquid crystals that manipulate light from a backlight, while OLEDs consist of organic compounds that emit light directly. Each pixel in these displays is divided into sub-pixels, each corresponding to red, green, or blue. By adjusting the brightness of these sub-pixels, the television can produce millions of colors, creating vibrant and detailed images.

3.3 LENSES AND OPTICAL INSTRUMENTS

Learning Outcomes

a) Know the properties of converging and diverging lenses, and how they are used in everyday life (k,u,s)
b) Understand how lenses are used in optical systems such as the magnifying glass, correcting sight in the human eye and in camera lenses (k, u, v/a)

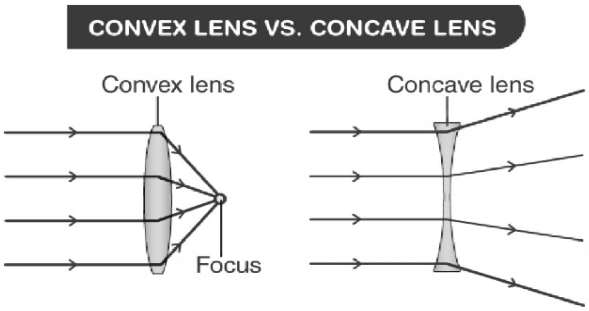
LENSES

- ✓ A lens is a transparent optical device designed to refract light, forming images by focusing or dispersing light rays. Lenses are used in optical instruments such as cameras, spectacles, microscopes and telescopes; they often have spherical surfaces and there are two types.
- ✓ A converging (or convex) lens is thickest in the centre and bends light inward. You may have used one as a magnifying glass or as a burning glass.
- ✓ A diverging (or concave) lens is thinnest in the centre and spreads light out; it always gives a diminished image.
- ✓ The centre of a lens is its optical centre, C; the line through C at right angles to the lens is the principal axis. The action of a lens can be understood by treating it as a number of prisms (most with the tip removed), each of which bends the ray towards its base. The centre acts as a parallel-sided block.
- ✓ Convex lenses converge light rays, making them ideal for magnifying objects, while concave lenses diverge light rays, often used to correct nearsightedness. The careful design and manufacture of lenses involve precise grinding or molding to achieve the desired optical properties.

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Two primary types of lenses: converging (convex) lenses and diverging (concave) lenses.



Convex/converging lenses

- ✓ A converging lens, also known as a convex lens, is an optical device that focuses parallel rays of light to a single point known as the focal point.
- ✓ When an object is placed outside this focal point, the lens produces a real, inverted image.
- ✓ If the object is positioned within the focal length, the lens generates a virtual, upright, and magnified image. This property makes converging lenses essential in various applications, including magnifying glasses, cameras, and microscopes.

Concave/diverging lenses

A diverging lens, also known as a concave lens, is designed to spread out parallel rays of light that pass through it. This lens is thinner at its center than at its edges, causing light rays to diverge as if they originated from a single point on the opposite side of the lens. Light rays refract and appear to diverge; creating a virtual image that is upright and smaller than the object.

HOW A LENS WORKS

When light enters a lens, it changes direction due to the lens's curved surfaces, allowing it to focus or disperse the light to form an image. Lenses are used in optical devices like cameras, glasses, and microscopes.

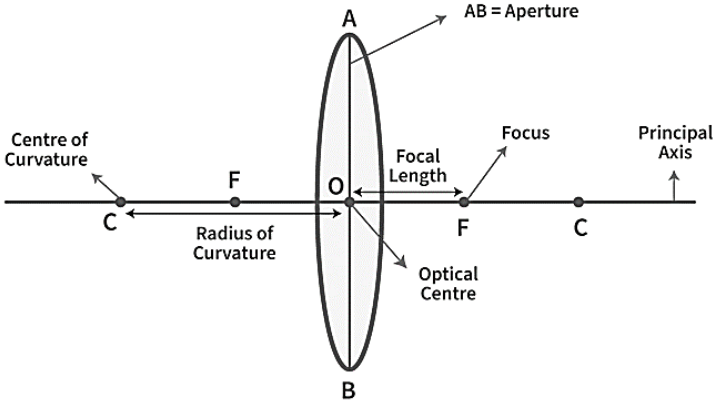
- ✓ **Convex lenses, which are thicker in the center, converge light rays to a focal point, making them ideal for magnifying objects.**
- ✓ **Concave lenses are thinner in the center and diverge light rays, which can be useful for correcting nearsightedness.**

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TERMS USED IN LENSES

Principal Axis

The principal axis is an imaginary straight line that passes through the center of the lens and connects its two curved surfaces. It is the reference line for analyzing lens behavior.



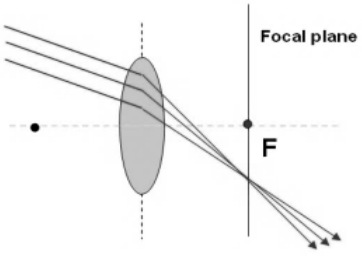
Principal Focus: When a beam of light parallel to the principal axis passes through a converging lens it is refracted to converge to a point on the axis called the **principal focus (focal point),** F. It is a real focus. A diverging lens has a virtual principal focus behind the lens, from which the refracted beam seems to diverge. Since light can fall on both faces of a lens it has two principal foci, one on each side, equidistant from C. The distance CF is the focal length f of the lens; it is an important property of a lens. The more curved the lens faces are, the smaller is f and the more powerful is the lens.

Principal focus (Focal point) point on the principal axis of a lens to which light rays parallel to the principal axis converge, or appear to diverge from.

Focal length is the distance between the optical centre and the principal focus of a lens. . A shorter focal length results in greater convergence or divergence.
Optical Center: The optical center is the point in the lens through which light rays pass without being refracted. For thin lenses, it lies in the geometric center of the lens.
Radius of Curvature (r): This refers to the radius of the sphere from which the lens surface is a segment. Each surface of a lens has its radius of curvature.
Aperture: The aperture of a lens is the effective diameter of the lens through which light passes. It determines the amount of light that enters the lens.
Power of a Lens: The power of a lens measures its ability to converge or diverge light, expressed in **diopters (D)**. It is the reciprocal of the focal length (in meters); $Power = \frac{1}{f(m)}$

Magnification: Magnification refers to how much larger or smaller an image is compared to the object. It is calculated as:$m = \frac{image\ height}{object\ height} = \frac{image\ distance}{object\ distance}$; $m = \frac{v}{u} = \frac{h_i}{h_0}$
Axis of the Lens: The axis of the lens is the line perpendicular to the lens surface at its center. It helps in aligning the lens correctly during imaging or analysis.
Chromatic Aberration: This is a lens defect caused by different wavelengths of light being refracted by different amounts, resulting in color fringes in the image.
Spherical Aberration: A lens defect where light rays passing through the edges of a lens focus at different points than rays passing through the center, leading to a blurred image.

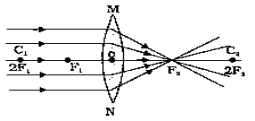
Focal plane of a lens

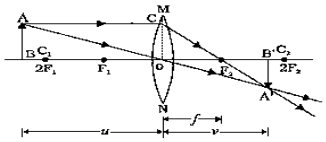


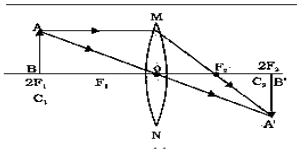
The focal plane of a lens is the flat area where light rays converge to create a sharp image. This plane is positioned at a specific distance from the lens, known as the focal length, which is essential for achieving the desired focus in an image.
Focal plane allows photographers to manipulate depth of field and focus, enhancing the overall composition of the final image.

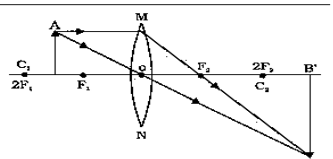
Image formation in lenses

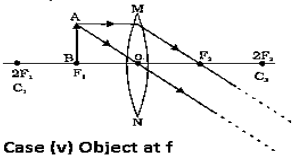
Image formation in convex lenses, or converging lenses, can create both real and virtual images depending on the object's distance from the lens.
When an object is placed at a finite distance, a virtual image is formed between the optical center and the focus. This image is **upright and smaller** than the object.
Concave lenses, or diverging lenses, consistently produce virtual images that are **erect and diminished.** The image appears on the same side as the object, and the light rays diverge, making it impossible to project the image onto a screen.

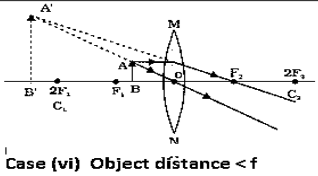

Case (i) Object at infinity


Case (ii) Object at beyond 2f


Case (iii) Object at 2f


Case (iv) Object in between f and 2f


Case (v) Object at f

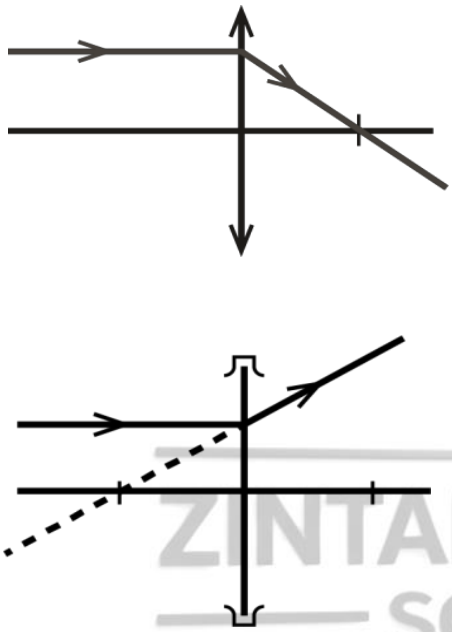

Case (vi) Object distance < f

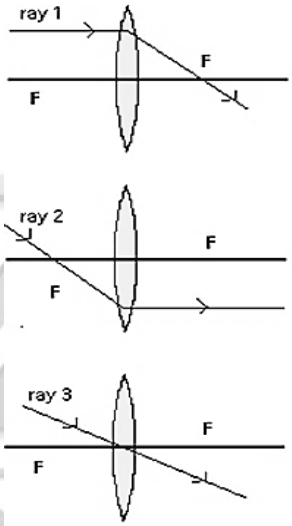
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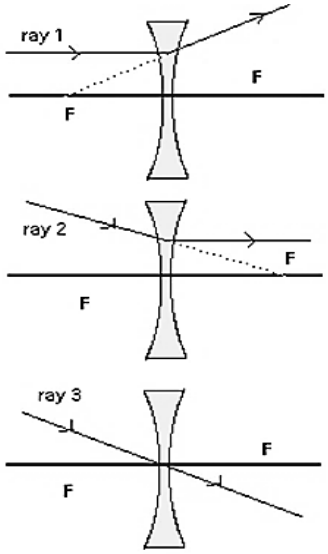
Drawing ray diagrams

Guidelines for rays falling on the concave and convex lenses

- ✓ When a ray strikes concave or convex lenses obliquely at its optical centre, it continues to follow its path.
- ✓ When a ray, parallel to the principal axis strikes concave or convex lenses, the reflected ray passes through a focus on the principal axis.
- ✓ When a ray, passing through focus strikes concave or convex lenses, the reflected ray will pass parallel to the principal axis.







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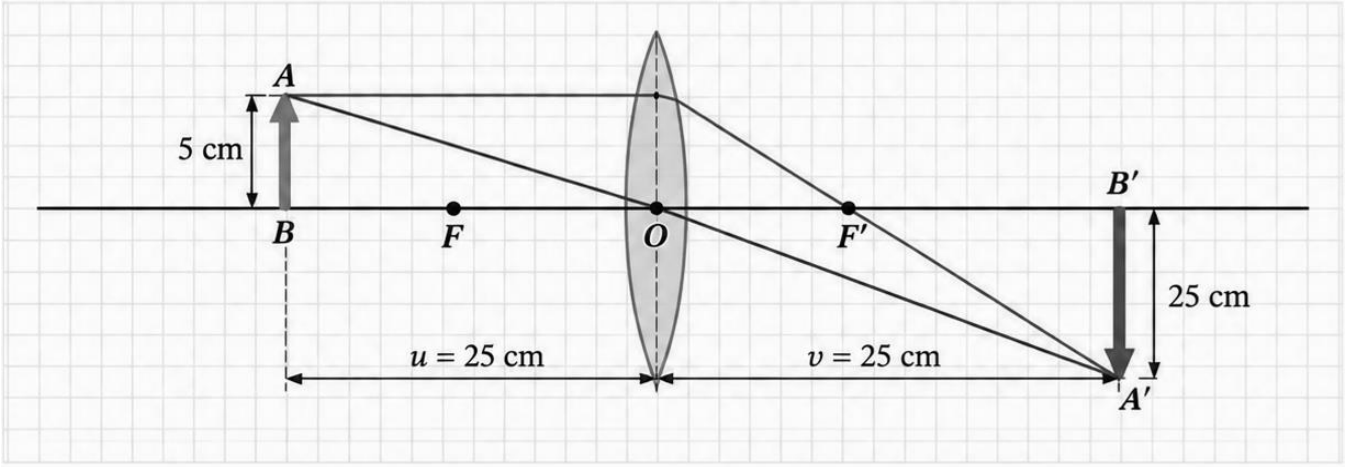
Scale drawing of ray diagrams

A line on a graph paper represents a lens.

Scale must be used= Use 5threads on paper to represent 1cm

1. An erect object 5cm high is placed at a point 25cm from a convex lens. A real image of the object is formed 25 cm high. Construct a ray diagram and use it to find the focal length of the lens

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Given:

Object height, $h_o = 5$ cm (erect)
Object distance, $u = 25$ cm
Image height, $h_i = 25$ cm (real, inverted)
(Convex lens)

To find:

Focal length of the lens, f.

Construction:

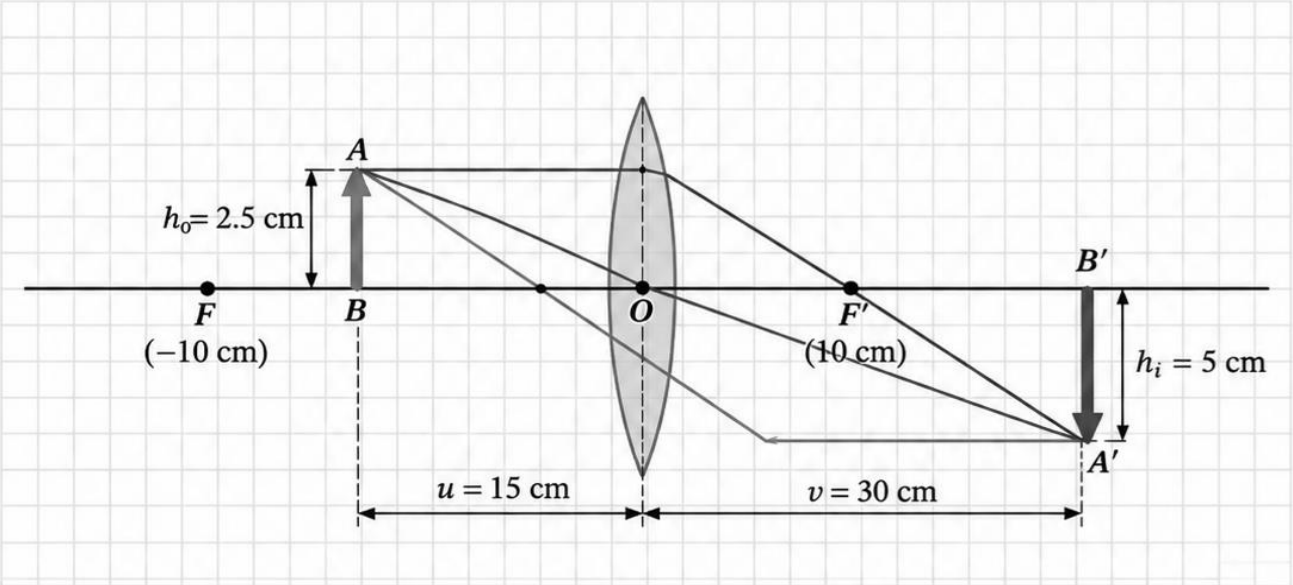
1. Draw the principal axis and mark the optical centre O.
2. Mark the focal points F and F' at equal distances from O (unknown distance).
3. Place the object AB (5 cm high) at 25 cm from O ($u = 25$ cm).
4. Draw two rays from the top of the object A:
   - A ray parallel to the principal axis, refracting through F'.
   - A ray through the optical centre O (straight line).
5. The rays meet at A', 25 cm from O, giving a real, inverted image of height 25 cm.
6. Measure the focal length from O to F (or F').

Result:

The focal length of the convex lens is $f = 25$ cm.

2. An object is placed at right angle to the principal axis of a thin covering lens of focal length 10cm. A real image of height 5cm is formed at 30cm from the lens. By construction, find the position and height of the object.

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Given:

Focal length of lens, $f = 10$ cm
Image distance, $v = 30$ cm
Image height, $h_i = 5$ cm (real, inverted)

To find:

Position of object (u) and height of object (h_o).

Construction:

1. Draw the principal axis and mark the optical centre O.
2. Mark the focal points F and F' at 10 cm from O.
3. Place the image 30 cm to the right of the lens (real, inverted, 5 cm).
4. From the top of the image, draw rays backwards to locate the object:
   - A ray through the centre O (straight line).
   - A ray parallel to the axis (refracts through F').
   - A ray through F (emerges parallel to the axis).
5. The rays meet at the object position, giving $u = 15$ cm and $h_o = 2.5$ cm.

Result:

The object is 15 cm in front of the lens and its height is 2.5 cm.

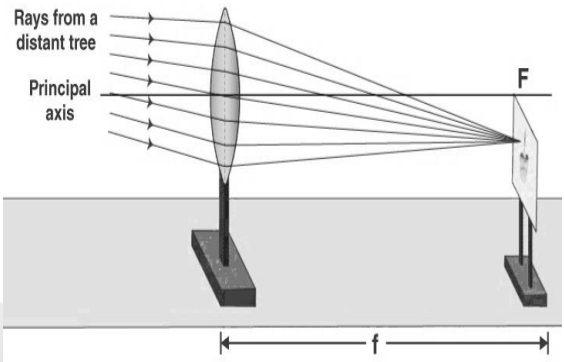
Activity

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1.)Object 5cm tall is placed 15cm away from a lens of focal length 10cm. By construction; determine the position, size and nature of the final image (use a scale 1cm: 5cm)

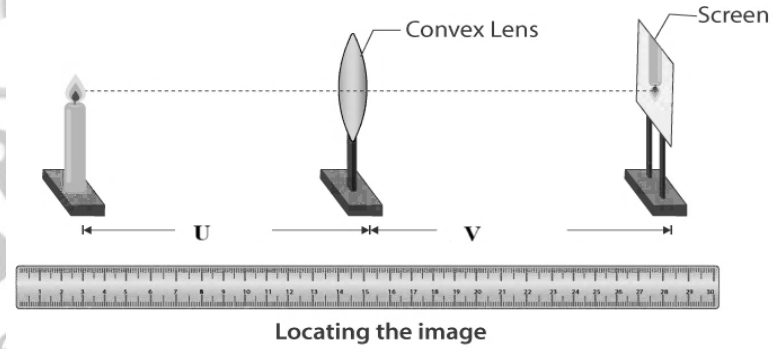
2.) A simple magnifying glass of focal length 5cm forms an erect image of the object 25cm from the lens. By graphical method, find the distance between the object and image, and the magnification

Determination of focal length using on illuminated object



1. Place a lens in a suitable holder with a plane mirror behind it so that light passing through the lens is reflected back.
2. Position the convex lens in front of a distant object, such as a tree or a building, ensuring that the object is far enough away to be considered at infinity.
3. The light rays from this distant object will converge after passing through the lens, forming a sharp image on a screen placed behind the lens.
4. Measure the distance between the lens and the screen; this gives the focal length (f) of the lens.

Using converging lens by measuring object and image distances



Locating the image

a) Fix the object at a known distance from the zero end of the meter rule.
b) Place the convex lens at a certain distance (more than the focal length) from the object.
c) Adjust the height of the screen to be in line with the lens and object.
d) Move the screen back and forth until a sharp image is formed.
e) Ensure that the image is real, inverted, and diminished or magnified, depending on the object's distance.
f) Record the distance between the lens and the object (u).
g) Record the distance between the lens and the image (v).
h) Change the position of the lens while keeping the object at the same position.
i) Repeat the process to obtain at least three sets of readings for u and v, ensuring accurate alignment each time.
j) Plot a graph of $\frac{1}{v}$ on the y-axis against $\frac{1}{u}$ on the x-axis.
k) Find the intercept on the y-axis gives ,$\frac{1}{v}$, when $\frac{1}{u} = 0$, *and the intercepts obtained from both axes as* c_1 *and* c_2.
l) Calculate the reciprocal of the y-intercept to get the focal length, $f = \frac{1}{c_1}$, and $f = \frac{1}{c_2}$. The mean value of intercepts f= $\frac{1}{2}(\frac{1}{c_1} + \frac{1}{c_2})$ *determined.*

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Alternately

a) Repeated the experiment with several different values of u, and obtain the corresponding values of v
b) Tabulated the table of results, including values of $uv\ and\ (u+v)$
c) Plot a graph of $uv\ against\ (u+v)$, and obtain the slope. The slope value is determined from $slope = \frac{\Delta uv}{\Delta(u+v)}$
d) Focal length is calculated from f = slope
e)

POWER OF A LENS

The power of a lens in optics is defined as the ability of a lens to bend light rays. Mathematically, it is expressed a **Power**

$(P) = \frac{1}{f(m)}$, where (P) represents the power of the lens and (f) is its focal length measured in meters. A lens with a shorter focal length has a higher optical power, indicating a greater ability to converge or diverge light. The unit of measurement for lens power is the diopter (D), which corresponds to a focal length of one meter.

For instance, a lens with a focal length of 0.5 meters has a power of +2 diopters, while a lens with a focal length of 2 meters has a power of +0.5 diopters. In practical terms, the power of a lens influences how effectively it can focus light, impacting image quality and clarity in various optical systems.

Application of lenses

- ✓ Far-sighted individuals struggle to focus on nearby objects because their eyes focus images behind the retina. Convex lenses help by converging the light before it enters the eye, enabling proper focus on the retina. Corrective glasses for far-sighted individuals. Convex lenses are used in eyeglasses to correct hyperopia (farsightedness) and presbyopia, allowing clearer vision.
- ✓ Microscopes and telescopes utilize lenses to magnify objects, enabling scientists and astronomers to explore the microscopic world and distant celestial bodies, respectively. Converging lenses are used to magnify distant celestial objects (telescopes) or tiny biological samples (microscopes) by forming real or virtual magnified images. Astronomers use telescopes to view distant stars and planets; scientists use microscopes to view cells and microorganisms.
- ✓ In magnifying Glasses, **c**onverging lenses are used in magnifying glasses to enlarge the appearance of small objects by converging light rays to produce a larger, upright virtual image. They are used to read small text or examine tiny objects.
- ✓ In cameras, converging lenses focus light from the object onto the film or sensor, forming a sharp, inverted image of the object. The lens system allows for the adjustment of focus. Almost all camera systems, whether digital or film-based, use converging lenses. Cameras also rely on lenses to focus light and create sharp images, making them essential tools for photography.
- ✓ In a projector, a convex lens is used to focus and enlarge an image or video onto a large screen. The projector forms a real image by directing light through a converging lens system. Used in classrooms, movie theaters, and presentations.

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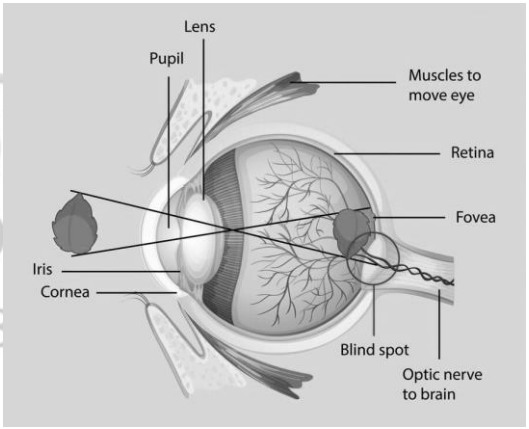
Uses of Diverging Lenses

- ✓ Near-sighted individuals (**myopia**) have trouble focusing on distant objects because their eyes focus images in front of the retina. Concave lenses spread the light rays slightly before they enter the eye, pushing the focal point back onto the retina. Concave lenses are widely used in eyeglasses for people with near-sightedness to correct their vision.
- ✓ Peepholes in Doors use diverging lenses to provide a wide-angle view of the outside. This gives the viewer a broader view of the area outside the door, despite the small size of the peephole. Peepholes are commonly installed in doors to allow the user to safely view who or what is outside.
- ✓ Laser Beam Expanders, **diverging** lenses are used in combination with other lenses to expand or diverge a narrow laser beam. This is useful in adjusting the width and focus of laser beams applications. Laser optics systems, such as those in scientific instruments and medical devices.
- ✓ In some optical devices, such as binoculars, diverging lenses are used in the eyepiece to widen the viewer's field of view while maintaining image clarity. Enhances viewing experience by providing a wider perspective in binoculars.

THE HUMAN EYE

It reacts to visible light, enabling us to perceive our surroundings. The eye consists of several key components, including the cornea, pupil, lens, and retina, all of which work in harmony to provide clear vision. The cornea and lens focus light onto the retina, where photoreceptors known as rods and cones convert light into electrical signals. In addition to vision, the human eye helps regulate circadian rhythms, influencing our sleep-wake cycles.

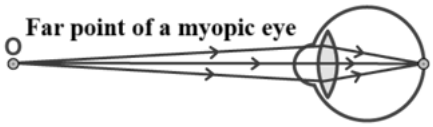
The iris, the colored part of the eye that regulates light entry by adjusting the size of the pupil. This dynamic control allows the eye to adapt to varying light conditions, ensuring optimal vision.



The lens, located behind the iris. The lens focuses light onto the retina, enabling clear images of objects at different distances. It works in conjunction with the cornea, which also helps to refract light. Together, these structures ensure that light rays converge accurately on the retina, where photoreceptor cells convert them into electrical signals. These signals are then transmitted to the brain, allowing us to perceive the world around us. The intricate functions of the iris and lens highlight the remarkable design of the human eye, facilitating our ability to see and interpret our environment.

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Accommodation. This is the process by which the human eye changes its size to focus the image on the retina. This process makes the eye to see both near and far objects.



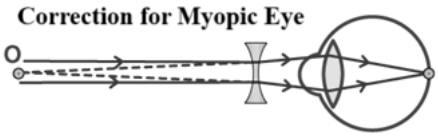
EYE DEFECTS AND THEIR CORRECTIONS

The normal eye can see objects clearly placed at infinity (far point) to see objects in greater details the eye sees it at the near point i.e. 25cm



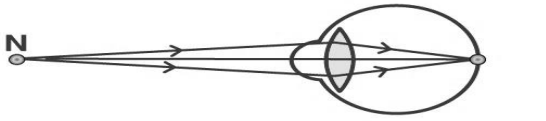
SHORT SIGHTEDNESS (MYOPIA)

Myopia (shortsightedness) is a refractive error that affects the ability to see distant objects clearly. This condition occurs when the eyeball is elongated or the cornea is overly curved, causing light to focus in front of the retina instead of directly on it. As a result, individuals with myopia struggle to see faraway objects, such as street signs or faces in a crowd.



Symptoms of myopia typically include blurred vision at a distance, squinting, and eye strain. It is increasingly prevalent, particularly among children, due to factors like excessive screen time and limited outdoor activities.

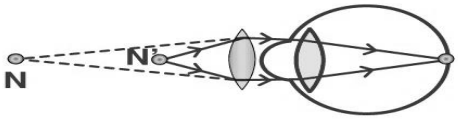
Treatment options for myopia include corrective lenses, such as glasses or contact lenses, and in some cases, refractive surgery. Lifestyle changes, like spending more time outdoors and reducing screen exposure, can also help manage the condition and slow its progression.



(a) Near point of a Hypermetropic eye



(b) Hypermetropic eye



(b) Correction for Hypermetropic eye

LONG SIGHTEDNESS

Long sightedness (**hyperopia**), is a common vision condition where distant objects may be seen more clearly than those that are near.

This occurs when the eyeball is too short or the cornea has too little curvature, causing light rays to focus behind the retina instead of directly on it. As a result, individuals may experience difficulty with tasks such as reading or sewing, leading to eye strain and discomfort.

Symptoms of long sightedness can include blurred vision, headaches, and difficulty concentrating on close-up tasks. Children may not always recognize their vision problems, which can affect their learning and development. Regular eye examinations are crucial for early detection and management.

Treatment options for hyperopia include corrective lenses, such as glasses or contact lenses, which help focus light correctly on the retina. In some cases, refractive surgery may be considered to provide a more permanent solution. A convex lens is placed in front of the eye to make the light parallel, so that it appears to come from a distant object as shown above.

Similarities and differences between the eye and camera

Both systems utilize lenses to focus light onto a light-sensitive surface; in the eye, this is the retina, while in a camera, it is the sensor or film.

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Both have mechanisms to control the amount of light entering; the iris in the eye and the diaphragm in a camera. However, there are notable differences between the two.
The human eye is a dynamic organ capable of adjusting focus and exposure in real-time, allowing for continuous visual processing. In contrast, cameras typically capture a single still image at a time. Furthermore, while the eye has a single lens, cameras can have multiple lenses to enhance image quality and versatility.

Examination item
At Kasangati Community Health Centre near Kampala, a health outreach team is conducting an eye screening exercise for students from nearby schools. During the screening, different optical devices are used such as magnifying glasses, spectacles, and a digital camera to observe and record eye conditions. During the activity, the health workers explain that the devices use different types of lenses. Some lenses make objects appear larger while others help correct blurred vision. The students observe that the magnifying glass enlarges small insects, spectacles help people with eye defects see clearly, and the camera lens focuses light to produce clear images. During the outreach activity, a student uses a magnifying glass of focal length 10 cm to observe a small insect since he was unable to clearly read words written on the classroom board that are close to him.

Tasks: Using your knowledge of Physics;

a) Explain the type of lens used in a magnifying glass and explain the properties of this type of lens.
b) Explain the type of lens used to correct short-sightedness (myopia) and how it helps a person see distant objects clearly.
c) If the insect is placed 8 cm from the lens, explain the nature of the image formed.
d) Explain why a magnifying glass must be held close to the object when observing very small objects.
e) Explain the type of lens used in a camera and explain how it forms clear images on the camera sensor.
f) Explain the similarities and differences between camera lens and the human eye lens images formation, and identify the type of lens used to correct this defect.
g) Using a simple explanation, describe how the lens corrects the vision problem.

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3.4 GENERAL WAVE PROPERTIES

Learning Outcomes

a) Understand that energy is transferred by waves, and these may be transverse or longitudinal (k,u)
b) Know and use the relationship between velocity, frequency, and wavelength (k, s)
c) Understand the propagation, properties, and uses of electromagnetic waves, and that white light is a mixture of frequencies but that light from a laser is a single frequency (k, u,v/a)

Introduction
Waves are disturbances or oscillations that transfer energy from one place to another without the transfer of matter. They occur in various forms and can be found in many aspects of daily life, including sound, light, water waves, and even seismic waves.
A wave is a disturbance that travels through a medium (such as air, water, or a solid material) or through a vacuum (as in the case of electromagnetic waves) by transferring energy.

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What is a wave?

A wave is a disturbance that travels through a medium, transferring energy from one location to another without the permanent displacement of particles. This phenomenon can be observed in various forms, such as sound waves in air, water waves on the surface of a lake, and light waves in a vacuum. Each type of wave exhibits unique characteristics, including wavelength, amplitude, and frequency, which define its behavior and properties.

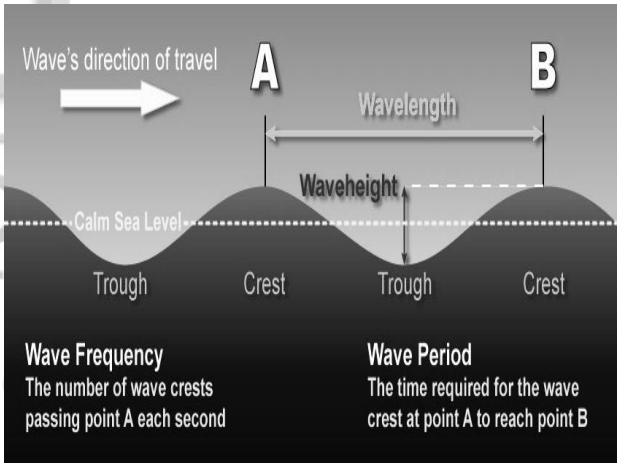
Waves can be classified into two main categories: mechanical and electromagnetic. Mechanical waves, like sound and water waves, require a medium to propagate, while electromagnetic waves, such as light, can travel through a vacuum.

The study of waves is essential in various fields, including physics, engineering, and acoustics, as they play a crucial role in communication, energy transfer, and many natural phenomena.

How Waves Transmit Energy

Waves transmit energy through various mechanisms. In mechanical waves, energy is transferred through the vibrations of particles within a medium, such as air or water. For instance, sound waves propagate by causing air molecules to oscillate, transferring energy from one location to another without moving the particles themselves.

Electromagnetic waves, transfer energy through oscillating electric and magnetic fields. This type of wave does not require a medium, allowing it to travel through the vacuum of space. The energy carried by these waves is directly related to their frequency and amplitude; higher frequency waves, such as gamma rays, carry more energy compared to lower frequency waves like radio waves.



The basic features of waves

Waves are characterized by several key features.

The **wavelength** (λ) is the distance between two successive peaks (maxima) or troughs (minima) in a wave.

The **amplitude** (A) represents the maximum height of the wave from its equilibrium position, indicating the energy carried by the wave; higher amplitudes correspond to greater energy.

Frequency, which refers to the number of wave cycles that pass a given point per unit time, typically measured in hertz (Hz).

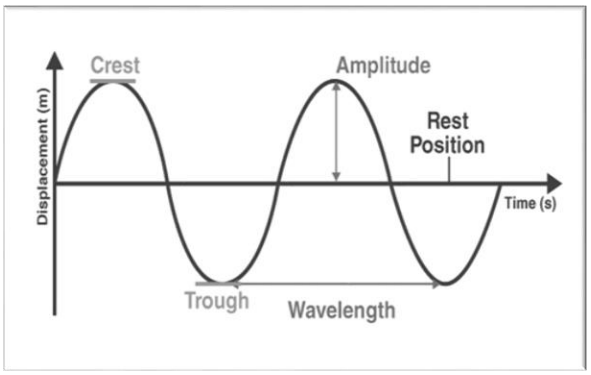
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Frequency, $f = \frac{\text{number of oscillations made(n)}}{\text{time taken (t)}}$

$f = \frac{n}{t}$.

Frequency is related to the period T by: $T = \frac{1}{f}$, *Where T is the time for one complete oscillation.*

The period, the inverse of frequency, is the time it takes for one complete wave cycle to pass.



Period of a wave expressed as;

$T = \frac{\text{time take to complete oscillation (t)}}{\text{number of oscillations (n)}}$.

$T = \frac{t(s)}{n}$

The speed of a wave is determined by the medium through which it travels, influencing how quickly energy is transferred.

Wave speed referring to the distance a wave travels over a specific period. It is typically measured in meters per second (m/s).

Speed $= \frac{\text{total distance}}{\text{time taken}}$. $V = \frac{n\lambda}{t} = \left[\frac{n}{t}\right]\lambda = f\lambda$, *since* $f = \frac{n}{t}$

Example

A vibrator produces waves which travel at a distance of 35.0cm in 2 seconds. If the distance between two successive wave crests is 5.0cm, determine the frequency of the vibrator.

Solution :

Speed of the wave is given by $v = d/t$, where d is distance moved and t is time taken.

$V = 35/2 = 17.5ms^{-1}$. Using $v = f\lambda$,$f = 17.5/5 = 3.5HZ$

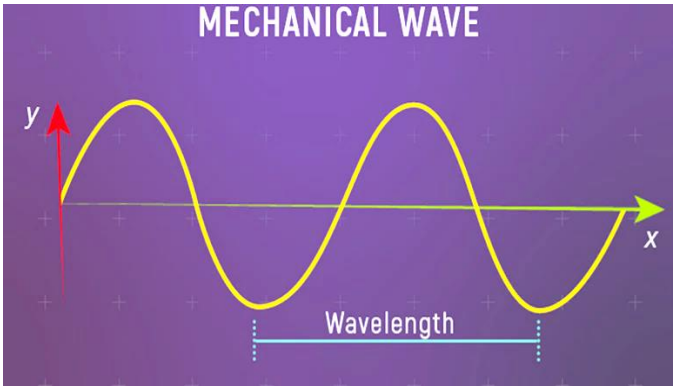
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ACTIVITY

1. A wave makes 10 cycles in 5 seconds. If the wavelength is 2cm, calculate its frequency, period and velocity.
2. A radio station produces waves of wavelength 2000cm and speed $3.0x10^8ms^{-1}$. Calculate frequency, periodic time and number of cycles completed in 5 hours.
3. James made 30 consecutive troughs. The total distance between the troughs is 50cm and the frequency of the wave is 18Hz. Determine the velocity of the waves made.

A progressive wave or travelling wave is a disturbance which carries energy from one place to another without transferring matter. There are two types, transverse and longitudinal waves.

Classification of waves



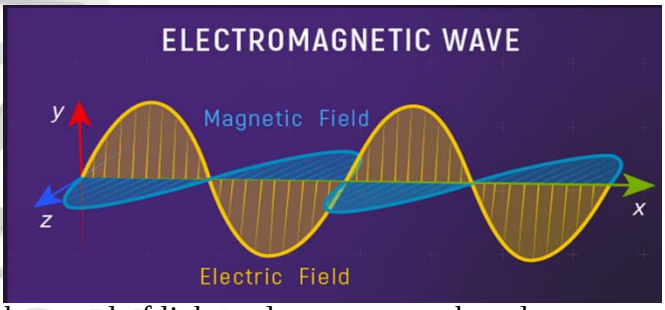
Several kinds of wave motion occur in physics.

Mechanical waves are produced by a disturbance, such as a vibrating object, in a material medium and are transmitted by the particles of the medium vibrating about a fixed position. Such waves can be seen or felt and include waves on a rope or spring, water waves.

There are two primary types of mechanical waves: **transverse and longitudinal.**

In transverse waves, the oscillation occurs perpendicular to the direction of wave propagation, as seen in waves on a string.

In contrast, longitudinal waves, like sound waves, involve oscillations parallel to the direction of travel, compressing and rarefying the medium. Mechanical waves play a crucial role in various natural phenomena, including seismic activity during earthquakes and the propagation of sound in musical instruments.

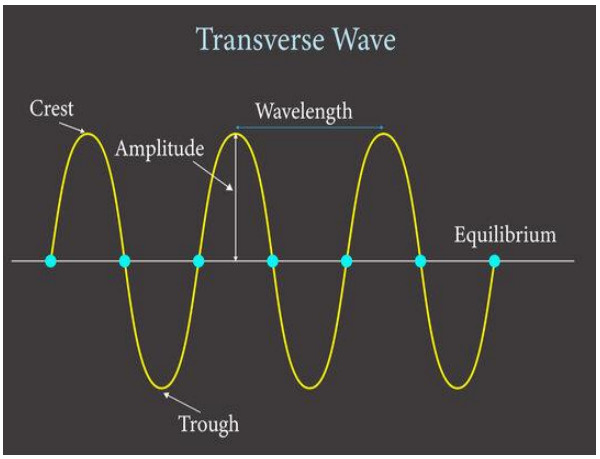


Electromagnetic waves (EM waves) are a fundamental aspect of physics, created by the interplay between electric and magnetic fields.

When charged particles accelerate, they generate changing electric fields, which in turn induce changing magnetic fields. This reciprocal relationship allows for the formation of EM waves that propagate through space. These waves travel at the speed of light and encompass a broad spectrum, including radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. Each type of EM wave has distinct properties and applications, from communication technologies using radio waves to medical imaging utilizing X-rays. The electromagnetic spectrum illustrates the range of these waves, highlighting their varying wavelengths and frequencies.

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Transverse Waves



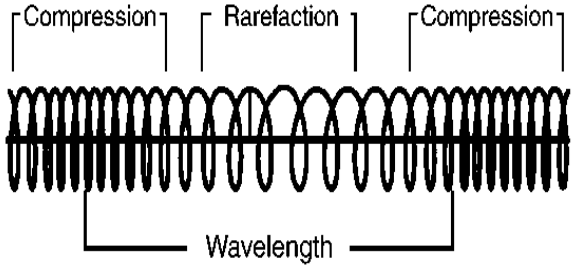
In a transverse wave, the direction of the disturbance is at right angles to the direction of propagation of the wave, which is the direction in which the wave travels. Energy is transmitted as particles move up and down while the wave moves horizontally. Example: Waves on the surface of water, vibrations in a string (guitar string), or light waves.

This means that as the wave travels, the particles of the medium move up and down or side to side, creating a distinct wave pattern. Common examples of transverse waves include surface ripples on water and waves on a string.

In contrast to longitudinal waves, where particle movement is parallel to the wave's direction, transverse waves exhibit unique properties. They can transfer

energy efficiently, making them essential in various applications, from musical instruments to electromagnetic radiation, such as light waves.

Longitudinal Waves

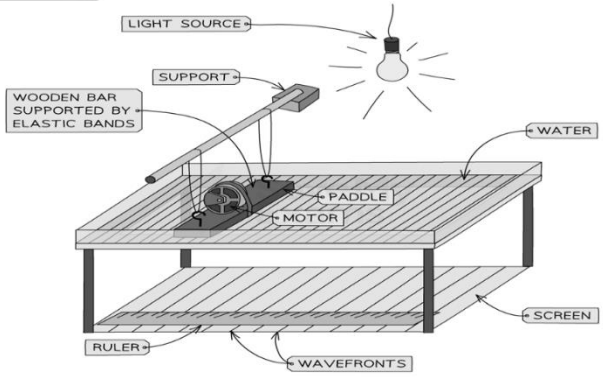


In a progressive longitudinal wave the particles of the transmitting medium vibrate back and forth along the same line as (parallel to) that in which the wave is travelling and not at right angles to it as in a transverse wave.

A longitudinal wave can be sent along a spring, stretched out on the bench and fixed at one end, if the free end is repeatedly pushed and pulled sharply. Common examples of longitudinal waves include sound waves, where compressions and rarefactions travel through air or other mediums. Examples Seismic P-waves (primary waves) and compressional waves in a spring or slinky.

In contrast to transverse waves, where particle displacement is perpendicular to wave motion, longitudinal waves are characterized by their ability to transmit energy through various materials. This property makes them essential in fields such as acoustics and seismology, where understanding wave behavior is crucial for applications like sound transmission and earthquake analysis.

In a sound wave, for example, vibrating air molecules collide with neighboring molecules, transferring energy as the wave moves through the medium. The energy is transmitted as the particles push and pull on each other, compressing and expanding as the wave travels. The higher the amplitude (compression and rarefaction intensity), the more energy the wave transmits.



The ripple tank

A ripple tank is a shallow glass container filled with water, designed to visually demonstrate the fundamental properties of waves. This tool allows students and researchers to observe various wave phenomena, including reflection, refraction, interference, and diffraction.

By using an overhead light source, the ripples created in the water can be illuminated, making it easier to study their behavior. The behaviour of water waves can be studied in a ripple tank. It consists of transparent tray containing water, having a light source above and a white screen below to receive the wave images.

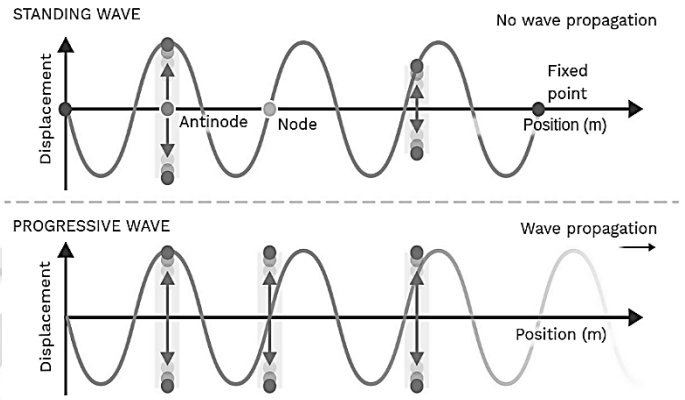
Pulses (i.e. short bursts) of ripples are obtained by dipping a finger in the water for circular ripples and a ruler for straight ripples. Continuous ripples are generated using an electric motor and a bar. The bar gives straight ripples if it just touches the water or circular ripples if it is raised and has a small ball fitted to it.

Continuous ripples are studied more easily if they are apparently stopped (‘frozen’) by viewing the screen through a disc with equally spaced slits, which can be spun by hand, i.e. a stroboscope. If the disc speed is such that the waves have advanced one wavelength each time a slit passes your eye, they appear at rest.

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PROGRESSIVE AND STATIONARY WAVES

Progressive waves are defined as waves that travel continuously through a medium in the same direction without any change in amplitude. These waves are essential for transferring energy from one location to another, while the medium itself remains largely undisturbed. The particles in the medium oscillate around their equilibrium positions, allowing energy to propagate without the actual movement of matter. There are two primary types of progressive waves: transverse and longitudinal. In transverse waves, the oscillation occurs perpendicular to the direction of wave travel, while in longitudinal waves, the oscillation occurs parallel to the direction of travel. Both types exhibit unique characteristics, such as wavelength, frequency, and speed, which are crucial for understanding wave behavior.



Stationary (Standing) Waves

Standing waves, also known as stationary waves, are unique waveforms that do not appear to travel through space.

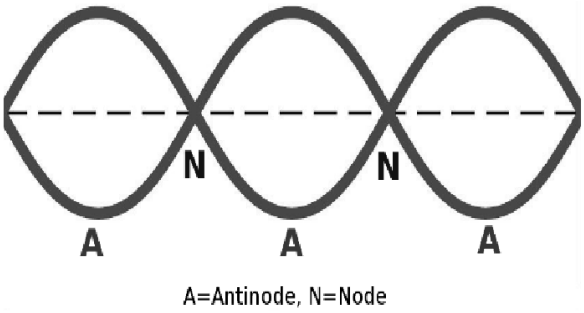
A standing wave is the superposition of two travelling waves of the same frequency and amplitude travelling in opposite directions. Unlike traveling waves, which propagate from one point to another, standing waves oscillate in place, creating fixed points known as nodes where there is no movement. This phenomenon occurs when two waves of equal frequency and amplitude travel in opposite directions and interfere with each other. Standing waves can be described as the superposition of these counter propagating waves. They can manifest in various forms, including longitudinal waves, like sound, and transverse waves, such as those seen in water.

Examples of standing waves is found in musical instruments, where strings vibrate to produce sound without the wave traveling along the string.

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Differences between standing and progressive waves

Standing and progressive waves exhibit distinct characteristics, primarily in their energy transfer and movement. Progressive waves, also known as traveling waves, propagate through a medium, transferring energy from one point to another.

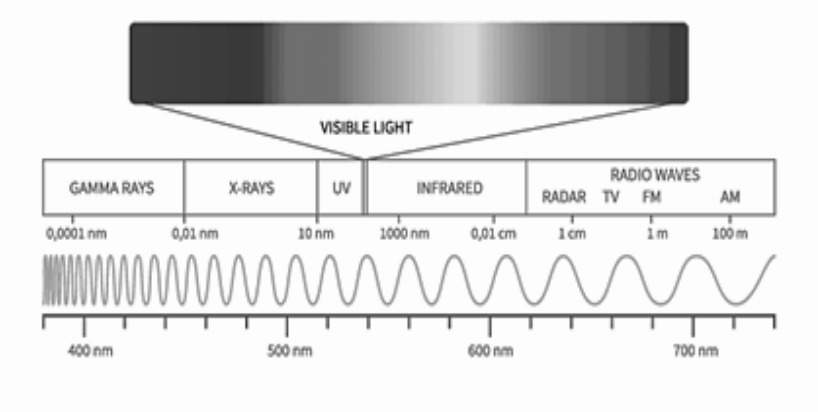


A=Antinode, N=Node

They are characterized by continuous motion, allowing them to carry energy across distances, such as ocean waves moving across the sea surface. In contrast, standing waves, or stationary waves, do not propagate. They form when two waves of the same frequency interfere, creating fixed points called nodes where there is no movement. The energy in standing waves oscillates between maximum and minimum values but does not result in a net transfer of energy.

ELECTROMAGNETIC WAVES

Electromagnetic Waves



Visible light is only a small part of the electromagnetic (EM) spectrum.

All electromagnetic waves travel at the same speed in a vacuum: approximately (3.0×10^8) m/s.

The electromagnetic spectrum is arranged according to frequency and wavelength:

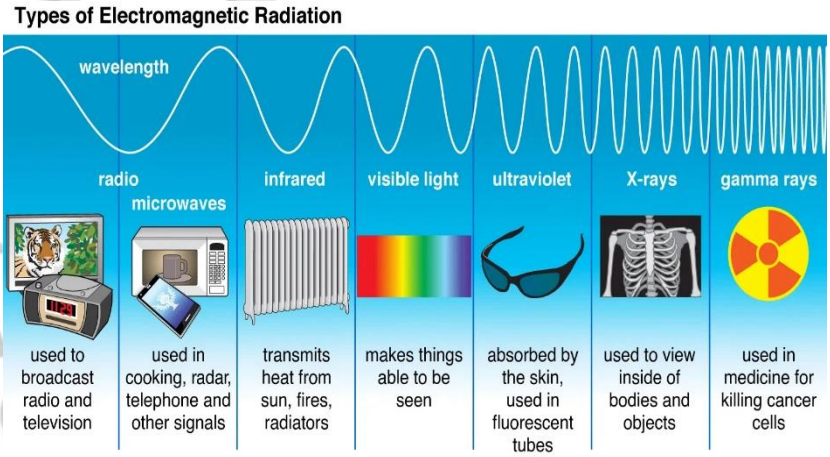
Radio waves → Microwaves → Infrared → Visible light → Ultraviolet → X-rays → Gamma rays.

Frequency increases from radio waves to gamma rays, while wavelength decreases.

The energy of an electromagnetic wave increases with frequency.

Electromagnetic waves are produced by accelerating electrically charged particles, which generate oscillating electric and magnetic fields.

Unlike mechanical waves, electromagnetic waves do not require a medium and can travel through the vacuum of space.



Different types of electromagnetic waves have different properties, energies and applications.

EM Wave	Major Uses
Radio waves	Radio/TV broadcasting, communication
Microwaves	Cooking, radar, satellite communication
Infrared	Heating, thermal imaging, remote controls
Visible light	Vision, lighting, photography
Ultraviolet	Sterilisation, detecting forged notes
X-rays	Medical imaging and diagnosis
Gamma rays	Cancer treatment and Sterilisation

Dangers

- ✓ Infrared: Can cause burns due to heating.
- ✓ Ultraviolet: Can cause sunburn and eye damage and increase the risk of skin damage.
- ✓ X-rays: Can cause damage to body cells with excessive exposure.
- ✓ Gamma rays: Highly penetrating and can cause serious cell and genetic damage. Therefore, high-frequency electromagnetic radiation generally poses greater biological risks.

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Emerging Technology

Advances in materials science have produced electromagnetic metamaterials. These materials can manipulate electromagnetic waves in unusual ways. They have potential applications in advanced communication, imaging, sensing and electromagnetic control.

As frequency increases, → energy increases → wavelength decreases → potential biological hazard generally increases.

Properties of electromagnetic waves.

- ✓ All types of electromagnetic radiation travel through a vacuum with the same high speed as light does. The speed of electromagnetic waves in a vacuum is 3×10^8m/s (300000km/s) and is approximately the same in air.
- ✓ They exhibit reflection, refraction and diffraction and have a transverse wave nature.
- ✓ They obey the wave equation, $v = f\lambda$, where v is the speed of light, f is the frequency of the waves and λ is the wavelength. Since v is constant in a particular medium, it follows that large f means small λ.
- ✓ They carry energy from one place to another and can be absorbed by matter to cause heating and other effects.

  The higher the frequency and the smaller the wavelength of the radiation, the greater is the energy carried, i.e. gamma rays are more 'energetic' than radio waves. Because of its electrical origin, its ability to travel in a vacuum (from the Sun to the Earth) and its wave-like properties, electromagnetic radiation is regarded as a progressive transverse wave. The wave is a combination of travelling electric and magnetic fields. The fields vary in value and are directed at right angles to each other and to the direction of travel of the wave

Applications of Electromagnetic Waves and Their Uses

1. Visible Light

- ✓ Visible light is the part of the electromagnetic spectrum detected by our eyes.
- ✓ Red: longest wavelength and lowest frequency.
- ✓ Violet: shortest wavelength and highest frequency.
- ✓ Light of a single frequency is called monochromatic light.
- ✓ Colour depends on frequency.
- ✓ Visible light is used for vision, illumination, photography, microscopes and telescopes.

2. Infrared Radiation: Detected mainly through its heating effect. Hot objects emit infrared radiation.

Uses include:

- ✓ Thermal imaging and night vision
- ✓ Remote controls
- ✓ Weather and land-use monitoring
- ✓ Intruder alarms
- ✓ Optical-fibre communication
- ✓ Drying paint and heat treatment
- ✓ High-intensity infrared can cause skin burns and eye damage.

3. Ultraviolet Radiation: Has a shorter wavelength than visible light. Causes tanning and helps produce vitamins in the skin.

Uses include:

- ✓ Sterilising water
- ✓ Security marking and detecting counterfeit notes
- ✓ Fluorescent lamps

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- ✓ Excessive exposure can cause skin cancer and eye damage.

4. Radio Waves: Have the longest wavelengths in the electromagnetic spectrum.
Used for:

- ✓ Radio and television broadcasting
- ✓ Long-distance communication
- ✓ RFID systems
- ✓ Radio astronomy
- ✓ Radar
- ✓ Long, medium and short radio waves can diffract around obstacles and may be reflected by the ionosphere.
- ✓ VHF and UHF require a more direct path and are widely used for local radio and television.

5. Microwaves: Have wavelengths of approximately a few centimetres.
Used for:

- ✓ Mobile phones
- ✓ Wi-Fi and wireless communication
- ✓ Satellite communication
- ✓ Radar
- ✓ Police speed detection
- ✓ Microwave ovens
- ✓ In microwave ovens, they cause water molecules in food to vibrate, producing heat.
- ✓ High exposure can heat and damage living cells.

6. X-rays: Produced when a metal target suddenly stops high-speed electrons. Have shorter wavelengths than ultraviolet radiation. Can penetrate soft materials but are absorbed more by bones, teeth and metals.
Uses:

- ✓ Medical and dental imaging
- ✓ Airport luggage scanning
- ✓ Industrial inspection of welded joints
- ✓ Excessive exposure can damage cells and cause cancer, so equipment is shielded with lead.

7. Gamma Rays: More penetrating and dangerous than X-rays.
Uses:

- ✓ Diagnosing and treating cancer
- ✓ Killing bacteria in food and surgical instruments
- ✓ Detecting flaws in metals
- ✓ High exposure can cause cell damage, mutations and cancer.

8. Electromagnetic Radiation Hazards

Radiation	**Main danger**
Microwaves	Heating and damage to cells
Infrared	Burns and eye damage
Ultraviolet	Skin cancer and eye damage
X-rays	Cell mutation and cancer
Gamma rays	Cell damage, mutations and cancer

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9. Communication Systems

- ✓ Electromagnetic waves are widely used to transmit information.
- ✓ Microwaves: mobile phones, Wi-Fi and satellite communication.
- ✓ Radio waves: broadcasting and short-range communication such as Bluetooth.
- ✓ Visible light and infrared: high-speed communication through optical fibres.
- ✓ Digital signals use discrete values, commonly high and low, while analogue signals vary continuously.
- ✓ Digital signals are generally advantageous because they can be transmitted faster, over longer distances, and with less effect from noise.

The effects of electromagnetic waves depend on their frequency, wavelength and intensity.

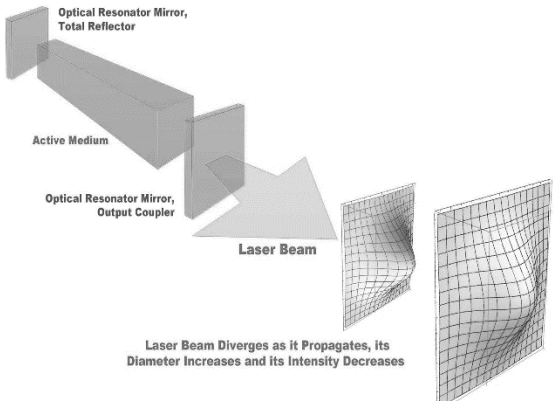
EM radiation	Main effects
Radio waves	Used to transmit information over long distances; generally have relatively low energy.
Microwaves	Cause heating by making water molecules vibrate. High exposure can heat and damage body cells.
Infrared (IR)	Produces a heating effect. High intensity can cause skin burns and eye damage.
Visible light	Stimulates the eyes, allowing us to see. It also produces heating when absorbed.
Ultraviolet (UV)	Causes sun tanning and helps produce vitamins in the skin. Excessive exposure can cause skin cancer and eye damage.
X-rays	Can penetrate body tissues and are used for imaging. Excessive exposure can cause cell damage, mutations and cancer.
Gamma rays	Highly penetrating and can damage or kill cells. Used to treat cancer and sterilise equipment and food. Excessive exposure can cause mutations and cancer.

As the frequency increases, the energy of EM radiation increases:
Radio → Microwaves → Infrared → Visible → Ultraviolet → X-rays → Gamma
Therefore, the higher-frequency radiations, particularly UV, X-rays and gamma rays, have greater potential to cause biological damage.

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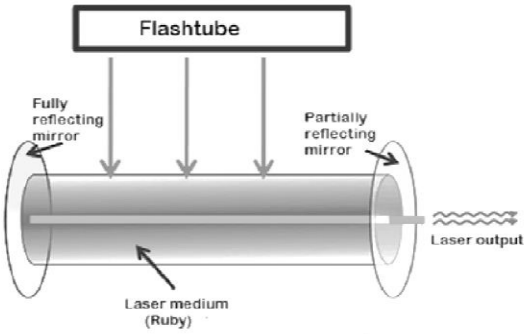
LASER BEAM

- ✓ The term "***LASER***" stands for **Light Amplification by Stimulated Emission of Radiation.**
- ✓ Light particles (**photons**) are excited with current causing them to emit energy in the form of light.
- ✓ This light forms the laser beam. Lasers are remarkable devices that emit coherent light through a process known as stimulated emission.
- ✓ This phenomenon occurs when excited electrons transition from a higher energy state to a lower one, releasing energy in the form of photons.
- ✓ The optical oscillator within a laser amplifies this light, maintaining its coherence allowing lasers to be used in various applications, from medical procedures to telecommunications.



- ✓ The ability to focus laser beams into narrow, intense streams of light makes them invaluable in cutting, welding, and even in scientific research. Under specific conditions, laser beams can cast shadows, behaving like opaque objects.

A laser beam is a focused, coherent stream of light produced by a device called a laser (Light Amplification by Stimulated Emission of Radiation).



Characteristics of Laser beam

- ✓ **Coherence:** Unlike regular light, which consists of many different wavelengths, a laser beam is made up of light waves that are synchronized. This means all the light waves have the same wavelength (color) and move in step with each other, resulting in a highly focused and intense beam.
- ✓ **Monochromatic:** Laser light is usually monochromatic, meaning it is made up of one single wavelength or color. This is different from white light, which is made up of many different wavelengths.
- ✓ **Directionality:** Laser beams are directional. The light emitted from a laser does not spread out much, allowing it to travel long distances with minimal dispersion. This is why laser beams appear as a narrow, straight line.
- ✓ **High Intensity:** Because the light is focused and not dispersed, a laser beam can carry a lot of energy in a small area, making it extremely intense and useful in applications requiring precision.
- ✓ **How Laser Beams are produced**
- ✓ **Stimulated Emission:** A material inside the laser (such as a gas, crystal, or semiconductor) is excited by an external energy source. When the atoms in the material return to a lower energy state, they emit photons. These photons stimulate other atoms to emit more photons of the same wavelength and phase, creating an amplified, coherent beam of light.
- ✓ **Optical Cavity**: The light bounces between two mirrors inside the laser, further amplifying the beam. One of the mirrors is partially transparent, allowing the laser beam to escape and be used.

Applications:

Laser beams are used across major global industries because of their high precision, intense energy density, and monochromatic light. Their key applications span medicine, manufacturing, telecommunications, consumer electronics, and defense.

1) Medicine and Healthcare

- ✓ Vision Correction: Reshaping the cornea during LASIK surgeries.
- ✓ Precision Surgery: Vaporizing tumors and cauterizing blood vessels.
- ✓ Dermatology: Performing tattoo removal and skin resurfacing.
- ✓ Urology: Breaking down painful kidney stones cleanly.

2) Manufacturing and Materials Processing

- ✓ Laser Cutting: Slicing through metals and dense textiles.
- ✓ Laser Welding: Joining dissimilar metals with minimal distortion.
- ✓ Engraving & Marking: Etching traceable serial numbers onto parts.
- ✓ Micro drilling: Piercing microscopic holes in aerospace components.

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3) Communications and Data Technology

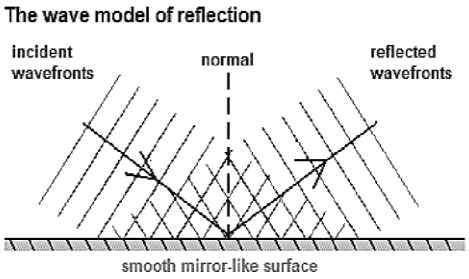
- ✓ Fiber Optics: Transmitting internet data over vast distances.
- ✓ Optical Storage: Reading data from CDs and Blu-ray discs.
- ✓ Barcode Scanning: Decoding product data instantly at retail checkouts.
- ✓ Laser Printing: Transferring high-resolution text onto paper sheets.

4) Military and Defense

- ✓ Target Designation: Guiding precision missiles directly to targets.
- ✓ Countermeasures: Intercepting and disabling incoming enemy drones.
- ✓ Range Finding: Calculating exact distances to distant objects.

5) Scientific Research and Measurement

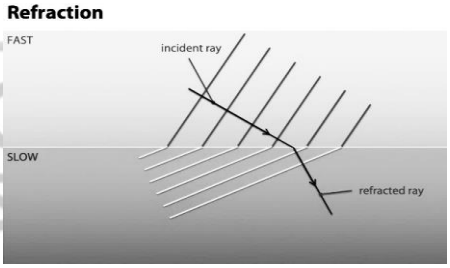
- ✓ Holography: Creating realistic 3D images without lenses.
- ✓ Metrology: Surveying land and checking construction alignment.
- ✓ Spectroscopy: Analyzing atomic structures of complex biological samples.



Waves behaviour

Wave behaviors describe how waves interact with surfaces, boundaries, and other waves through processes like reflection, refraction, diffraction, and interference.

Reflection occurs when a wave encounters a boundary and changes direction, bouncing back into the original medium. This phenomenon is crucial in various applications, from acoustics to optics, as it determines how sound and light behaves when they meet surfaces.

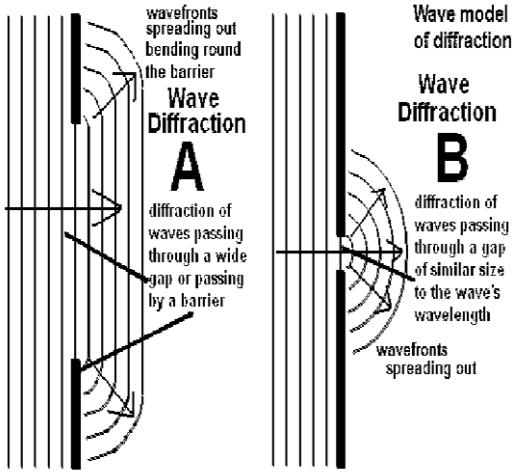


Refraction, involves a change in direction as waves pass from one medium to another, influenced by the media's properties. This bending of waves is essential in understanding phenomena such as the bending of light in lenses and the behavior of sound in different environments.

Diffraction refers to the spreading of waves when they encounter obstacles or openings. These three processes; reflection, refraction, and diffraction play a vital role in wave behavior, impacting technologies ranging from telecommunications to medical imaging.

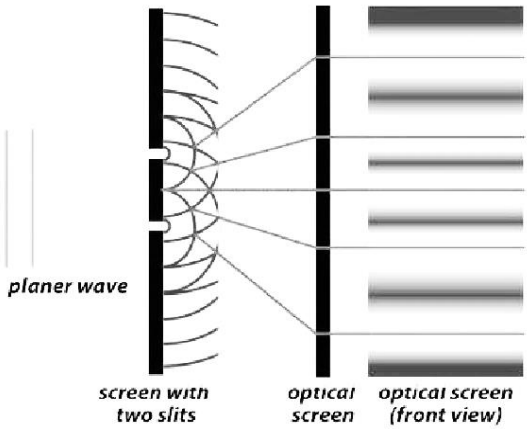
Sound waves are more diffracted than light waves because the wave length is greater than that of light. Therefore, sound can be heard in hidden corners. When waves undergo diffraction, wavelength and velocity remain constant.

Diffraction through a narrow gap straight water: If the gap is narrow and the wave fronts curve around the edges of the gap producing a circular wave front and spread out in all directions.



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Diffraction due to an edge or wide gap: If the gap is wide (10cm) compared with the wavelength and the wave front remains straight, except at the edges of the gap where some curvature around the edges occurs. The spreading of waves at the edges of obstacles is called diffraction; when designing harbours, engineers use models like that to study it.

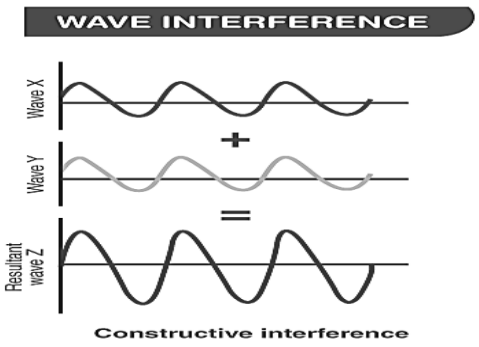


INTERFERENCE OF WAVES: This is the superposition of two identical waves travelling in the same direction to form a single wave with a larger amplitude or smaller amplitude. The two waves should be in phase (matching).

Wave interference occurs when two or more waves meet while traveling through the same medium. This interaction can lead to two primary outcomes: constructive interference, where the waves combine to produce a wave of greater amplitude, and destructive interference, where they cancel each other out, resulting in a wave of lower amplitude.

For interference to occur, at least two coherent waves are required. When these waves overlap, their amplitudes add or subtract, creating a new resultant wave.

CONSTRUCTIVE INTERFERENCE

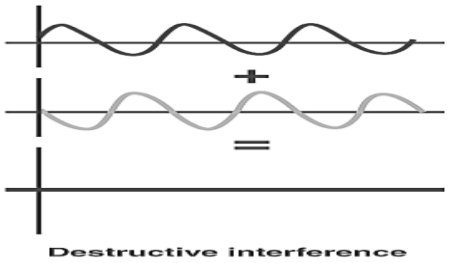


Constructive interference of waves occurs when two or more waves overlap in such a way that their crests and troughs align; resulting in a wave of greater amplitude (The resulting amplitude is the sum of the individual amplitudes). This phenomenon is often described as the waves being "in-phase," meaning they share the same phase relationship.

When the peaks of the waves coincide, the energy is effectively combined, leading to a stronger resultant wave. This type of interference can enhance signals in communication systems or amplify sound in acoustics. For instance, in musical instruments, constructive interference can create richer tones when sound waves from different sources combine.

DESTRUCTIVE INTERFERENCE

Destructive interference of waves occurs when two waves overlap in such a way that they cancel each other out, resulting in a reduced amplitude or even complete cancellation. This phenomenon is most evident when the crest of one wave aligns with the trough of another, leading to a net displacement that is less than either wave alone. In essence, the waves are said to be 180 degrees out of phase, which is a critical condition for achieving destructive interference. This type of interference helps in acoustics and optics. For instance, noise-canceling headphones utilize destructive interference to reduce unwanted ambient sounds by generating sound waves that are out of phase with the noise.



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VIBRATION IN STRINGS

When a string is plucked, it vibrates at multiple frequencies, with the lowest frequency known as the fundamental frequency. This phenomenon occurs because standing waves form on the string, which only happen when a whole number of wavelengths fit between the fixed ends. The tension, mass, and length of the string significantly influence its vibration characteristics. Thicker and heavier strings vibrate more slowly, resulting in lower pitches, while tighter strings produce higher frequencies.

Vibration in strings

Wave's travels along a horizontal rope fixed at one end, and the other end is free to move. Sound wave is generated from a fixed string that is allowed to move at the other end.

The vibrating wire produces a sound of the lowest possible note whose frequency is called **fundamental frequency**. The mode of vibration is giving rise to the fundamental mode of vibration.

The distance between the two consecutive mode is $\frac{\lambda}{2}$ and this is equal to the

Length of the string L. **L = $\frac{\lambda}{2}$ or λ= 2L**

For any wave we have that $v = f\lambda$, where v is the velocity, f, the frequency, and λ the wavelength.

Vibrations produced in closed pipes.

In a closed pipe, $f_0 = \frac{v}{4L}$, only odd numbers of harmonics are present as overtones accompanying the fundamental note. The possible harmonics are

fo , 3fo , 5fo , 7fo etc., where f_0 = fundamental frequency.

Vibrations produced in open pipes are given by $f_0 = \frac{v}{2L}$

In an open pipe the harmonics present are:

2fo, 3fo, 4fo,5fo etc., that is, both odd and even harmonics are present as overtones.

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Example:

The shortest length of the air column in a resonance tube closed at one end, which resonates to a frequency of 560Hz, is found to be 20cm. What is the wavelength of this sound in air?

Wavelength of the sound

For a resonance tube closed at one end, the shortest resonating length is the first resonance: L = λ/4. Given: L = 20 cm = 0.20 m

Therefore: λ = 4L = 4(0.20), **λ = 0.80 m**

Determine the frequency of the first overtone of a closed pipe of length 30cm, if the end correction is 0.8cm and the velocity of sound is 340m/s.

First overtone of a closed pipe

For a pipe closed at one end, the first overtone is the third harmonic: $f_3 = \frac{3v}{4L_e}$

Given: Length of pipe, L = 30 cm = 0.30 m, End correction = 0.8 cm = 0.008 m, Velocity of sound, v = 340 m/s

Effective length: L_e = 0.30 + 0.008 = 0.308 m

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Hence: $f^3 = \frac{3x340}{4x0.308} = \frac{1020}{1.232}$, **$f_3 \approx$ 828 Hz**

Note: A closed pipe supports only odd harmonics. Therefore, the first overtone is the third harmonic.

Chapter Assessment

During a science exhibition at a secondary school in Kampala, students demonstrate different types of waves. One group stretches a long rope between two poles and shakes one end up and down to show how waves move along the rope. Another group uses a speaker connected to a signal generator to produce sound waves in air. The sound produced by the speaker has a frequency of **500 Hz** and travels through air at a velocity of **340 m/s**. At the same time, a physics teacher demonstrates how electromagnetic waves are used in communication by showing a mobile phone receiving signals and a laser pointer producing a narrow beam of red light during the presentation. During the demonstration, the laser pointer emits light of a single frequency while ordinary white light contains many frequencies. The teacher explains that waves carry energy from one place to another and that the speed of a wave depends on its frequency and wavelength.

Tasks: Use the knowledge of physics:

a) With examples, differentiate between **transverse wave** and **longitudinal wave**, and explain how each transfers energy.

b) Determine the **wavelength** of the sound wave.

c) Explain how **electromagnetic waves** from a mobile phone can transmit information over long distances without the need for a material medium.

d) Explain the **difference between lasers light and white light**.

e) State **two practical uses of electromagnetic waves** in everyday life that are similar to the examples demonstrated during the exhibition.

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3.5 SOUND WAVES

Learning Outcomes

Understand that sound is an example of a wave form that requires a medium through which to travel, and determine its velocity in air by the echo method (k, s)

Introduction

Sound waves are produced by vibrating sources. Whether from the vibrations in your vocal cords, a violin string or a loudspeaker, all the speech, music and noise we hear around us are transmitted by sound waves. Like waves on a spring, sound waves are longitudinal waves and they require a medium in which to travel. Reflected sound waves, used in sonar depth sounding at sea, can locate the position of a shoal of fish. Ultrasound, with frequencies above the range of human hearing (around 20 kHz), is used for material testing and medical imaging. An ultrasonic cleaner could help remove the dirt.

What are sound waves?

Sound waves are patterns of disturbance caused by the movement of energy through various media, such as air, water, or solids.

These waves consist of alternating compressions and rarefactions, which are regions of high and low pressure, respectively. As sound waves travel, they transfer energy from one location to another, allowing us to perceive sounds.

Sound waves are classified as longitudinal waves, meaning the particle displacement is parallel to the direction of wave propagation. This characteristic allows sound to travel efficiently through different materials, with speed varying based on the medium's density and elasticity.

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Sound waves are a type of mechanical wave that propagate through a medium (such as air, water, or solids) due to the vibration of particles within the medium. They are longitudinal in nature, meaning that the oscillations of the particles occur parallel to the direction of the wave's propagation.

How Sound is produced as a Form of Energy

Sound energy is a form of energy produced by the vibrations of objects. When an object vibrates, it creates pressure waves in the surrounding medium, such as air, water, or solids.
These waves travel through the medium, allowing sound to be heard when they reach our ears. The energy from these vibrations is transferred in waves, which is why sound can travel over distances. The process begins when a force, such as a plucked guitar string or a vibrating speaker cone, causes an object to vibrate. This mechanical energy is then converted into sound energy, which propagates as longitudinal waves. The frequency of these waves determines the pitch of the sound, while the amplitude relates to its loudness.
It's used in communication, entertainment, and even in technologies like sonar and ultrasound.

Production of Sound

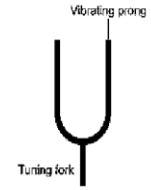
Sound is produced by the vibration of matter. Various actions, such as plucking, scratching, blowing, hitting, rubbing, and shaking objects, lead to these vibrations. For instance, when a guitar string is plucked, it vibrates, creating sound waves that travel through the air, allowing us to hear music. Blowing into a flute causes air to vibrate within the instrument, producing melodious sounds. The science behind sound production is rooted in the movement of air particles. When an object vibrates, it disturbs the surrounding air, causing particles to collide and transmit energy in the form of sound waves.



When we hit the drum, membrane of drum vibrates producing sound.



When we play a guitar, the string on it makes to and fro motion and produces sound.

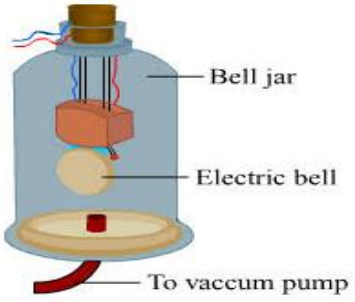


Sound produced by vibrating prong of tuning fork.

This principle is essential in understanding how we perceive sound in our environment. In summary, sound is an energy form generated by vibrations, and its production can be observed in everyday activities, from playing musical instruments to the simple act of speaking.

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TRANSMISSION OF SOUND



Sound transmission is the process by which sound waves propagate through various mediums, such as air, liquids, and solids.
Sound transmission refers to how sound travels through building elements like walls and floors. Animals also utilize sound transmission for communication. Elephants can send low-frequency sound waves that travel several kilometers, enabling them to communicate over long distances.
When an object vibrates, it creates compressions and rarefactions in the air. Molecules in the air collide with adjacent molecules, transferring energy. The compressions (areas of high pressure) move outward as sound waves, while the rarefactions (areas of low pressure) follow. This process continues as molecules pass kinetic energy from one to another.

Experiment to Show That Sound Cannot Pass Through a Vacuum

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Objective:
To demonstrate that sound waves require a medium (air, water, or solids) to travel and cannot propagate through a vacuum.
Apparatus:
Bell jar (glass jar with a vacuum pump), Electric bell or buzzer (small, battery-operated), Vacuum pump (used to remove air from the jar), Power supply or batteries for the bell, and Glass plate (to seal the bell jar)
Procedure:

a) The setup involves placing a ringing electric bell inside an airtight bell jar connected to a vacuum pump. Turn on the power supply to the electric bell, the bell rings, sound waves travel through the air, allowing us to hear the loud sound.
b) However, as the vacuum pump removes the air from the jar, the sound diminishes until it becomes inaudible (no sound is heard). Though the hammer is seen hitting the gong, even though the sound will not reach your ears.
c) Gradually allow air back into the bell jar through the vacuum pump. As the air re-enters, the loud sound of the bell will become audible again.

Explanation:

d) Before removing the air: Sound waves travel through the air in the bell jar. These waves are longitudinal waves that require a medium (air in this case) to propagate. Hence, the sound of the bell can be heard.
e) After removing the air: As the air is removed from the bell jar by the vacuum pump, the medium through which the sound waves travel is reduced. In a complete vacuum, there are no air particles to transmit the sound vibrations, so the sound cannot travel, and the bell becomes inaudible.
f) When air is reintroduced: Once the air is let back into the jar, the medium for sound transmission is restored, and the sound waves can once again travel to your ears, making the bell audible.
g) This experiment demonstrates that sound cannot travel through a vacuum because there is no medium (such as air) for the sound waves to propagate through. Sound requires a medium like air, water, or solids to travel, unlike light, which can travel through a vacuum.

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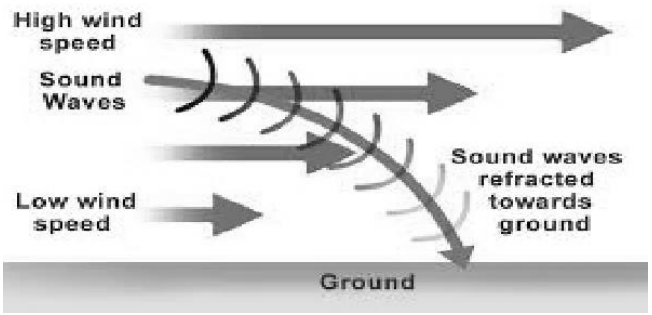
Transmission of sound through air, water, and solids

Sound is transmitted through waves that travel across different mediums: gases, liquids, and solids.
In air, sound waves travel relatively slowly due to the greater distance between molecules. This allows for the propagation of sound, but at a limited speed of approximately 343 meters per second. Sound travels faster in water, reaching speeds of about 1,480 meters per second, as the molecules are closer together, facilitating quicker energy transfer. When sound waves move through solids, they travel even faster, often exceeding 5,000 meters per second. This is because the tightly bonded molecules in solids allow for more efficient transmission of sound energy. The differences in speed across these mediums highlight the importance of molecular structure in sound propagation.

An experiment to determine the transmission of sound through air, water, and solids

By utilizing simple materials like tuning forks, students can observe how sound waves travel differently through various mediums.

A tuning fork is struck and held near the surface of water, the vibrations can be felt more intensely than in air, demonstrating that sound travels faster in water.



To measure sound speed, students can conduct a straightforward experiment using two blocks of wood and a stopwatch.

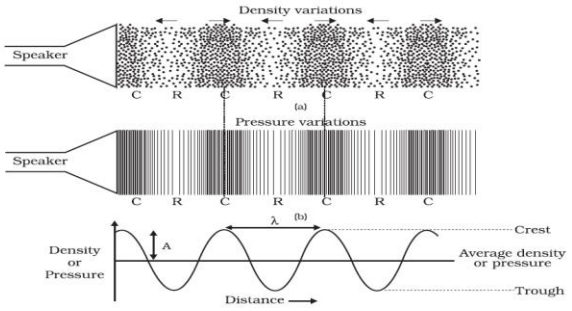
By striking the blocks together, and recording the time the sounds travel over a known distance, then calculating the speed of sound in air. This experiment highlights that sound travels approximately four times faster in water and about thirteen times faster in solids like wood compared to air. Through these experiments, students gain a deeper understanding of sound wave behavior and the factors influencing sound transmission across different mediums.

Sound propagation and density

Sound propagation is significantly influenced by the density of the medium through which it travels. Denser materials can transmit sound waves more effectively, but this relationship is nuanced. For instance, while sound travels faster in liquids than in gases, denser solids may exhibit slower sound transmission due to their molecular structure. Larger molecules in a dense medium require more energy to transmit sound, resulting in a slower speed of sound. The interplay between density and pressure also plays a crucial role in sound propagation. In gases, higher density corresponds to higher pressure, which can enhance sound transmission. However, the absolute pressure in a sound wave remains relatively constant, indicating that other factors, such as temperature, also affect sound speed.

Compression and rarefaction.

A sound wave, produced for example by a loudspeaker, consists of a train of compressions C (where the air molecules are closer together) and rarefactions R (where the air molecules are further apart) in the air. The speaker has a cone which is made to vibrate in and out by an electric current. When the cone moves out, the air in front is compressed; when it moves in, the air is rarefied (becomes 'thinner'). The wave progresses through the air but the air as a whole does not move. The air particles (molecules) vibrate backwards and forwards a little as the wave passes. When the wave enters your ear the compressions and rarefactions cause small, rapid pressure changes on the eardrum and you experience the sensation of sound. The number of compressions produced per second is the frequency f of the sound wave (and equals the frequency of the vibrating loudspeaker cone); the distance between successive compressions is the wavelength λ. As with transverse waves, the speed $v = f\lambda$



Sound propagation and pressure

Sound propagation is intricately linked to air pressure, although the speed of sound remains relatively constant regardless of pressure changes. This phenomenon occurs because sound waves are essentially pressure variations traveling through a medium, such as air. While the speed of sound is primarily influenced by temperature, the intensity of sound is more closely related to the density of the air, which is

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affected by pressure. In lower pressure environments, sound waves can travel further due to reduced atmospheric attenuation. This means that in high-pressure conditions sound may not propagate as effectively, as the increased density can dampen the sound intensity. In low-pressure scenarios, sound waves experience less resistance, allowing them to travel greater distances.

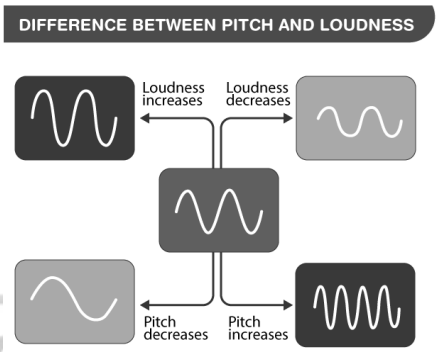
Sound propagation and air pressure is crucial in areas like acoustics, meteorology, and even animal communication, where sound plays a vital role in navigation and interaction.

Sound propagation can be affected by pressure, but the speed of sound in air is primarily determined by temperature. Sound is a vibration that travels through particles in a medium, such as air, as a wave. This wave is created by a series of compressions and rarefactions in the medium. Compression is a region of high pressure, and rarefaction is a region of low pressure.

In an ideal gas, pressure and density both contribute equally to the velocity of sound, so the effect of pressure cancels itself out. However, pressure can affect sound in other ways, such as harmonic distortion and shock waves. High amplitude sound waves can distort as they travel through a medium, such as water. This is because sound speed is a function of the pressure associated with the wave.

Vibrations and Pitch

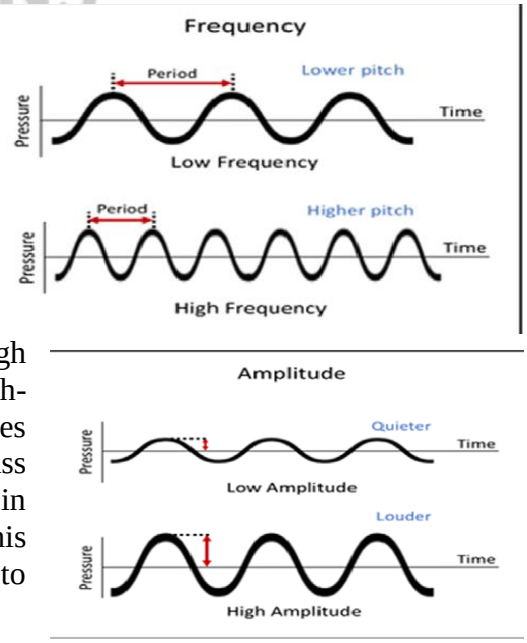
Frequency of Vibration: The frequency at which an object vibrates directly influences the pitch of the sound produced. Faster vibrations produce higher frequencies and thus higher pitches. Example: A shorter guitar string vibrates faster than a longer one, producing a higher pitch. This is why instruments with shorter strings (like violins) produce higher notes than those with longer strings (like cellos).



Loudness and Pitch

Pitch is determined by the frequency of sound waves; higher frequencies produce higher pitches, while lower frequencies yield lower pitches. For instance, a thin string vibrates faster, creating a higher pitch compared to a thicker string, which vibrates more slowly.

On the other hand, loudness is related to the amplitude of sound waves. Greater amplitude results in louder sounds, while smaller amplitude produces softer sounds. This relationship means that two sounds can have the same pitch but differ in loudness, affecting how we perceive them in various environments.



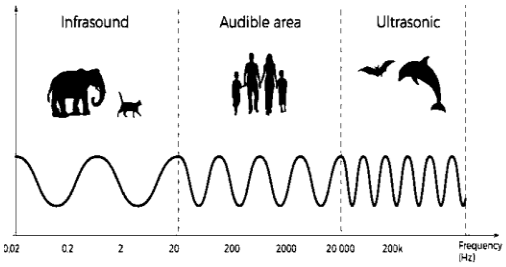
Frequency and pitch of sound waves

Frequency, measured in hertz (Hz), refers to the number of vibrations or cycles a sound wave completes in one second. A high frequency indicates a rapid vibration, which we perceive as a high-pitched sound, such as a whistle. Low-frequency sound waves vibrate more slowly, resulting in lower-pitched sounds, like a bass drum. This connection between frequency and pitch is crucial in various fields, from music to acoustics. Musicians rely on this principle to create harmonious sounds, while scientists study it to understand how sound interacts with different environments.

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For instance, the pitch of a sound can change based on the medium through which it travels, affecting how we perceive it.

Types of sound waves



Sound waves are vibrations that travel through various mediums, characterized by their frequency, amplitude, and wavelength. They can be classified into three main types: audible, infrasonic, and ultrasonic waves.

Humans hear only sounds with frequencies from about 20Hz to 20000Hz. These are the limits of audibility in a healthy human ear; the upper limit decreases with age.

Audible sound waves fall within the frequency range of 20 Hz to 20 kHz, which is detectable by the human ear. Infrasonic waves (subsonic), have frequencies below 20 Hz and are often associated with natural phenomena like earthquakes.

Ultrasonic waves exceed 20 kHz and are utilized in various applications, including medical imaging and cleaning. In terms of wave types, sound waves are primarily longitudinal waves, where particle oscillations occur parallel to the direction of wave travel. This characteristic allows sound to propagate efficiently through gases, liquids, and solids. These types of sound waves are crucial in fields such as acoustics, where they are applied in designing soundproof rooms, musical instruments, and audio technology.

Musical notes

Irregular vibrations, such as those of motor engines, cause noise; regular vibrations, such as occur in the instruments of a brass band, produce musical notes, which have three properties – pitch, loudness and quality. Musical instruments produce regular sound vibrations.

Pitch:

The pitch of a note depends on the frequency of the sound wave reaching the ear, i.e. on the frequency of the source of sound. A high-pitched note has a high frequency and a short wavelength. The frequency of middle C is 256 vibrations per second or 256Hz and that of upper C is 512Hz. Notes are an octave apart if the frequency of one is twice that of the other. Pitch is like colour in light; both depend on the frequency. Notes of known frequency can be produced in the laboratory by a signal generator supplying alternating electric current (a.c.) to a loudspeaker. The cone of the speaker vibrates at the frequency of the a.c. which can be varied and read off a scale on the generator. A set of tuning forks with frequencies marked on them can also be used. A tuning fork has two steel prongs which vibrate when struck; the prongs move in and out together, generating compressions and rarefactions.

Loudness.

A note becomes louder when more sound energy enters our ears per second than before. This will happen when the source is vibrating with a larger amplitude. If a violin string is bowed more strongly, its amplitude of vibration increases, as does that of the resulting sound wave, and the note heard is louder because more energy has been used to produce it.

Quality

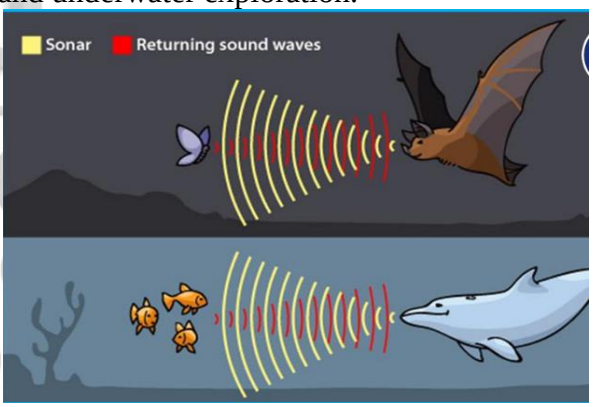
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The same note on different instruments sounds different; we say the notes differ in quality or timbre. The difference arises because no instrument (except a tuning fork and a signal generator) emits a 'pure' note, i.e. of one frequency. Notes consist of a main or fundamental frequency mixed with others, called overtones, which are usually weaker and have frequencies that are exact multiples of the fundamental. The number and strength of the overtones decides the quality of a note. A violin has more and stronger higher overtones than a piano. Overtones of 256Hz (middle C) are 512Hz, 768Hz and so on. The waveform of a note played near a microphone connected to a cathode ray oscilloscope (CRO) can be displayed on the CRO screen. Their different shapes show that while they have the same fundamental frequency, their quality differs. The 'pure' note of a tuning fork has a sine waveform and is the simplest kind of sound wave. Note that although the waveform on the CRO screen is transverse, it represents a longitudinal sound wave.

Example: The frequency of middle C is 256Hz. If the speed of sound in air is 340m/s, calculate the wavelength in air. From the equation $v = f\lambda$; gives$\lambda = \frac{v}{f}$. Taking v = 340m/s, then $\lambda = \frac{340\text{m}}{256Hz} = 1.3\text{m}$

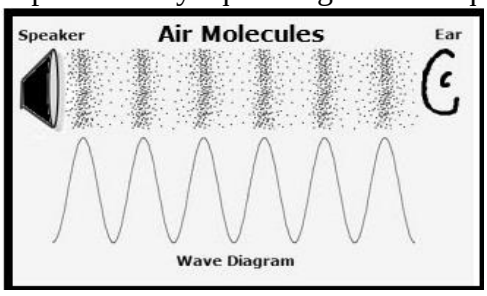
Applications of ultrasonic sound waves

Ultrasonic sound waves have a wide range of applications across various fields, showcasing their versatility and effectiveness. In medicine, ultrasound is primarily known for its diagnostic capabilities, particularly in prenatal care, where it provides crucial images of developing fetuses. It is used to treat soft tissue injuries and alleviate pain associated with conditions like bursitis and collagen diseases. Beyond healthcare, ultrasonic waves play a vital role in navigation and underwater exploration. By emitting sound waves and measuring their return time, these waves help map underwater terrains and locate objects. Furthermore, ultrasonic technology is employed in industrial settings for nondestructive testing, ensuring the integrity of materials without causing damage. Ultrasound also finds applications in cleaning, mixing, and communication, demonstrating its broad utility.



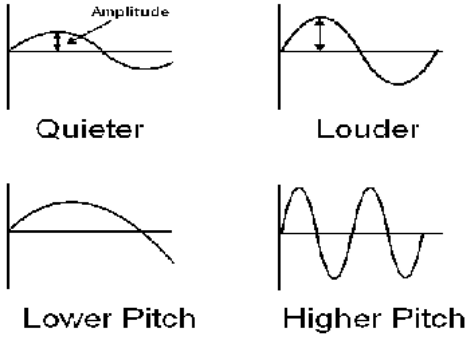
Loudness of sound

Loudness is the subjective perception of sound pressure, distinguishing how loud or soft a sound appears to a listener. While closely related to sound intensity, loudness is not synonymous with it. Instead, **it reflects the auditory sensation produced by sound waves**, influenced by their **amplitude**. The *greater the amplitude*, the *louder the sound perceived* by the human ear. For instance, musicians and sound engineers often manipulate loudness to create a balanced auditory experience. Tools like sound pressure level (SPL) meters or smartphone apps can help measure loudness, ensuring that audio levels are appropriate for different environments. Advancements in technology, such as equal loudness apps, enhance listening experiences by equalizing sound frequencies.



Amplitude and loudness

A larger amplitude corresponds to a louder sound, while a smaller amplitude results in a softer sound. This relationship is fundamental to how we perceive sound, as the amplitude reflects the pressure variations exerted on our ears. Human ears are remarkably sensitive, capable of detecting a vast range of loudness levels. The intensity of sound waves, which is directly related to their amplitude, plays a significant role in this perception. As sound waves travel, their amplitude diminishes, leading to a decrease in loudness. It used in the design of hearing aids and cochlear implants. These devices rely on manipulating sound waves to enhance auditory experiences for individuals with hearing impairments.

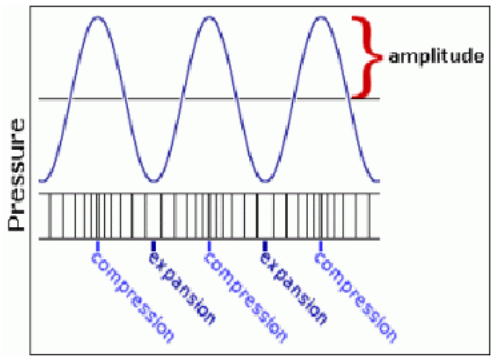


Amplitude is a physical property of a sound wave that indicates the maximum displacement of particles in the medium caused by the wave. It determines the energy carried by the wave, with higher amplitudes representing greater energy. On a graph, amplitude is the height of the wave from its equilibrium point, and it is a key factor influencing the perception of sound intensity.

Loudness, on the other hand, is the subjective perception of how strong or soft a sound appears to a listener. It depends on the amplitude of the sound wave but is also influenced by factors like frequency and individual sensitivity to sound. For instance, the human ear is more sensitive to frequencies between 2,000 and 5,000 Hz, making sounds in this range seem louder even at the same amplitude as lower or higher frequencies. A sound wave with higher amplitude generally produces a louder sound, but this relationship is not perfectly linear due to the complexities of human hearing.

Amplitude and intensity

Amplitude refers to the maximum displacement of particles in a medium caused by a sound wave, essentially measuring the wave's energy. The greater the amplitude, the louder the sound perceived. **Sound intensity is defined as the sound power per unit area, indicating how much energy passes through a specific area over time.** As amplitude increases, so does intensity. This relationship can be mathematically expressed, showing that intensity is proportional to the square of the pressure amplitude. This means that even small increases in amplitude can lead to significant increases in intensity, affecting how we perceive sound. These concepts help in various fields, from acoustics to neuroscience, where changes in sound intensity can influence brain function and perception. On a graph, amplitude is represented by the height of the wave, and larger amplitudes indicate stronger vibrations.



Intensity measures the amount of energy transmitted by the wave per unit area per unit time. It is a physical quantity that depends on both the square of the amplitude and the frequency of the wave. Intensity is expressed in watts per square meter (W/m^2) and provides an objective measure of the sound's power as it spreads through a medium. The relationship between amplitude and intensity is quadratic, meaning that if the amplitude of a sound wave doubles, its intensity increases by a factor of four. While amplitude represents the energy within the wave, intensity accounts for how this energy is distributed in space, making it a key factor in understanding the propagation of sound.

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SPEED OF SOUND WAVES

The speed of sound waves varies significantly depending on the medium through which they travel. In dry air at sea level, sound travels at approximately 761 mph (or 343 meters per second). This speed can fluctuate based on environmental factors, primarily temperature and humidity. For instance, sound travels faster in warmer air due to increased molecular activity, while higher humidity can also enhance sound speed. In contrast, sound waves move more rapidly in solids than in liquids or gases. This is attributed to the rigidity and density of the material; sound waves can transmit energy more efficiently in denser and more rigid substances. For example, sound waves can travel at speeds of 4 to 7 km/s in solids, compared to 1.5 km/s in water.

Factors affecting speed of sound in a medium

The speed of sound in a medium is influenced by (i) temperature, (ii) density, and (iii) elasticity.

1). As temperature increases, the speed of sound also rise because warmer molecules vibrate more rapidly, facilitating quicker energy transfer. In colder conditions, sound travels slower due to reduced molecular motion.

2). Density plays a crucial role as well. Sound travels faster in denser materials, but this is nuanced by the material's elasticity. For instance, while sound moves quickly through solids due to their high density and elasticity, it travels slower in gases, where lower density and elasticity hinder sound propagation.

3). Pressure can also affect sound speed, particularly in gases. Increased pressure typically raises density, which can enhance sound speed.

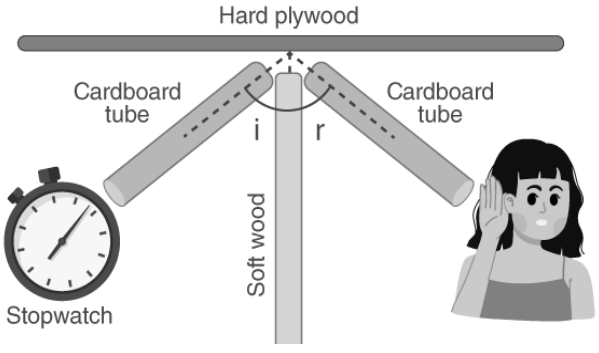
ACTIVITY

Kate and Kitty stood at a distance apart besides along metal rail on a still day. Kate placed his ear against the rail while Kitty gave the rail a sharp knock with a hammer. Two sounds were separated by a time intervals of 0.5s were heard by Kate. If the speed of sound in air is $330ms^{-1}$ and that in the metal rail is $5300ms^{-1}$. Establish the actual distance between the two.

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Reflection and Echoes of sound waves

Sound waves are reflected well from hard, flat surfaces such as walls or cliffs and obey the same laws of reflection as light. The reflected sound forms an echo; an echo is the reflection of a sound wave. 169 Measurement of the speed of sound. if the reflecting surface is nearer than 15m from the source of sound, the echo joins up with the original sound which then seems to be prolonged. This is called reverberation. Some is desirable in a concert hall to stop it sounding ‘dead’, but too much causes ‘confusion’. Modern concert halls are designed for the optimal amount of reverberation. Seats and some wall surfaces are covered with sound-absorbing material.



It has applications, from architectural acoustics to musical performances. The effectiveness of sound reflection is influenced by the surface's shape and material; flat surfaces tend to reflect sound more efficiently than irregular ones. In practical terms, sound reflection can lead to phenomena such as echoes and reverberation. An echo occurs when sound waves reflect off a distant surface, returning to the listener after a noticeable delay. Reverberation is the persistence of sound in a space due to multiple reflections, creating a rich auditory experience. Sound reflection is essential for designing spaces that optimize acoustics, such as concert halls and recording studios.

EXPERIMENT TO VERIFY THE LAWS OF REFLECTION OF SOUND

a). Put a ticking clock on a cardboard tube on a table and make it to face a hard plane surface e.g. a plywood.

b). Put the ear near a cardboard tube and move it on either sides until the ticking sound of the clock is heard loudly.

c). Measure angle i and r, which are the angles of incidence and reflection.

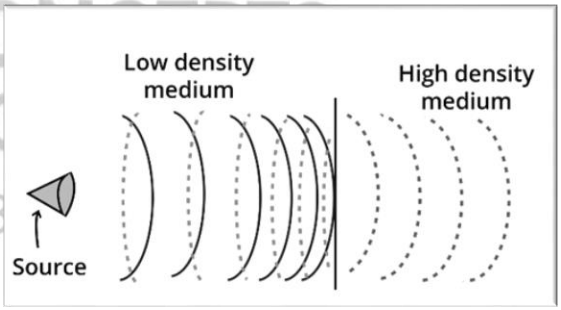
From the experiment, sound is heard distinctly due to reflection. Angle of incidence (i) and angle of reflection (r) are equal and lie along XY in the same plane. This verifies the laws of reflection.

ECHOES

Echoes occur when sound waves reflect off hard surfaces and return to the listener. This reflection is crucial in **acoustics**, where it influences the design of concert halls and auditoriums. The quality of sound in these spaces is significantly affected by how echoes are managed, ensuring that music is heard clearly and harmoniously.

Beyond acoustics, echoes serve practical **purposes in scientific measurements**. For instance, they are employed in **sonar technology to determine distances** and map underwater terrains. By analyzing the time it takes for sound waves to return after bouncing off an object, scientists can calculate its distance and shape. This principle is also utilized in **medical imaging techniques**, such as ultrasound, where echoes help create detailed images of internal body structures. Echoes are being explored in fields like **superconductivity and gravitational wave detection**, showcasing their versatility and importance in modern physics.

The occurrence and strength of echoes



Echoes are resulting from the reflection of sound waves off hard surfaces. When a sound is produced, it travels through the air until it encounters a hard surface, such as a wall or a mountain. If the surface is hard and smooth, it reflects the sound waves effectively, allowing the listener to hear the echo after a brief delay. The strength of an echo is influenced by the absorptive properties of the reflecting surface; denser and smoother surfaces yield stronger echoes. In practical applications, echoes are used in acoustics, particularly in concert halls and auditoriums, where sound quality is paramount. The design of these spaces often considers how echoes will enhance or detract from the auditory experience.

Speed of sound

In air: The speed of sound in air is approximately 330–350m/s.

In other materials, the speed of sound depends on the material through which it is passing. It is faster in solids than in liquids and faster in liquids than in gases because the molecules in a solid are closer together than in a liquid and those in a liquid are closer together than in a gas.

Some values are given. Speed of sound in different materials Material air (0°C), Speed/m/s 330–350, water 1400m/s, concrete 5000 m/s, steel 6000 m/s.

In air the speed increases with temperature and at high altitudes, where the temperature is lower, it is less than at sea level. Changes of atmospheric pressure do not affect it.

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Measurement of the speed of sound Echo method

An estimate of the speed of sound in air can be made directly if you stand about 100 metres from a high wall or building and clap your hands. Echoes are produced. When the clapping rate is such that each clap coincides with the echo of the previous one, the sound has travelled to the wall and back in the time between two claps, i.e. one interval.

By timing 30 intervals with a stopwatch, the time t for one interval can be found. Also, knowing the distance d to the wall, a rough value is obtained from: $speed\ of\ sound\ in\ air\ = \frac{distance}{time} = \frac{2d}{t}$.

Direct method

The speed of sound in air can be found directly by measuring the time t taken for a sound to travel past two microphones separated by a distance d:

$speed\ of\ sound\ in\ air\ = \frac{distance\ travelled\ by\ the\ sound}{time\ taken}$.

This method can also be used to find the speed of sound in different materials. For example, placing a metal bar between the microphones would allow the speed of sound in the metal to be determined.

Investigating the velocity of sound in air using the echo method

The echo method is a practical way to measure the velocity of sound in air. It involves producing a sound, allowing it to travel a known distance (d), and measuring the time (t) it takes for the sound to return as an echo.

The velocity of sound (v) can be calculated using the formula:$\boldsymbol{v = \frac{2d}{t}}$, *where: d = distance traveled by sound, t= time taken for the echo to return*

Assumptions

The sound travels at a constant speed in the medium (air) under controlled conditions (e.g., similar temperature, humidity). The distance measured is the one-way distance to the reflecting surface; thus, the total distance for the echo is twice the one-way distance.

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Equipment Needed

A sound source, measuring tape, and stopwatch or timer for measuring the time interval

Procedure

i). Choose an open area where a hard surface (like a wall or a large rock) can reflect sound waves.

ii). Measure the distance (d) from the sound source to the reflecting surface.

iii). Generate a loud sound (such as clapping hardboard or using a whistle) at the chosen distance.

iv). Start the stopwatch at the moment the sound is made and stop it when the echo is heard. Record the time (t) taken for the echo to return.

v). Use the formula $v = \frac{2d}{t}$,to calculate the speed of sound in air. Since the time measured is for the sound to travel to the wall and back, divide the time by 2 before using it in the formula.

vi). Repeat the experiment, and get two values of velocity, and determine the average speed.

Other applications of sound waves/Echoes

Submarines use sound waves, specifically sonar (Sound Navigation and Ranging), for navigation and obstacle detection underwater. Sonar systems emit sound pulses and measure the time it takes for the echoes to return after reflecting off objects. This helps determine distances, locate other vessels, and navigate safely in the depths where visibility is limited.

Fisheries rely on echo sounders, a type of sonar technology, to locate schools of fish. Sound waves are transmitted into the water, and the reflected signals from fish or other underwater objects provide

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information about their position and size. This helps optimize fishing efforts while reducing overexploitation.

Oceanographers use sound waves for seabed mapping, employing techniques like multi-beam sonar. These systems emit sound waves that travel to the ocean floor and return as echoes, creating detailed topographic maps. This data is essential for studying marine ecosystems, underwater navigation, and geological research.

Ultrasound

Ultrasound is defined as sound with a frequency higher than 20 kHz. The frequency of ultrasound is too high to be detected by the human ear but can be detected electronically and displayed on a cathode ray oscilloscope (CRO). Ultrasound waves are produced by a quartz crystal which is made to vibrate electrically at the required frequency; they are emitted in a narrow beam in the direction in which the crystal oscillates. An ultrasound receiver also consists of a quartz crystal, but it works in reverse, i.e. when it is set into vibration by ultrasound waves it generates an electrical signal which is then amplified. The same quartz crystal can act as both a transmitter and a receiver.

Ultrasound echo techniques

Ultrasound waves are partially or totally reflected from surfaces at which the density of the medium changes. This property is exploited in techniques such as the non-destructive testing of materials, sonar and medical ultrasound imaging. A bat emitting ultrasound waves can judge the distance of an object from the time taken by the reflected wave or 'echo' to return. Ships with sonar can determine the depth of a shoal of fish or the seabed in the same way; motion sensors also work on this principle.

Example: A research ship is using sonar to map the seabed. How deep is the water if an ultrasound pulse reflected from the seabed takes 1.5s to return to the ship?

Hint: Take the speed of sound in water to be 1400m/s.

From the equation for speed $v = \frac{s}{t}$; = to give $s = v \times t$. If the depth of the seabed is d, the ultrasound must travel a distance of 2d during time t between the transmission and reception of the signal, then

$2d = vt$ and $d = \frac{vt}{2}$; $d = \frac{1400x1.5}{2} = 1050m$.

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Activity:

1). A fishing vessel is using sonar to monitor the position of shoals of fish. Calculate the depth of a shoal if an ultrasound pulse reflected from the shoal takes 0.5s to return to the ship.

Hint: Take the speed of sound in water to be 1400m/s.

2). Sonar is being used on a research vessel to measure the height of an underground sea mount. Calculate the distance from the ship to the summit of the sea mount if an ultrasound pulse reflected from the summit takes 2s to return to the ship. Take the speed of sound in water to be 1400m/s.

Ultrasound Applications

Ultrasound, which involves high-frequency sound waves exceeding 20,000 Hz, is widely used in various fields due to its precision and non-invasive nature. These sound waves travel through different materials, reflecting back when they encounter changes in density, which enables detailed analysis and effective applications.

Medical Imaging

In healthcare, ultrasound is a critical tool for creating images of internal structures, such as organs, tissues, and developing fetuses. The machine emits high-frequency sound waves that penetrate the body and

reflect off tissues, producing echoes that are converted into visual images. This method is non-invasive, radiation-free, and widely used in prenatal care, abdominal imaging, and cardiac examinations.

In medical ultrasound imaging, used in antenatal clinics to monitor the health and sometimes to determine the sex of an unborn baby, an ultrasound transmitter/receiver is scanned over the mother's abdomen and a detailed image of the fetus is built up. Reflection of the ultrasound pulses occurs from boundaries of soft tissue, in addition to bone, so images can be obtained of internal organs that cannot be seen by using X-rays. Less detail of bone structure is seen than with X-rays, as the wavelength of ultrasound waves is larger, typically about 1 mm, but ultrasound has no harmful effects on human tissue

Industrial Cleaning

Ultrasound is employed in industrial cleaning to remove dirt, grease, and contaminants from intricate or delicate items, such as surgical tools, jewelry, and machine parts. High-frequency sound waves create microscopic bubbles in a cleaning solution, a process known as cavitation. These bubbles collapse, producing intense pressure that effectively cleans without damaging the items.

Non-Destructive Testing (NDT)

Ultrasound is a vital technique in NDT for inspecting materials like metals, composites, and concrete without causing damage. High-frequency sound waves are directed into the material, and the reflected waves are analyzed to detect cracks, voids, or other imperfections. This method is extensively used in industries like aerospace, construction, and manufacturing for quality assurance and safety checks.

Applications of Sound Spectrum:

In music, the spectrum is used to analyze the different harmonic components of musical notes and instruments. The richness of a musical sound comes from the combination of multiple harmonics, each contributing a unique frequency to the sound.

The sound spectrum is crucial in speech analysis. Different vowels and consonants have characteristic frequency patterns, and the study of these patterns helps in fields like speech recognition and phonetics.

In audio engineering, the sound spectrum is analyzed and adjusted to enhance or reduce certain frequencies (equalization) to improve sound quality for music, radio, or film.

Other uses Ultrasound can also be used in ultrasound drills to cut holes of any shape or size in hard materials such as glass and steel. Jewellery, or more mundane objects such as street lamp covers, can be cleaned by immersion in a tank of solvent which has an ultrasound vibrator in the base.

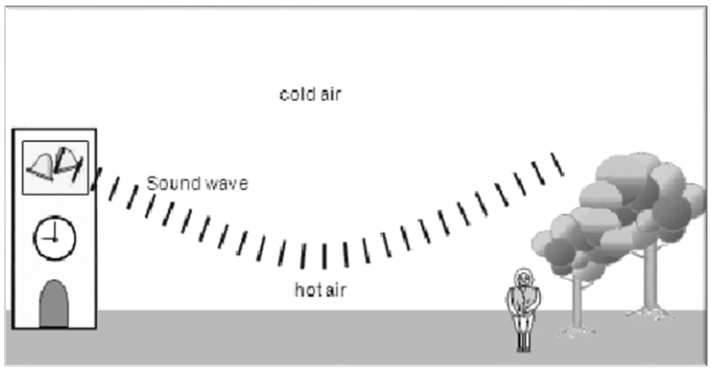
REFRACTION OF SOUND WAVES

Refraction of sound waves is a fascinating phenomenon that occurs when sound travels through different media or varying temperatures. This bending of sound waves is primarily due to changes in wave speed, which can be influenced by factors such as air temperature.

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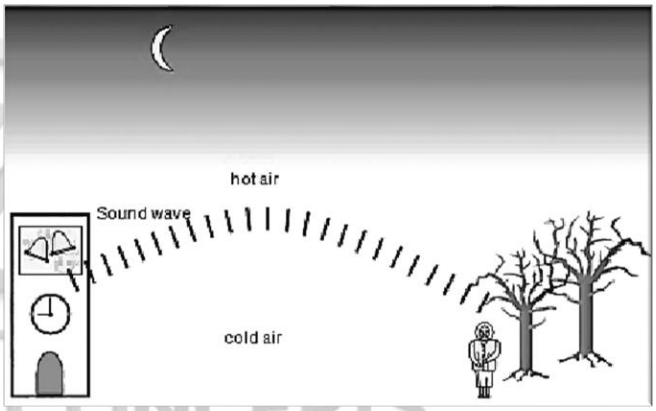
For instance, sound waves may refract when moving over water, as they transition between air and the water surface, altering their speed and direction. The critical angle plays a significant role in sound refraction, determining how sound waves behave as they encounter different mediums. When sound waves reach this angle, they can either reflect or refract, depending on the properties of the media involved.



Refraction occurs when speed of sound waves changes. The speed of sound in air is affected by temperature. Sound waves are refracted when they are passed through areas of different temperature.

This explains why it is easy to hear sound waves from distant sources at night than during day.

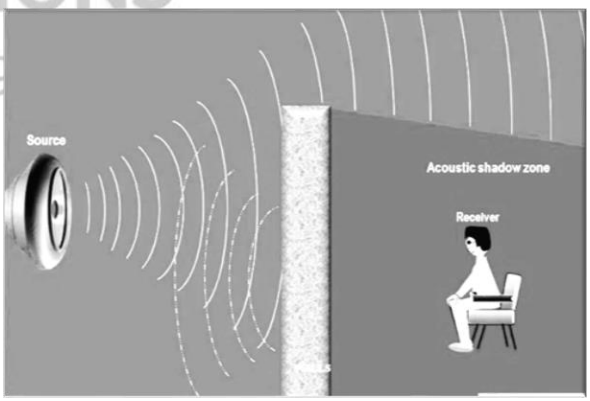
During day, the ground is hot and this makes the layers of air near the ground to be hot while that above the ground is generally cool. The wave fronts from the source are refracted away from the ground.



During night, the ground is cool and this makers layers of air near the ground to be cool while above to be warm. The wave fronts from the source are refracted towards the ground making it easier to hear sound waves over long distances.

DIFRACTION OF SOUND

This refers to the spreading of sound waves around corners or in gaps when sound waves have wavelength similar to the size of the gap. It is due to refraction that a person behind the house can hear sound from inside.

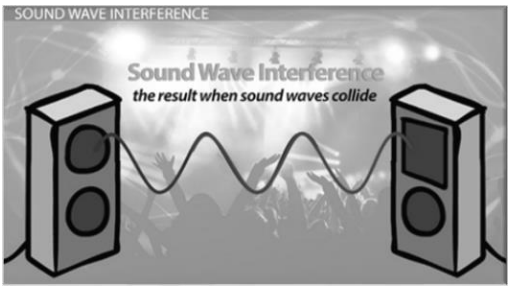


Diffraction of sound waves occurs when sound waves encounter obstacles or openings. This bending and spreading of waves allows sound to travel around corners and through small openings, making it possible to hear sounds even when the source is not directly in line with the listener.

The extent of diffraction is influenced by the wavelength of the sound; longer wavelengths, such as those produced by lower frequencies, diffract more easily than shorter wavelengths. For instance, when sound waves pass through a doorway, they spread out into the adjacent room, allowing us to hear conversations or music from another space. This property of sound diffraction is crucial in various applications, from architectural acoustics to audio engineering, as it helps in designing spaces that enhance sound quality.

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INTERFERENCE OF SOUND



When two sound waves from two different sources overlap, they produce regions of loud sound and regions of quiet sound. The regions of loud sound are said to undergo constructive interference while regions of quiet are said to undergo destructive interference. Sound wave interference occurs when two or more sound waves occupy the same space, leading to interactions that can alter their amplitudes.

Constructive interference happens when waves combine to create a larger amplitude, while destructive interference occurs when waves cancel each other out, resulting in a smaller amplitude. The interference pattern is influenced by the wavelength of the sound waves.

As the wavelength increases, the points of constructive and destructive interference become more spaced out, leading to fewer interference points. This principle is often demonstrated in experiments using speakers, where sound waves from two sources meet and interact.

Seismic waves:

Earthquakes produce both longitudinal waves (P-waves) and transverse waves (S-waves) that are known as seismic waves. These travel through the Earth at speeds of up to 13000m/s, with frequencies less than 100 Hz. When seismic waves pass under buildings, severe structural damage may occur. If the earthquake occurs under the sea, the seismic energy can be transmitted to the water and produce tsunami waves that may travel for very large distances across the ocean. As a tsunami wave approaches shallow coastal waters, it slows down (see Topic 3.1) and its amplitude increases, which can lead to massive coastal destruction. This happened in Sri Lanka (see Figure 3.4.10) and Thailand after the great 2004 Sumatra–Andaman earthquake. The time of arrival of a tsunami wave can be predicted if its speed of travel and the distance from the epicentre of the earthquake are known; it took about 2 hours for tsunami waves to cross the ocean to Sri Lanka from Indonesia. A similar time was needed for the tsunami waves to travel the shorter distance to Thailand. This was because the route was through shallower water and the waves travelled more slowly. If an early-warning system had been in place, many lives could have been saved.

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Reverberation

Reverberation is the persistence of sound after its source has stopped, caused by multiple reflections of the sound waves off surfaces in an enclosed space. Unlike an echo, which is a distinct repetition of a sound, reverberation involves a continuous blending of the sound as it reflects and gradually diminishes in intensity.

Reverberation is the overlapping and continuation of sound caused by reflection in a confined space. It creates a sense of fullness or richness in the sound but does not produce a distinct repetition of the sound. Echo, on the other hand, is a distinct repetition of the original sound. For an echo to occur, the reflected sound must travel a longer distance (more than 17 meters) so that it is heard separately from the original sound.

Causes of Reverberation

Large rooms or spaces with high ceilings tend to have longer reverberation times because sound waves travel longer distances before being absorbed or dissipated. Irregularly shaped rooms can also contribute to reverberation by creating complex patterns of reflected sound. Hard, reflective surfaces like glass, concrete, or marble reflect sound more effectively, leading to more reverberation. Soft, absorbent surfaces

like carpets, curtains, and foam panels absorb sound energy, reducing reverberation by preventing multiple reflections. The larger the distance between surfaces (walls or ceiling), the longer it takes sound waves to bounce back and reach the listener, which can lead to a more noticeable reverberation effect.

Examples of Reverberation

Reverberation in concert halls gives music a rich, full quality by allowing sound to linger slightly after it is produced. However, the reverberation time must be carefully controlled to avoid creating a muddled or indistinct sound.

Due to their large size and hard stone surfaces, cathedrals typically have long reverberation times. This is why spoken words or music in such spaces often sounds echoed and prolonged.

Recording studios are often designed to have minimal reverberation. This allows for cleaner recordings of sound without the unintended effects of reflections from walls or other surfaces. Acoustic treatments like foam panels and baffles are used to absorb sound and reduce reverberation time.

Effects of Reverberation on Sound Quality

Many cases, reverberation can enhance the quality of sound, especially in music. The reflection of sound waves can create a sense of spaciousness and depth, giving the sound a more natural and immersive quality.

Too much reverberation can distort sound. When reverberation time is excessively long, individual sounds (such as spoken words) can overlap and become difficult to distinguish, leading to a loss of clarity and intelligibility.

In environments with excessive reverberation, speech may sound garbled or echoes because the reflections of earlier sounds interfere with new ones, making it harder to understand what is being said.

Controlling Reverberation

Soft materials, like foam or fabric-covered panels, can be installed on walls or ceilings to absorb sound waves and reduce reverberation. These panels are commonly used in recording studios, theaters, and auditoriums to control the acoustics of the room.

Adding carpets or curtains can also absorb sound, helping to reduce the amount of reflection and thus minimizing reverberation in smaller spaces like homes or offices.

Designing rooms with irregular shapes or adding furniture can break up sound waves and prevent them from reflecting as strongly. This is useful in reducing reverberation in spaces where clear, crisp sound is important, such as conference rooms or classrooms.

Chapter Assessment

A girl stands 160m away from a high wall and claps her hands at a steady rate so that each clap coincides with the echo of the one before. If her first clapping rate is 60 per minute, and if she then moves 40m closer to the wall and she finds the clapping rate has to be 80 per minute. She moves again further, and finds the clapping rate reduced to 30 per minute.

Task: Use the knowledge of physics to;

a). determine the value this gives for the speed of sound.

b). determine the speed in the second instance,

c). determine how far she is from the wall basing on the value in (b) above.

d). Explain one application of echo method.

e). State how far a compression and the nearest rarefaction are apart in terms of the wavelength of a sound wave.

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f). Explain the factors that might affect the speed of sound above.
g). Explain the possible application of echoes in large concert halls.

3.6 HEAT QUANTITIES AND VAPOURS



Learning Outcomes

a) Understand and use the concepts of heat capacity and latent heat (k, u,s)
b) Know and explain the implications of the high values of the specific latent heat and the specific heat capacity of water (k,u)
c) Carry out calculations and investigations on specific heat capacity and specific latent heat (u,s)
d) Understand the concept of latent heat and change of state, and use them to explain melting and boiling point (u,s)
e) Understand the meaning of saturated and unsaturated vapours, saturated vapour pressure, and how these terms relate to boiling and evaporation(u)
f) Appreciate the cooling effect of evaporation and how this contributes to maintaining constant body temperature (k, u, s,v/a)

Introduction

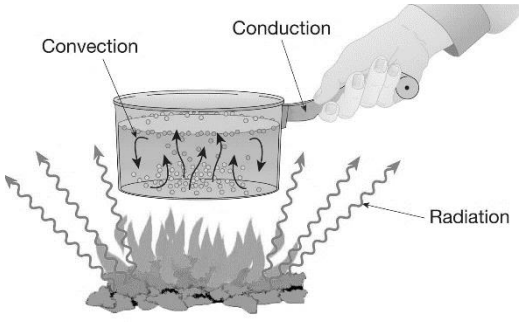
Some materials require more heat than others to raise their temperature. The increase in the kinetic energy associated with this motion raises the internal energy of the object. The extent of the increase in kinetic energy of the particles in a material when it is heated depends on the nature of the material and its state, and is measured in terms of specific heat capacity.
The specific heat capacity of Aluminium is higher than that of copper, so copper is a more energy efficient material to use for saucepans.

In practical applications, heat capacity is significant in designing systems such as heat pumps and thermal storage solutions, ensuring efficient energy use and temperature regulation in various environments.

The **internal energy** of an object is the energy associated with the motion of its particles. When an object is heated and its temperature rises, there is an increase in the internal energy of the object.

Internal energy

The particle theory regards temperature as a measure of the average kinetic energy of the particles of the body. The greater this is, the faster the particles move and the higher the temperature of the body. Increasing the temperature of an object increases its internal energy because the kinetic energy of all the particles increases.



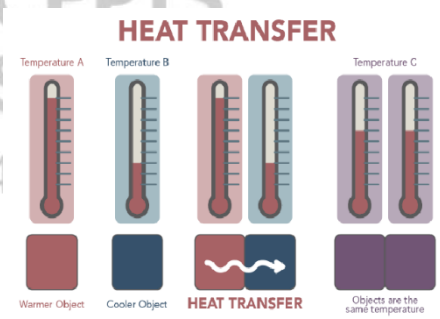
Thermal energy and temperature

A red-hot spark from a fire is at a higher temperature than the boiling water in a saucepan. In the boiling water the average kinetic energy of the particles is lower than

in the spark; but since there are many more water particles, their total energy is greater, and therefore more thermal energy can be supplied by the water than by the spark.
Thermal energy is transferred from a body at a higher temperature to one at a lower temperature. This is because the average kinetic energy (and speed) of the particles in the hot body falls as a result of the collisions with particles of the cold body whose average kinetic energy, and therefore temperature, increases.
When the average kinetic energy of the particles is the same in both bodies, they are at the temperature. For example, if the red-hot spark landed in the boiling water, thermal energy would be transferred from it to the water even though much more thermal energy could be obtained from the water.

Heat energy
Heat energy (heat), is the transfer of energy that results due to temperature difference (from a higher temperature body to a lower temperature one) between two points of a substance.
The movement of tiny particles atoms, molecules, or ions within solids, liquids, and gases generates thermal energy, which directly influences temperature.
There are three primary mechanisms of heat transfer: conduction, convection, and radiation.
Conduction occurs through direct contact, convection involves the movement of fluids, and radiation transfers energy through electromagnetic waves. Heat energy is produced from various sources, including the sun, combustion of fuels, and chemical reactions.

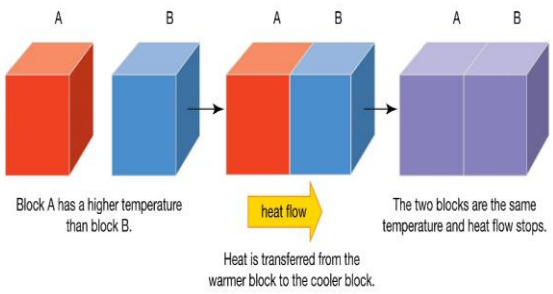
Heat energy is the energy transferred between objects at different temperatures. It is the **capacity to do work by moving matter**.
Heat capacity, refers to the amount of heat energy required to raise the temperature of a substance by one degree Celsius. For instance, substances with high heat capacity can absorb more heat without a significant temperature change, making them ideal for applications requiring thermal stability.
Specific heat capacity, closely related to heat capacity, measures the heat required to change the temperature of a unit mass of a substance by one degree Celsius.



How does heat energy flow?
Heat energy flows through three primary mechanisms: conduction, convection, and radiation.

- ✓ Conduction occurs when heat is transferred directly between substances in contact, such as a metal spoon in a hot pot of soup. The heat moves from the hotter substance to the cooler one until thermal equilibrium is reached.
- ✓ Convection involves the movement of heat through fluids (liquids and gases) as warmer, less dense areas rise and cooler, denser areas sink. This is observed in boiling water or atmospheric circulation.
- ✓ Radiation is the transfer of heat through electromagnetic waves, such as infrared radiation from the sun warming the Earth.

Unlike conduction and convection, radiation does not require a medium to transfer heat, allowing energy to travel through the vacuum of space.



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Heat capacity

Heat capacity is a fundamental physical property of matter, defined as the amount of heat energy required to raise the temperature of an object by one degree Celsius.
It is expressed in units such as calories per degree or joules per degree.

To investigate how different liquids of the same volume acquire heat
An experiment can be conducted using equal amounts of various liquids, such as water, oil, and alcohol.
a). Begin by measuring 100 mL of each liquid and placing them in identical calorimeters.
b). Use a thermometer to monitor the temperature of each liquid as they are heated uniformly, ensuring that they all receive the same amount of heat energy.
c). As the liquids are heated, record the temperature changes at regular intervals. This data will reveal how quickly each liquid's temperature rises.

Observation
The experiment shows that different liquids expand at different rates due to their unique molecular structures and intermolecular forces. For instance, water may heat up more slowly than alcohol, indicating a higher specific heat capacity.
Conclusion
By analyzing the temperature data, one will conclude that equal volumes of different liquids do indeed acquire heat at varying rates, demonstrating the principles of thermodynamics and material properties.

Heat Capacity

Different substances have different heat capacities due to variations in molecular structure and bonding. Solids, liquids, and gases have different heat capacities, with gases generally having higher heat capacities than solids. Heat capacity can change with temperature; as substances heat up, their ability to store thermal energy may vary.

Heat capacity, C, of an object $c = \frac{heat\ supplied\ (J)}{change\ in\ temperature\ (K)}$, $C = \frac{Q}{\Delta\theta}$. *The SI unit of heat capacity is ;* $\frac{joule}{kelvin}$ *or* JK^{-1}

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Investigating the effect of mass on the heat capacity of a substance
Objective: to investigate how increasing the mass of a substance affects its overall heat capacity while keeping other factors constant.

Variables
Independent Variable: *Mass of the substance.*
Dependent Variable: *Heat capacity (C) and temperature change*
Controlled Variables: *Heat source, heating duration, and starting temperature*.

Experimental Setup
Materials: A substance with a known specific heat capacity (e.g., water), A heat source (e.g., a heater), Insulated containers, A thermometer or temperature probe, Measuring scales.
Procedure:

a) Measure and record different masses of the substance (100 g, 200 g, 300 g).
b) Place each sample in an insulated container.
c) Heat each sample with a constant heat source for a fixed time (e.g., 5 minutes).

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d) Record the temperature change (Δθ) for each mass.
e) Tabulate the table of results including values of $\theta_1, \theta_2, and\ \Delta\theta = (\theta_2 - \theta_1)$
f) A graph of mass (m) against $(\theta_2 - \theta_1)$ *will plotted*
g) The nature of the graph obtained, and conclusion generated, from which

Expected Results

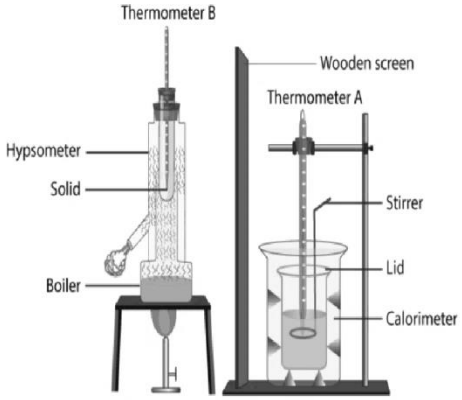
As the mass increases, the total heat capacity will increase proportionally.
The temperature change (Δθ) for larger masses will be smaller if the same amount of heat is applied, demonstrating that larger masses require more energy to achieve the same temperature rise.

Specific heat capacity

If 1 kg of water and 1kg of paraffin are heated in turn for the same time by the same heater, the temperature rise of the paraffin is about twice that of the water. Since the heater gives equal amounts of thermal energy to each liquid, it seems that different substances require different amounts of energy to cause the same temperature rise in the same mass, say 1°C in 1kg.
The amount of heat required to raise the temperature of a particular substance by one degree is measured by its specific heat capacity (symbol c).

Specific heat capacity refers to the amount of heat required to raise the temperature of one unit (kg) of mass of a substance by one degree Celsius (1°C). This property, denoted by '**C**', varies among different materials, influencing how they respond to heat. For instance, water has a notably high specific heat capacity, which allows it to absorb and retain heat longer than many other substances. This characteristic plays a role in regulating climate and weather patterns. The specific heat capacity of various materials can be found in comprehensive tables, which list values for common substances. For example, aluminum has a specific heat capacity of 0.89 J/g°K, while concrete has a higher value of 0.88 J/g°K.

Specific heat capacity is defined as: $\boldsymbol{c = \frac{\Delta Q}{m\Delta\theta}}$**,** where: c = specific heat capacity (measured in joules per kilogram per degree Celsius, J/ (kg·°C)), m = mass of the substance (measured in kilograms, kg), ΔQ and Δθ are the same as defined earlier. Different substances have distinct specific heat capacities. For example: Water =4,200 J/ (kg·°C) (high specific heat, which is why it moderates temperatures)**,** and Iron: =450 J/ (kg·°C) (lower specific heat compared to water)



Determination of specific heat of solid by method of mixture

Determining the Specific Heat Capacity of a Substance by the Method of Mixtures

The method of mixtures is a practical approach to determine the specific heat capacity (c) of a substance. It is based on the principle of conservation of energy, where heat lost by a hotter object equals the heat gained by a cooler one, assuming no heat loss to the surroundings.

Principle: The heat lost by the hotter substance is given to the cooler substance until thermal equilibrium is reached. Mathematically: For a substance, heat transfer is calculated as Q=mcΔθ

Materials: A calorimeter (insulated container), Thermometer, Balance (to measure mass), A hot solid (e.g., a metal block), A known volume of water (to act as the cooler substance), and Heat source (to heat the solid).

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Procedure

a). Measure the mass of the solid, m_s and its initial temperature θ_0 *after heating.*

b). Measure the mass of water,m_w *and initial temperature of the water* θ_1 *in the calorimeter.*

c). Quickly place the heated solid into the water in the calorimeter.

d). Stir gently and record the final equilibrium temperature of the mixture.

Energy Balance

Assume no heat is lost to the surroundings or the calorimeter.

Calculate the heat lost by the solid: $Q_s = m_s c_s(\theta_0 - \theta_2)$

Calculate the heat gained by the water: $Q_w = m_w c_w(\theta_2 - \theta_1)$

Since Q_s=Q_w, *rearrange to solve for* $c_s = \frac{m_w c_w(\theta_2 - \theta_1)}{m_s(\theta_0 - \theta_2)}$

Expected Outcome

The specific heat capacity of the solid can be calculated accurately if heat losses are minimized. Typical values of specific heat capacities for common materials (e.g., metals) can be compared to validate the results.

Sources of Error

Heat loss to the environment or calorimeter,

Inaccurate measurement of temperatures or masses,

Uneven heat distribution in the solid or water

Example

1). Jane is supposed to boil 0.25 kg of water from 20°C to 100°C. The specific heat capacity of water is 4,180 J/kg°C, how much thermal energy is needed to get the water up to boiling point?

Change in thermal energy = mass × specific heat capacity × temperature change

$\boldsymbol{\Delta E = mc\Delta\theta \quad E = 0.25x4180x(100 - 20) = 0.25x4180x80 = 83,600J}$

2). If 20000J is supplied to a mass of 5kg and its temperature rises from 15°C to 25°C, calculate the specific heat capacity of the mass.

Using $\boldsymbol{c = \frac{\Delta E}{m\Delta\theta}}$; $c = \frac{20000J}{5kgx(25-15)} = \frac{20000}{50} = 400Jkg^{-1}K^{-1}$

3). A tank containing 60 kg of water is heated using a 3 kW electric immersion heater. The specific heat capacity of water is 4200 J kg⁻¹°C⁻¹. Estimate the time required for the temperature of the water to increase from 10°C to 60°C.

Response

The heat energy required to raise the temperature of a substance is given by the equation:

$\boldsymbol{\Delta E = mc\Delta\theta,}$ where, ΔE is the heat energy supplied, m is the mass, c is the specific heat capacity, and Δθ is the change in temperature.

Change in temperature: $\Delta\theta = 60°C - 10°C = 50°C$

Energy required by the water:$\Delta E = 60\,kg \times 4200\,J\,kg^{-1}°C^{-1} \times 50°C;\ \Delta E = 12{,}600{,}000\,J$

The heater supplies energy at a rate of $3\,kW = 3000\,J/s$.

Energy supplied by heater = Power × time, $3000 \times t = 12{,}600{,}000;\ t = 12{,}600{,}000 / 3000;\ \boldsymbol{t = 4200\,seconds}$

Converting to minutes:$\boldsymbol{4200 \div 60 = 70\,minutes.}$

Therefore, the estimated time required to heat the water is about 4200 s or approximately 70 minutes.

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4). A piece of aluminium with a mass of 0.5 kg is heated to 100°C and then placed in 0.4 kg of water at 10°C. The final temperature of the mixture becomes 30°C. If the specific heat capacity of water is 4200 J $kg^{-1}°C^{-1}$, determine the specific heat capacity of aluminium.

Principle: When two substances at different temperatures are mixed, heat flows from the hotter substance to the cooler one until both reach the same final temperature. If no heat is lost to the surroundings:

Heat lost by aluminium = Heat gained by water
Using the heat equation $\Delta E = mc\Delta\theta$.
Heat lost by aluminium
Mass = 0.5 kg, $Temperature\ change = 100°C - 30°C = 70°C;\ Heat\ lost = 0.5 \times c \times 70$

Heat gained by water
Mass = 0.4 kg, Specific heat capacity of water = 4200 J $kg^{-1}°C^{-1}$,
Temperature change = 30°C − 10°C = 20°C
$Heat\ gained = 0.4 \times 4200 \times 20$
Equating the two energies
$0.5 \times c \times 70 = 0.4 \times 4200 \times 20;\ 0.5 \times 70c = 33{,}600$
$35c = 33{,}600;\ c = \frac{33{,}600}{35};\ \boldsymbol{c = 960\ J\ kg^{-1}°C^{-1}}$
Therefore, the specific heat capacity of aluminium is approximately **960 J $kg^{-1}°C^{-1}$.**

ACTIVITY
1). During a science practical lesson at a secondary school laboratory, students investigate how heat energy affects different materials. In one experiment, a metal block of mass **2 kg** is heated using an electric heater. The students measure the temperature change and observe that when **25,000 J** of heat energy is supplied, the temperature of the metal rises from **10°C to 35°C**. In another experiment, a different material with a known **specific heat capacity of 500 J $kg^{-1}°C^{-1}$** is used. The students plan to heat a **3 kg** sample of this material to observe how much energy is required to increase its temperature by **10°C**. The teacher explains that understanding heat energy and specific heat capacity helps engineers choose suitable materials for cooking utensils, engines, and building materials.
Tasks: Use the knowledge of physics to:
a) Using the information from the first experiment, calculate the specific heat capacity of the metal block.
b) Determine the amount of heat energy required to raise the temperature of the 3 kg material by 10°C.
c) Explain why materials with different specific heat capacities are useful in everyday applications, giving one real-life example.

2). During a morning break at a school staffroom, a teacher switches on an electric kettle rated at 3 kW to prepare hot tea. The kettle contains 1 kg of water initially at 30°C. After some time, the water reaches its boiling temperature of 100°C. The teacher explains to the students observing the process that electrical energy from the kettle is converted into heat energy, which increases the temperature of the water. The specific heat capacity of water is 4200 J $kg^{-1}°C^{-1}$.
Tasks:
a) Calculate the heat energy required to raise the temperature of the water from 30°C to 100°C.
b) Estimate the time required for the water to reach 100°C.

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c) State one reason why electric kettles are designed with high power ratings when used for heating water at home or in schools.

3). In a school laboratory experiment, students investigate how heat energy is transferred between substances at different temperatures. A metal sphere of mass 100 g is heated in boiling water until its temperature reaches 100°C. The hot metal sphere is then carefully placed into a beaker containing 200 g of water at 20°C. After some time, the mixture reaches a final temperature of 25°C. The students assume that no heat is lost to the surroundings and that the specific heat capacity of water is 4200 J $kg^{-1}°C^{-1}$.
Tasks:
a) Explain why heat flows from the metal sphere to the water when they are mixed.
b) Calculate the heat gained by the water.
c) Determine the specific heat capacity of the metal sphere.
d) Give one practical application where understanding heat transfer between metals and water is important in everyday life.

Applications of High Specific Heat Capacity
In heating systems, for instance, materials with high specific heat capacity, like water, are preferred for their ability to store and transfer heat efficiently. This property is also essential in cooking, where understanding the specific heat of different materials helps determine how quickly food heats up or cools down.

In construction, materials with high specific heat, such as wood, serve as effective insulators. During hot summer months, wooden houses maintain cooler indoor temperatures, showcasing the practical benefits of specific heat capacity in energy efficiency. Large bodies of water absorb and store heat from the sun, moderating coastal temperatures and creating a more stable climate. This helps prevent extreme temperature fluctuations in coastal regions. The ocean acts as a heat reservoir, absorbing heat during the summer and releasing it during the winter, influencing weather patterns and climate stability.

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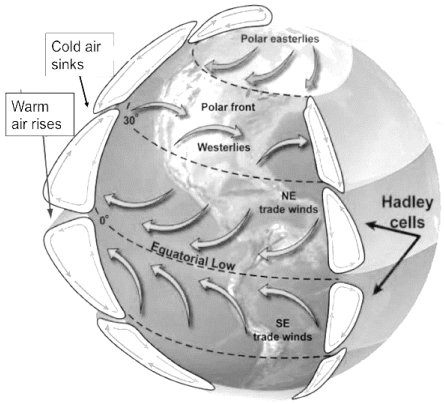
It's vital in material characterization across industries. By measuring this property, scientists can identify and select materials suitable for specific applications, enhancing performance in fields ranging from engineering to environmental science.

High specific heat capacity of water
It's used in cooling systems, particularly in nuclear power plants, where water absorbs excess heat, preventing overheating. This property is also vital in automotive and marine engines, where water is used to maintain optimal operating temperatures, ensuring safety and efficiency.
In everyday life, water's ability to retain heat is harnessed in heating systems, such as radiators and central heating. These systems rely on water to absorb and distribute heat effectively, providing warmth in homes and buildings.
Water is commonly used in firefighting, as it can absorb large amounts of heat, helping to extinguish flames more effectively. Water's high specific heat capacity is essential for maintaining stable body temperatures in living organisms, allowing for proper physiological functions. These characteristic underscores the importance of water in both industrial and biological contexts.

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Ocean currents:

An ocean current is a continuous, directed movement of seawater generated by a number of forces acting upon the water, including wind, the Coriolis effect, breaking waves, cabbeling, and temperature and salinity differences. Depth contours, shoreline configurations, and interactions with other currents influence a current's direction and strength. Ocean currents move both horizontally, on scales that can span entire oceans, as well as vertically, with vertical currents (upwelling and downwelling) playing an important role in the movement of nutrients and gases, such as carbon dioxide, between the surface and the deep ocean.



Effects of oceans on ocean currents

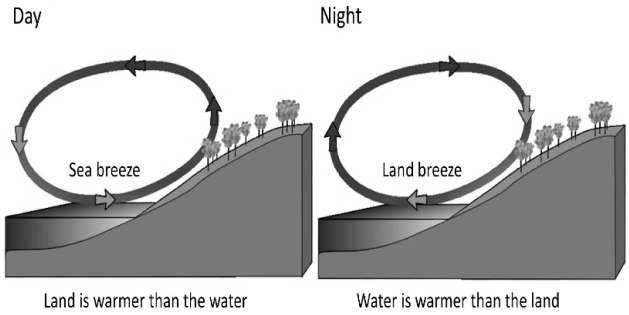
- ✓ **Ocean temperature** – Warm water is less dense and tends to move toward colder regions, while cold, dense water sinks and moves toward warmer regions. This creates thermohaline currents.
- ✓ **Salinity** – Water with high salt content is denser and sinks, while less salty water tends to remain near the surface. Differences in salinity therefore drive deep-ocean currents.
- ✓ **Ocean depth and shape** – Continents, ocean basins, ridges and trenches guide and redirect ocean currents.
- ✓ **Winds** – Winds blowing over the ocean surface push surface water and produce major surface currents.
- ✓ **Earth's rotation** – The Coriolis effect causes currents to be deflected: to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
- ✓ **Tides** – The gravitational pull of the Moon and Sun causes periodic movement of seawater, especially near coastlines.

Ocean currents are mainly controlled by wind, differences in temperature and salinity, Earth's rotation, tides, and the shape of ocean basins.

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The land and sea heat up and cool at different rates

During the summer, land heats up much faster than water due to its composition and physical properties. Land is a better conductor of heat, allowing it to absorb solar energy more quickly. This rapid heating result in higher temperatures on land compared to the cooler, slower-heating ocean.



LAND BREEZE

A land breeze is a local wind phenomenon that occurs during the night, characterized by a flow of air from land to sea. This occurs when the land cools more rapidly than the water, resulting in denser, cooler air over the land that moves offshore to replace the warmer, buoyant air over the sea.

At Night, land cools down more quickly than water. The heat absorbed during the day dissipates rapidly from the land, while the ocean retains heat longer due to its higher specific heat capacity.

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SEA BREEZE:

During the day, Sea breezes are a fascinating meteorological phenomenon that occurs during hot summer days due to the unequal heating of land and water. As the sun heats the land more quickly than the ocean, the air above the land warms up and rises, creating a low-pressure area.

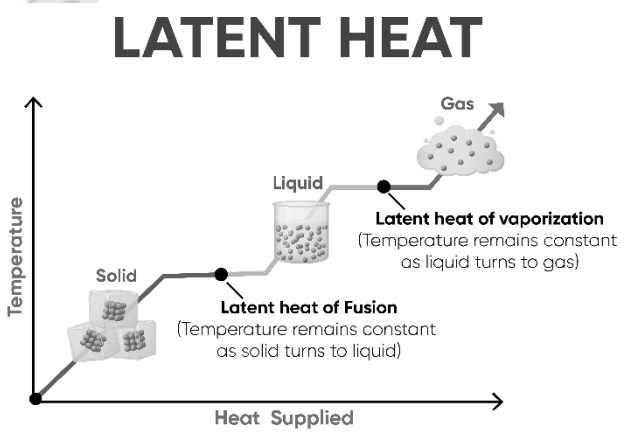
The cooler, denser air over the water moves in to fill this void, resulting in a refreshing breeze that flows from the sea to the land. The circulation consists of two opposing flows: the cool, moist air moving from the ocean and a return flow of warmer air aloft. This dynamic interaction not only provides relief from the heat but also plays a crucial role in local climate patterns

LATENT HEAT

Energy that is transferred to a solid during melting or given out by a liquid during solidification is called latent heat of fusion. Latent means hidden and fusion means melting. Latent heat does not cause a temperature change; it seems to disappear.

Latent heat refers to the hidden energy absorbed or released by a substance during a phase change, such as melting or vaporization, without altering its temperature or pressure.

For instance, when ice melts into water, it absorbs latent heat, which is essential for the transition from solid to liquid. Solar radiation is converted into both sensible and latent heat, influencing weather patterns and climate dynamics.

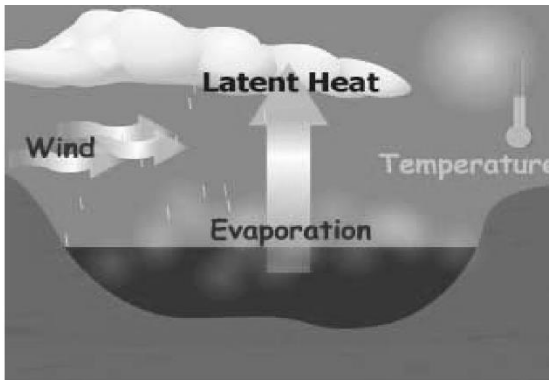


Demonstrating Latent Heat

Latent heat refers to the heat absorbed or released by a substance during a phase change (melting, boiling) without a change in temperature. The demonstration of latent heat typically involves observing these phase changes and measuring the heat involved.

Objective: To demonstrate latent heat during melting (solid to liquid) and boiling (liquid to gas) processes and understand the concept of heat absorption without a temperature change.

Materials: Ice cubes or a block of ice, Water, A thermometer or temperature probe, a heat source (Bunsen burner or electric heater), Beaker, and Stopwatch (optional).



Procedure

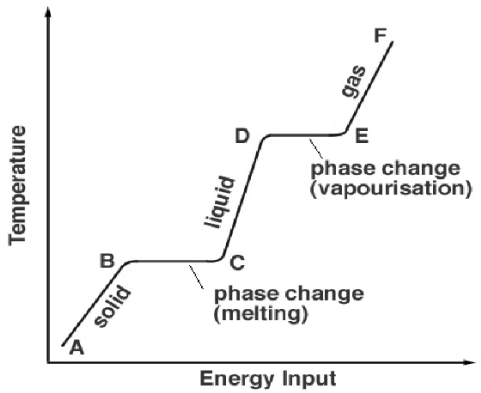
1. Demonstrating Latent Heat of Fusion (Melting Ice)

a). Place a few ice cubes in a beaker.

b). Insert a thermometer into the beaker to measure the temperature.

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c). Gradually heat the beaker using a heat source.
d).Observe the temperature as the ice begins to melt into water.
Observation: The temperature remains constant at 0∘C while the ice melts, despite continuous heating. The absorbed heat is used to overcome intermolecular forces, not to raise the temperature.



2. Demonstrating Latent Heat of Vaporization (Boiling Water)
a). Fill a beaker with water and measure its temperature.
b). Heat the water gradually until it starts boiling.
c). Monitor the temperature as the water boils and turns to steam.
Observation: The temperature remains constant at 100∘C during boiling, even though heat is continuously supplied. The heat absorbed is used to break bonds in the liquid, converting it into vapor.

Experiment to determine the total heat required to convert ice to steam

This experiment involves measuring the total heat required to convert a given mass of ice at 0∘C The total heat comprises three parts: the heat to melt the ice into water, the heat to raise the temperature of the water to boiling point, and the heat to convert the water to steam.

Apparatus: ***Ice (at 0∘C), Beaker, Thermometer, Bunsen burner or electrical heater, Stirring rod, Stopwatch, Measuring scale (to measure the mass of ice), Heatproof mat, and Data table or recording sheet***

Procedure

PART 1: Mass Measurement

a) Weigh a specific mass of ice (e.g., m=200g) using a scale.
b) Measure and record the temperature of ice as 0∘C by storing it in a controlled environment like an ice bath.

PART 2: Melting Ice to Water

c) Place the ice in a beaker.
d) Insert the thermometer into the ice-water mixture to monitor temperature changes.
e) Heat the beaker gently using a Bunsen burner or electrical heater.
f) Stir continuously to ensure uniform heat distribution.
g) Record the time (t) and temperature when all the ice has melted (final temperature remains 0◦C).

HINT: Heat supplied by water is equal to heat absorbed by the ice and the beaker. $Q_{fusion} = power * time = pt$

PART 3: Heating Water to Boiling Point

h) Continue heating the water in the beaker.
i) Monitor the temperature using the thermometer.
j) Record the time (t) and the temperature once the water reaches 100◦C

HINT: Heat supplied, $Q_{heating} = mc\Delta\theta$

PART 4: Converting Water to Steam

k) Keep heating until the water is completely converted to steam.
l) Measure the time taken (t) for the water to evaporate fully, while maintaining the temperature at 100◦C.

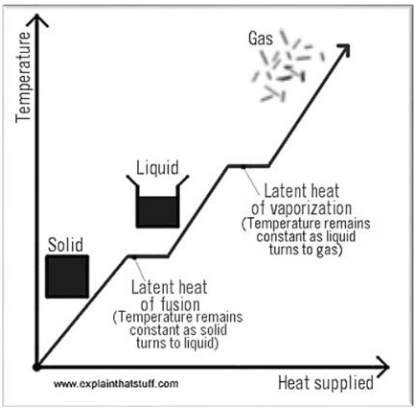
HINT: Heat supplied to covert boiling water into steam, $Q_{vaporisation} = ml_v$

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Heat Calculations

The total heat Q_{total} required can be calculated as: $Q_{\text{total}} = Q_{\text{fusion}} + Q_{\text{heating}} + Q_{\text{vaporization;}}$ Where $Q_{fusion} = ml_f$, *Heat required to melt ice, where* L_f is the latent heat of fusion (334 J/g), $Q_{heating} = mc\Delta\theta$, *Heat required to raise the temperature of water, where ccc is the specific heat capacity of water (4.18* J/g °C and $\Delta\theta = (100 - 0)^o$, $Q_{vaporisation} = ml_v$, Heat required to vaporize water, where *L*v is the latent heat of vaporization (2260 J/g)



Precautions

i). Use a consistent heat source to ensure even heating.
ii). Avoid water loss due to splashing.
iii). Monitor the temperature closely to ensure accurate data collection.
iv). Minimize heat loss to the environment by using an insulated setup, if possible.

The **latent heat of fusion refers to the energy required to change ice at 0°C into liquid water at the same temperature.**
During this phase change, the ice absorbs heat without a change in temperature. This energy is used in breaking the hydrogen bonds that hold the water molecules in a solid structure.
As heat is applied to the ice, it begins to melt, transitioning into water. This process continues until all the ice has converted to liquid. The temperature remains constant at 0°C during this phase, despite the continuous absorption of heat.
Once all the ice has melted, the resulting water can then increase in temperature as it continues to absorb heat. This increase occurs at a rate of 1.00 cal/g·°C, leading to further heating until it reaches its boiling point at 100°C.

The **latent heat of vaporization** is a crucial process in the transformation of water into steam. When liquid water reaches 100°C, it requires an additional 540 calories of heat per gram to convert into steam without changing its temperature. This energy is absorbed by the water molecules, allowing them to overcome the hydrogen bonds that hold them together in the liquid state.
During this phase change, the temperature remains constant at 100°C, even as heat is continuously supplied. This phenomenon illustrates the concept of latent heat, which refers to the hidden energy required for a substance to change its state without altering its temperature.
Once the water molecules gain enough energy, they break free from the liquid phase and enter the gaseous state as steam. This process is essential in various applications, including cooking, power generation, and even weather patterns, highlighting the importance of understanding latent heat in both scientific and practical contexts.

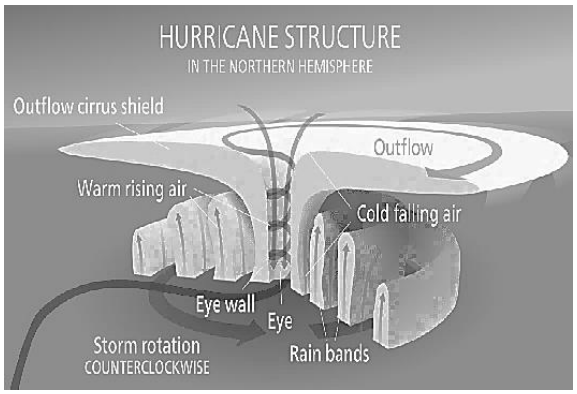
ENERGY IN THE STORM

A storm is a weather system involving strong winds, heavy rainfall, lightning, thunder, and sometimes hail.
A storm contains and transfers large amounts of energy, mainly originating from the Sun. The Sun heats the Earth's surface unevenly. Water on oceans, lakes and other water bodies absorbs this energy, causing water to evaporate. The water vapour carries latent heat energy into the atmosphere. As warm, moist air rises, it expands and cools. The water vapour condenses into tiny water droplets or ice crystals, forming clouds.

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During condensation, latent heat is released into the surrounding air. This released heat makes the surrounding air warmer and less dense, causing it to rise further. The release of latent heat strengthens upward movement of air, called an updraft.



Strong updrafts can carry water droplets and ice particles high into the atmosphere. The stronger the updraft, the more powerful the storm can become.
Water droplets and ice particles lifted high into a cloud gain gravitational potential energy. When these particles fall as rain or hail, this energy is converted mainly into kinetic energy.

Inside a thunderstorm, collisions between ice crystals, hail and water droplets cause electrical charges to separate. Different parts of the cloud become electrically charged. When the potential difference becomes sufficiently large, an electrical discharge occurs. This produces lightning. Lightning converts electrical energy into Light energy, Heat energy and Sound energy. The rapid heating and expansion of air produces thunder.
Pressure differences within the storm cause air to move from areas of higher pressure toward areas of lower pressure. The moving air possesses kinetic energy. This kinetic energy is responsible for the destructive effects of strong winds. Energy transformations in a storm

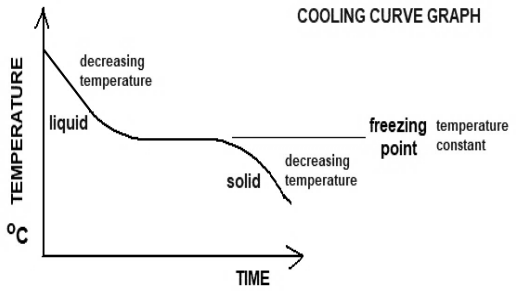
A simplified energy chain is **solar energy → evaporation → latent heat energy → convection → kinetic energy of winds → electrical energy → lightning, heat and sound**

A storm can be thought of as a large natural energy-conversion system. Energy from the Sun is stored in water vapour and atmospheric temperature differences and is later transformed into the movement of air, rainfall, lightning, thunder and other forms of energy.

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Stearic acid changes with temperature
Stearic acid, a saturated fatty acid, exhibits distinct changes in its physical state with temperature variations. The melting point of stearic acid is typically around 69.3°C, while its freezing point can vary slightly depending on purity.

During the phase transition from solid to liquid, the temperature remains constant, indicating that energy is being absorbed to break intermolecular forces rather than increasing kinetic energy.
In a cooling curve experiment, stearic acid is cooled at a constant rate, starting from a liquid state above its freezing point. As it cools, the temperature decreases steadily until it reaches the melting point, where it flattens out, signifying the phase change.
Once fully solidified, the temperature continues to drop, demonstrating the cooling process of the solid state.



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Experiment to investigate how stearic acid changes with temperature

Materials Needed: *Stearic acid (solid), Heating apparatus (water bath or hot plate), Thermometer, Beaker, Ice bath (optional, for cooling), Stirring rod, and Scale (for measuring mass)*

Procedure

a). Place a known mass of stearic acid in a beaker.

b). Set up the heating apparatus to gradually heat the beaker while monitoring the temperature with a thermometer.

c). Gradually heat the stearic acid while stirring gently to ensure uniform temperature distribution.

d). Record the temperature at regular intervals (e.g., every 1-2 minutes).

e). Observe the state of the stearic acid (solid, liquid) at each temperature.

f). Continue heating until you notice a change in state from solid to liquid.

g). Carefully note the temperature at which the stearic acid begins to melt (melting point).

h). Once the stearic acid is fully melted, remove it from the heat and allow it to cool naturally or place it in an ice bath.

i). Record the temperature at regular intervals as it cools and observe the state change back to solid, and note the temperature at which the stearic acid begins to solidify (freezing point).

Findings and Explanation

Melting Phase: As the temperature increases and reaches the melting point, stearic acid absorbs heat (latent heat of fusion) without a temperature increase. During this phase change, the energy is used to break the intermolecular forces holding the solid structure, allowing particles to move more freely in the liquid state.

Liquid Phase: Once completely melted, the stearic acid exists as a liquid, and further heating raises its temperature until reaching its boiling point (if applicable). The liquid, increasing the kinetic energy of the particles, absorbs heat.

Cooling Phase: When cooling, stearic acid loses heat (latent heat of solidification) as it transitions from liquid to solid. During this phase change, the energy released allows the particles to arrange themselves into a solid structure, which involves the formation of intermolecular bonds.

Freezing Phase: The temperature remains constant during the phase change from liquid to solid, as the energy is released rather than resulting in a temperature decrease.

The investigation demonstrates that stearic acid undergoes phase changes (melting and freezing) at specific temperatures, during which it absorbs or releases heat without a change in temperature. This behavior illustrates the concepts of latent heat and the energy dynamics involved in phase transitions.

SPECIFIC LATENT HEAT

Specific latent heat (L) is the amount of energy required to change the phase of a 1kg mass of a substance without altering its temperature.

This energy transfer occurs during phase changes, such as melting or boiling, where the temperature remains constant despite the absorption or release of heat. Expressed mathematically **as $Q = mL$,** $\mathbf{L = \frac{Q(J)}{m(kg)}}$**,** where Q is the heat (thermal) energy, m is the mass, and L is the specific latent heat. For instance, the specific latent heat of fusion refers to the energy needed to convert a solid into a liquid at a constant temperature, while the specific latent heat of vaporization pertains to the energy required to transform a liquid into a gas.

Units: joules per kilogram (J/kg). The formula to calculate latent heat is: Q=mL, Where: Q = heat energy absorbed or released (in joules, J), m = mass of the substance (in kilograms, kg), L = specific latent heat

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of the substance (in J/kg). Let us assume you are melting 0.5 kg of ice at 0°C. The latent heat of fusion for ice is approximately 334,000 J/kg.
$Q=mL_f=0.5kg\times334{,}000kgJ$ $Q=167{,}000J$.
This means **167,000 joules** of heat are required to melt 0.5 kg of ice without raising its temperature.

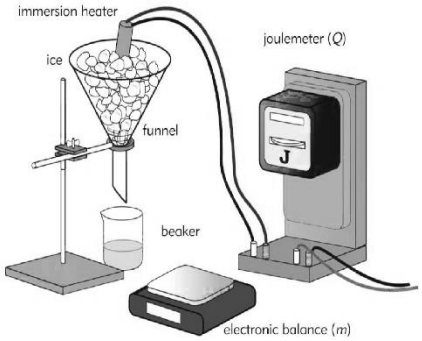
Specific Latent Heat of Fusion

The specific latent heat of fusion is the amount of heat energy required to convert a 1kg mass of a solid into a liquid at a constant temperature (without temperature change).
This process occurs without any change in temperature, highlighting the idea of "**hidden" energy**. For instance, the specific latent heat of fusion for water i.e. solid into a liquid at its melting point (e.g., ice to water). is approximately 334 kJ/kg (334,000 J/kg), meaning that this amount of energy is needed to melt 1 kg of ice into water. Mathematically; $\boldsymbol{Q = mL_f}$, *and* where $\boldsymbol{L_f = \frac{Q(J)}{m(kg)}}$.

***Experimental investigation of specific latent heat (latent heat of fusion)* of fusion for ice**

Apparatus: Ice, Calorimeter (or insulated container), Water at room temperature, Thermometer, Balance (for mass), and joulemeter or heating element
Method:
Measure the mass of the calorimeter $\boldsymbol{m_c}$ ***and*** stirrer, add some warm water in it and weigh again $\boldsymbol{m_w}$
Record the initial temperature of the water in calorimeter $\boldsymbol{\theta_1}$
Add ice $\boldsymbol{0^0C}$ ***into the water and allow it to melt completely while stirring to ensure even distribution of temperature.***
Record the final temperature $\boldsymbol{\theta_2}$ of the water after all the ice has melted.
Measure the mass of the calorimeter and its contents $\boldsymbol{m_2}$ to determine the mass of the melted ice, from $\boldsymbol{m_{ice} = m_2 - (m_c + m_w)}$.
Using the formula $\boldsymbol{Q = mc\Delta\theta}$, to find the energy lost by the water as it cools.
Use Q= ml_f, to calculate the specific latent heat of fusion for ice, where Q is the energy absorbed by the ice to melt.

Measuring Specific Latent Heat of Fusion



From energy conservation, Energy supplied=Energy gained.
Total Energy gained by ice to melt and boil to 100°C**,**
$\boldsymbol{E = m_{ice}l_f + m_{ice}c_{water}\theta_2}$.
Energy supplied $\mathbf{E_{supplied} = (m_c c_c + m_w c_w)(\theta_1 - \theta_2)}$
Finally use the equation to find latent heat of fusion of ice;
$\boldsymbol{m_{ice}l_f + m_{ice}c_{water}\theta_2 = (m_c c_c + m_w c_w)(\theta_1 - \theta_2)}$

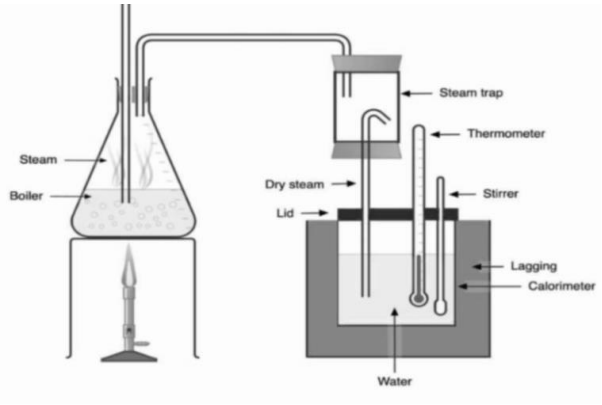
Specific Latent Heat of Vaporization

Specific latent heat of vaporization is the amount of heat energy required to convert a unit mass of a substance from its liquid state to vapor without any change in temperature.
For instance, when water boils, it absorbs heat energy, allowing it to transition into steam while remaining at 100°C.This latent heat is found in applications including meteorology, cooking, and industrial processes. The specific latent heat of vaporization for water is approximately 2260 kJ/kg, meaning that 2260 kilojoules of energy (liquid into a gas at its boiling point (water to steam).

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For water, this is approximately (2,260,000 J/kg, heat energy required to change a liquid into a gas at its boiling point (e.g., water to steam) are needed to vaporize one kilogram of water. This high energy requirement explains why boiling water takes time, even when heat is continuously applied.

Experimental investigation of specific latent heat (latent heat of vaporization)



Apparatus

Calorimeter, lagging, beaker, conical flask fitted with stopper and delivery tube or steam generator, steam trap, retort stand, heat source, thermometer accurate to 0.1 °C and electronic balance.

Procedure

a) Half fill the conical flask or steam generator with water and fit with the delivery tube.
b) Heat until steam issues freely.
c) Find the mass of the empty calorimeter with stirrer, m_c
d) Half fill the calorimeter with water cooled to approximately 10 °C below room temperature.
e) Find the mass of the water plus calorimeter, m_0
f) The mass of the cooled water, $m_w = (m_0 - m_c)$.
g) Record the temperature of the calorimeter plus water, θ_o
h) Allow dry steam to pass into the water in the calorimeter until the temperature has risen by about 20 °C.
i) Remove the steam delivery tube from the water, taking care not to remove any water from the calorimeter in the process.
j) Record the final temperature of the calorimeter plus water plus condensed steam, θ_1. *The fall in temperature of the steam is,* $\Delta\theta = (100 - \theta_1)°C$
k) The rise in the temperature of the calorimeter plus water, $\Delta T = \theta_1 - \theta_o$
l) Find the mass of the calorimeter plus water plus condensed steam, m_1. *Hence the mass of the condensed steam* $m_s = (m_1 - m_o)$

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Results

Mass of the calorimeter	m_c
Mass of the water plus calorimeter	m_0
Mass of the cooled water	$m_w = (m_0 - m_c)$
Temperature of the calorimeter plus water	θ_o
Final temperature of the calorimeter plus water plus condensed steam	θ_1
Fall in temperature of the steam	$\Delta\theta = (100 - \theta_1)°C$
Rise in the temperature of the calorimeter plus water	$\Delta T = \theta_1 - \theta_o$
Mass of the calorimeter plus water plus condensed steam	m_1
Mass of the condensed steam	$m_s = (m_1 - m_o)$

Calculations

Assume heat losses to the surroundings cancel heat gains from the surroundings. Given that the specific heat capacity of water c_w and the specific heat capacity of copper c_c *are already known, the specific latent heat of vaporization of water* L_V *may be calculated from the following equation:*

Energy lost by steam = energy gained by calorimeter + energy gained by the water

Energy lost by steam $= \boldsymbol{m_s l_f + m_s c_w}(100 - \theta_1)°$

Energy gained by calorimeter + Energy gained by the water $= (\boldsymbol{m_w c_w + m_c c_c})(\theta_1 - \theta_o)$

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$\boldsymbol{m_s l_f + m_s c_w}(100 - \theta_1)°= =(\boldsymbol{m_w c_w + m_c c_c})(\theta_1 - \theta_o)$

Effect of Latent Heat of Vaporization of Steam
Latent heat of vaporization is the amount of heat energy required to change 1 kg of a liquid into vapour at constant temperature.

For water: **Lv≈2.26×10^6 J/kg**. This means 1 kg of water requires about 2.26 MJ of energy to change into steam at its boiling point without a change in temperature.

Why steam causes a greater heating effect
When water is converted into steam, it absorbs a large amount of latent heat. This energy is stored in the steam. When the steam meets a cooler object, it condenses back into water and releases the stored latent heat. Therefore, steam at 100°C can cause more severe burns than water at 100°C because steam releases additional latent heat when it condenses on the skin.

Example
Suppose 0.1 kg (100 g) of steam at 100°C condenses to water at 100°C. The heat released is: $Q = mLv, Q = 226{,}000J,$ Therefore, 100 g of steam releases 226 kJ of energy simply by condensing.
If the resulting water then cools from 100°C to body temperature, it releases even more heat.
Applications
- ✓ Steam turbines for generating electricity.
- ✓ Steam irons for removing wrinkles from clothes.
- ✓ Sterilization of medical equipment.
- ✓ Cooking, especially pressure-cooking.
- ✓ Heating systems in industries.
- ✓ In storms

Latent heat of vaporization aids storm formation. Water evaporates from oceans and other water bodies, absorbing energy. When the water vapour rises and condenses in clouds, this energy is released as latent heat, warming the surrounding air and providing energy that can strengthen thunderstorms.
Evaporation absorbs latent heat, while condensation of steam releases latent heat. This released energy can produce a powerful heating effect.

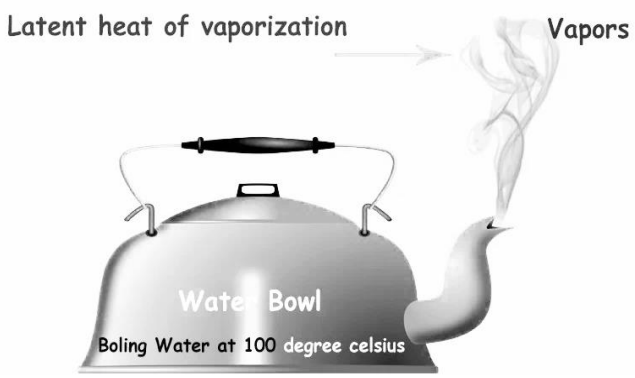
Industrial Applications
- ✓ Electricity generation. Produces high-pressure steam. Steam drives turbines connected to generators.
- ✓ Industrial heating: Provides heat for manufacturing processes. Used in food, textile, paper and chemical industries.
- ✓ Sterilization: Kills microorganisms using high-temperature steam. Used for medical and laboratory equipment.
- ✓ Food processing: Used for cooking, pasteurization and blanching. Helps maintain hygienic production.
- ✓ Drying: Provides controlled heat for drying paper, textiles, timber and agricultural products.
- ✓ Steam cleaning: Removes dirt, grease, oil and microorganisms from machinery and surfaces.
- ✓ Chemical processing: Used for heating, evaporation and distillation.

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- ✓ Petroleum refining: Provides heat during petroleum separation and processing.
- ✓ Mechanical work: Steam drives turbines and steam engines to produce mechanical energy.

Main reason for using steam:
Steam transfers large amounts of heat energy because it releases substantial latent heat when it condenses.



Climatic and Environmental Effects

- ✓ Evaporation causes cooling by absorbing latent heat from the surroundings.
- ✓ Sweating cools the body through evaporation.
- ✓ Evaporation from lakes, rivers and oceans helps regulate temperatures.
- ✓ During condensation, stored latent heat is released into the atmosphere.
- ✓ Released heat drives convection currents and contributes to storms, thunderstorms and hurricanes.
- ✓ Latent heat is essential to the water cycle.
- ✓ The absorption and release of latent heat helps maintain Earth's energy balance.

Applications of high specific latent heat of water

Water has a high specific heat capacity, meaning it requires a large amount of heat energy to raise its temperature. Therefore, water can absorb or store a lot of heat without changing temperature rapidly.

- ✓ Main uses
- ✓ Cooling engines: Water is used as a coolant in car engines and industrial machines because it absorbs large amounts of heat.
- ✓ Cooling power stations: Water absorbs heat from machinery and steam-generation systems in power plants.
- ✓ Central heating systems: Hot water carries large amounts of thermal energy from a boiler to rooms in buildings.
- ✓ Temperature regulation in living organisms: Water in the body absorbs heat and helps maintain a relatively constant body temperature.
- ✓ Climate regulation: Oceans and large lakes absorb large amounts of solar heat, helping to moderate temperatures in coastal and surrounding areas.
- ✓ Heating and cooling systems: Water can store considerable thermal energy and is therefore useful in thermal energy storage systems.
- ✓ High specific heat capacity → water absorbs a lot of heat with only a small rise in temperature → effective cooling, heating and temperature regulation.

Oceans role in regulating global temperatures through several mechanisms

Oceans regulate global temperatures through several important mechanisms:

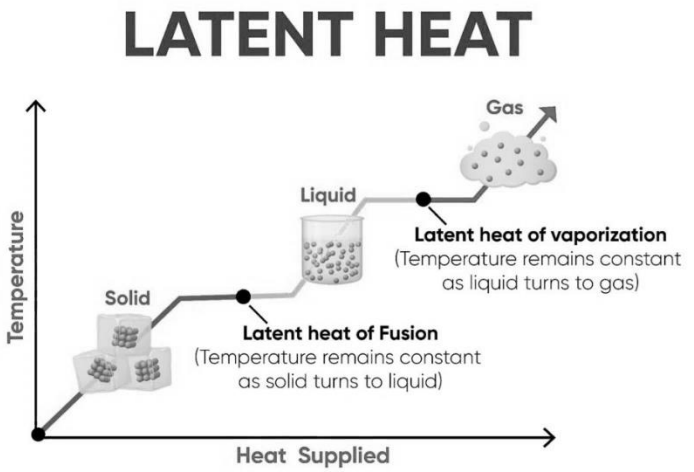
- ✓ **High specific heat capacity:** Water absorbs large amounts of heat with only a small rise in temperature. Oceans therefore store large amounts of solar energy.
- ✓ **Ocean currents:** Currents transport heat from warm tropical regions toward colder regions and return colder water toward warmer regions. This distributes heat around the Earth.

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- ✓ **Evaporation:** Evaporation absorbs large amounts of heat from the ocean surface, producing a cooling effect. The water vapour later releases this heat when it condenses.
- ✓ **Cloud formation:** Ocean evaporation supplies water vapour for cloud formation. Clouds can reflect some incoming solar radiation, reducing the amount of energy reaching Earth's surface.
- ✓ **Latent heat transfer:** Heat absorbed during evaporation is transported in water vapour. When vapour condenses, the stored latent heat is released into the atmosphere, influencing weather and climate.
- ✓ **Moderation of coastal temperatures:** Oceans heat and cool more slowly than land. Coastal areas therefore generally experience smaller temperature variations than inland areas.

Oceans act as a giant global heat reservoir: they absorb, store, transport and release heat, helping to prevent extreme temperature changes and maintain Earth's climate balance.

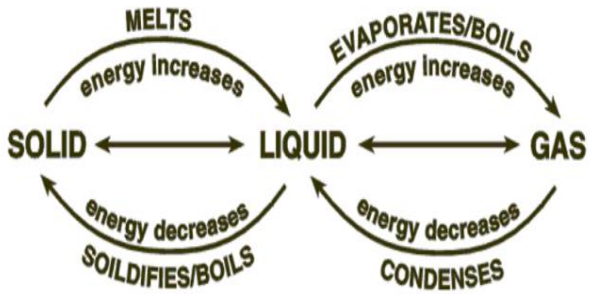
Latent heat and change of state



Latent heat refers to the energy absorbed or released by a substance during a phase change, such as melting or boiling, without altering its temperature. This hidden energy is helps in understanding how materials transition between solid, liquid, and gas states.

The amount of latent heat involved in these changes depends on the number and strength of molecular bonds within the substance.

For instance, the latent heat of fusion is the energy required to convert a solid into a liquid at its melting point, while the latent heat of vaporization is the energy needed to transform a liquid into a gas at its boiling point. These processes are reversible; a liquid can solidify back into a solid when cooled, releasing the same amount of latent heat.



Kinetic theory and change of state of a substance

Melting and solidification

The kinetic particle model explains the energy absorbed in melting as being the energy that enables the particles of a solid to overcome the intermolecular forces that hold them in place, and when it exceeds a certain value, they break free. Their vibratory motion about fixed positions changes to the slightly greater range of movement they have as liquid particles, and the solid melts.

In the reverse process of solidification in which the liquid returns to the solid state, where the range of movement of the particles is less, potential energy is transferred from the particles to thermal energy in the surroundings.

The energy input in melting is used to increase the potential energy (ΔEp) of the particles, but not their average kinetic energy (Ek) as happens when the energy input causes a temperature rise.

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Vaporisation and condensation

Evaporation occurs when faster-moving particles escape from the surface of the liquid. The average speed and therefore the average kinetic energy of the particles left behind decreases, i.e. the temperature of the liquid falls. This energy increases the potential energy of the particles but not their kinetic energy. Energy is also required to push back the surrounding atmosphere in the large expansion that occurs when a liquid vaporises.

Cooling by contact: When evaporation occurs from a liquid and the average kinetic energy of the remaining particles decreases, the liquid cools. If an object is in contact with the liquid during evaporation, thermal energy will flow from the object to the liquid. The object will cool until its temperature equals that of the liquid.

Conditions affecting evaporation

Evaporation happens more rapidly when

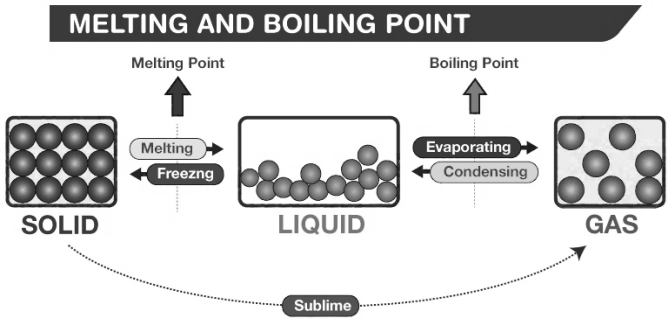
- ✓ the temperature is higher, since then more particles in the liquid are moving fast enough to escape from the surface
- ✓ the surface area of the liquid is large, so giving more particles a chance to escape because more are near the surface
- ✓ a wind or draught is blowing over the surface carrying vapour particles away from the surface, thus stopping them from returning to the liquid and making it easier for more liquid particles to break free. (Evaporation into a vacuum occurs much more rapidly than into a region where there are gas particles.)

In the reverse process of condensation, in which a vapour returns to the liquid state, where the particles are closer together, potential energy is transferred from the particles to thermal energy in the surroundings.

Uses of evaporation

- ✓ Water evaporates from the skin when we sweat. This is the body's way of losing unwanted heat and keeping a constant temperature. After vigorous exercise there is a risk of the body being overcooled, especially in a draught; it is then less able to resist infection.
- ✓ Ether acts as a local anaesthetic by chilling (as well as cleaning) your arm when you are having an injection. Refrigerators, freezers and air-conditioning systems use cooling by evaporation on a large scale.
- ✓ Volatile liquids are used in perfumes.

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Boiling and melting

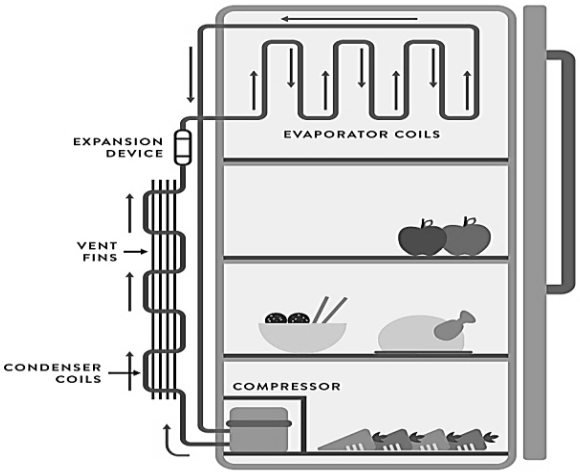
In solids, particles are closely packed and vibrate in fixed positions, resulting in a definite shape and volume. When heat is applied, the particles gain energy, leading to melting, and the transition from solid to liquid. At the melting point, the added energy breaks the bonds holding the particles together, allowing them to move more freely.

For a pure liquid, boiling occurs at a definite temperature called its **boiling temperature** and is accompanied by bubbles that form within the liquid, containing the gaseous or vapour form of the particular substance.

Energy is needed in both evaporation and boiling and is stored in the vapour, from which it is released when the vapour is cooled or compressed and changes to liquid again.

At this temperature, the particles gain enough energy to overcome the attractive forces between them, transitioning into the gas phase. This process involves the formation of vapor bubbles within the liquid, which rise and escape into the air. Both melting and boiling illustrate how energy input affects particle movement and state changes, highlighting the dynamic nature of matter as described by the kinetic theory.

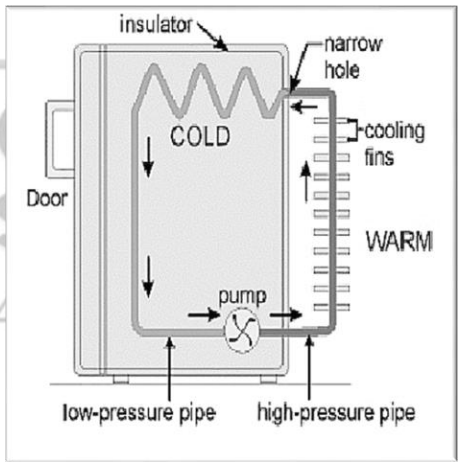
Application of latent heat in refrigerators



Refrigerators use latent heat during evaporation and condensation of a refrigerant to transfer heat from inside the refrigerator to the surroundings.

How it works

- ✓ **Evaporation – cooling effect.** A refrigerant evaporates inside the evaporator coils. It absorbs a large amount of latent heat from the refrigerator compartment. This removes heat and cools the food and air inside.
- ✓ **Compression:** the compressor compresses the refrigerant vapour. Its pressure and temperature increase.
- ✓ **Condensation – heat release.** The hot refrigerant passes through the condenser coils outside the refrigerator. It condenses into a liquid and releases the absorbed heat to the surroundings.
- ✓ **Expansion:** The liquid refrigerant passes through an expansion device, where its pressure and temperature decrease. It then returns to the evaporator to absorb more heat.
- ✓ Energy transfer
- ✓ **Inside refrigerator:** Heat absorbed → refrigerant evaporates → cooling
- ✓ **Outside refrigerator:** Refrigerant condenses → heat released → warming of surroundings



Refrigerators use the high latent heat of vaporization of a refrigerant to absorb heat during evaporation and release it during condensation. The refrigerator continuously transfers heat from a cold region to a warmer surrounding environment.

VAPOURS

A vapor is a gaseous phase of a substance that typically exists as a liquid or solid at room temperature. It can coexist with its condensed phases, meaning it can transition back to liquid or solid under certain conditions, such as changes in pressure or temperature.

A gas is defined as a single substance in the gaseous state at a given temperature and pressure, without any coexistence with its liquid or solid forms. Gases do not condense into liquids or solids under normal conditions, making them more stable in their gaseous state.

Summary, while both vapors and gases are in the gaseous state, vapors are associated with substances that can transition between phases, whereas gases are stable, single-phase substances. This characteristic allows vapours to be condensed into liquids under certain conditions. The process of crystallization from vapour involves gas molecules attaching to a surface and arranging themselves into a crystal structure,

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which is crucial in various scientific applications. Vapour pressure refers to the pressure exerted by vapour in equilibrium with its liquid phase. This pressure is solely influenced by temperature, affecting phenomena such as evaporation rates.

Saturated and Unsaturated Vapours

A saturated vapor is a vapor that is in contact with its own liquid within a confined space, **meaning it cannot hold any more moisture at a given temperature.** When the enclosed space above a liquid is saturated with vapor molecules and can hold no more molecules, the pressure exerted by this saturated vapor is said to be the saturated vapor pressure (s. v. p) of the liquid. The vapor is said to be saturated when the number of molecules escaping from the liquid per unit is equal to the number returning to the liquid per unit time. The saturated vapor is thus said to be in a state of dynamic equilibrium with its own liquid. Saturated vapor pressure increases with temperature. As temperature increases, the saturated vapour pressure also rises, allowing the air to hold more water vapour. This is crucial in understanding weather patterns and humidity levels.

U**nsaturated vapour exists when the vapor is not in contact with its liquid phase, meaning it can still absorb more moisture**. The unsaturated vapor is the vapor which is not in contact with its own liquid in a confine space. It is not in dynamic equilibrium with its own liquid. The rate at which the liquid evaporates is greater than the rate at which the liquid condenses. Thus, the pressure exerted by a vapor which is not in contact with its own liquid in a confined space is called unsaturated vapor pressure. Unsaturated vapour can transition to a saturated state by either decreasing the volume or increasing the temperature, which is essential in various applications, including HVAC systems and environmental science. The differences between these types of vapours is vital for fields such as meteorology, engineering, and environmental studies, as they influence processes like condensation, evaporation, and humidity control.

Vapor Pressure: When a liquid evaporates in a closed container, the vapor formed above the liquid exerts a pressure. According to kinetic molecular theory, the molecules of the vapor are in constant motion and will hence exert a pressure just like the molecules of a gas. This pressure is called the vapor pressure of the liquid.

Saturated vapour pressure (SVP) is the pressure exerted by a vapour when it is in equilibrium with its liquid at a specific temperature. At this point, the maximum amount of vapour that can exist above the liquid has been reached. SVP depends on temperature: as temperature increases, the kinetic energy of the liquid's molecules increases, leading to higher evaporation rates, and hence a higher saturated vapour pressure.

Relation to Boiling and Evaporation

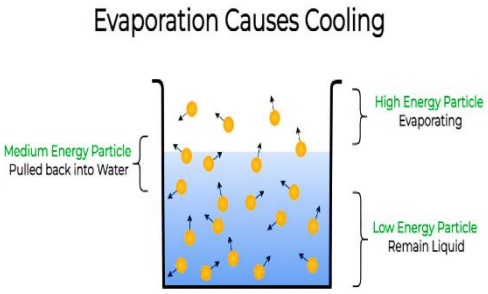
Evaporation is the process where molecules at the surface of a liquid gain enough energy to escape into the vapour phase**.** Evaporation can occur at any temperature**,** as long as the vapour above the liquid is unsaturated. It only affects surface molecules, and it continues until the vapour becomes saturated, meaning the rate of condensation matches the rate of evaporation. Evaporation is a slower process and does not require the liquid to reach its boiling point. Boiling occurs when the vapour pressure of the liquid equals the external (atmospheric) pressure**.** At this point, bubbles of vapour can form within the liquid and rise to the surface. The boiling point is the temperature at which the saturated vapour pressure of the liquid equals the atmospheric pressure. Unlike evaporation, which only happens at the surface, boiling occurs throughout the entire liquid because bubbles of vapour can form inside the liquid once the saturated vapour pressure matches the external pressure.

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Boiling and Evaporation

Boiling is the rapid change of a liquid into a gas throughout the entire liquid. According to particle theory, as a liquid is heated, its particles gain kinetic energy and move faster. At the boiling point, the particles have enough energy to overcome the intermolecular forces holding them together in the liquid. At this temperature, the liquid's vapour pressure becomes equal to the external (atmospheric) pressure, and bubbles of vapour form within the liquid and rise to the surface to escape into the gas phase. Boiling happens at a specific temperature (the boiling point), which depends on the external pressure. Evaporation is the slow change of a liquid into a gas at the surface of the liquid. Unlike boiling, evaporation can occur at any temperature. The particles at the surface of the liquid with the highest kinetic energy are able to escape the liquid phase and enter the gas phase. This process happens because some surface particles have enough energy to overcome the intermolecular forces binding them to the liquid, even at lower temperatures. Evaporation only occurs from the surface and does not require the liquid to reach its boiling point.

Perspiration in Mammals



Mammals, including humans, use perspiration (sweating) to regulate their body temperature, especially in hot environments or during physical exertion. When mammals sweat, their bodies release water onto the surface of the skin. The evaporation of this sweat cools the body. The water molecules in sweat absorb latent heat from the skin as they transition from liquid to gas. This energy is used to break the bonds between the water molecules, allowing them to evaporate. As a result, heat is removed from the body, leading to a cooling effect and helping to maintain a constant internal temperature. This process is part of thermoregulation, ensuring that mammals stay within a safe temperature range despite environmental changes.

Cooling Effect of Evaporation

The cooling effect of evaporation occurs when a liquid transitions into a gas. This process requires energy, which is drawn from the surrounding environment, resulting in a decrease in temperature. For instance, when alcohol evaporates quickly, it cools the surface of the skin, demonstrating how rapid evaporation enhances cooling. Evaporative cooling is not only a natural occurrence but also a principle utilized in various technologies. Systems designed for evaporative cooling, such as those used in air conditioning, leverage this effect to lower temperatures efficiently. As water evaporates, it absorbs heat from the remaining liquid, leading to a cooler environment. Innovations, like self-cooling artificial grass, harness this principle to combat urban heat. By allowing rainwater to evaporate, these surfaces can remain significantly cooler than traditional materials, showcasing the practical applications of evaporative cooling in managing extreme weather conditions.

How Evaporation Causes Cooling

Evaporation is a natural process that leads to cooling, due to the energy dynamics of liquid molecules. When a liquid, such as water, is exposed to air, the molecules at the surface gain energy from their surroundings. This energy allows them to overcome intermolecular forces and transition into vapor. As these high-energy molecules escape, the average kinetic energy of the remaining liquid decreases, resulting in a drop in temperature. This cooling effect is evident in everyday scenarios, such as when sweat evaporates from our skin, providing a refreshing sensation on a hot day. The process is not only limited

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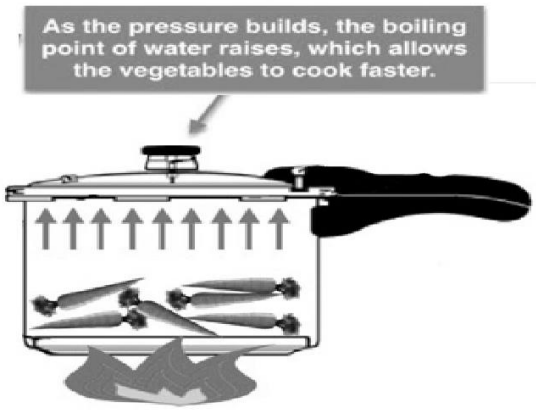
to water; any liquid can exhibit this cooling effect during evaporation. During evaporation, the molecules with the highest energy (highest velocity) are the ones that escape the liquid's surface. As the more energetic molecules leave the liquid, they take their heat energy with them. The average kinetic energy (which determines temperature) of the remaining molecules in the liquid decreases, leading to a cooling effect. This process of removing higher-energy particles reduces the temperature of the remaining liquid. For example, if water evaporates from your skin, the surface temperature of your skin drops because the water molecules absorb heat from the skin to evaporate.

Why water boils at a temperature less than 100°c at the top of a mountain.

The boiling point of water decreases at higher altitudes because of the reduction in atmospheric pressure. At sea level, atmospheric pressure is higher, and water boils at 100°C because the vapour pressure of the water must match the atmospheric pressure to allow bubbles of vapour to form within the liquid. At higher altitudes, the atmospheric pressure is lower, so water needs less energy (i.e., lower temperature) to reach the point where its vapour pressure equals the external pressure. For example, on top of a mountain, where the atmospheric pressure is much lower than at sea level, water may boil at 90°C or even lower, depending on the height.

How a Pressure Cooker Works?

A pressure cooker is a specialized kitchen appliance that utilizes steam and high pressure to cook food more quickly than traditional methods. A pressure cooker is a sealed cooking pot that increases the pressure inside by trapping steam. This elevated pressure allows the temperature of boiling water to rise above its normal boiling point of 100°C, speeding up the cooking process. When a liquid inside the pressure cooker is heated, it boils and turns into steam. This steam cannot escape, leading to an increase in pressure within the chamber.



As the pressure rises, the boiling point of water also increases, allowing food to cook at higher temperatures. The pressure might rise to 15 psi (pounds per square inch) above atmospheric pressure, which increases the boiling point of water to about 121°C (250°F). At this higher temperature, food cooks faster because the increased kinetic energy of the water molecules speeds up the chemical reactions involved in cooking. The higher pressure also forces moisture into the food, further accelerating the cooking process, but also helps retain moisture and flavor in the food. The high-pressure steam penetrates food more effectively, resulting in tender and flavorful dishes. Pressure cookers can significantly reduce cooking times for various foods, from beans to tough cuts of meat.

Chapter Assessment

1). In many homes in rural parts of Uganda, families store milk and other liquids without refrigerators. One common method is placing bottles of milk inside a porous clay pot filled with water and keeping the pot in a windy or airy place to keep the milk cool. At a nearby secondary school laboratory, learners are also investigating how liquids cool and eventually solidify. During one experiment, a pure solid is heated until it melts and then allowed to cool while students carefully record temperature changes over time. A learner is heating 10 g of a liquid in the laboratory. The liquid has a specific heat capacity of 4.0 J $g^{-1}°C^{-1}$. Its temperature rises from 20°C to 50°C. At home, a bottle of milk keeps fresh longer when it is placed in water inside a porous clay pot and kept in a draught (moving air).

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Task: Use your knowledge of physics;
a) Calculate the amount of heat energy required to cause the temperature change.
b) Explain why the pot helps to keep the milk cool and fresh.

2). During a school experiment, a pure solid is heated in a test tube placed in hot water until it melts completely and reaches 90°C. The test tube is then removed from the hot water and the temperature of the liquid is recorded every 2 minutes as it cools and eventually becomes solid.

Time (minutes)	0	2	4	6	8	10	12	14	16	18
Temperature (°C)	90	86	82	81	80	80	79	76	73	72

a) Plot a graph of temperature (°C) against time (minutes).
b) From the graph or table, estimate the melting temperature of the solid and explain how you obtained your answer.
c) Explain what happens to the arrangement and movement of particles in the liquid as it changes into a solid.

3.7 STARS AND GALAXIES

Learning Outcomes

a) Know the source of energy in stars and appreciate the importance of the energy produced by the sun to the people on Earth (k,u)
b) Appreciate that stars vary in colour and brightness(u)
c) Know that stars have life cycles and that the fate of stars (white dwarfs, neutron stars and black holes) depends on their initial size (k,u)



Introduction

The Sun is our closest star and is so bright that it banishes the darkness of space with its light.
The radiation it emits comes from glowing hydrogen and provides energy for all life on the Earth. The hydrogen is heated by the energy released in nuclear reactions in the Sun's interior. In stable stars these reactions involve the conversion of hydrogen into helium by nuclear fusion. Stars have several stages in their life cycle and our Sun is currently in its stable phase which will last for a few more billion years

A star's life begins with the gravitational collapse of a gaseous nebula of material largely comprising hydrogen, helium, and trace heavier elements. Its total mass mainly determines its evolution and eventual fate. A star shines for most of its active life due to the thermonuclear fusion of hydrogen into helium in its core. This process releases energy that traverses the star's interior and radiates into outer space. At the end of a star's lifetime as a fusor, its core becomes a stellar remnant: a white dwarf, a neutron star, or if it is sufficiently massive a black hole.
A galaxy is a massive system composed of stars, stellar remnants, interstellar gas, dust, and dark matter, all bound together by gravity.

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Meanwhile, studies reveal that isolated dwarf galaxies have experienced an early end to their star-forming activities, highlighting the complex dynamics of gas and star formation. As we continue to explore the cosmos, tools like the Hubble Space Telescope unveil intricate details of galaxies, allowing us to appreciate the vastness and beauty of the universe.

Origin of the stars

Stars are giant balls of hot gases that can produce their own light. Stars give out energy by converting Hydrogen gas into Helium in their cores. When interstellar clouds of dust and gas containing hydrogen collapse under the force of gravitational attraction, a protostar is formed. As the mass of the protostar increases, its core temperature rises; gravitational potential energy is transferred to kinetic energy as the protostar contracts under internal gravitational forces. When the core is hot enough, nuclear fusion can start; hydrogen is converted into helium, and a star is born. If the young star has a very large mass, it forms a blue or white star. If it has a smaller mass, such as our Sun, it forms a yellow or red dwarf and this is more common. Stars vary in size, temperature, and brightness and they can be classified into different types based on these characteristics. Some stars are visible to the naked eye, while others require telescopes to be seen. The life cycle of a star includes stages such as formation, main sequence, and eventual death, which can result in phenomena like supernovae or the formation of black holes.

Classification of celestial bodies

Planets

Planets are large (almost) spherical objects that revolve around the sun. Planets move in fixed orbits around the sun. There are 8 planets in our solar system. Planets may be made of rocks, metals and gases like hydrogen, nitrogen and methane. The earth is also a planet and is the only known place in the universe which supports life. Planets that revolve around other stars are called exoplanets.

Satellites

Satellites are objects that revolve around planets. They form the essential part of the celestial bodies. These may be of natural origin or sent by humans. The moon is a natural satellite of the earth and revolves around it because it is bound by the Earth's gravitational pull. Man has also placed artificial or man-made satellites around the earth and other planets to study them and for communication purposes.

Comets

These are small chunks of ice and rock that come from the outer edge of the solar system. When its orbit brings it closer to the sun, the ice on them vaporizes, creating a beautiful tail behind them.

Asteroids

These are small irregularly shaped rocks made up of metal or minerals that orbit the sun. Most of them are found between Mars and Jupiter in an area known as the asteroid belt.

Meteors and meteorites

These are objects from space that enter our atmosphere as they are pulled by the earth's gravity. Meteors usually are small and burn up in the atmosphere as they enter the earth. This creates streaks in the sky as though a star has fallen. They are commonly called ***SHOOTING STARS.*** If a meteor is large enough it can reach the ground and create a crater. Such objects are called meteorites.

Galaxies

Galaxies are large groups of stars held together by gravity. The sun and the solar system are a part of a galaxy known as the Milky Way. Other galaxies are usually so far away that they look like stars in the night sky. The Andromeda galaxy and the Large Magellanic Cloud are galaxies that can be seen with the naked eye on a clear night.

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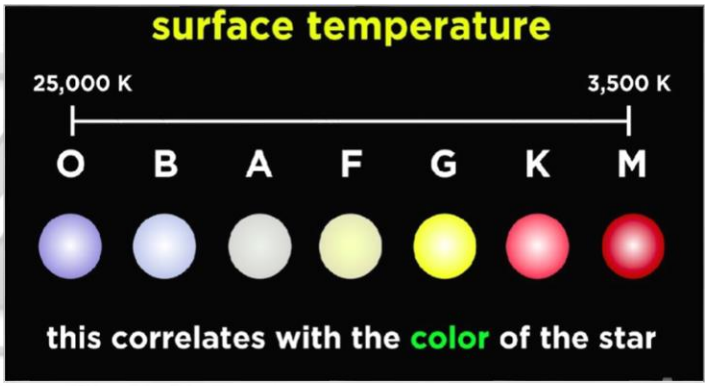
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Classification of stars

A star is a celestial body made of a brilliant spheroid of plasma glued together by its gravity. The closest star to the Earth is the Sun. Numerous stars are observable to the naked eye at night time. As they are very far away from our location, they always appear as fixed light points in the night sky. The significant stars have been grouped into asterisms and constellations. Astronomers have developed star catalogues that recognise and give standardised star names. Our Milky itself has around 200 billion stars. Due to the optical restrictions, most are not visible to the human eye from the Earth.

Star Formation

Stars are created within the clouds of matter and stellar dust scattered in most galaxies. These dust clouds are mostly called Nebulae. One of the most known examples of such clouds is the Orion Nebula. Compressed disturbances within these bodies generate regions with concentrated matter and energy. In those regions, dust and gas can start to collapse under the influence of their own inherent gravitational attraction. As the dust and gases collapse, matter at the centre starts to heat up. The earliest form of a star is called a **protostar**. It is this molten core of the collapsing cloud that eventually becomes a star. Computer simulation of star formation shows that the rotating clouds of collapsing dust and gas may split into multiple blobs of matter. This might be the reason why most of the stars in our galaxy are in groups or pairs.



Classification of Stars

There are numerous types of stars in the visible Universe, from protostars to blackholes.

They are classified based on their ***temperature, mass, spectra absorption, and stages of evolution***.

The classification of stars based on their spectral class and brightness.



According to the spectral characteristics, stars are classified into O, B, A, F, G, K, and M. B and I are the most common ones. Group B and O are very rare. They are immensely bright and hot. M stars are the most abundant type of stars. They are much dimmer and cooler. In this classification, dying stars are not considered at all. An updated system of classification was developed in the 1920s, which consists of about 225,300 stars.

It was known as the Henry Draper Catalogue.

Stellar classification is a systematic approach to categorizing stars based on their temperature, color, and luminosity. The primary classification system divides stars into seven main types: O, B, A, F, G, K, and M. This sequence, from hottest to coolest, is often remembered by the mnemonic “Oh Be A Fine Guy, Kiss Me.” O and B stars are rare, extremely hot, and luminous, while M stars are the most common and cooler. Each class is further divided based on luminosity, indicated by Roman numerals. For instance,

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supergiants are classified as I, bright giants as II, giants as III, and subgiants as IV. This classification not only helps astronomers understand the physical properties of stars but also their lifecycle and evolution.

In the case of the MK system, a factor called the **luminosity class** is considered with the spectral class using Roman symbols. This model is built around particular absorption lines in the spectrum of stars. These values change with the atmosphere's density. It differentiates gigantic stars from dwarf stars. Hypergiant stars are grouped into the luminosity class 0 or Ia+, supergiants in class I, bright giants II, regular giants in class III, subgiants in class IV, main-sequence stars in class V, subdwarfs in class VI (sd), and white dwarfs in class VII (D). Our Sun comes under the class of main-sequence stars as it has a surface temperature of about 5,800 K.

Different Types of Stars Based on Star Evolution

Protostar

A protostar is the earliest compact form of a star. It is an accumulation of gas that has been collapsed and compressed down from a huge dust-gas cloud. This early phase of a star has a time period of about 100,000 years. As time passes, pressure and gravity rise, which pushes the baby star to collapse into a denser form. Almost all the energy emitted by the protostar arises from the heat generated from the gravitational force. In this state, there is enough energy to start the nuclear reactions.

T Tauri Star

A T Tauri star is an intermediate stage just before a star transforms into a mature state. This phase begins after the end of the protostar stage when the gravitational force glueing the star together is the reason for its entire energy. These stars don't possess enough temperature and pressure at their cores to kickstart a nuclear fusion. In spite of this, these stars look similar to main-sequence stars. They both have identical temperatures. T Tauri stars have strong X-ray flares and intense stellar winds. Stars stay in the T Tauri phase for about 100 million years.

Main Sequence Star

Most stars in the visible Universe are main-sequence stars. In fact, the Sun, Alpha Centauri A, and Sirius are the most familiar examples of this class of stars. Different main sequence stars can vary in mass, brightness, and size. The fundamental similarity is the existence of a nuclear fusion core, converting hydrogen atoms into helium atoms. A huge amount of energy is emitted along with this process. A star in the main sequence phase is usually in hydrostatic equilibrium. Gravity pulls that star's matter inward. Outward forces cancel out one another, thus continuing to exist as a spherical shape. The size of these stars directly depends on their mass. In other words, the strength of gravity pulling the star inward determines the size of the star.

Red Giant Star

As the hydrogen depletes in the core of a star, the fusion reaction slows down. Once the star consumes the entire reserve of hydrogen, fusion ceases to exist, and the star fails to produce the outward pressure to counterbalance the inward pressure of its gravity. Ignition of the remaining hydrogen in the star continuously drives the star and causes it to enlarge its size drastically. The star transforms into a red giant star. The ageing star can be 100 times bigger than what it was as a main-sequence star. When the entire stock of hydrogen fuel is consumed, helium and heavier elements can be used in nuclear fusion. This phase only lasts a few hundred million years until it runs out of essential fuel. In the end, it turns into a white dwarf.

Red Dwarf Star

A red dwarf star is the coolest and smallest type of star in the main-sequence phase. They are the most common class of stars in the Milky Way. As per the latest estimation, they make up 75% of the stars in

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our galaxy. Even though they are very common, they are not easily detectable due to their relatively low luminosity. Proxima Centauri is a red dwarf, just like the majority of our nearest stars. They are much cooler and dimmer than the Sun. Even though they are exhausted from a lack of adequate fuel, they are still able to squeeze available hydrogen into their core. They are able to conserve fuel for a much longer time than other stars. The smallest red dwarf stars are 0.075 times the Sun's mass.

White Dwarf Star

When a star loses its entire reserve of hydrogen fuel in the core and lacks enough mass to push heavier elements into a nuclear fusion reaction, it transforms into a white dwarf star. The outward push from the fusion reaction stops, and the stellar core collapses inward due to its own overwhelming gravitational pull. As it is hot enough to emit light, it shines to a mediocre extent. On the other hand, there is no nuclear fusion happening inside the core. It will continue to lose its heat and energy until it reaches the Universe's background temperature. This phenomenon takes about hundreds of billions of years to complete.

Neutron Stars

Stars with a mass between 1.35 and 2.1 times that of the Sun don't transform into white dwarfs when their core collapses. In this scenario, stars do not disintegrate into a supernova explosion; instead, they become extremely dense celestial bodies called neutron stars. The stellar core collapses into a much denser form with extremely high gravitational pull. As the name suggests, they are entirely made of neutrons. Gravitational force is so strong that the matter collapses to the level of a neutron. Gravity crushes protons and electrons together to form neutrons. If stars are much more massive, then the stars explode as supernovas and ultimately turn into black holes.

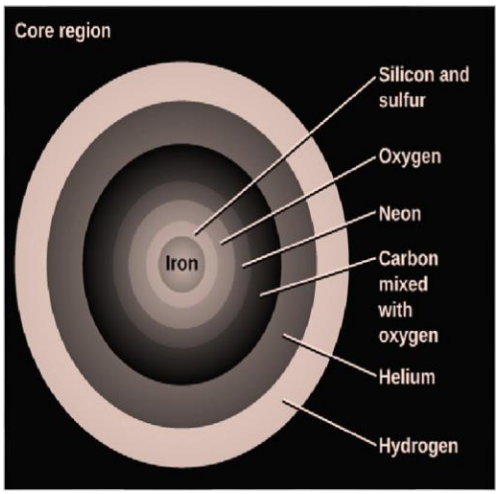
Average stars

An average star, often referred to as an intermediate-mass star, has an initial mass ranging from 0.5 to 8 times that of the Sun. These stars are primarily powered by nuclear fusion occurring in their cores, which allows them to shine brightly for billions of years. The Sun itself is considered an average star, a classification that highlights its typical characteristics compared to the vast diversity of stars in the universe. Stars are born in stellar nurseries, such as the Orion Nebula, where clouds of gas and dust collapse under gravity to form new stars. Throughout their life cycle, average stars spend the majority of their time in the main sequence phase, where they fuse hydrogen into helium. Eventually, they will exhaust their nuclear fuel and undergo significant transformations, leading to their eventual demise.

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Massive stars

Massive stars, defined as **those with a solar mass at least eight times greater than that of the Sun,** play a crucial role in the universe. They form from the densest regions of gas and dust clouds, undergoing rapid fusion processes that create heavier elements. Unlike smaller stars, massive stars burn hotter and faster, leading to a relatively short lifespan. The life cycle of a massive star culminates in a spectacular event known as a supernova. As these stars exhaust their nuclear fuel, they undergo gravitational collapse, resulting in an explosive release of energy that can outshine entire galaxies. This process not only disperses heavy elements into space but also contributes to the formation of new stars and planetary systems. Despite their rarity, massive stars are significant sources of light and energy in the cosmos. Their existence influences the evolution of



galaxies and the chemical composition of the universe, making them essential to our understanding of stellar life cycles.

Sources of energy in stars

Stars, including our Sun, derive their energy primarily from nuclear fusion, a process where hydrogen nuclei combine to form helium. This reaction occurs in the core of stars, where extreme temperatures and pressures facilitate the fusion of light elements. The most common fusion process in stars is the proton-proton chain, which converts hydrogen into helium while releasing vast amounts of energy in the form of light and heat. In addition to the proton-proton chain, stars also utilize the CNO cycle and the triple alpha process for energy production. The CNO cycle involves carbon, nitrogen, and oxygen as catalysts in the fusion of hydrogen into helium, while the triple alpha process fuses helium nuclei into carbon. These nuclear reactions are fundamental to the life cycle of stars and contribute to the synthesis of heavier elements.

The sun

The Sun is our closest star and is so bright that it banishes the darkness of space with its light.
The radiation it emits comes from glowing hydrogen and provides energy for all life on the Earth. The hydrogen is heated by the energy released in nuclear reactions in the Sun's interior. In stable stars these reactions involve the conversion of hydrogen into helium by nuclear fusion. Stars have several stages in their life cycle and our Sun is currently in its stable phase which will last for a few more billion years.
The Sun is a medium-sized star which consists mainly of hydrogen and helium. The radiant energy it emits is mostly in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.
This radiation is emitted from glowing hydrogen which is heated by the energy released in nuclear reactions within the Sun.

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Nuclear reactions in stars

Stars are powered by nuclear reactions. Stable stars such as our Sun are hot and dense enough in their centre (core) for nuclear fusion of hydrogen into helium to occur.
The high temperature in the core required to sustain the nuclear reactions is maintained by the large amount of energy released in the fusion process; the Sun is powered by nuclear fusion.
Some of the energy generated in the core is transferred to the outer layers of the star. These are cooler and less dense than the core, but are still hot enough for the hydrogen gas to glow, and emit electromagnetic radiation into space.
Stars vary in age, size, mass, surface temperature, colour and brightness. Colour and brightness both depend on surface temperature which in turn increases with the mass of the star. Stars that are white or blue are hotter and brighter (surface temperatures of 6000 to 25000°C) than those that are red or yellow (surface temperatures 3000 to 6000°C).

The sun as source of energy

The sun is the ultimate source of energy for Earth, driving essential processes that sustain life. Through nuclear fusion, hydrogen atoms collide and release vast amounts of energy, which radiates as sunlight. This solar radiation is crucial for the Earth's climate system, influencing weather patterns and supporting photosynthesis in plants, which forms the foundation of our food chain. Harnessing solar energy has become increasingly important as we seek sustainable alternatives to fossil fuels. Technologies such as solar panels convert sunlight into electricity, providing a clean and renewable energy source. Innovations

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in solar energy, including the potential to produce hydrogen fuel through water splitting, promise to revolutionize our energy landscape.

Importance of solar energy

One of its primary advantages is its environmental benefits; solar power significantly reduces carbon emissions, helping combat climate change. As a renewable energy source, it is inexhaustible and can be harnessed anywhere sunlight is available, making it a versatile option for energy generation. Solar energy is a reliable and cost-effective alternative to traditional fossil fuels. By investing in solar systems, homeowners can reduce their electricity bills and enjoy long-term savings. This energy independence not only fosters economic stability but also enhances national security by reducing reliance on imported fuels. In addition to its economic and environmental benefits, solar energy promotes energy innovation. As technology advances, solar solutions become more efficient and accessible, paving the way for a cleaner, more sustainable future.

The size of the sun

The Sun is an immense celestial body, measuring approximately 864,400 miles (1,391,000 kilometers) in diameter. This size makes it about 109 times wider than Earth, showcasing its colossal scale. In terms of mass, the Sun weighs around 333,000 times more than our planet, highlighting its dominant presence in the solar system. With a mean radius of about 432,450 miles (696,000 kilometers), the Sun's vastness is difficult to comprehend. It contains 99.86% of the total mass of the solar system, making it the central gravitational anchor for all planets, including Earth. The Sun's surface temperature reaches about 10,000 degrees Fahrenheit (5,500 degrees Celsius), contributing to its brightness and energy output.

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Variation in color and brightness of the stars

Stars exhibit a fascinating variation in color and brightness, which are key indicators of their temperature and intrinsic properties. The hottest stars, with surface temperatures reaching up to 40,000ºC, appear blue or blue-white, while the coolest stars, around 3,000ºC, shine in shades of red. This color spectrum not only reflects the star's temperature but also provides insights into its life cycle and evolutionary stage. Brightness in stars is influenced by both luminosity and distance from Earth. A star's luminosity is its inherent brightness, while apparent brightness is how bright it appears from our perspective. For instance, a faint star that is relatively close can outshine a more luminous star that is much farther away. This complexity in brightness helps astronomers understand the vast distances and varying characteristics of celestial bodies.

The brightness and color of stars as observed from Earth are influenced by several key factors.

Primarily, a star's luminosity, which is the total energy it emits, plays a crucial role. A more luminous star will appear brighter than a less luminous one, regardless of distance. However, the distance from the observer also significantly affects apparent brightness; as light travels through space, it diminishes in intensity, making distant stars appear fainter. In addition to luminosity and distance, a star's color is determined by its surface temperature. Hotter stars emit blue light, while cooler stars emit red light. This relationship is governed by Wien's Law, which states that the peak wavelength of radiation emitted by a black body is inversely proportional to its temperature. Thus, the color observed can provide insights into a star's temperature and, consequently, its size and age.

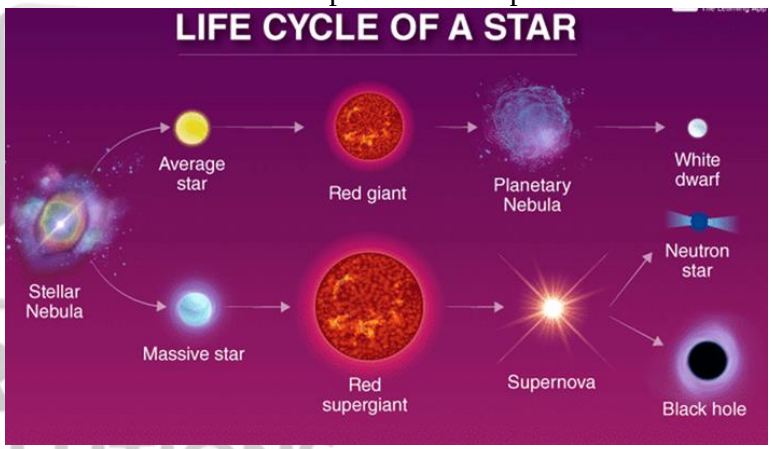
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Why the stars appear to twinkle?



Stars appear to twinkle due to the effects of Earth's atmosphere on the light they emit. As starlight travels through the atmosphere, it encounters varying temperatures and densities of air, which bend and distort the light. This phenomenon, known as refraction, causes the light to shift in color and intensity, creating the twinkling effect we observe from the ground. Planets do not twinkle in the same way as stars. This is because planets are closer to Earth and appear as small disks rather than point sources of light. The light from planets travels through less atmosphere, resulting in less distortion and a steadier appearance. The twinkling of stars is more pronounced when they are near the horizon, where their light passes through a greater thickness of atmosphere. Thus, the shimmering beauty of stars is a captivating reminder of the complex interactions between celestial bodies and our planet's atmosphere.

The Lifecycle of a star



In a stable star, such as our Sun, the very strong forces of gravity pulling it inwards are balanced by the opposing forces trying to make it expand due to its extremely high temperature. This thermal pressure arises from the kinetic energy of the nuclei in the core. When the forces are balanced, the star is in a stable state which may last for up to 10 000 million years (1010 = 10 billion years), during which time most of the hydrogen in the core is converted to helium. When the star starts to run out of hydrogen as a fuel for nuclear reactions, it becomes unstable.

There is less energy being produced by nuclear fusion to sustain the outward thermal pressure and the core collapses inward under gravitational attraction; potential energy is transferred to kinetic energy, so that the core becomes hotter. There is a fast burn-up of the remaining hydrogen envelope (in contrast to the core) and a huge expansion and subsequent cooling of the surface gases; the star turns into a red giant (or red supergiant if the star is very massive). As the core heats up, its temperature becomes high enough for the nuclear fusion of helium into carbon to occur. This will happen to our Sun (which is halfway through its stable phase) in about 5000 million years' time from now. The inner planet Mercury will then be engulfed and life on Earth destroyed.

Seven Main Stages of a Star

Stars come in a variety of masses and the mass determines how radiantly the star will shine and how it dies. Massive stars transform into supernovae, neutron stars and black holes while average stars like the sun, end life as a white dwarf surrounded by a disappearing planetary nebula. All stars, irrespective of their size, follow the same 7 stage cycle, they start as a gas cloud and end as a star remnant.

1. **Giant Gas Cloud:** A star originates from a large cloud of gas. The temperature in the cloud is low enough for the synthesis of molecules. The Orion cloud complex in the Orion system is an example of a star in this stage of life.

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2. **Protostar:** When the gas particles in the molecular cloud run into each other, heat energy is produced. This results in the formation of a warm clump of molecules referred to as the Protostar. The creation of Protostars can be seen through infrared vision as the Protostars are warmer than other materials in the molecular cloud. Several Protostars can be formed in one cloud, depending on the size of the molecular cloud.
3. **T-Tauri Phase:** A T-Tauri star begins when materials stop falling into the Protostar and release tremendous amounts of energy. The mean temperature of the Tauri star isn't enough to support nuclear fusion at its core. The T-Tauri star lasts for about 100 million years, following which it enters the most extended phase of development – the Main sequence phase.
4. **Main Sequence:** The main sequence phase is the stage in development where the core temperature reaches the point for the fusion to commence. In this process, the protons of hydrogen are converted into atoms of helium. This reaction is exothermic; it gives off more heat than it requires and so the core of a main-sequence star releases a tremendous amount of energy.
5. **Red Giant**: A star converts hydrogen atoms into helium over its course of life at its core. Eventually, the hydrogen fuel runs out, and the internal reaction stops. Without the reactions occurring at the core, a star contracts inward through gravity causing it to expand. As it expands, the star first becomes a subgiant star and then a red giant. Red giants have cooler surfaces than the main-sequence star, and because of this, they appear red than yellow.
6. **The Fusion of Heavier Elements:** Helium molecules fuse at the core, as the star expands. The energy of this reaction prevents the core from collapsing. The core shrinks and begins fusing carbon, once the helium fusion ends. This process repeats until iron appears at the core. The iron fusion reaction absorbs energy, which causes the core to collapse. This implosion transforms massive stars into a supernova while smaller stars like the sun contract into white dwarfs.
7. **Supernovae and Planetary Nebulae:** Most of the star material is blasted away into space, but the core implodes into a neutron star or a singularity known as the black hole. Less massive stars don't explode, their cores contract instead into a tiny, hot star known as the white dwarf while the outer material drifts away. Stars tinier than the sun, don't have enough mass to burn with anything but a red glow during their main sequence. These red dwarves are difficult to spot. But, these may be the most common stars that can burn for trillions of years.

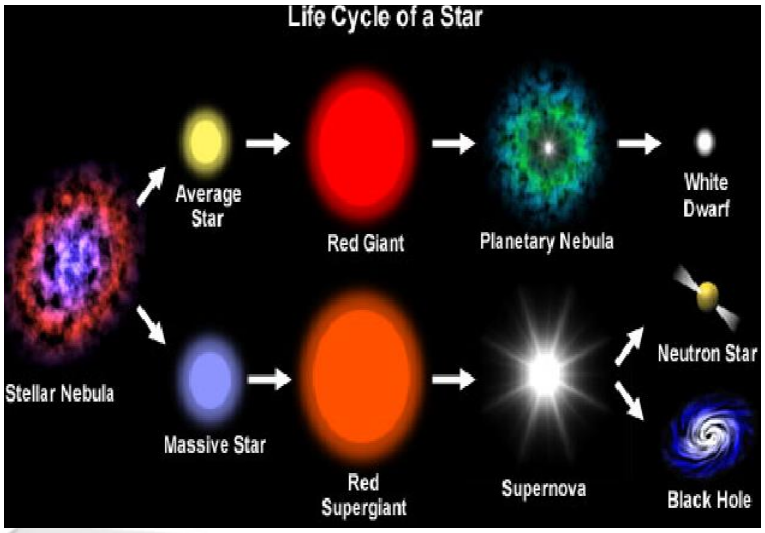
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Lifecycle of small and average stars

For stars with a mass up to about eight times that of our Sun, when all the helium is used up, the core of the red giant collapses under its own gravity, and enough energy is released to cause the outer layers to be expelled. The small core becomes a **white dwarf** at the centre of a glowing shell of ionised gas known as a **planetary nebula**. Planetary nebulae are thought to play an important role in distributing elements formed in the star into the interstellar medium. They have been photographed from the Hubble Space telescope, but have a short lifetime of about 10000 years and appear to mark the transition of the red giant into a white dwarf. The white dwarf has a lifetime of about a billion years and eventually cools into a cold **black dwarf** consisting mainly of carbon. This will be the fate of our Sun. In contrast, larger stars may end their lives in spectacular supernova explosions, but small and average stars conclude their lifecycle more quietly, contributing to the cosmic recycling of elements.

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Lifecycle of massive stars



Stars with a mass greater than about eight times that of our Sun are hotter than the Sun and use up their hydrogen more quickly; their stable stage is shorter and may last for only about 100 million years. The core then collapses into a **red supergiant** and nuclear fusion of helium into carbon occurs.

When all the helium has been used up, the core collapses further under gravity and it becomes hot enough for the nuclear fusion of carbon into oxygen, nitrogen and finally iron to occur. Nuclear fusion then stops and the energy of the star are released in a **supernova** explosion.

In the explosion there is a huge increase in the star's brightness and the temperature becomes high enough for fusion of nuclei into many elements heavier than iron to occur. Material, including these heavy elements, is thrown into space as a nebula, and becomes available for the formation of new stars and their associated planetary systems. The Crab Nebula is the remains of the supernova seen by Chinese astronomers on Earth in 1054. It is visible through a telescope as a hazy glow in the constellation Taurus. The centre of the supernova collapses to a very dense **neutron star**, which spins rapidly and acts as a **pulsar**, sending out pulses of radio waves. If the red giant is very massive, the remnant at the centre of the supernova has such a large density that its gravitational field stops anything escaping from its surface, even light; this is a **black hole.** In a black hole matter is packed so densely that the mass of the Earth would only occupy the volume of one cubic centimeter! Since neither matter nor radiation can escape from a black hole, we cannot see it directly. However, if nearby material, such as gas from a neighbouring star, falls towards a black hole, intense X-ray radiation may be emitted which alerts us to its presence. Objects believed to be massive black holes have been identified at the centre of many spiral galaxies.

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Supernova

A supernova is one of the most spectacular events in the universe, marking the explosive death of a star. This phenomenon occurs when a star exhausts its nuclear fuel, leading to a dramatic increase in brightness and energy output. Supernovae can outshine entire galaxies for a brief period, releasing an immense amount of light and energy, making them the brightest explosions observed in the cosmos. There are two primary types of supernovae: Type I and Type II. Type I supernovae occur in binary star systems, where one star siphons material from its companion until it reaches a critical mass and explodes. In contrast, Type II supernovae result from the collapse of massive stars that have depleted their nuclear fuel. Both types scatter essential elements like hydrogen, helium, and carbon into space, contributing to the formation of new stars and planets. The remnants of a supernova often form a nebula, a vast cloud of gas and dust that can give rise to new celestial bodies.

Brightness of supernova

Supernovae are among the most luminous events in the universe, capable of outshining entire galaxies. Their peak optical luminosity can reach between $5x10^{43}$ and $2x10^{46}$ $ergs^{-1}$, making them incredibly bright celestial phenomena. For instance, a supernova occurring 100 light-years away would appear about

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100 times brighter than a full moon, showcasing their immense brightness. The brightness of a supernova is not just a fleeting moment; it can last for weeks or even months before gradually fading. This dramatic increase in luminosity is often accompanied by a rapid change in brightness, with some supernovae exhibiting a change of up to three magnitudes within just 15 days. Such rapid fluctuations highlight the dynamic nature of these stellar explosions.

Supernovae are extraordinary cosmic events that illuminate the night sky, providing valuable insights into stellar evolution and the universe's expansion. Their brightness serves as a reminder of the powerful forces at play in the cosmos.

Black-hole and neutron star

Black holes and neutron stars are two of the universe's most enigmatic entities, each representing extreme states of matter and gravity. A neutron star, formed from the remnants of a supernova, is incredibly dense, with a sugar-cube-sized amount of its material weighing as much as a mountain. In contrast, black holes are regions in space where gravity is so intense that not even light can escape, resulting from the collapse of massive stars. Astronomers have long been intrigued by the mass gap between neutron stars and black holes. The heaviest known neutron star teeters on the brink of becoming a black hole, highlighting the delicate balance of gravitational forces at play. Observations have shown that neutron star mergers, providing insights into their transition, revealing that such collisions can lead to the formation of black holes.

Formation of black-holes

Black holes are fascinating cosmic entities formed primarily through the death of massive stars. When these stars exhaust their nuclear fuel, they undergo a dramatic transformation. The core collapses under its own gravity, leading to a supernova explosion that ejects the outer layers of the star. What remains is an incredibly dense core, which can become a black hole if its mass exceeds a certain threshold. There are different types of black holes, with stellar black holes being the most common. These typically form from stars with at least three times the mass of our Sun. In contrast, super-massive black holes, found at the centers of galaxies, may have formed through more complex processes, possibly involving the merging of smaller black holes or the influence of dark matter. The study of black holes not only enhances our understanding of the universe but also challenges our grasp of physics, particularly regarding gravity and space-time.

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Galaxies

A galaxy is a massive system composed of stars, stellar remnants, interstellar gas, dust, and dark matter, all bound together by gravity. The term "galaxy" originates from the Greek word for "milky," reflecting our own Milky Way galaxy. Galaxies can vary significantly in size and structure, containing anywhere from millions to trillions of stars, and they often exist in vast cosmic clusters. Galaxies are categorized into several types, including spiral, elliptical, and irregular. Spiral galaxies, like the Milky Way, feature distinct arms that wind outward from the center, while elliptical galaxies appear more rounded and lack the defined structure of spirals. Irregular galaxies do not fit neatly into these categories and often exhibit chaotic shapes.

The Milky Way

The Milky Way Galaxy, a barred spiral galaxy, is home to our Solar System and contains approximately 100 billion stars, including our Sun. Spanning about 100,000 light-years in diameter, it features a distinct hazy band of light visible from Earth, which is composed of countless stars and cosmic dust. This galaxy

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is estimated to be around 13.6 billion years old, making it a significant part of our cosmic history .At the center of the Milky Way lies a super massive black hole, surrounded by a bulge of older stars. The galaxy's structure includes large spiral arms that extend outward, hosting various celestial phenomena such as nebulae and star clusters. The Milky Way is accompanied by several satellite galaxies, with the Large and Small Magellanic Clouds being the most notable.

The Universe

a) Know that the Universe is made up of billions of galaxies, the Milky Way being just one.
b) Describe redshift and know that light emitted from stars in distant galaxies appears red shifted, which is evidence the Universe is expanding and supports the Big Bang Theory.

Introduction

Stars cluster together in galaxies. A typical galaxy has a diameter of around 30000 light-years with neighbouring galaxies around 3 million light-years away. The Universe is composed of billions of galaxies that all appear to be receding from the Earth so that the light from glowing hydrogen takes on a redder colour. Redshift measurements of the light from distant galaxies suggest that the Universe is expanding and support the Big Bang theory of the origin of the Universe.

The Universe: The Milky Way is one of the billions of galaxies that make up the Universe. The diameter of the Milky Way galaxy is around 100000 light-years and it contains 800 billion or more stars.

The expanding Universe

In developing a theory about the origin of the Universe, two discoveries about galaxies have to be taken into account. The first is that light emitted from glowing hydrogen in stars in distant galaxies, is 'shifted' to the red end of the spectrum (longer wavelength) in comparison with the value on Earth.

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The second is that the further away a galaxy is from us, the greater is this **redshift**. These observations can be explained if other galaxies are moving away from us very rapidly, and the further away they are, the faster is their speed of recession. Evidently the Universe is expanding. This interpretation is based on the Doppler Effect, which occurs when a source of waves is moving. If the source approaches us, waves are crowded into a smaller space and their wavelength seems smaller and their frequency greater. If the source moves away, the wavelength seems larger. Receding stars and galaxies are therefore shifted to the red end of the spectrum.

The Doppler Effect occurs with sound waves and explains the rise and fall of pitch of a siren as the vehicle approaches and passes us. The same effect is shown by light. When the light source is receding, the wavelength seems longer, that is the light is redder. From the size of the redshift of starlight, the speed of recession of the galaxy can be calculated; the most distant ones visible are receding with speeds up to one-third of the speed of light. The redshift in the light from distant galaxies provides evidence that the Universe is expanding and gives support to the Big Bang theory of the formation of the Universe.

The Big Bang theory

If the galaxies are receding from each other, it follows that in the past they must have been closer together. It is therefore possible that initially all the matter in the Universe was packed together in an extremely

dense state. The Big Bang theory proposes that this was the case, and that the Universe started about 14 billion years ago from one place with a huge explosion – the Big Bang.
The resulting expansion of the Universe continues today, but predictions vary about what will happen in the future. The critical factor appears to be the density of matter in the Universe. This is difficult to calculate because scientists currently believe that as much as 80% of the material in the Universe is invisible, since it does not emit radiation. It may be that this hidden mass exerts sufficient gravitational force to lead the Universe to collapse. The gravitational force between masses not only determines the motion and evolution of planets, stars and galaxies, but will also control the ultimate fate of the Universe.

Chapter Assessment;
Students at Katikamu Observatory in Luweero District are participating in a night sky observation program organized by the astronomy club. Using a digital telescope connected to a spectroscope, they observe light from several distant galaxies. When the light from these galaxies is analyzed, the spectral lines appear shifted toward the red end of the spectrum compared to the same spectral lines produced in a laboratory on Earth.
During the discussion, the club teacher also explains that stars like the Sun undergo a long life cycle beginning with the formation of a dense cloud of gas and dust in space. Over millions of years, gravitational forces compress the material to form a stable star that shines by producing energy in its core. Eventually, the star expands into a red giant before ending its life in later stages.
Tasks: Using your knowledge of Physics

a) Explain what is meant by the redshift of starlight.
b) Explain what the redshift of starlight tells us about the motion of distant galaxies.
c) Describe how a stable star is formed and how it is powered.
d) Explain the conditions under which a stable star turns into a red giant.
e) State the forces, and give their directions, which are balanced when a star is in a stable state.
f) State the sequence of stages in the life cycle of a star like the Sun.

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3.8 SATELLITES AND COMMUNICATION

Learning Outcomes

a) Understand what artificial satellites are and how we make use of the min research and in everyday life (u,s)
b) Appreciate the importance of space exploration (u,v/a)



Introduction
Satellites play a crucial role in modern communication, serving as relay stations in space that facilitate the transfer of voice, video, and data across vast distances. By orbiting the Earth, these artificial satellites enable seamless connectivity for various applications, including television broadcasting, internet services, and emergency communications. The technology behind satellite communication involves transmitting signals from ground stations to satellites, which then relay the information back to

other locations on Earth. This system allows for global coverage, making it indispensable for remote areas where traditional communication infrastructure may be lacking. Innovations, such as the HMD Off Grid, a compact satellite communication device for smartphones, highlight the ongoing advancements in this field. As satellite technology continues to evolve, it promises to enhance connectivity and accessibility, further integrating into our daily lives and supporting critical services worldwide.

Satellites

A satellite is defined as an object that orbits a larger celestial body. This can include natural satellites, like the Moon, which orbits Earth, and artificial satellites, which are human-made objects designed to orbit planets or other celestial bodies. According to NASA, satellites maintain their orbits through a balance between their speed and the gravitational pull of the body they orbit. Artificial satellites serve various purposes, including communication, weather monitoring, and scientific research. They are crucial for modern technology, enabling global communication networks and providing data for climate studies. The term "satellite" can also refer to any object that orbits another, such as Earth itself, which is a satellite of the Sun. These artificial satellites are launched into space and can orbit Earth or other planets. As of May 2024, there are approximately 9,900 active satellites in various orbits, highlighting their significance in modern technology and science. Satellites can be categorized into different types, including weather satellites, which are essential for forecasting and monitoring climate patterns. There are two main types: polar orbiting and geostationary satellites, each with unique characteristics that allow them to gather data effectively. Organizations like NOAA utilize satellite data to provide timely environmental information. Recent advancements in satellite technology include the launch of mega constellations, such as China's Thousand Sails and SpaceX's Starlink, aimed at enhancing global internet connectivity and monitoring capabilities.

Artificial satellite

Artificial satellites are human-made objects launched into orbit around celestial bodies, primarily Earth. Since the launch of Sputnik 1 by the Soviet Union in 1957, which was the first artificial satellite, the number of active satellites has surged to over 3,000. These satellites serve various purposes, including communication, weather monitoring, navigation, and scientific research. Satellites can be classified into two categories: natural and artificial. Recent advancements in satellite technology include the development of Gen-3 satellites by BlackSky Technology, set for launch in February 2025, and innovative projects like Proba-3, which aims to create artificial solar eclipses for solar studies. As technology evolves, artificial satellites will continue to play a vital role in understanding our planet and beyond. They are categorized into several types based on their functions. Navigation satellites, for instance, assist in determining precise locations on Earth, essential for GPS systems. Communication satellites relay and amplify signals, enabling global telecommunications, including television and internet services. Weather satellites monitor atmospheric conditions, providing vital data for forecasting and climate research.
Earth observation satellites capture images and data about the planet's surface, aiding in environmental monitoring and disaster management. Lastly, astronomical satellites are designed to observe celestial phenomena, contributing to our understanding of the universe. These satellites operate in various orbits, including geostationary and polar orbits, each serving specific purposes.

Artificial satellites are critical to modern life, providing essential infrastructure for global communication (TV, internet), precise navigation (GPS), and real-time weather forecasting. They enable environmental monitoring, scientific research, and military surveillance, while also connecting remote areas and aiding in disaster management.

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Areas of importance include:
Communication: Enabling global television, radio, telephone, and high-speed internet, including to remote, underserved, or rugged locations.
Navigation & Positioning: Powering GPS for air, sea, and land transportation, allowing for precise location tracking.
Environmental & Weather Monitoring: Providing data for weather forecasting, climate change tracking, and observing deforestation or urbanization.
Military & National Security: Facilitating surveillance, reconnaissance, and secure, real-time communications for defense operations.
Scientific Research: Supporting space exploration, astronomy, and data collection, such as monitoring from the International Space Station

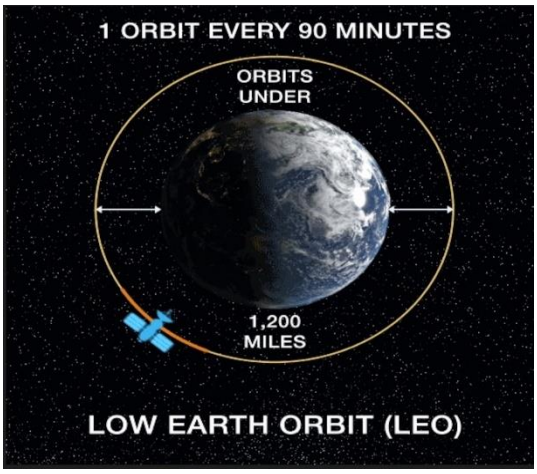
Natural satellite



Natural satellites, commonly known as moons, are celestial bodies that orbit larger astronomical entities, such as planets. These moons vary significantly in size, shape, and composition, with some, like Saturn's Titan, being larger than the planet Mercury. Currently, Saturn boasts the highest number of moons, with 146 confirmed natural satellites, showcasing the diversity of these celestial companions. Most natural satellites are solid bodies and typically lack substantial atmospheres. They play crucial roles in their respective planetary systems, influencing phenomena such as tides and geological activity.
For instance, Earth's Moon not only stabilizes our planet's axial tilt but also regulates ocean tides, making Earth more habitable. In total, over 300 natural satellites orbit six planets and seven dwarf planets in our solar system. Understanding these celestial bodies enhances our knowledge of planetary formation and the dynamics of our solar system.

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Sizes and altitude of satellites



Artificial satellites vary significantly in size and altitude, depending on their purpose and orbit. Low-Earth orbit (LEO) satellites, such as the International Space Station (ISS), typically orbit at altitudes ranging from 200 to 2,000 kilometers (approximately 124 to 1,243 miles). The ISS, for instance, maintains an altitude of about 400 kilometers (248 miles) and travels at speeds of around 28,000 kilometers per hour (17,500 miles per hour).Medium Earth orbit (MEO) satellites, which include navigation systems like GPS, operate at altitudes between 2,000 kilometers (1,200 miles) and just below geosynchronous orbit at 35,786 kilometers (22,236 miles). In contrast, geostationary satellites remain fixed relative to the Earth's surface at approximately 35,786 kilometers, providing consistent coverage over specific areas.

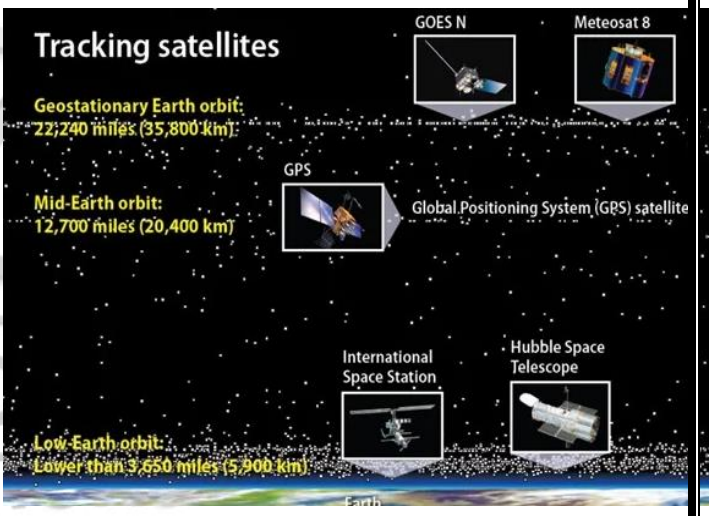
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Satellite and orbits

Satellites play roles in modern technology, orbiting Earth in various paths dictated by gravity. These orbits are classified primarily into three categories: low Earth orbit (LEO), medium Earth orbit (MEO), and geosynchronous orbit (GEO). Each type serves distinct functions, from communication and weather monitoring to navigation and Earth observation. Low Earth orbit, typically ranging from 160 to 2,000 kilometers above the Earth, is favored for satellites that require close proximity for high-resolution imaging, such as those used in environmental monitoring. In contrast, geosynchronous satellites, positioned approximately 36,000 kilometers above the Earth, maintain a fixed position relative to the planet, making them ideal for telecommunications. The European Space Agency (ESA) and NASA are at the forefront of satellite technology, continuously launching new satellites to enhance our understanding of Earth and beyond. As satellite technology evolves, so too does our ability to monitor and respond to global challenges.

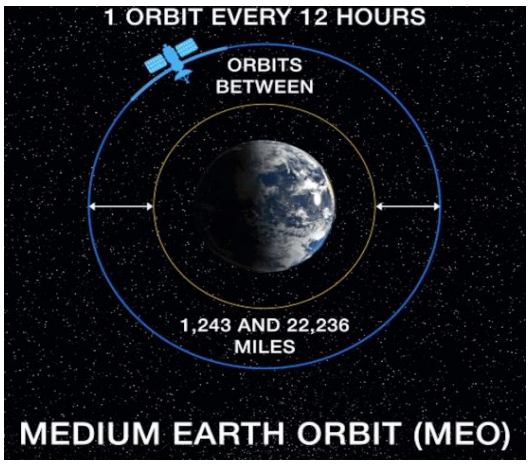
Types of Satellites by Orbit

Low Earth Orbit (LEO): Low Earth Orbit (LEO) satellites are positioned at altitudes ranging from 200 to 2,000 kilometers above Earth, making them crucial for various applications. These satellites complete an orbit approximately every 90 to 128 minutes, allowing them to provide real-time data and communication services. The European Space Agency (ESA) emphasizes the importance of LEO for scientific research, Earth observation, and telecommunications. The LEO economy is rapidly evolving, driven by advancements in technology and increasing demand for satellite services. This economic sector encompasses the production, distribution, and trade of goods and services in LEO, attracting significant investment from various industries. As more companies launch LEO satellites, the potential for innovation and growth in this area continues to expand. Investors are increasingly recognizing the opportunities within the LEO satellite market, as these satellites enhance broadband connectivity and support military reconnaissance.



Medium Earth Orbit (MEO): Altitude: 5,000–20,000 km. **Applications:** Navigation systems (e.g., GPS), enabling global positioning and low-latency data communication. Balances coverage area and data transmission rates, requiring fewer satellites than LEO systems. Limitation: Weaker signals and longer transmission delays compared to LEO. Medium Earth Orbit (MEO) satellites operate at altitudes ranging from 2,000 to 36,000 kilometers (1,243 to 22,300 miles) above Earth. These satellites have orbital periods of less than 24 hours, with the lowest MEO altitude allowing for a minimum period of about 2 hours.

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This unique positioning enables MEO satellites to provide a balance between coverage and latency, making them ideal for various applications, including Global Navigation Satellite Systems (GNSS) and Internet of Things (IoT) services. MEO satellites are particularly significant for delivering high-speed connectivity in remote areas where traditional fiber optics are impractical. They utilize Ku-band and Ka-band frequencies to ensure robust data transmission. Recent advancements have seen countries like China launching their first MEO broadband satellites, highlighting the growing interest and investment in this orbital range. As the demand for satellite-based services continues to rise, MEO satellites are poised to play a crucial role in enhancing global communication and navigation capabilities.

Geostationary Orbit (GEO): Geostationary orbit (GEO) is a unique orbital position approximately 22,300 miles (35,800 kilometers) above the Earth's equator. In this orbit, satellites maintain a fixed position relative to the Earth's surface, appearing stationary to observers on the ground. This characteristic makes GEO ideal for telecommunications, weather monitoring, and broadcasting, as a single satellite can cover about one-third of the Earth. Satellites in GEO are launched into a temporary orbit before being maneuvered into their designated "slot." The orbital period of these satellites matches the Earth's rotation, allowing them to maintain a constant view of the same geographic area. This stability is crucial for applications requiring continuous data transmission and monitoring. As technology advances, the role of GEO satellites continues to expand, enhancing global communication and observation capabilities.

Sun-Synchronous Orbit (SSO): Sun-synchronous orbit (SSO), also known as Helio synchronous orbit, is a specialized polar orbit that allows satellites to maintain a consistent angle with respect to the Sun. This unique characteristic enables satellites to pass over the same point on Earth at the same local solar time, making SSO ideal for Earth observation and reconnaissance missions. Typically, SSO satellites operate at altitudes between 600 to 800 kilometers, with an inclination of about 20 to 30 degrees. The precession of the satellite's orbital plane matches the Earth's rotation around the Sun, ensuring that the satellite's observations are consistent throughout the year. This is particularly beneficial for applications such as weather monitoring, agricultural assessments, and environmental studies, where consistent lighting conditions are crucial. Recent advancements in SSO technology have led to successful launches, such as the Sentinel-1C satellite for the European Union's Copernicus program, further enhancing our ability to monitor and understand our planet.

Applications: Cyclone forecasting, wildfire monitoring, and deforestation tracking, and change detection.
Limitation: Smaller regional coverage, requiring multiple satellites for continuous monitoring.

Geostationary Transfer Orbit (GTO): A transitional orbit used to transfer satellites to GEO or higher altitudes. Minimizes resource use during the transition phase. This orbit allows satellites to transition from a lower orbit to a geostationary orbit, where they can maintain a fixed position relative to the Earth's surface. In GTO, a satellite is launched into an elliptical orbit, reaching its highest point, or apogee, before firing its engines to circularize its orbit at geostationary altitude. Satellites in geostationary orbit (GEO) orbit the Earth at approximately 35,786 kilometers above the equator, synchronizing their rotation with the planet. This unique positioning enables them to provide consistent coverage over specific areas, making them ideal for telecommunications, weather monitoring, and broadcasting services. Geostationary

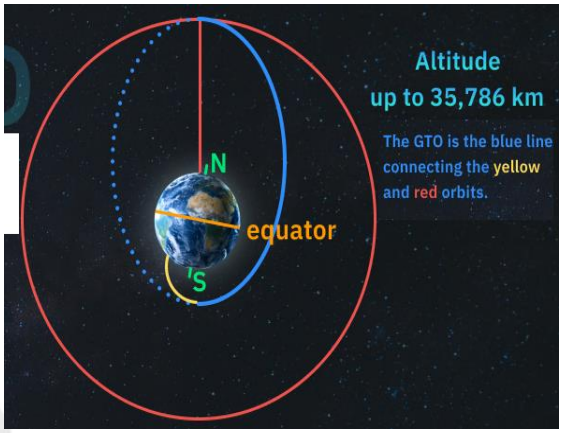
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satellites are equipped with transponders that receive, amplify and retransmit radio signals to and from Earth. These signals can be used for a wide range of applications, including telecommunications, broadcasting, remote sensing and navigation. Satellite technology, such as NOAA's GOES-U, demonstrate the importance of GTO in modern space operations.

Specialized Satellite Types

Earth Observation Satellites:



Purpose: Monitor environmental changes, support emergency response, and provide weather and GIS data. Categories: Weather satellites (e.g., GEO), remote sensing satellites (e.g., LEO, GEO), and GIS satellites for mapping. Example: EOS SAT-1, designed for precision agriculture and forestry monitoring.

Navigation Satellites: Functions: Provide geolocation and positioning data. Types: Global Navigation Satellite System (GNSS): Offers worldwide coverage (e.g., GPS, Galileo, BeiDou). Regional Navigation Satellite System (RNSS): Covers specific regions (e.g., India's IRNSS).

Astronomical Satellites: Function as space telescopes, free from atmospheric distortions.

Applications: Study celestial bodies, map stars, monitor black holes, and conduct climate research. Examples: Climate research satellites for ocean and atmospheric studies, and biosatellites for biological experiments.

Importance of artificial satellites

Satellites serve various essential functions; they facilitate in-flight phone communications on airplanes and provide voice communication in rural areas where traditional networks may be lacking. Satellites are crucial for weather forecasting, offering accurate and timely information about climate patterns and natural disasters. Earth observation satellites monitor environmental changes, such as wildfires, volcanic eruptions, and the health of ecosystems. This data is invaluable for scientific research and helps combat climate change by mapping plant life and tracking geological changes. Military organizations also utilize satellite imagery for intelligence purposes, showcasing the diverse applications of satellite technology. Moreover, satellites support navigation systems like GPS, enabling precise location tracking for transportation and logistics. Overall, the multifaceted uses of satellites underscore their importance in communication, environmental monitoring, and scientific advancement, making them indispensable tools in our interconnected world.

Satellites in Navigation

Satellite navigation systems, commonly known as satnav, utilize a network of satellites to provide precise positioning and timing information globally. These systems, classified as Global Navigation Satellite Systems (GNSS), enable users to determine their location anywhere on Earth by receiving signals from multiple satellites. The most well-known GNSS is the Global Positioning System (GPS), which consists of a constellation of satellites that continuously broadcast navigation signals. The operation of satellite navigation relies on the principle of triangulation, where the position of a receiver is calculated based on the time it takes for signals from satellites to reach it. This technology is crucial for various applications, including aviation, maritime navigation, and personal navigation devices.

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Global Positioning System (GPS)

The Global Positioning System (GPS) is a vital US-owned utility that offers positioning, navigation, and timing (PNT) services globally. This satellite-based navigation system, originally known as Navstar GPS, consists of a constellation of at least 24 operational satellites orbiting the Earth. These satellites work in conjunction with ground monitoring stations and receivers to provide users with precise location data. GPS technology operates by triangulating signals from multiple satellites, allowing users to determine their exact position anywhere on the planet. This capability has revolutionized various sectors, including transportation, agriculture, and emergency services, enhancing efficiency and safety. The GPS market is projected to grow significantly, with estimates reaching USD 472.16 billion by 2033. GPS continues to evolve, integrating with other systems like Europe's Galileo, ensuring users benefit from highly accurate and reliable navigation services worldwide.

GPS, or the Global Positioning System, is a global navigation satellite system that provides location, velocity and time synchronization. GPS is everywhere. You can find GPS systems in your car, your smartphone and your watch. GPS helps you get where you are going, from point A to point B. The Global Positioning System (GPS) is a navigation system using satellites, a receiver and algorithms to synchronize location, velocity and time data for air, sea and land travel. The satellite system consists of a constellation of 24 satellites in six Earth-centered orbital planes, each with four satellites, orbiting at 13,000 miles (20,000 km) above Earth and traveling at a speed of 8,700 mph (14,000 km/h). While we only need three satellites to produce a location on earth's surface, a fourth satellite is often used to validate the information from the other three. The fourth satellite also moves us into the third-dimension and allows us to calculate the altitude of a device.

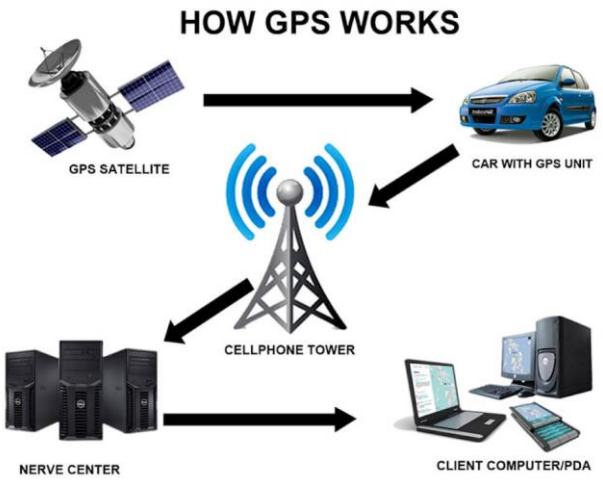


What are the three elements of GPS?

GPS is made up of three different components, called segments, that work together to provide location information. The three segments of GPS are: **Space** (**Satellites**); the satellites circling the Earth, transmitting signals to users on geographical position and time of day. **Ground control**; The Control Segment is made up of Earth-based monitor stations, master control stations and ground antenna. Control activities include tracking and operating the satellites in space and monitoring transmissions. There are monitoring stations on almost every continent in the world, including North and South America, Africa, Europe, Asia and Australia. **User equipment**; GPS receivers and transmitters including items like watches, smartphones and telematics devices.

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How does GPS technology work?



GPS works through a technique called trilateration. Used to calculate location, velocity and elevation, trilateration collects signals from satellites to output location information. It is often mistaken for triangulation, which is used to measure angles, not distances. Satellites orbiting the earth send signals to be read and interpreted by a GPS device, situated on or near the earth's surface. To calculate location, a GPS device must be able to read the signal from at least four satellites. Each satellite in the network circles the earth twice a day, and each satellite sends a unique signal, orbital parameters and time. At any given moment, a GPS device can read the signals from six or more satellites. A single satellite broadcasts a microwave signal which is picked up by a GPS device and used to calculate the distance from the GPS device to the satellite. Since a GPS device only gives information about the distance from a satellite, a single satellite cannot provide much location information. Satellites do not give off information about angles, so the location of a GPS device could be anywhere on a sphere's surface area. When a satellite sends a signal, it creates a circle with a radius measured from the GPS device to the satellite. When we add a second satellite, it creates a second circle, and the location is narrowed down to one of two points where the circles intersect.

With a third satellite, the device's location can finally be determined, as the device is at the intersection of all three circles. We live in a three-dimensional world, which means that each satellite produces a sphere, not a circle. The intersection of three spheres produces two points of intersection, so the point nearest Earth is chosen. As a GPS device moves, the radius (distance to the satellite) changes. When the radius changes, new spheres are produced, giving us a new position. We can use that data, combined with the time from the satellite, to determine velocity, calculate the distance to our destination and the ETA. GPS is a powerful and dependable tool for businesses and organizations in many different industries. Surveyors, scientists, pilots, boat captains, first responders, and workers in mining and agriculture, are just some of the people who use GPS on a daily basis for work. They use GPS information for preparing accurate surveys and maps, taking precise time measurements, tracking position or location, and for navigation. GPS works at all times and in almost all weather conditions.

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There are five main uses of GPS:

Location: Determining a position.

Navigation: Getting from one location to another.

Tracking: Monitoring object or personal movement.

Mapping: Creating maps of the world.

Timing: Making it possible to take precise time measurements. GPS use cases include: **Emergency Response**: During an emergency or natural disaster, first responders use GPS for mapping, following and predicting weather, and keeping track of emergency personnel. In the EU and Russia, the e-Call regulation relies on GLONASS technology (a GPS alternative) and telematics to send data to emergency services in the case of a vehicle crash, reducing response time.

Entertainment: GPS can be incorporated into games and activities like Pokémon Go and Geocaching.

Health and fitness: Smart watches and wearable technology can track fitness activity (such as running distance) and benchmark it against a similar demographic.

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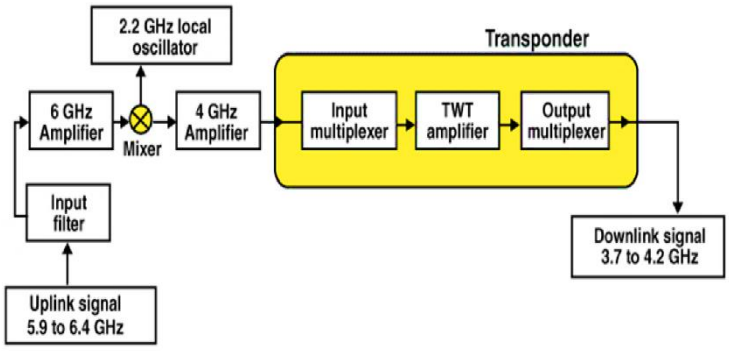
Construction, mining and off-road trucking: From locating equipment, to measuring and improving fleet asset allocation, GPS enables companies to increase return on their assets.
Transportation: Logistics companies implement telematics systems to improve driver productivity and safety. A lorry tracker can be used to support fleet route optimization, fuel efficiency, driver safety and fleet compliance. Other industries where GPS is used include: agriculture, autonomous vehicles, sales and services, the military, mobile communications, security, and fishing.

How accurate is GPS?
GPS device accuracy depends on many variables, such as the number of satellites available, the ionosphere, the urban environment and more. Some factors that can hinder GPS accuracy include: Physical obstructions: Arrival time measurements can be skewed by large masses like mountains, buildings, trees and more. Atmospheric effects: Ionospheric delays, heavy storm cover and solar storms can all affect GPS devices. Ephemeris: The orbital model within a satellite could be incorrect or out-of-date, although this is becoming increasingly rare. Numerical miscalculations: This might be a factor when the device hardware is not designed to specifications. Artificial interference: These include GPS jamming devices or spoofs. Accuracy tends to be higher in open areas with no adjacent tall buildings that can block signals. This effect is known as an urban canyon. When a device is surrounded by large buildings, like in downtown Manhattan or Toronto, the satellite signal is first blocked, and then bounced off a building, where it is finally read by the device. This can result in miscalculations of the satellite distance.

Satellite Communication

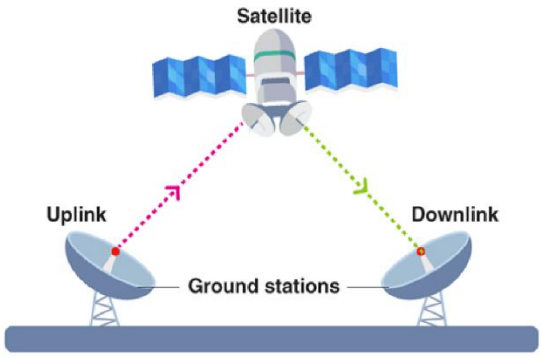
Satellite communication is transporting information from one place to another using a communication satellite in orbit around the Earth. Watching the English Premier League every weekend with your friends would have been impossible without this. A communication satellite is an artificial satellite that transmits the signal via a transponder by creating a channel between the transmitter and the receiver at different Earth locations. Telephone, radio, television, internet, and military applications use satellite communications. Believe it or not, more than 2000 artificial satellites are hurtling around in space above your heads.

How Satellite Communications Work?
The communication satellites are similar to the space mirrors that help us bounce signals such as radio, internet data, and television from one side of the earth to another. Three stages are involved, which explain the working of satellite communications.
These are: **Uplink, Transpon ders,** and **Downlink**



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Consider an example of signals from a television. In the first stage, the signal from the television broadcast on the other side of the earth is first beamed up to the satellite from the ground station on the earth. This process is known as *uplink*. The second stage involves transponders such as radio receivers, amplifiers, and transmitters. These transponders boost the incoming signal and change its frequency so that the outgoing signals are not altered. Depending on the incoming signal sources, the transponders vary. The final stage involves a downlink in which the data is sent to the other end of the receiver on the earth. It is important to understand that usually, there is one uplink and multiple downlinks.



The need for satellite communication becomes evident when we want to transmit the signal to far-off places, where the Earth's curvature comes into play. This obstruction is overcome by putting communication satellites in space to transmit the signals across the curvature. Satellite communication uses two types of artificial satellites to transmit the signals:

Passive Satellites: If you put a hydrogen balloon that has a metallic coating over it up in the air, it technically becomes a passive satellite. Such a balloon can reflect microwave signals from one place to another. The passive satellites in space are similar. These satellites just reflect the signal back towards the Earth without amplification. Since the satellite orbit height can range from 2000 to 35786 km, attenuation due to the atmosphere also comes into play, and due to this, the received signal is often very weak.

Active Satellites: Active Satellites, unlike passive satellites, amplify the transmitted signals before re-transmitting it back to Earth, ensuring excellent signal strength. Passive satellites were the earliest communication satellite, but now almost all the new ones are active satellites.

To avoid mixing up and interference signals, every user is allocated a specific frequency for transmitting. The International Telecommunication Union does this frequency allocation. Geosynchronous satellites are of note here. Geostationary orbit is present at 35786 km above Earth's surface. If you can spot such a satellite with a telescope from Earth, it will appear stationary to you. The satellite's orbital period and the Earth's rotational rate are in sync.

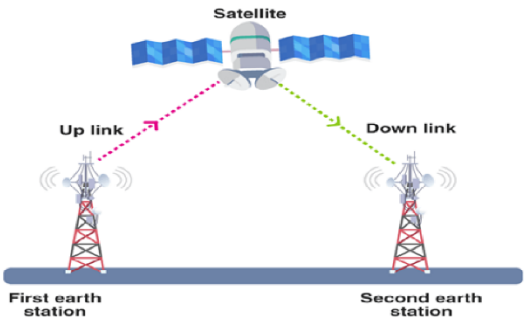
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Satellite Communication Services

There are two categories in which satellite communication services can be classified:

One-way Satellite Communication

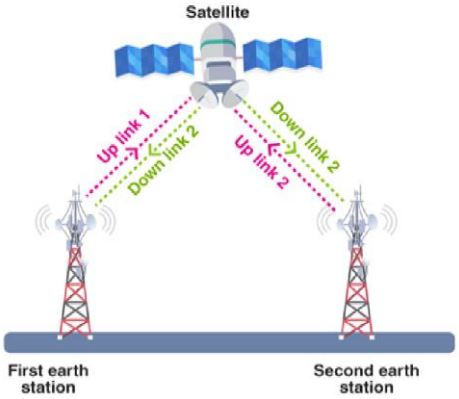
In one-way satellite communication, the communication usually takes place between either one or multiple earth stations through the help of a satellite. The communication takes place between the transmitters on the first earth satellite to the receiver which is the second earth satellite. The transmission of the signal is unidirectional.



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Two-Way Satellite Communication

In two-way satellite communication, the information is exchanged between any two earth stations. It can be said that there is a point to point connectivity. The signal is transmitted from the first earth station to the second earth station such that there are two uplinks and two downlinks between the earth stations and the satellite.



Advantages of Satellite Communication

The following are the advantages of satellite communication:
Installments of circuits are easy.
The elasticity of these circuits is excellent.
With the help of satellite communication, every corner of the earth can be covered.
The user fully controls the network.

Disadvantages of Satellite Communication

The following are the disadvantages of satellite communication:
Initial expenditure is expensive.
There are chances of blockage of frequencies.
Propagation and interference.
Applications of Satellite Communication

Telephone, Television, Digital cinema, Radio broadcasting, Amateur radio, Internet access, Military, and Disaster Management

Trilateration is defined as the process of determining the location based on the intersections of the spheres. The distance between the satellite and the receiver is calculated by considering a 3-D sphere such that the satellite is located at the centre of the sphere. Using the same method, the distance for all the 3 GPS satellites from the receiver is calculated. Following are the parameters that are calculated after trilateration: Time of sunrise and the sunset, Speed, and Distance between the GPS receiver to the destination GPS systems are remarkably versatile and can be obtained in almost any industry sector. They can be used to map forests, help farmers harvest their fields and navigate aeroplanes on the ground or in the air.

Space exploration

Space exploration is the investigation of the universe beyond Earth's atmosphere, utilizing both crewed and uncrewed spacecraft. This endeavor has a rich history, particularly in the latter half of the 20th century when advancements in rocket technology enabled humanity to overcome gravitational forces and achieve orbital velocities. The first manned mission to the moon in 1969 marked a significant milestone, showcasing the potential of space travel. The motivations for exploring space are vast. Organizations like NASA emphasize that space exploration inspires global unity, drives groundbreaking discoveries, and creates new opportunities for technological advancements. The ongoing missions and research not only expand our understanding of the cosmos but also lead to innovations that benefit life on Earth. Despite its potential, human spaceflight poses risks and challenges, as evidenced by historical incidents. By studying celestial bodies and phenomena, we unlock the mysteries of black holes, planets, and the origins of life. This knowledge not only satisfies human curiosity but also inspires future generations to pursue careers in science and technology. Space exploration has tangible benefits for life on Earth. Research conducted

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in space has led to advancements in health care, such as improved vaccines and treatments for conditions like bone loss and eye disorders. The technologies developed for space missions often find applications in everyday life, enhancing weather forecasting, climate monitoring, and telecommunications. Space exploration fosters international collaboration, uniting nations in the pursuit of knowledge and innovation. As we continue to explore the cosmos, we not only gain insights into the universe but also create opportunities for technological advancements that can improve life on our planet.

Hubble Space Telescope (HST)

The Hubble Space Telescope is named after the astronomer Edwin Hubble, whose contribution in the field of astronomy and cosmology are remarkable. It is a large space telescope and was launched in 1990 and is still operational. It is expected to decay by 2030-2040. Hubble features a 2.4-meter mirror, and its four main instruments include ultraviolet, visible, and near-infrared regions of the electromagnetic spectrum. It is the only telescope that has been designed in a manner that it can be serviced by astronauts in space. Till date 5 Space Shuttle missions have been conducted to repair and upgrade the parts of the telescope. The telescope has been built by NASA, along with contributions from the European Space Agency (ESA). It is one of the largest space telescopes which can perform versatile missions.

Significance of a Space Telescope

A lot of cosmic activities happen in space and to learn about them and the future of human existence, scientists and researchers felt the requirement to have a space telescope.

The significance regarding the need of a Space Telescope:

- ✓ For the purpose of Cosmic Revelations
- ✓ It can show the evolution of galaxies
- ✓ To discover the undiscovered planets and stars
- ✓ Space Telescope will help in studying the Science of tomorrow

Observations under Hubble Space Telescope Mission

Since 1990, Hubble has made over 1.4 million observations, 17,000+ research papers have been written over these observations, and has managed to track the interstellar and celestial bodies present in space.

The major observations made on the basis of the Hubble Space Telescope (HST):

It has helped in discovering the moons around Pluto

Hubble's domain extends from the ultraviolet through the visible and into the near-infrared

Dusty disks and stellar nurseries have been discovered by Hubble, although the Milky Way. These may one day be studied in the atmosphere and planetary features

Evidences regarding the existence of black holes have been emerged based on the observations through Hubble

- ✓ The birth of stars through turbulent clouds of gas and dust have also been observed.
- ✓ The Hubble telescope made observations of six galaxies merging together
- ✓ On February 11, 2021, the Hubble made observations of small concentrations of black holes.

Observations of Hubble Space Telescope

The Hubble space telescope is the main instrument in discovering the moons (hydra and nix) around the planet Pluto. It made observations of six galaxies merging together, HST obtained small concentrations of black holes. The Hubble Space Telescope could find infrared radiations too.

Hubble's constant was determined after HST observed the Cepheid variables in nearby galaxies. Hubble has recorded the birth of stars through turbulent clouds of gas and dust. Hubble is the main reason behind discovering dusty disks and stellar nurseries although the Milky Way. Using Hubble, the presence of black holes is proved.

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International Space Station

The **International Space Station** is a **floating laboratory in space where scientists and astronauts study science and technology to help humanity understand space and improve life on Earth.**

The **International Space Station (ISS)** is a large spacecraft that orbits the Earth and serves as a **space laboratory where astronauts live and conduct scientific research in space**. It is one of the biggest international scientific projects ever built.

The ISS is a **habitable artificial satellite** that travels around Earth in **low Earth orbit** at about **400 km above the Earth's surface**.

Astronauts from different countries live and work there for several months at a time.

It moves at a speed of about **28,000 km/h**, completing **one orbit around Earth roughly every 90 minutes**.

The station is a joint project of several space agencies: National Aeronautics and Space Administration (USA), Roscosmos (Russia), European Space Agency, Japan Aerospace Exploration Agency, and Canadian Space Agency

These organizations share the cost, technology, and scientific work. The ISS is mainly used for **scientific research and technology testing**. Some key activities include:

- ✓ Studying **microgravity (weightlessness)** and how it affects humans, plants, and materials.
- ✓ Testing technologies needed for future missions to the **Moon and Mars**.
- ✓ Observing **Earth's climate, weather, and natural disasters** from space.
- ✓ Conducting experiments in **physics, biology, medicine, and materials science**.

The ISS is made of several connected modules that were launched into space separately and assembled in orbit. Major parts include: **Living modules** – where astronauts sleep and eat, **Laboratories** – where experiments are carried out, **Solar panels** – produce electricity from sunlight, and the **Robotic arms** – used for moving equipment and assisting spacewalks

Astronauts on the ISS experience **microgravity**, so they float instead of walking. Because of this: Food is specially packaged, Astronauts exercise about **2 hours daily** to keep their muscles and bones strong, and Water and air are **recycled** to support long missions.

From Earth, the ISS can sometimes be seen **with the naked eye** shortly after sunset or before sunrise. It appears as a **bright object moving quickly across the sky**.

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Uses of International Space Station

The ultimate goal of the International Space Station is to facilitate long-term space exploration and create useful inventions for the goodness of humanity. There are six cutting-edge laboratories enabling premium research projects in various fields of science and technology. Complex and volatile experiments can be easily conducted in microgravity spaces. Especially in medicine, we are witnessing revolutionary research projects that were impossible to perform in earthly conditions. Studies on hyper and microgravity help understand the effects of alien conditions on the human body. Cultivating protein crystals in space could help scientists develop better treatment solutions for many diseases that have no cure. In addition, there are numerous innovative space research projects that are designed to study celestial bodies. The International Space Station acts as a doorway to new horizons in space exploration. It is a place where we can learn and experiment on living and surviving on alien planets. The long-term consequences of weightlessness and radiation on the human body are the most crucial research areas, which will allow us to prepare astronauts for crewed interplanetary missions.

Significant Contributions of International Space Station

9/11/2026

The International Space Station is aiding in the research of water purification technology. In the space station, scientists are able to conduct advanced experiments which are not possible on the Earth. In space, the external variables are significantly less compared to the Earth. Fewer constraints mean less probability of errors. High-quality protein crystals are being developed in the space station. Space has the perfect conditions to examine these structures. Microgravity is conducive to the optimal cultivation of rare and complex protein crystal structures. These are some of the crucial substances in medical diagnosis. Space station ultrasound technology. Eye surgery methods with space station hardware and tools (helmet feeding highly efficient image-processing chips). Robotic arms can be used to operate complex tumors. Research on the characteristics of various fluids to improve existing medical devices. They are developing fine-tuned diets and exercises for preventing bone loss or degradation. Practical experiences in the space station help better understand osteoporosis development. The International Space Station gives excellent opportunities for students to conduct their own scientific experiments in space. It helps to monitor water quality. It also enables us to monitor and predict natural calamities from space. There have been projects for developing optimal methods for cultivating crops in space. In turn, it also helps to find solutions for mould prevention in medical labs, homes and large-scale food storage.

Chapter Assessment:

A group of senior students at a secondary school in Kampala are watching a televised science program showing activities aboard the International Space Station. The program explains how artificial satellites orbit the Earth and help scientists collect information about weather, communication signals, and environmental changes. The presenter also shows how satellites are used to improve weather forecasting, guide aircraft and ships, support mobile phone communication, and help scientists monitor natural disasters such as floods and droughts in East Africa. After the program, the teacher asks the learners to discuss how artificial satellites help people on Earth and why countries continue to invest in space exploration. The International Space Station moves around the Earth approximately once every 90 minutes.

Task: Use the knowledge of physics to:

a) Explain what is meant by an artificial satellite.

b) Describe two ways artificial satellites are used in scientific research.

c) Identify three ways satellites are useful in everyday life for people in Uganda.

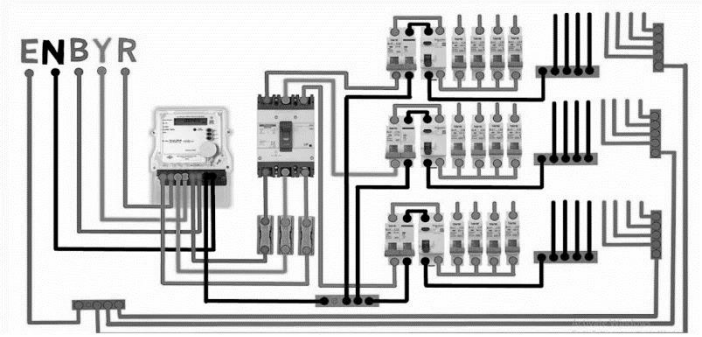
d) Explain two reasons why space exploration is important for humanity.

e) Explain why artificial satellites are able to remain in orbit around the Earth instead of falling to the ground.

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SENIOR FOUR



4.1 INTRODUCTION TO CURRENT ELECTRICITY

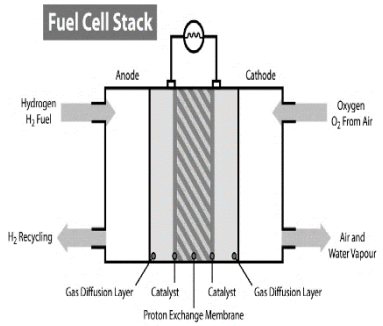
Learning Outcomes

a) *Understand what e.m.f is (u)*
b) *Understand that cells convert chemical energy into electrical energy, producing current and also the force needed to create a flow of current in a circuit (u, s)*
c) *Understand that electric cells are very useful but have their limitations (u, v/a)*
d) *Understand the nature of electric current, its sources, what makes it flow around circuits and how and it is measured (u, s)*
e) *Know that some materials are electrical conductors and other are insulators(k)*
f) *Recognize, understand and apply knowledge of series and parallel circuits (k, u, s,v/a)*
g) *Appreciate that circuits may be represented as circuit diagrams consisting of an agreed set of symbols to represent components (k, u, s)*

Introduction

Current electricity is the flow of electric charge, primarily electrons, through a conductor, such as a wire. This flow is measured in amperes (amps), which quantify the number of charges passing a point in the circuit per second. Electric current can be compared to water flow; just as water flows through pipes, electric current flows through conductors. The relationship between voltage (the potential difference) and current is described by Ohm's Law, which state that current is directly proportional to voltage and inversely proportional to resistance. This fundamental principle is crucial for designing and analyzing electrical circuits. In summary, current electricity is a vital concept in physics and engineering, underpinning the operation of countless devices and systems in our daily lives. Understanding its principles allows for advancements in technology and energy efficiency.

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Electromotive force (e.m.f) refers to the voltage generated by a source that drives electric current in a circuit. It is a measure of the energy supplied per coulomb of charge and can be thought of as the "push" that moves electrons through a conductor.

Sources of e.m.f

Chemical Sources

Batteries: Batteries convert chemical energy into electrical energy through electrochemical reactions. Example: In a common alkaline battery, zinc and manganese dioxide undergo a chemical reaction, resulting in a flow of electrons from the anode (negative terminal) to the cathode (positive terminal).

Fuel Cells: Fuel cells convert the chemical energy of fuels (like hydrogen or methanol) directly into electricity through a chemical reaction with oxygen, typically producing water as a byproduct. Example: Hydrogen fuel cells generate e.m.f. by combining hydrogen and oxygen, producing electricity, water, and heat.

Electromagnetic Sources

Generators: Generators convert mechanical energy into electrical energy through electromagnetic induction, where a conductor (like a wire) moves through a magnetic field, inducing an e.m.f. in the conductor. Example: In a simple AC generator, a coil of wire rotates within a magnetic field, producing alternating current due to the changing magnetic flux.
Alternators: Similar to generators, alternators produce alternating current by rotating coils within a magnetic field, inducing an e.m.f. that changes direction with time. Example: Alternators are commonly used in vehicles to charge batteries and power electrical systems while the engine runs.

Thermoelectric Sources
Thermocouples: Thermocouples generate e.m.f. by exploiting the Seebeck effect, where a voltage is produced in a circuit made of two different conductors when there is a temperature difference between their junctions. Example: Used in temperature measurement, where the voltage produced correlates to the temperature difference, allowing for precise readings.
Thermoelectric Generators (TEGs): TEGs convert heat energy directly into electrical energy using thermoelectric materials that generate e.m.f. when subjected to a temperature gradient.
Example: Used in space applications and waste heat recovery systems to convert waste heat into usable electrical energy.
Photovoltaic Sources
Photovoltaic (PV) sources are essential in harnessing solar energy, converting sunlight directly into electricity through solar cells. A PV cell, typically small and made from semiconductor materials, is the fundamental unit of this technology. When sunlight strikes the cell, it excites electrons, generating an electric current. The efficiency of PV systems is a primary focus of ongoing research, aiming to make solar energy more cost-competitive with traditional energy sources. Various materials are utilized in PV cells, each contributing to the overall performance and efficiency of solar panels. As the demand for clean, renewable energy grows, photovoltaic sources are increasingly recognized for their cost-effectiveness and environmental benefits.
Solar Cells: Solar cells convert light energy directly into electrical energy through the photovoltaic effect, where photons knock electrons loose from atoms in a semiconductor material, creating a flow of current. Example: Used in solar panels to generate electricity from sunlight for residential, commercial, and utility applications.

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Piezoelectric Sources

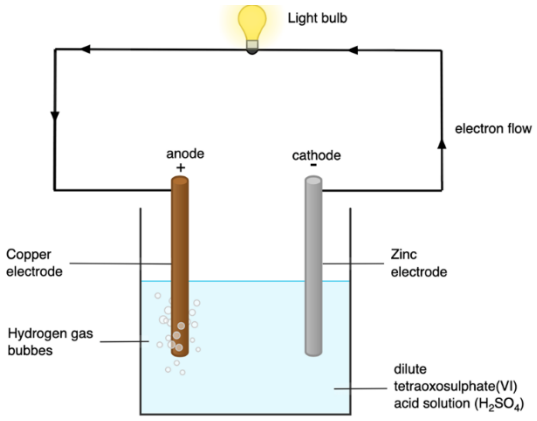
Piezoelectric materials generate e.m.f. when mechanical stress is applied, causing a displacement of charges within the material. Example: Used in sensors and actuators, as well as in applications like energy harvesting from vibrations or mechanical movements. Various sources of e.m.f. are vital for supplying electrical energy in different applications. Chemical reactions in batteries and fuel cells, mechanical movement in generators and alternators, thermal gradients in thermocouples and TEGs, light energy in solar cells, and mechanical stress in piezoelectric materials all serve to produce voltage that drives electric current in circuits. These are devices that can produce electricity by chemical action.

Different types of electric cells
Simple cells, Dry cells, Leclanche cells (wet cells), Lead acid accumulator and alkaline cells (Nickel iron cells).
Simple cells

A simple cell consists of a copper plate as the anode (positive) and the zinc plate the cathode (negative), dipped in dilute Sulphuric acid as the electrolyte. The more reactive metal in the reactivity series forms the cathode i.e. zinc is higher than copper in the reactivity series therefore zinc cathode and copper anode.

How a simple cell works?

The electrolyte undergoes ionization. The zinc plate slowly dissolves and goes into the solution as zinc ions which displace hydrogen ions to form zinc-sulphate. The displaced hydrogen ions move to the copper plate. They gain electrons and become neutralized. The two of these atoms combine to form gas that appears as bubbles on the copper plate. This flow of electrons from the cathode to anode causes the flow of electricity from the anode to the cathode hence if a voltmeter is connected between anode and cathode, it deflects.



Defects of a simple cell

The two primary faults are polarization and local action. Polarization occurs when the cell is in use, leading to the accumulation of gases, particularly hydrogen, at the electrodes. This buildup reduces the current flow, causing the cell to operate less effectively over time. As the reaction progresses, the voltage drops, making it challenging to maintain a consistent output.

Prevention/ reduction of polarization

This can be reduced by Occasional brushing of the anode, and adding a depolarizer e.g. potassium dichromate ($K_2Cr_2O_7$) which oxidizes hydrogen to form water.

Local action refers to the unintended reactions occurring at the electrodes, which can lead to energy loss and reduced efficiency. This phenomenon is often caused by impurities in the materials used for the electrodes, gradual wearing down of the zinc electrode (cathode) as a result of impurities on the plate reacting with the acid to hydrogen bubbles, resulting in unwanted side reactions that consume reactants without contributing to the intended electrochemical process.

Prevention of local action: The zinc plate is cleaned in concentrated acid and then rubbed with mercury. The mercury zinc amalgam covers up the impurities thereby preventing their contact with acid electrolyte.

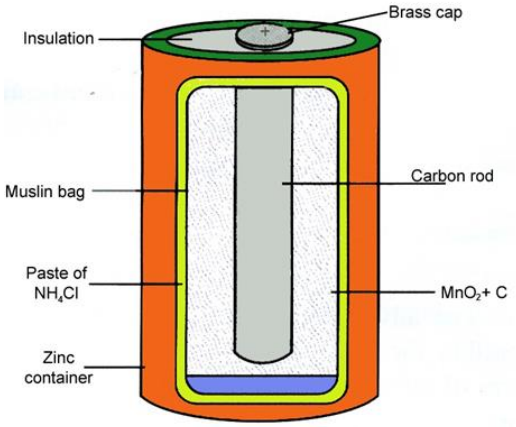
PRIMARY AND SECONDARY CELLS

Primary cell

This is one in which current is produced as a result of an irreversible reactions i.e. cannot be recharged when it runs down e.g. simple cells, dry cells and Leclanché cells. Whenever the cell runs out, it implies that all ionized ions in the electrolyte have reacted to release electrodes.

Primary cells are electrochemical cells that generate electric energy through irreversible chemical reactions. Once the chemical reactants are exhausted, these cells cannot be recharged and must be replaced. Primary cells are commonly used in various applications due to their convenience and ease of use.

Dry cell as a primary cell



It is used in torches, radios and has an E.M.F of 1.5 volts.
It uses Ammonium chloride jelly as the electrolyte.
The anode is the carbon rod placed in the centre of the Zinc container which forms the cathode.

Action of a dry cell

The source of energy is chemical action between Zinc and ammonium chloride jelly. As a result, hydrogen gas is produced which collects at the carbon rod and polarizes the cell. The manganese (iv) oxide oxidizes the hydrogen to water in the cell and enables it to supply current for some time. Local action cannot be completely stopped in dry cells and therefore the cell deteriorates with time.

The other different types of primary cells include:



Alkaline Cells: These cells typically consist of zinc (anode) and manganese dioxide (cathode) with an alkaline electrolyte (potassium hydroxide).They higher energy density than other primary cells, stable voltage output over a longer period, and better performance at lower temperatures compared to other types. They are widely used in household devices like remote controls, toys, and flashlights.

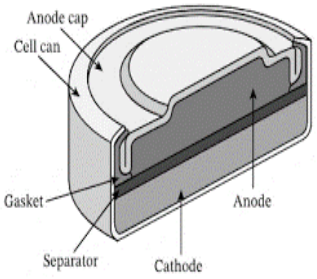
Zinc-Carbon Cells: This traditional type consists of a zinc anode, carbon rod as the cathode, and an electrolyte made of a paste of ammonium chloride or zinc chloride. They have lower cost compared to alkaline cells, has a lower energy density and shorter shelf life and voltage drops quickly under load, making it less suitable for high-drain applications. They are commonly used in low-drain devices like clocks, flashlights, and remote controls.

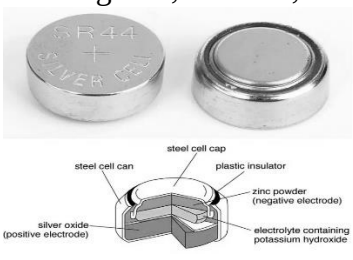


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Lithium Cells: These cells use lithium metal or lithium compounds as the anode and various materials (like manganese dioxide or cobalt oxide) as the cathode, often with a lithium salt electrolyte**.** They have a high energy density and long shelf life, can operate in a wide temperature range, and generally have a stable voltage output. Used in a variety of applications, including watches, cameras, calculators, and medical devices.

Mercury Cells: Composed of mercury (anode), zinc (cathode), and a potassium hydroxide electrolyte. Stable voltage output, High energy density, and have environmental concerns due to mercury toxicity. Previously used in hearing aids, cameras, and some types of watches, but usage has declined due to environmental regulations.





Silver-Oxide Cells: These cells have a silver oxide cathode, zinc anode, and an alkaline electrolyte (typically potassium hydroxide). They have high energy density and stable voltage output, more expensive than other primary cell types. Commonly used in watches, hearing aids, and other small electronic devices due to their compact size and reliability.

Secondary cells



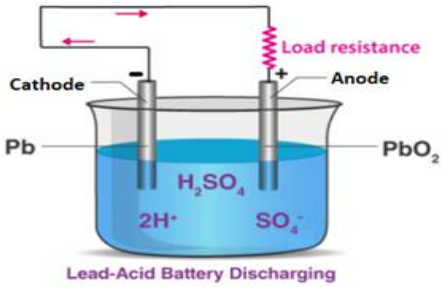


Secondary cells, commonly known as rechargeable batteries, are essential components in modern technology. Unlike primary cells, which are designed for single-use, secondary cells can be charged and discharged multiple times. This capability is achieved by reversing the chemical reactions that occur during discharge, allowing the battery to restore its energy. There are various types of secondary cells, including lithium-ion, lead-acid, and flow batteries. Each type has unique characteristics, such as energy density and internal resistance, which make them suitable for different applications. For instance, lithium-ion batteries are widely used in portable electronics due to their high energy density and low self-discharge rates. The development of advanced materials, such as carbon nanotubes, is enhancing the performance of secondary batteries, making them more efficient and longer-lasting. As technology continues to evolve, the importance of secondary cells in energy storage and sustainability will only increase, driving innovation in this vital sector.

Lead acid accumulators as a secondary cell



Lead-Acid Battery charging



Lead-Acid Battery Discharging

Lead-acid accumulators, commonly known as lead-acid batteries, are a type of rechargeable battery that utilizes a chemical reaction to store and release electrical energy. They consist of two lead-based plates immersed in a sulfuric acid solution, with a negative electrode made of spongy lead to facilitate the formation and dissolution of lead. While lead-acid batteries have a relatively low energy density compared to modern rechargeable batteries, they excel in providing high surge currents, making them ideal for automotive applications. These batteries have a moderate lifespan and are not subject to the memory effect seen in nickel-based systems, allowing for better charge retention. Flooded lead-acid batteries, or wet cell batteries, are the most traditional and widely recognized type, used extensively in vehicles and backup power systems. During discharge, both electrodes change to Lead Sulphate and the acid becomes more dilute. When fully charged, the relative density of the acid is 1.25 which falls to 1.18 at cell discharge.

Care and maintenance of lead acid accumulators

The liquid level must be maintained using distilled water. This ensures that the electrodes are not exposed. The cell should be charged if the relative density of the electrolyte falls below 1.25.

The battery should be kept clean so that the current does not lick away across the casing and across the terminal. The positive terminal should not be connected directly to the negative terminal. When this is done (short circuit), too much current is taken from the cell. This tends to destroy it. The battery should be charged regularly and should not be left uncharged condition for a long time. The effect of charging current is to change lead sulphate on both positive and negative plate into lead (ii) oxide and to return the sulphate into the electrolytes.

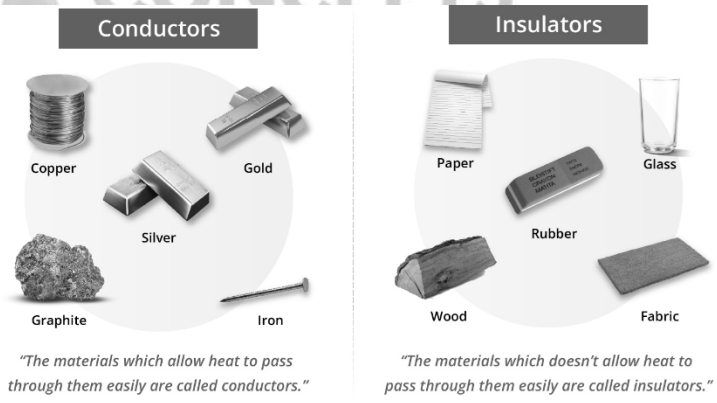
The Nickel- Cadmium Alkaline Cells or Nife Accumulators

Nickel-Cadmium (NiCd) batteries, also known as NiFe accumulators, are a type of rechargeable battery that utilizes nickel oxide hydroxide and metallic cadmium as electrodes. These batteries are known for their durability and ability to deliver high discharge rates, making them suitable for various applications, including power tools, emergency medical equipment, and two-way radios. NiCd batteries operate effectively in extreme temperatures and have a long cycle life, which contributes to their popularity in industrial settings. However, they do have some drawbacks, such as the memory effect, which can reduce their capacity if not properly maintained. Have environmental concerns regarding cadmium, a toxic heavy metal, have led to increased scrutiny and regulations surrounding their disposal and recycling.

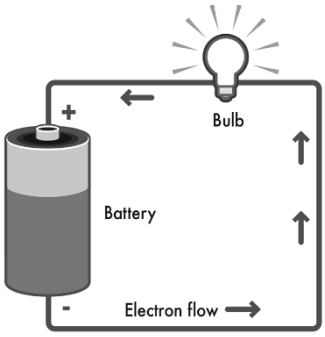
Electric Current

Electric Current is the rate of flow of electrons in a conductor. The SI Unit of electric current is the Ampere.$1A = 1Cs^{-1}$. Electrons are minute particles that exist within the molecular structure of a substance. Sometimes, these electrons are tightly held, and other times they are loosely held. When electrons are loosely held by the nucleus, they are able to travel freely within the limits of the body. Electrons are negatively charged particles hence when they move, a number of charges move, and we call this movement of electrons as electric current. It should be noted that the number of electrons that are able to move governs the ability of a particular substance to conduct electricity. Some materials allow the current to move better than others. Based on the ability of the material to conduct electricity, materials are classified into conductors and insulators.

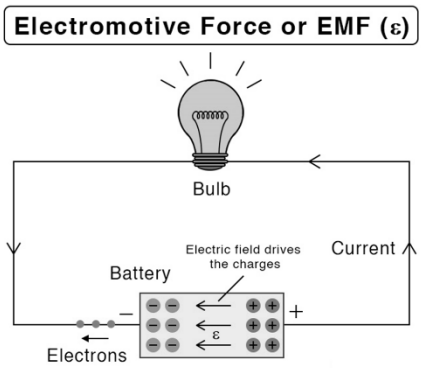
Conductors: These materials allow the free flow of electrons from one particle to another. Conductors allow for charge transfer through the free movement of electrons. The flow of electrons inside the conducting material or conductor generates an electric current. The force that is required to drive the current flow through the conductor is known as voltage. Conductors of electricity are classified into two main categories: good conductors and bad conductors. Good conductors, such as copper and aluminum, iron, silver and gold, allow electric current to flow through them easily due to their abundance of free-moving electrons. Silver is the best conductor of electricity. This property makes them ideal for electrical wiring and components, ensuring efficient energy transfer. Bad conductors, or insulators, resist the flow of electricity. Materials like rubber, glass, and wood fall into this category, as they have high resistance and few free electrons. Insulators are materials that restrict the free flow of electrons from one particle to another. The particles of the insulator do not allow the free flow of electrons; subsequently, the charge is seldom distributed evenly across the surface of an insulator. Examples of Insulators: Plastic, Wood and Glass



Current flow in a conductor



Electric current is the flow of charged particles, primarily electrons, through a conductor. In metallic conductors, these electrons move in response to an electric field, creating a chain reaction of mutual repulsion that allows them to flow almost simultaneously. This movement is essential for the functioning of electrical circuits, where current travels from a higher potential (positive terminal) to a lower potential (negative terminal).The behavior of current flow can vary depending on the type of electricity. Direct current (DC) flows uniformly through the entire cross-section of a conductor, while alternating current (AC) experiences the skin effect, where it tends to flow near the surface of the conductor at higher frequencies. Understanding these dynamics is crucial for designing efficient electrical systems.



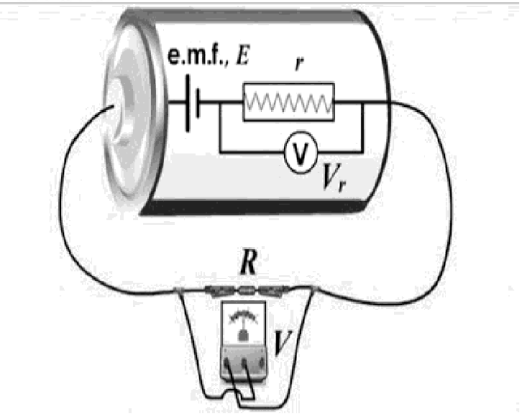
Electromotive Force

Electromotive force (EMF) refers to the potential difference generated by a source, such as a battery or generator, which drives electric charges through a circuit. It is the energy supplied per unit charge to move charges from the negative to the positive terminal of the source, enabling the flow of current. EMF is the maximum voltage the source can provide when no current flows and is measured in volts (V). When a circuit is complete, the actual voltage available to the external circuit is slightly less than the EMF due to energy losses within the source caused by its internal resistance. EMF acts as the driving energy behind the flow of electric current in a circuit. If a force acts on electrons to make them move in a particular direction, then up to some extent random motion of the electrons will be eliminated. An overall movement in one direction is achieved. The force that acts on the electrons to make them move in a certain direction is known as electromotive force, and its quantity is known as voltage and is measured in volts.

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Measurement of e.m.f of a cell

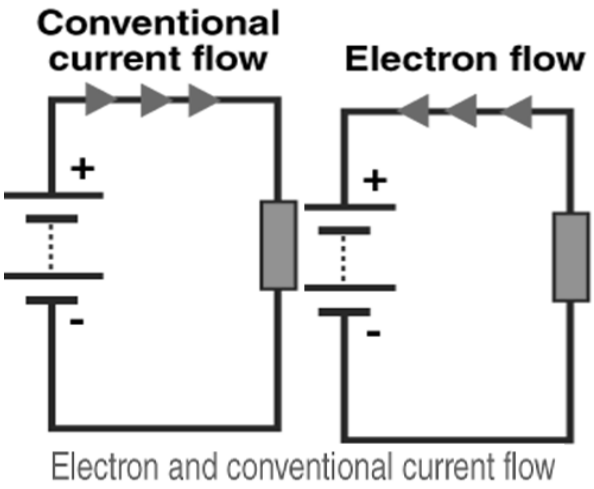
Unit of Electric Current



The magnitude of electric current is measured in coulombs per second. The SI unit of electric current is *Ampere* and is denoted by A. Ampere is defined as one coulomb of charge moving past a point in one second. If there are 6.241 x 10^{18} electrons flowing through our frame in one second, then the electrical current flowing through it is 'One Ampere.' The unit Ampere is widely used within electrical and electronic technology along with the multipliers like milliamp (0.001A), microamp (0.000001A), and so forth.

Visualizing Electric Current

To gain a deeper understanding of what an electric current is and how it behaves in a conductor, we can use the water pipe analogy of electricity. Certainly, there are some limitations but they serve as a very basic illustration of current and current flow.



Electron and conventional current flow

Conventional current flow versus electron flow

There is a lot of confusion around conventional current flow and electron flow.

Conventional Current Flow

The conventional current flow is from the positive to the negative terminal and indicates the direction in which positive charges would flow.

Electron Flow

The electron flow is from negative to positive terminal. Electrons are negatively charged and are therefore attracted to the positive terminal as unlike charges attract.

Properties of Electric Current

After we define electric current, let us learn the properties of electric current. Electric current is an important quantity in electronic circuits. We have adapted electricity in our lives so much that it becomes impossible to imagine life without it. Therefore, it is important to know what is current and the properties of the electric current. We know that electric current is the result of the flow of electrons. The work done in moving the electron stream is known as electrical energy. Electrical energy can be converted into other forms of energy such as heat energy, light energy, etc. For example, in an iron box, electric energy is converted to heat energy. Likewise, the electric energy in a bulb is converted into light energy.

There are two types of electric current known as alternating current (AC) and direct current (DC). The direct current can flow only in one direction, whereas the alternating direction flows in two directions.

Direct current is seldom used as a primary energy source in industries. It is mostly used in low voltage applications such as charging batteries, aircraft applications, etc.

Alternating current is used to operate appliances for both household and industrial and commercial use. The electric current is measured in ampere. One ampere of current represents one coulomb of electric charge moving past a specific point in one second. The conventional direction of an electric current is the direction in which a positive charge would move. Henceforth, the current flowing in the external circuit is directed away from the positive terminal and toward the negative terminal of the battery.

Effects of Electric Current

After defining electric current, let us learn various effects of electric current. When a current flow through a conductor, there are a number of signs which tell if a current is flowing or not. Following are the most prominent signs:

Heating Effect of Electric Current

When our clothes are crumpled, we use the iron box to make our clothes crisp and neat. Iron box works on the principle of heating effect of current. There are many such devices that work on the heating effect.

When an electric current flows through a conductor, heat is generated in the conductor. The heating effect is given by the following equation$power\ dissipated\ as\ heat\ = I^2Rt.$
The heating effect depends on the following factor:

- The time 'for which the current flows. The longer the current flows in a conductor more heat is generated.
- The electrical resistance of the conductor. Higher the resistance, the higher the heat produced.
- The amount of current. The larger the amount of current higher the heat produced.

If the current is small, then the amount of heat generated is likely to be very small and may not be noticed. However, if the current is larger than it is possible that a noticeable amount of heat is generated.

Magnetic Effect of Electric Current

Another prominent effect that is noticeable when an electric current flows through the conductor is the build-up of the magnetic field. We can observe this when we place a compass close to a wire carrying a reasonably large direct current, and the compass needle deflects. The magnetic field generated by a current is put to good use in a number of areas. By winding a wire into a coil, the effect can be increased, and an electromagnet can be made.

Chemical Effect of Electric Current

When an electric current passes through a solution, the solution ionizes and breaks down into ions. This is because a chemical reaction takes place when an electric current passes through the solution.
Electroplating and electrolysis are the applications of the chemical effect of electric current.
Electric current is the flow of electric charge through a conductor, typically measured in amperes (A). This flow of charge is caused by a difference in electric potential (voltage) across the conductor, which creates an electric field, pushing charges from one point to another.

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Types of Electric Current

Direct Current (DC): Electric charge flows in a single, constant direction. They are commonly used in batteries, electronic devices, and DC motors.
Alternating Current (AC): Electric charge periodically changes direction. They are widely used for household and industrial power supply because AC can be easily transformed to different voltages.

Measuring Electric Current

Electric current is measured in amperes (A), where one ampere represents one coulomb of charge passing through a point in the conductor per second. It can be measured using an ammeter in series with the circuit.
Electric Current Flow:
Defined as the flow of positive charge from the positive to the negative terminal. *Electron Flow*: Actual flow of electrons, which move from the negative to the positive terminal.

Ohm's Law

Electric current (I) in a conductor is directly proportional to the voltage (V) across it and inversely proportional to the resistance (R) of the conductor: where I is current, V is voltage, and R is resistance.$V = IR, I = \frac{V}{R}$
Applications of Electric Current

- Provides energy to devices like lights, motors, and electronic devices.
- Used in industrial processes to extract or refine metals.

- Provides energy for electric heaters and light sources.

Safety Considerations

Electric current can be dangerous if not managed properly. High current can cause burns, shocks, or fires, so insulation, grounding, and circuit protection (fuses, circuit breakers) are essential for safe operation.

Electromotive Force

Electromotive force is defined as the electric potential produced by either an electrochemical cell or by changing the magnetic field.

E.M.F is the commonly used acronym for electromotive force.

A generator or a battery is used for the conversion of energy from one form to another. In these devices, one terminal becomes positively charged while the other becomes negatively charged. Therefore, *an electromotive force is a work done on a unit electric charge.*

Electromotive force is used in the electromagnetic flow meter which is an application of Faraday's law.

- *Terminal voltage (V) is defined as the potential difference across the terminals of a load when the circuit is on while EMF (E) is defined as the maximum potential difference that is delivered by the battery when there is no flow of current.*
- *A voltmeter is used for measuring the terminal voltage whereas a potentiometer is used for measuring the EMF.*
-

Symbol for Electromotive Force

The electromotive force symbol is ε.

What is Electromotive Force Formula?

The formula for electromotive force: $\varepsilon = V + Ir$, where, V is the voltage of the cell, I is the current across the circuit, r is the internal resistance of the cell and ε is the electromotive force. The unit for electromotive force is **Volt**. EMF is numerically expressed as the number of Joules of energy given by the source divided by each Coulomb to enable a unit electric charge to move across the circuit.$volts = \frac{joules}{coulomb}(JC^{-1})$.

EMF is given as the ratio of work done on a unit charge which is represented as follows: $e.m.f = \frac{joules}{coulomb}(JC^{-1})$

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Measuring the e.m.f of a cell

To determine the electromotive force (e.m.f.) of a cell, a simple circuit can be set up with a voltmeter and variable resistor (rheostat) to measure the voltage across the cell when different currents are drawn. *This method is known as the voltmeter and ammeter method.*

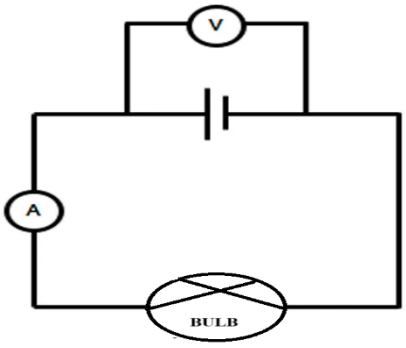
Apparatus

A cell, Voltmeter, Ammeter, Bulb or Rheostat or variable resistor, Connecting wires, and Switch

Procedure

a) Connect the cell, ammeter, voltmeter, and rheostat in a circuit.
b) The voltmeter should be connected in parallel across the cell, while the ammeter is in series with the cell and rheostat.

c) Close the switch to complete the circuit, allowing current to flow.
d) Adjust the rheostat to change the current flowing through the circuit.
e) For each position of the rheostat, record the current I (from the ammeter) and the voltage V (from the voltmeter).
f) Repeat for several different settings to obtain a range of I and V readings.
g) Open the switch between readings to prevent the cell from discharging too quickly and affecting accuracy.



h) Plot a graph of V (on the y-axis) against I (on the x-axis). The graph should yield a straight line with a negative slope.
i) The ***intercept of the V-axis (where I=0) gives the e.m.f (E). of the cell***.
j) The slope of the line represents the internal resistance r of the cell, as the relationship between V and I follows the equation: $V=E-Ir$.

Explanation

The e.m.f. of the cell is the open-circuit voltage (the voltage when no current flows), represented by the y-intercept on the V-I graph. This is because, at zero current, the voltage across the cell is entirely due to the e.m.f., without any voltage drop across the internal resistance of the cell.
This method allows for both the e.m.f. and internal resistance to be determined accurately by analyzing the straight-line graph obtained.

Cells in Series and Parallel

Cells generate electricity and also drive chemical reactions. One or more electrochemical cells are batteries. Every cell has two terminals namely:
Anode: Anode is the terminal from where the current flows in from out i.e. it provides an incoming channel for the current to enter the circuit or the device.
Cathode: Cathode is the terminal from where the current flows out i.e. it provides an outgoing current flow from the circuit or the device.
There are two simplest ways for cell connectivity:
Series Connection: Series connection is the connectivity of the components in a sequential array of components.
Parallel Connection: Parallel connection is the connectivity of the components alongside to other components.

Cells in Series Connection

In series, *cells are joined end to end so that the same current flows through each cell*. In case if the cells are connected in series the emf of the battery is connected to the sum of the emf of the individual cells. Suppose we have multiple cells and they are arranged in such a way that the positive terminal of one cell is connected to the negative terminal of the another and then again the negative terminal is connected to the positive terminal and so on, then we can that the cell is connected in series.

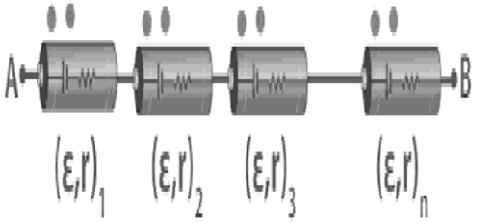
Equivalent EMF/Resistance of Cells in Series

If E is the overall e.m.f of the battery combined with n number cells and E_1, E_2, E_3, E_n is the e.m.fs of individual cells. Then $E_1 + E_2 + E_3 + \ldots\ldots E_n$

Similarly, if r_1, r_2, r_3, r_n are the internal resistances of individual cells, then the internal resistance of the battery will be equal to the sum of the internal resistance of the individual cells; $r = r_1 + r_2 + r_3 + \ldots + r_n$

Cells in Series

In a series arrangement, cells are connected end-to-end, with the positive terminal of one cell connected to the negative terminal of the next cell. This increases the total voltage of the battery pack while keeping the current the same as that of a single cell.



Advantages of Cells in Series

Increased Voltage: The total voltage of the series connection is the sum of the individual cell voltages. For example, three 1.5V cells in series provide a total of 4.5V.

Useful for applications requiring higher voltages, like some power tools or motor-driven devices.

Series connections are straightforward and do not require complex wiring or additional circuitry, making them easy to implement.

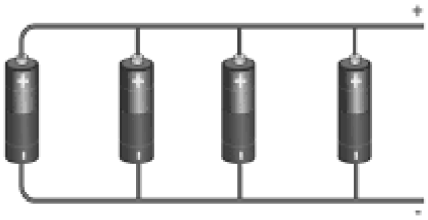
Disadvantages of Cells in Series

Single Cell Failure Affects the Whole Chain: If one cell fails or is depleted, it breaks the circuit, and the entire battery stops working. This limits the reliability of the series configuration, especially if using cells with different capacities.

Cells in series must have the same capacity; otherwise, cells with lower capacities will discharge faster and potentially get damaged, affecting overall performance.

Cells in Parallel Connection

Cells are in parallel combination if the current is divided among various cells. In a parallel combination, the entire positive terminal is connected together and the entire negative terminals are connected together.



Equivalent EMF/Resistance of Cells in Parallel

If e.m.f of each cell is identical, then the e.m.f of the battery combined with n numbers of cells connected in parallel is equal to the e.m.f of each cell. The resultant internal resistance of the combination is, $\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \cdots + \frac{1}{r_n}$

Equivalent EMF/Resistance of Cells in Series and Parallel

Assume the e.m.f of each cell is E and internal resistance of each cell is r. As n numbers of cells are connected in series, the total e.m.f of the cell as well as the battery will be $\boldsymbol{E_t = nE}$. The equivalent resistance of the series is $\boldsymbol{r_t = nr}$. As, **m** the number of cells connected in parallel, equivalent internal resistance of the cells for the parallel battery is $\frac{1}{r_t} = \frac{m}{r}$,.

Cells in Parallel

In a parallel arrangement, all positive terminals are connected together, and all negative terminals are connected together. This increases the current capacity while keeping the voltage the same as that of a single cell.

Advantages of Cells in Parallel

Increased Current Capacity: The total current output is the sum of the currents from each cell, making parallel connections ideal for applications that need higher current, like high-power lights or appliances. Extends battery life by providing a larger total charge (amp-hour rating).
If one cell fails, the others can still provide power, allowing the device to continue functioning.
Ideal for applications requiring long-term reliability, as individual cell failures have less impact on the circuit.

Disadvantages of Cells in Parallel
The voltage remains the same as that of a single cell, which may be insufficient for devices requiring higher voltages. Not suitable for applications requiring a voltage boost.
Parallel-connected cells may require special balancing during charging to avoid overcharging or undercharging certain cells. Without proper management, cells can discharge unevenly, leading to inefficiency and shortened cell lifespan.

4.2 VOLTAGE, RESISTANCE AND OHM'S LAW

Learning Outcomes

a) Understand electrical resistance, how it is measured, its relationship to current and voltage, and the factors that affect it (k, u, s)
b) Know the function and use of a diode, transistor, thermistor, LDR. Led and potentiometer (k,s)

Electrical work and voltage

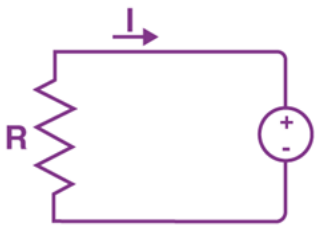
Electrical Energy

Electrical energy is the work done in moving an electric charge by an electric force. The SI unit of electrical energy is the Joule (J). This electrical energy is accompanied with a rise in temperature so this energy may be given out as heat energy.. This explains why wires become hot when electricity passes through them. As current is switched on, electrons start moving through the wire. Due to resistance of the wire, the electrons are opposed from moving and they collide with the molecules of the wire. They lose some of their kinetic energy to the molecules of the wire which causes a rise in temperature (heat energy).

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Electrical Power

This is the rate of doing work on a charged particle. The SI unit of electrical power is the Watt (W).
Calculating electrical energy is essential for understanding power consumption in various applications. The fundamental equation for electric energy is $E = P \times t$, where E represents energy in kilowatt-hours (kWh), P is power in kilowatts (kW), and t is time in hours. This formula allows users to determine how much energy is consumed over a specific period, making it crucial for managing electricity costs. To further break it down, one kilowatt-hour equals 1,000 watts used for one hour. This means that if an appliance operates at 1 kW for one hour, it consumes 1 kWh of energy. Additionally, using Ohm's Law, power can also be calculated by multiplying voltage (in volts) by current (in amps), providing another method to assess energy consumption in electrical circuits.



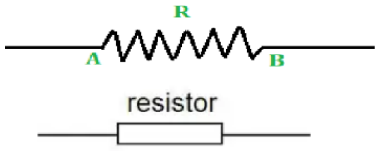
Electrical resistance

Electrical resistance is the opposition encountered by the flow of charge, which can be influenced by the material's properties, temperature, and physical dimensions. The unit of measurement for resistance is the ohm (Ω), and it plays a crucial role in determining how much current will flow for a given voltage, as described

by Ohm's Law. Different materials exhibit varying levels of resistance; for instance, silver has the highest conductivity, followed by copper and gold.

Types of resistors

Resistors are essential components in electronic circuits, serving to control current flow. They can be categorized into two main types: fixed and variable resistors. Fixed resistors maintain a constant resistance, while variable resistors allow for adjustable resistance levels, making them versatile for various applications. Among the specialized types of resistors are thermistors, which change resistance with temperature, and varistors, which protect circuits from voltage spikes. Photoresistors, or light-dependent resistors (LDRs), adjust their resistance based on light exposure, making them ideal for light-sensing applications. Surface mount resistors are compact and designed for modern electronic devices, facilitating efficient circuit design.

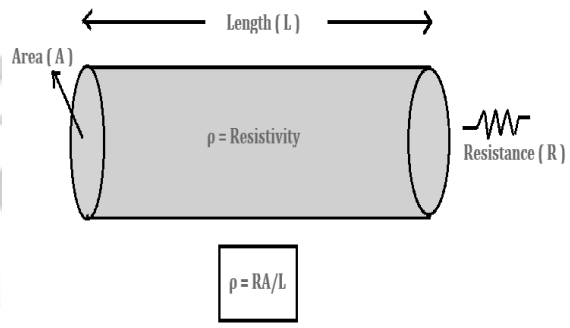


Fixed resistors are resistors with a specific value. Fixed resistors one of the most widely used types of resistor. Fixed resistors are used in electronics circuits to set the correct conditions in a circuit. Variable Resistors consist of a slider which taps onto the main resistor element and a fixed resistor element. Simply we can say that a variable resistor is a potentiometer with only 2 connecting wires instead of 3.

Factors affecting the resistance of a wire

The electrical resistance of a conductor is dependent on the following factors:

- ✓ The cross-sectional area of the conductor
- ✓ Length of the conductor
- ✓ The material of the conductor
- ✓ The temperature of the conducting material



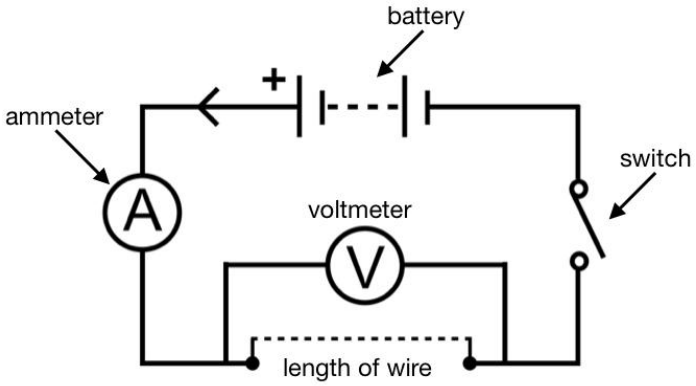
Electrical resistance is directly proportional to length (L) of the conductor and inversely proportional to the cross-sectional area (A). It is given by the following relation.

$R = \rho \frac{L}{A}$; Where ρ is the resistivity of the material (measured in Ωm, ohm meter).

Resistivity is a qualitative measurement of a material's ability to resist flowing electric current. Obviously, insulators will have a higher value of resistivity than that of conductors. The resistivities of a few materials are given below for comparison. Materials with a low value of resistivity conduct electricity very well.

To investigate the factors affecting the resistance of a wire

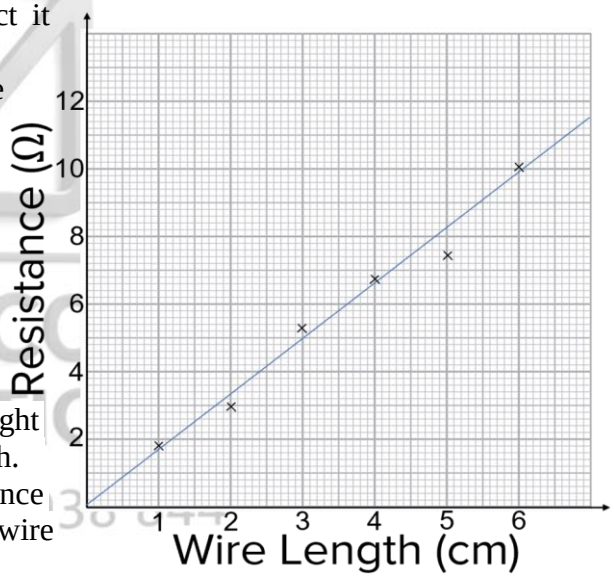
Conduct a practical experiment focusing on three main variables: length, cross-sectional area, and material.



The resistance of a wire is directly proportional to its length; as the length increases, so does the resistance. This relationship can be demonstrated by measuring the resistance of wires of varying lengths while keeping other factors constant. A wire with a larger cross-sectional area will have lower resistance compared to a thinner wire of the same material and length. This is because a thicker wire allows more electrons to flow through it, reducing resistance. The material of the wire significantly influences resistance. Different materials have varying atomic structures, affecting how easily electrons can move.

PART A (using Nickle SWG28)

a) Measure a length of wire, L=20.0cm, connect it across the voltmeter as shown in the circuit,
b) Close the switch, read and record both the ammeter reading, I, and voltmeter reading, V.
c) Repeat the experiment by adjusting the lengths of the wire L=30,40,50,60,and 70.0cm
d) Tabulate the table of results including both the values of $\frac{V}{I}$
e) Plot a graph of $\frac{V}{I}$ *against L*
f) Draw a **line of best fit**. This should be a straight line that **passes through the origin** of the graph.
g) The line of best fit shows that the resistance is **directly proportional** to the wire length. **NOTE:** $\boldsymbol{R = \frac{V}{I}}$

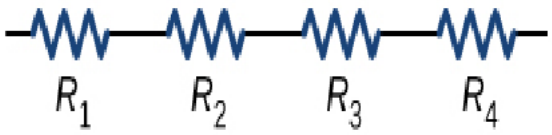


PART B

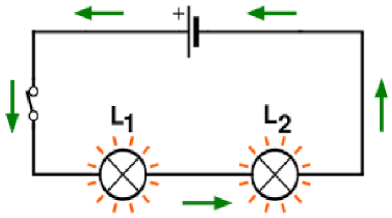
a) Using the same experimental setup shown above,
b) Connect another wire of **SWG28** and using a length of L=40.0cm,repeat the same procedures , and read and record both values of I and V
c) Repeat procedure (b) above with different wires of **SWG30**,and **SWG32**
d) **Tabulate your results including values of** $\frac{V}{I}$
e) **Plot a graph of** $\frac{V}{I}$ *against SWG number*
f) **Determine the slope and give your conclusions**

Arrangement of resistors in circuits

Series arrangement of resistors



In a series arrangement, resistors are connected end-to-end, creating a single path for current to flow. This means that the same current passes through each resistor sequentially. The total resistance in a series circuit is simply the sum of the individual resistances, which can be calculated using the formula: $R_{total} = R_1 + R_2 + R_3 + \ldots + Rn$. *According to Ohm's Law, the voltage drop across a resistor is proportional to its resistance, meaning larger resistors will have a greater voltage drop. This arrangement is commonly used in applications where the same current is required through multiple components, such as in string lights or certain types of sensors.*



Following are the conclusions from the above investigation

In series circuit all the appliances work simultaneously when switch is closed. Conversely, all appliances stop working when switch is open. In series circuit, if any, of the appliances goes out of order, the other appliances stop working. As the bulbs were not glowing very brightly, it can be concluded that in series the appliances do not work to their full capacity. The same current flows through each resistor in series. Individual resistors in series do not get the total source voltage, but divide it.

Example

A solar technician in Kampala is repairing a small backup lighting system used in a rural health outpost. The system uses a **12.0 V battery** connected to three protective resistors placed in **series** to regulate the current before electricity reaches sensitive LED lamps. During testing, the technician measures the resistor values as follows: R_1 = 1.00Ω, R_2 = 6.00Ω, R_3 = 13.0 Ω. To ensure the lighting system operates safely and efficiently, the technician needs to analyze the electrical characteristics of the circuit.

Tasks: Using your knowledge of Physics to:

a) Determine the total resistance of the circuit.
b) Calculate the current flowing in the circuit.
c) Determine the voltage drop across each resistor, and the total the voltage drops
d) Calculate the power dissipated by each resistor.
e) Determine the total power output of the battery and the total power dissipated in the resistors.

Response

(a). The total resistance is the sum of the individual resistances, given by this equation:
$R_s=R_1+R_2+R_3=1.00\ \Omega+6.00\ \Omega+13.0\ \Omega=20.0\ \Omega$

(b).The current is found using Ohm's law, $V = IR$. Entering the value of the applied voltage and the total resistance yields the current for the circuit:
I=VRs=12.0 V20.0 Ω=0.60 AI=VRs=12.0 V20.0 Ω=0.60 A.

(c). The voltage drop $=IR$, in a resistor is given by Ohm's law. Entering the current and the value of the first resistance yields
$V_1 = IR_1 = (0.600\text{A})(1.0\Omega) = 0.600\text{V}$, $V_2 = IR_2 = (0.600\text{A})(6.0\Omega) = 3.60\text{V}$, $V_3 = IR_3 = (0.600\text{A})(13.0\ \Omega) = 7.80$ V.

(c). The three *IR* drops add to 12.0 V, as predicted: $V_1 + V_2 + V_3 = (0.600 + 3.60 + 7.80)$ V = 12.0 V.

(d). The easiest way to calculate power in watts (W) dissipated by a resistor in a dc circuit is to use *Joule's law*, $P = IV$, where P is electric power. In this case, each resistor has the same full current flowing through it. By substituting Ohm's law $V = IR$ into Joule's law, we get the power dissipated by the first resistor as

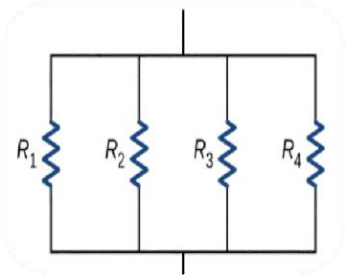
$P_1 = I^2R_1$ = (0.600 A)2(1.00 Ω) = 0.360 W,$P_2 = I^2R_2$ = (0.600 A)2(6.00 Ω) = 2.16 W.,
$P_3 = I^2R_3$ = (0.600 A)2(13.0 Ω) = 4.68 W.

(d). Power can also be calculated using either $P = IV$ or $P = \frac{V^2}{R}$, *where V* is the voltage drop across the resistor (not the full voltage of the source). The same values will be obtained.

(e). The easiest way to calculate power output of the source is to use $P = IV$, where V is the source voltage. This gives P = (0.600 A)(12.0 V) = 7.20 W. Note, that the total power dissipated by the resistors is also 7.20 W, the same as the power put out by the source. That is, $P_1 + P_2 + P_3$ = (0.360 + 2.16 + 4.68) W = 7.20 W.

Power is energy per unit time (watts), and so conservation of energy requires the power output of the source to be equal to the total power dissipated by the resistors.

Parallel arrangement of resistors



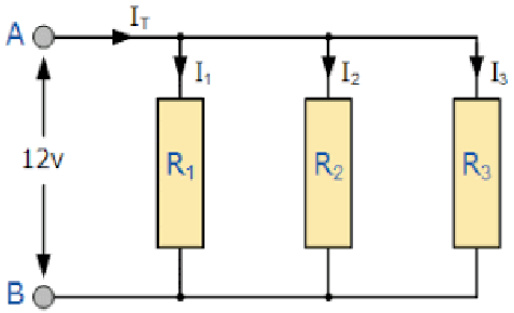
Resistors are connected in parallel when their terminals are linked, allowing multiple pathways for current to flow. In this arrangement, the voltage across each resistor remains constant, while the total current is the sum of the currents through each resistor. This configuration results in a lower total resistance compared to individual resistors, making it an efficient choice for various electrical applications. When resistors are connected in parallel, the formula for calculating the total resistance (RT) is given by the reciprocal of the sum of the reciprocals of each resistor's resistance (R_1, R_2, R_3, etc.).$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$

This means that adding more resistors in parallel decreases the overall resistance, which can be advantageous in circuits requiring higher current flow. The parallel arrangement of resistors is crucial in electronics, allowing for increased current capacity and flexibility in circuit design.

Resistors are in parallel when each resistor is connected directly to the voltage source by connecting wires having negligible resistance. Each resistor thus has the full voltage of the source applied to it. Each resistor draws the same current it would if it alone were connected to the voltage source (provided the voltage source is not overloaded). For example, an automobile's headlights, radio, and so on, are wired in parallel, so that they utilize the full voltage of the source and can operate completely independently. The same is true in your house, or any building.

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Following conclusions can be drawn from above investigation.



In parallel circuit all the appliances work independently, in parallel circuit if one appliance goes out of order, the other continues working. It means that each appliance in parallel circuit can be operated independently by a switch, As the bulbs glow brightly, it means each appliance gets enough electric energy, and hence, works to its full capacity.

Example

An electrician installing a backup lighting system in a community study centre in Kampala decides to connect several protective resistors in parallel so that different lighting units can receive the same voltage from a 12.0 V battery. During installation, the electrician measures the resistances of the three branches as follows: R_1 = 1.00Ω, R_2 = 6.00Ω, R_3 = 13.0 Ω. The electrician must analyse the circuit to ensure the battery can safely supply the required current and power.

Tasks: Using your knowledge of Physics to:
a) Determine the total resistance of the circuit.
b) Calculate the total current supplied by the battery.
c) Determine the current flowing through each resistor.
d) Calculate the power dissipated in each resistor.
e) Determine the power output of the battery and show that it equals the total power dissipated by all the resistors.

Response:

The total resistance for a parallel combination of resistors is found using the equation below. Entering known values gives$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}, \frac{1}{R} = \frac{1}{1} + \frac{1}{6} + \frac{1}{13}$, *Thus,* $\frac{1}{R_P} = 1.2436$ (Note that in these calculations, each intermediate answer is shown with an extra digit.) We must invert this to find the total resistance Rp. This yields $R_P = 0.8041 ohms$. The total resistance with the correct number of significant digits is R_p = 0.804 Ω

(a). R_p is, as predicted, less than the smallest individual resistance.

(b). The total current can be found from Ohm's law, substituting R_p for the total resistance. This gives $I = \frac{V}{R_P}$=12.0Vx0.8041 Ω=14.92 A

(b). Current *I* for each device is much larger than for the same devices connected in series (see the previous example). A circuit with parallel connections has a smaller total resistance than the resistors connected in series. The individual currents are easily calculated from Ohm's law, since each resistor gets the full voltage. Thus, $\boldsymbol{I_1 = \frac{V}{R_1} = \frac{12}{1} = 12.0A, I_2 = \frac{V}{R_2} = \frac{12}{6} = 2.0A, I_3 = \frac{V}{R_3} = \frac{12}{13} = 0.92A}$

(c). The total current is the sum of the individual currents: $\boldsymbol{I_1 + I_2 + I_3}$ **= 14.92 A.** This is consistent with conservation of charge.

(d). The power dissipated by each resistor can be found using any of the equations relating power to current, voltage, and resistance, since all three are known. Let us use $P = \frac{V^2}{R}$, *since each resistor gets full voltage. Thus,* $P = \frac{V^2}{R}, P_1 = \frac{12^2}{21} = 144W,\ P_2 = \frac{12^2}{6} = 24W,\ P_3 = \frac{12^2}{13} = 11.1W,$.

(d). The power dissipated by each resistor is considerably higher in parallel than when connected in series to the same voltage source.

(e). The total power can also be calculated in several ways. Choosing *P = IV*, and entering the total current, yields *P = IV* = (14.92 A)(12.0 V) = 179 W.

(e). Total power dissipated by the resistors is also 179 W: $P_1 + P_2 + P_3$ = 144 W + 24.0 W + 11.1 W = 179 W. This is consistent with the law of conservation of energy.

Note that both the currents and powers in parallel connections are greater than for the same devices in series.

Activity

A technician is installing a small electrical training kit in a secondary school laboratory in Kampala. The kit is designed to help students understand how series and parallel circuits work in practical electrical systems such as solar lighting installations and household wiring.

The circuit contains four identical resistors, each with a resistance of 10.0 Ω.

Resistors R_1 and R_2 are connected in series, Resistors R_3 and R_4 are connected in parallel.

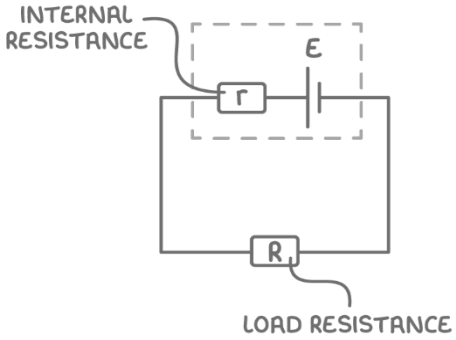
The series combination is then connected to the parallel combination and powered by a battery.

During an experiment, the technician observes that a current of 2.0 A flows through resistor R_1.

Tasks: Using your knowledge of physics to:

a) Determine the equivalent resistance of the parallel combination (R_3) and (R_4).
b) Determine the total resistance of the entire circuit.
c) Using the current through R_1, determine the voltage supplied by the battery.
d) State one real-life electrical system where a series–parallel circuit arrangement may be used.

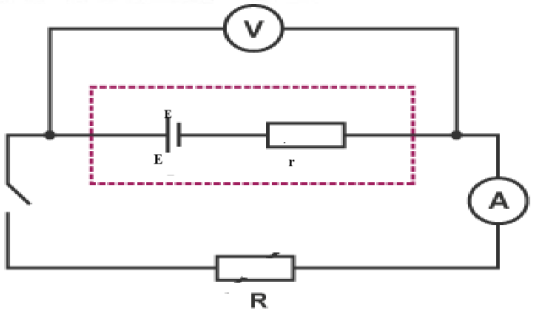
Internal resistance of a cell



The internal resistance of a cell is a factor that affects its performance and efficiency. It refers to the resistance encountered by the flow of current within the cell's electrolyte and electrodes. This resistance can lead to a voltage drop when the cell is under load, meaning the voltage output is lower than the electromotive force (EMF) when no current is flowing. Typically, the internal resistance of a lead-acid cell is relatively low, while dry cells often exhibit higher internal resistance.
A cell has two terminals; positive and negative terminal. The positive terminal is known as the **cathode** and the negative terminal is known as the a**node**. They both are the electrodes of a cell. Two or more cells combine together serially or parallel to form a battery. Internal Resistance of a cell is scaled in ohms. The terminal of the cell is connected with a wire to make a closed circuit. Electric current flows from the positive terminal of cell to negative terminal through the wire and at the same time positive ions in the electrolyte flow from lower to higher potential due to which some resistance is offered to the current flow.

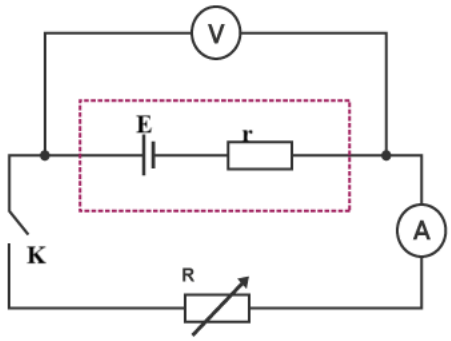
Internal Resistance

It is the resistance (opposing force) in the flow of current when the circuit gets because of electrolyte and electrodes present in the battery/cell. It is present within the cell or battery. Measures in ohm. Fresh/new cell has low internal resistance but increases with continuous use. Potential drops across the terminal as the current flows.



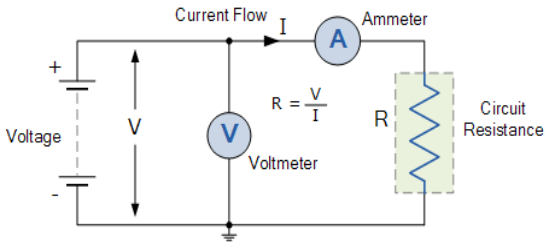
Formula for Internal Resistance of a Cell
$\mathscr{E}$: emf of a cell (in volts),
V: Potential difference across a cell (in Volts),
I: Current flowing through a conductor,
r: Internal Resistance, R: External resistance.
Emf is the work done by the cell to carry a unit charge through the closed circuit. So, it is the sum of the work done to carry the charge through the conducting wire with external resistance(R) and cell with internal resistance (r).
$\varepsilon = V + V^1$……*(*1), By Ohms Law $V = IR$ ……..(2),$V^1 = Ir$……*(3)*
From equation (2) and (3), $\mathcal{E} = IR + Ir, V = I(r + R), I = \frac{\varepsilon}{r+R}$……*(4)*
Substituting (4) in (2) $V = IR = \frac{R\varepsilon}{r+R}$, Now, from equation (1),$V = \varepsilon - V^1, V = \varepsilon - Ir$, $Ir = \varepsilon - V$
$r = \frac{\varepsilon - V}{I}$, *hence* $V = -Ir + \varepsilon$, where V is the potential difference across the resistor, R, ε is the e.m.f of the cell, and r is the internal resistance, which is in the form $y = mx + c$ (the equation of the line graph).

Experiment to determine the internal resistance of a cell



a) With the switch K, open, read an record the voltmeter reading, and call it E_o
b) Close the switch, K, adjust the value variable resistor R, until the voltmeter reading V=0.20V.
c) Read and record the ammeter reading I,
d) Repeat the procedures of the experiment for different values of V=0.30, 0.40, 0.50, 0.60, 0.70 and 0.80V.
e) Tabulate the results in a table of results,
f) Plot a graph of V against I
g) Determine the slope and make conclusions

Note: At the point where the line meets the current axis, (the x-axis intercept) the maximum current is drawn from the cell. This happens when the load resistance, R=0Ω. This would be achieved by short circuiting the cell (this should be avoided as the cell could overheat and it is potentially dangerous). The **maximum current** is called the **short circuit current**, I_{SC}. To find the internal resistance of the cell the gradient of the line is calculated. This has a negative value. The internal resistance of the cell is the same value but without the negative sign. For example, if the slope of the line is −4 then the internal resistance is 4Ω. The internal resistance can also be found by dividing the EMF, E, by the short circuit current, I_{SC}.

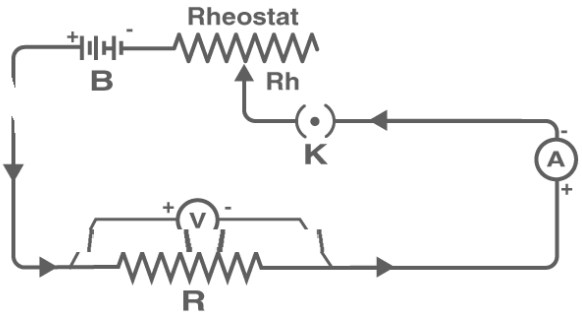


Relationship between current, voltage and resistance

The relationship between voltage, current, and resistance is described by Ohm's law. This equation, $I = \frac{V}{R}$, *tells us that the current, I, flowing through a circuit is directly proportional to the voltage, V, and inversely proportional to the resistance, R.*

Ohm's law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperatures remain constant. In certain components, increasing the current raises the temperature. An example of this is the filament of a light bulb, in which the temperature rises as the current is increased. In this case, Ohm's law cannot be applied. The light bulb filament violates Ohm's Law.

Experimental Verification of Ohm's Law



Ohm's Law can be easily verified by the following experiment: Resistor, Ammeter, Voltmeter, Battery, Plug Key, and Rheostat

Procedure

a) Initially, the key K is closed and the rheostat is adjusted to get the minimum reading in ammeter A and voltmeter V.
b) The current in the circuit is increased gradually by moving the sliding terminal of the rheostat. During the process, the current flowing in the circuit and the corresponding value of potential difference across the resistance wire R are recorded.
c) Different sets of values of voltage, V, and current, I, are obtained and a table of results tabulated.

d) A graph of the current (I) against the potential difference (V) is plotted; it will be a straight line. This shows that the current is proportional to the potential difference.

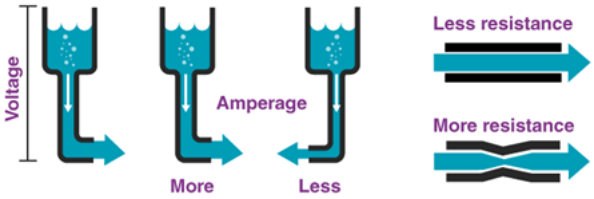
Water pipe analogy for ohm's law

The relationship between current, voltage and resistance is expressed by Ohm's Law.

Ohms law states that the current flowing in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance of the circuit, provided the temperature remains constant.

Ohm's Law: $Current\ (I) = \frac{Voltage\ (V)}{Resistance\ (R)}$

Ohm's Law describes the current flow through a resistance when different electric potentials (voltage) are applied at each end of the resistance.



Since we can't see electrons, the water-pipe analogy helps us understand the electric circuits better. Water flowing through pipes is a good mechanical system that is analogous to an electrical circuit. Here, the voltage is analogous to water pressure, the current is the amount of water flowing through the pipe, and the resistance is the size of the pipe. More water will flow through the pipe (current) when more pressure is applied (voltage) and the bigger the pipe (lower the resistance).

The overall resistance of an object depends on a number of properties including its length, cross-sectional area and the type of material. The longer a conductor, the greater its resistance; for example, a two metre wire has twice the resistance of a one metre wire of similar properties. The larger the cross-section of a conductor, then the lower its resistance: overhead power cables have a much lower resistance than a lamp flex of the same length. Different materials also have different abilities to conduct electricity.

Metals conduct very well but materials such as ceramics or glass do not usually conduct electricity at all and are known as insulators.

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Ohm's Law Applications

The main applications of Ohm's law are:

- ✓ To determine the voltage, resistance or current of an electric circuit.
- ✓ Ohm's law maintains the desired voltage drop across the electronic components.
- ✓ Ohm's law is also used in DC ammeter and other DC shunts to divert the current.

Limitations of Ohm's Law

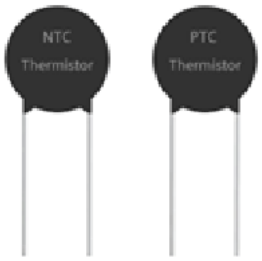
Following are the limitations of Ohm's law:

- ✓ Ohm's law is not applicable for unilateral electrical elements like diodes and transistors as they allow the current to flow through in one direction only.
- ✓ For non-linear electrical elements with parameters like capacitance, resistance etc. the ratio of voltage and current won't be constant with respect to time making it difficult to use Ohm's law.

Ohmic and Non Ohmic conductors

Ohmic conductors, such as resistors and standard wires, adhere to Ohm's Law, which states that the current through a conductor is directly proportional to the voltage across it. This results in a linear current-voltage (I-V) relationship, represented graphically as a straight line. In contrast, non-ohmic conductors do not follow Ohm's Law. Their resistance can vary with changes in voltage or current, leading to a non-linear I-

V relationship. Examples of non-ohmic conductors include diodes and thermistors, which exhibit unique behaviors under different electrical conditions.



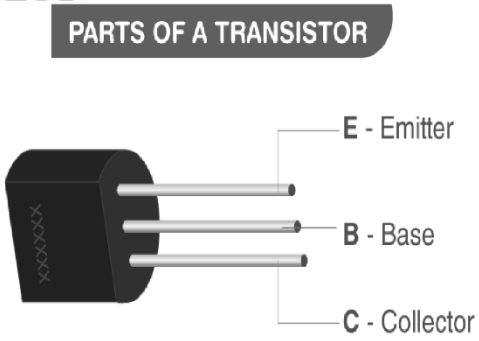
Thermistors: A thermistor is a type of semiconductor resistor whose resistance varies significantly with temperature changes. The term "thermistor" combines "thermal" and "resistor," highlighting its primary function as a temperature-sensitive device. Unlike standard resistors, thermistors exhibit a much stronger response to temperature fluctuations, making them ideal for precise temperature measurements. Thermistors can be classified into two main types: Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). NTC thermistors decrease in resistance as temperature increases, while PTC thermistors do the opposite. This unique property allows thermistors to be used in various applications, including temperature sensing, circuit protection, and in medical devices for monitoring body temperature. In recent years, the demand for disposable thermistors has increased, particularly in hospital settings, where they are favored for their convenience and hygiene. Leading companies in the thermistor market include Vishay, Littelfuse, and TDK, reflecting the growing importance of these devices in modern technology.

Transistors: A transistor is a device that controls an electrical current by amplifying, facilitating or stopping it. Transistors can be found in computer memory chips, cell phones and car engines, among other applications. The most common type of transistor is the metal-oxide-semiconductor field-effect transistor (MOSFET), which is widely used in electronic devices such as computers, smartphones and televisions. A transistor as an amplifier, a transistor can increase the electrical output, even if the input is small. As a switch, a transistor can alternate between ‘on’ and ‘off’ phases to manage the electrical current. These abilities have made transistors important for everyday applications, ranging from computers to space satellites.

Transistors can control the flow of electricity in circuits, allowing them to amplify signals or act as on/off switches. There are various types of transistors, including Bipolar Junction Transistors (BJTs) and Field-Effect Transistors (FETs), each serving specific applications.

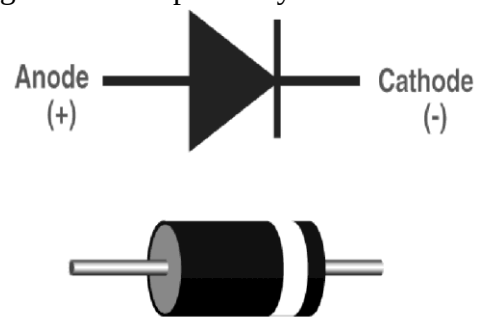
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The working principle of a transistor involves the manipulation of charge carriers (electrons and holes) within a semiconductor material, enabling it to either allow or block current flow based on input signals. Transistor diagrams typically illustrate the three terminals: the collector, emitter, and base for BJTs, or the source, gate, and drain for FETs.

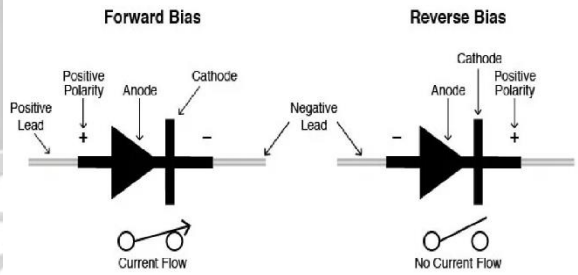


Diodes

A diode is a two-terminal electronic component that conducts electricity primarily in one direction. It has high resistance on one end and low resistance on the other end. A diode is a semiconductor device that functions as a one-way switch for electrical current, allowing it to flow primarily in one direction. Typically made from silicon, diodes have two terminals: the anode (positive) and the cathode (negative). When a voltage is applied in the forward direction, the diode conducts electricity; however, it blocks current when the voltage is reversed, demonstrating its asymmetric conductance. Diodes are widely used in various applications, including rectification in power supplies, signal modulation, and protection circuits. They are essential components in converting alternating current (AC) to direct current (DC) and are found in devices such as radios, televisions, and computers. Testing diodes is crucial for ensuring their functionality. A multimeter can be used to check for proper conduction in the forward direction and to confirm that the diode blocks current in the reverse direction.



Diodes can be made of either of the two semiconductor materials, silicon and germanium. When the anode voltage is more positive than the cathode voltage, the diode is said to be forward-biased, and it conducts readily with a relatively low-voltage drop. Likewise, when the cathode voltage is more positive than the anode, the diode is said to be reverse-biased. The arrow in the diode symbol represents the direction of conventional current flow when the diode conducts.

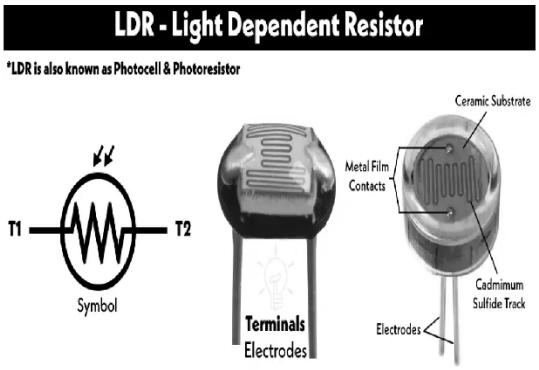


Applications and Uses of diodes

The most basic function would be changing AC current to DC current by removing some part of the signal. This functionality would make them rectifiers. They are used in electrical switches and are used in surge protectors because they can prevent a spike in the voltage. Diodes help in performing digital logic. Millions of diodes are used similar to logic gates and used in modern processors. They are used for isolating signals from a supply. For example, one of the major uses of diodes is to remove negative signals from AC current. This is known as signal demodulation. This function is basically used in radios as a filtering system in order to extract radio signals from a carrier wave. They are also used in creating power supplies and voltage doublers. Using a full wave rectifier will help to deliver a more stable voltage. Combination of a diode with a capacitor will help to make small AC voltage multiply to create a very high voltage. The light emitting diodes or LEDs are used in sensors and also in laser devices any many other light illumination devices. Zener diodes are used as voltage regulators and varactors are used in electronic tuning and varistors are used in suppressing AC lines. Diodes are the basis of op-amps and transistors.

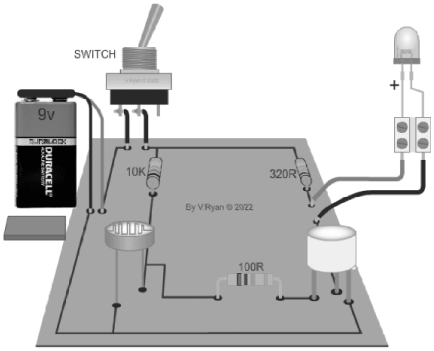
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LDR

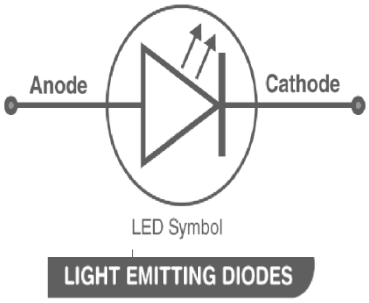


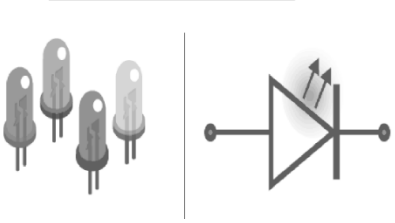
LDR (Light Dependent Resistor) as the name states is a special type of resistor that works on the photoconductivity principle means that resistance changes according to the intensity of light. Its resistance decreases with an increase in the intensity of light. It is often used as a light sensor, light meter, Automatic Street light, and in areas where we need to have light sensitivity.

LDR is also known as a Light Sensor. LDR are usually available in 5mm, 8mm, 12mm, and 25mm dimensions. A Light Dependent Resistor (LDR), also known as a photo resistor, is a passive electronic component that alters its resistance based on light intensity. When exposed to light, the resistance of an LDR decreases, allowing more current to flow through the circuit. This property makes LDRs essential in various applications, including light sensing, automatic lighting systems, and camera exposure controls. LDRs are commonly used in devices that require light detection, such as streetlights that turn on at dusk and off at dawn. They can also be found in alarm systems and light meters, where they help in monitoring ambient light levels. The simplicity and effectiveness of LDRs make them a popular choice for hobbyists and professionals alike. Their ability to adjust resistance based on light intensity enables innovative solutions across various fields.

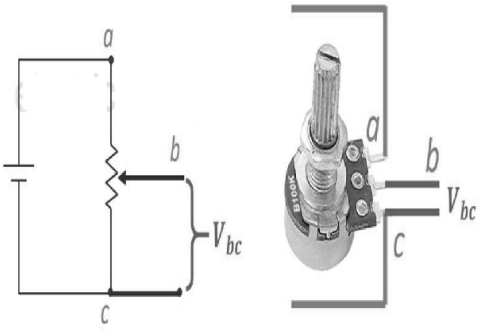


LED





Light Emitting Diodes (LEDs) are semiconductor devices that convert electrical energy into light through a process called electroluminescence. When an electric current flows through the LED, it excites electrons in the semiconductor material, causing them to release energy in the form of light. This technology operates in contrast to photodiodes, which convert light into electricity. LEDs are known for their energy efficiency, producing light up to 90% more efficiently than traditional incandescent bulbs. This efficiency not only reduces energy consumption but also leads to lower electricity bills and a smaller carbon footprint. LEDs have a longer lifespan, often lasting tens of thousands of hours, making them a cost-effective lighting solution. As the demand for sustainable and efficient lighting solutions grows, LEDs are becoming increasingly popular in residential, commercial, and industrial applications. Their versatility and performance make them a key player in the future of lighting technology.

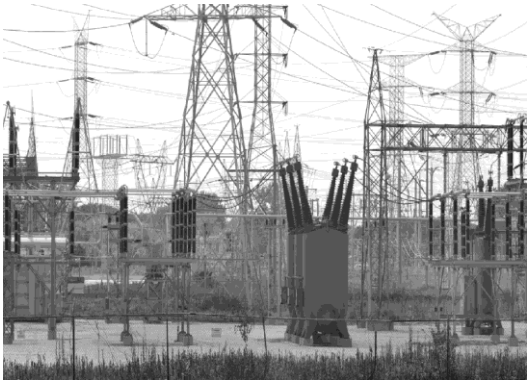


Potentiometer

A potentiometer is a three-terminal variable resistor that plays a crucial role in controlling electrical devices. Common applications include volume controls in audio equipment and

speed regulation in fans. By adjusting the position of a wiper along a resistive element, users can modify the resistance and, consequently, the voltage output in a circuit. In addition to its control functions, a potentiometer is instrumental in measuring unknown voltages by comparing them with known references. This capability makes it valuable in determining electromotive force (EMF) and internal resistance in various electronic applications. Recent advancements have led to the development of self-powered potentiometric sensors, which can monitor changes in concentration without external power. These innovations highlight the versatility of potentiometers, extending their use into fields such as wearable technology for real-time monitoring of ions in human sweat, showcasing their importance in both everyday devices and cutting-edge research.

4.2 ELECTROMAGNETIC EFFECTS



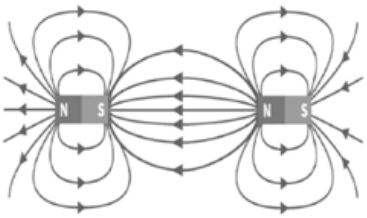
Learning Outcomes

a) Investigate the behaviour of magnets and magnetic fields(s)
b) Understand that a current carrying conductor produces a magnetic field that can be detected. (u,s)
c) Understand the application of electromagnets in devices such as motors, bells, and generators (u,s)
d) Understand the difference between a.c. and d.c (u)
e) Know how a.c. and d.c. can be inter-converted using rectifiers and inverters (k)
f) Understand the action and applications of transformers (u, s,v/a)

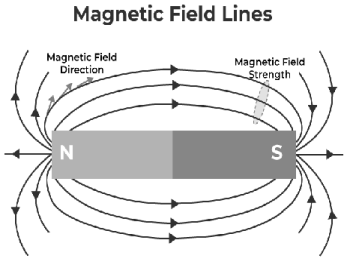
ELECTROMAGNETISM

Introduction

Electricity and magnetism are closely linked. You will learn that an electrical conductor moving through a magnetic field can induce a current. Similarly, an electrical conductor in a changing magnetic field acquires an electromotive force (e.m.f.). Electromagnetic induction plays an important role in many electrical applications from induction cookers and motors to electricity generators. The effect of producing electricity from magnetism was discovered in 1831 by Faraday and is called **electromagnetic induction**. It led to the construction of generators for producing electrical energy in power stations.



Electromagnetism is a fundamental branch of physics that explores the interactions between electrically charged particles through electromagnetic fields. This interaction is crucial as it governs the behavior of charged particles, influencing everything from atomic structure to the forces that hold matter together. The electromagnetic force is responsible for keeping electrons in orbit around atomic nuclei, making it essential for the stability of matter. The relationship between electricity and magnetism is a key aspect of electromagnetism. Moving electric charges generate magnetic fields, which can, in turn, exert forces on other moving charges. This principle underlies many technologies, including electric motors and generators, showcasing the practical applications of electromagnetic theory. As one of the four fundamental forces of nature,

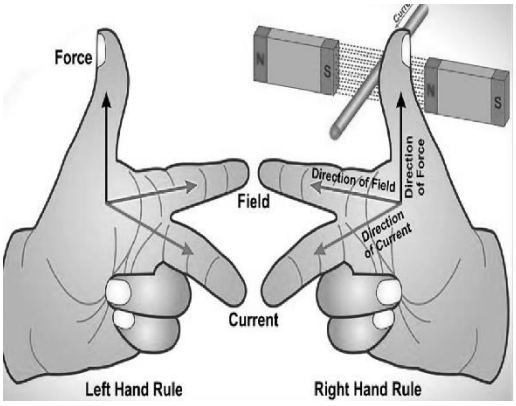


electromagnetism plays a vital role in various scientific fields, including materials science and superconductivity.

Magnetic fields

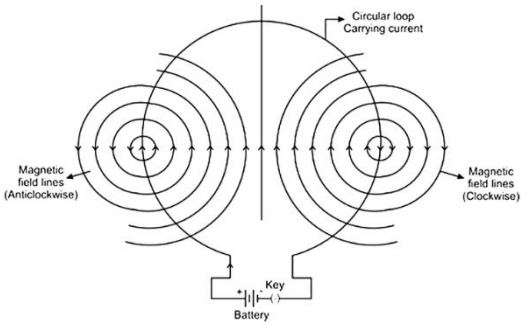
Magnetic fields are regions around magnetic materials or moving electric charges where magnetic forces are exerted. They arise whenever electric charges are in motion, with the strength of the field increasing as more charge is set in motion. This phenomenon is fundamental in physics, influencing the behavior of charged particles and electric currents. The force exerted by magnetic fields can cause charged particles to move in circular or helical paths. This principle is crucial in various applications, from electric motors to particle accelerators. Magnetic fields play a significant role in astronomical phenomena, such as the formation of stars and planets, by influencing the dynamics of charged particles in space.

Magnetic Field of a Current Carrying Conductor (Wire)



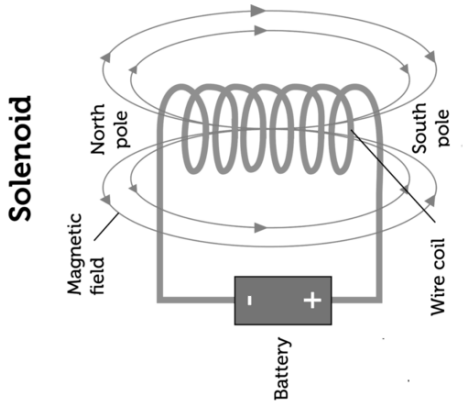
When an electric current flows through a wire, it creates a magnetic field that forms concentric circles around the wire. The interaction between a magnetic field and a current-carrying conductor results in a magnetic force. This force is crucial in various applications, including electric motors and generators, where it enables the conversion of electrical energy into mechanical energy**.** The direction of the magnetic field can be determined using the right-hand rule, which This rule states that *"If a current-carrying conductor is held by the right hand, keeping the thumb straight and if the direction of electric current is in the direction of thumb, then the fingers will curl in the direction of the magnetic field lines''.*

Magnetic field due to current through a circular loop



When an electric current flows through a circular loop, it generates a magnetic field that is most concentrated at the center of the loop. The magnetic field lines form closed loops around the wire, and their direction can be determined using the right-hand thumb rule: if the thumb points in the direction of the current, the curled fingers indicate the direction of the magnetic field. The strength of the magnetic field at the center of the loop is directly proportional to the current and inversely proportional to the radius of the loop. Every point on the wire carrying current gives rise to a magnetic field around it would become larger and larger as we move away from the wire and by the time we reach the center of the circular loop, the arcs of these circles would appear as a straight line.

Magnetic field due to current flowing in a solenoid

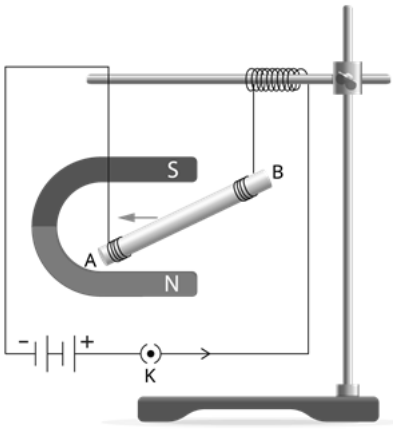


A solenoid is essentially a coil of wire, and when an electric current passes through it, a magnetic field is created. Inside the solenoid, the magnetic field is nearly uniform and parallel to the axis of the coil. This uniformity makes solenoids particularly useful in various applications, such as

electromagnets and inductors. When a ferromagnetic material, like iron, is placed inside the solenoid, it becomes magnetized, significantly enhancing the magnetic field strength. The magnetic field due to a solenoid is crucial for advancements in technology, including electric motors and magnetic resonance imaging (MRI).

Force on a Current Carrying Conductor in a magnetic field

Procedure



Take a small aluminium rod of about 5cm and name its ends as A and B. Using two connecting wires, hang it horizontally from a stand, as shown in the figure. Locate a strong horseshoe magnet so that the rod rests between the two poles with the magnetic field directed upwards. For this, put the magnet's north pole vertically below and the south pole vertically above the aluminium rod (as shown in the figure).The aluminium rod, battery, switch and rheostat are connected in series (as in the figure). Allowing a current flow through the aluminium rod from end B to end A**.**

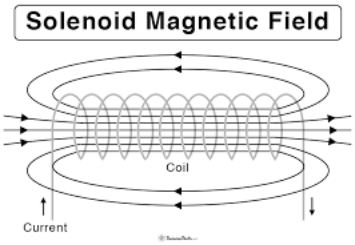
Observation:

It is seen that the rod is relocated towards the left. You will see that the rod gets relocated. Reverse the direction of current flowing through the rod (end A to B) and notice the direction of its displacement. **The rod is now relocated towards the right**.

Conclusion:

The displacement of the aluminium rod suggests that a force is exerted on the current-carrying conductor when it is placed in a magnetic field. It also shows that when the direction of the current through the conductor is reversed, the direction of force is also reversed.

Magnetic field and number of turns of the coil



The magnitude of the magnetic field gets summed up with the increase in the number of turns of the coil. If there are '**N**' turns of the coil, the magnitude of the magnetic field will be '**N**' times the magnetic field in case of a single turn of the coil.

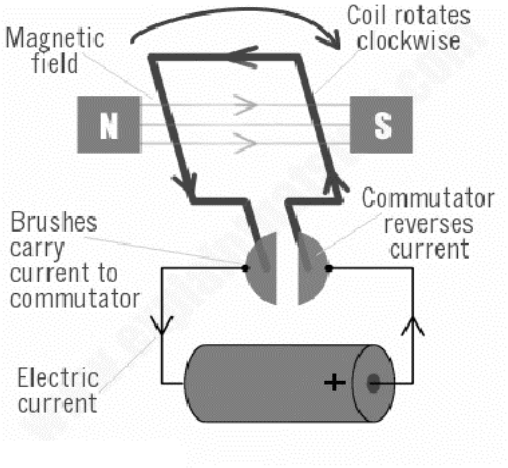
The radius of the coil (r): The strength of the magnetic field is inversely proportional to the radius of the coil. If the radius increases, the magnetic strength at the center decreases.

The number of turns in the coil (N): As the number of turns in the coil increase, the magnetic strength at the center increases, because the current in each circular turn is having the same direction, thus, the field due to each turn adds up.

The strength of the current flowing in the coil (B): As the strength of the current increases, the strength of three magnetic fields also increases.

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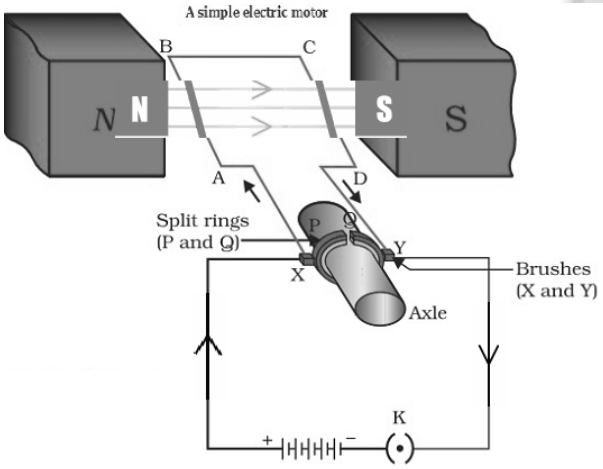
The Electric Motor



An electric motor is a vital machine that transforms electrical energy into mechanical energy, primarily in the form of rotational motion. This conversion is achieved through the interaction of magnetic fields and electric currents, allowing electric motors to power a wide range of applications, from household appliances to electric vehicles. There are two main types of electric motors: direct current (DC) motors and alternating current (AC) motors. DC motors utilize direct current to generate motion, while AC motors operate on alternating current.

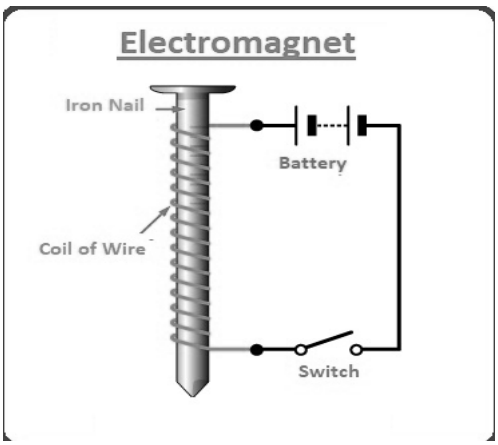
Operation of a simple Electric Motor

A simple electric motor operates on the principles of electromagnetism, converting electrical energy into mechanical motion. At its core, the motor consists of a coil of wire, a power source (like a battery), and a permanent magnet. When electricity flows through the coil, it generates a magnetic field, turning the coil into an electromagnet. When current is supplied to the armature, one end becomes a north pole, and the other end a south pole, magnetically. Since the armature lies in a magnetic field, there are magnetic forces acting on the armature, such that the North Pole end of the armature is attracted to the south pole of the external field. A similar attractive force will exist between the South Pole end of the armature and the north pole of the field. These two forces create a torque that causes the armature to rotate. The split ring commutator causes the armature current to reverse direction when the armature turns and the brushes contact alternate ring segments, which causes the polarity of the armature to reverse. Thus, as the North Pole end of the armature swings by the south pole of the field, it reverses to a south pole itself and is now repelled by the field, and pushed toward the other pole of the field. The continual reversal of the polarity of the armature, whenever it has turned 180^{o}, is what permits the rotation to continue.



Electromagnetic Induction

Electromagnetic induction is the generation of electromotive force (e.m.f) across a conductor when it is exposed to a changing magnetic field. This phenomenon occurs when there is relative motion between a magnetic field and an electrical conductor, leading to the production of voltage and, consequently, electric current in a closed circuit. The principle of electromagnetic induction is the backbone of various technologies, including electric generators and motors. These devices convert mechanical energy into electrical energy and vice versa, showcasing the practical applications of this principle in everyday life. **Faraday's Law of Induction quantifies this relationship, stating that the induced emf in a circuit is directly proportional to the rate of change of the magnetic field.** In addition to its applications in energy generation, electromagnetic induction is also utilized in fields such as geophysics and archaeology, where it aids in locating unmarked graves and mapping cemeteries.



Electromagnets: An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. Unlike permanent magnets, electromagnets can be turned on and off and their strength can be varied by changing the current flowing through them. The principle behind electromagnets is Ampère's Law, which states that an electric current flowing through a conductor produces a magnetic field around it.

Making an electromagnet

Materials Required: *Insulated copper wire, Iron core, Power source, Switch (optional), To control the flow of current, Connecting wires.*

Procedures:

a) Take a piece of soft iron, such as a nail or iron rod. The core helps concentrate the magnetic field generated by the coil of wire.
b) Take the insulated copper wire and begin wrapping it tightly around the iron core.
c) Make multiple turns of the wire around the core to form a coil. The more turns in the coil, the stronger the electromagnet will be.
d) Ensure the wire is neatly wound, as overlapping wires can reduce efficiency. Leave both ends of the wire free to connect to the power source.
e) Attach the two free ends of the wire to the terminals of the battery or power supply.
f) Connect the switch between one end of the wire and the battery to control the current flow.

Observation

When the switch is closed; when the current flows through the coil, the iron core becomes magnetized, and the electromagnet can attract ferromagnetic materials such as paperclips or nails. Disconnect the power source or turn off the switch to stop the flow of current. The iron core will lose its magnetism almost instantly, as it is not a permanent magnet.

Principles operation behind Electromagnets

According to Ampere's Law, when electric current flows through a conductor, it creates a circular magnetic field around the wire. Coiling the wire increases the strength of the magnetic field because the fields from each turn of the wire combine, creating a stronger overall effect. The iron core becomes magnetized due to the alignment of its magnetic domains, significantly amplifying the magnetic field produced by the coil.

Applications of Electromagnets (Applications of the magnetic effect of a current)

The most significant uses are in electric motors and generators, where they convert electrical energy into mechanical energy and vice versa. This principle is foundational in powering everything from household appliances to large industrial machines.

In addition to motors, electromagnets are integral to devices like relays, electric bells, and buzzers, which rely on magnetic fields to operate.

They are also essential in audio technology, found in headphones and loudspeakers, where they convert electrical signals into sound. Electromagnets are utilized in data storage devices, enhancing the efficiency of information retrieval and storage.

In healthcare, powerful electromagnets are employed in MRI machines, generating strong magnetic fields for imaging.

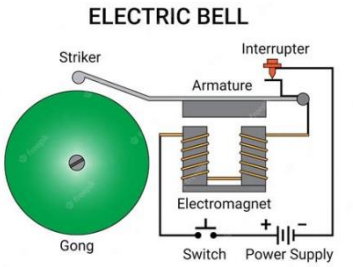
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Uses in Home Appliances: Most of the electric appliances used in the home use electromagnetism as the basic working principle. Some electromagnet uses in the home include an electric fan, electric doorbell, induction cooker, magnetic locks, etc. In an electric fan, the electromagnetic induction keeps the motor rotating on and on making the blade of the fan to rotate. Also in an electric doorbell when the button is pressed, due to the electromagnetic forces the coil gets energized and the bell sounds.

Uses in Medical Field: The uses of electromagnets are also seen in the medical field. MRI scan which is short for Magnetic Resonance Imaging is a device that uses electromagnets. The device can scan all the tiny details in the human body with the help of electromagnetism.

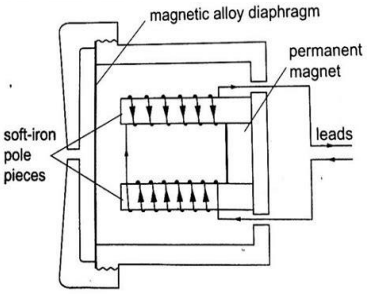
Uses in Memory Storage Devices and Computer Hardware: The data in ebook gadgets and phones are stored in the electromagnetic format in the form of bytes and bits. The computer hardware is also having a magnetic tape which works on the principle of electromagnetism. Even in the olden days' electromagnets had a huge role in the data storage of VCP and VCR.

Uses in Communication Devices and Power Circuits: Without electromagnets, the mobiles and the telephones we used to make phone calls over a long distance could not have taken shape. The electromagnetic pulses and the interaction of the signals make mobiles and telephones very handy.



Some of the other applications of Electromagnets

The electric bell: An electric bell changes electrical energy to sound energy. When the circuit is completed, by someone pressing the bell push, current flows in the coils of the electromagnet which becomes magnetised and attracts the soft iron bar (the armature).The hammer hits the gong but the circuit is now broken at the point C of the contact screw. The electromagnet loses its magnetism (becomes demagnetised) and no longer attracts the armature. The springy metal strip is then able to pull the armature back, remaking contact at C and so completing the circuit again. This cycle is repeated so long as the bell push is depressed, and continuous ringing occurs.



The telephone receiver: A telephone receiver changes electric energy to sound energy**.** A microphone changes sound energy to electric energy**.** The varying current from the microphone passes through the coils of the electromagnet**.** This magnetizes the electromagnet which pulls the diaphragm towards itself at varying distances depending on the strength of the current through the electromagnet from the microphone. The diaphragm moves in and out and produces sound waves at the same frequency as those that entered the microphone.

Relay

A relay is a switch based on the principle of an electromagnet. It is useful if we want one circuit to control another, especially if the current and power are larger in the second circuit.

When a current is in the coil from the circuit connected to AB, the soft iron core is magnetised and attracts the L-shaped iron armature. This rocks on its pivot and closes the contacts at C in the circuit connected to

DE. The relay is then ‘energised’ or ‘on’. The current needed to operate a relay is called the pull-on current and the drop-off current is the smaller current in the coil when the relay just stops working.

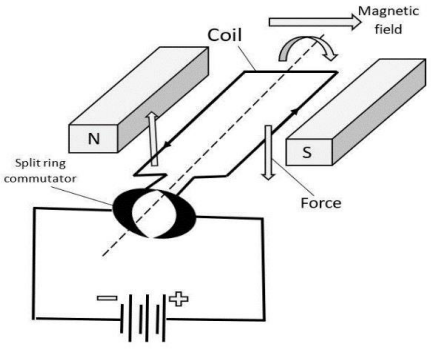
Loudspeaker

Varying currents from a radio, CD player, etc. pass through a short cylindrical coil whose turns are at right angles to the magnetic field of a magnet with a central pole and a surrounding ring pole. The magnetic fields around the coil and the magnet interact and the coil vibrates with the same frequency as the a.c. of the electrical signal it receives. A paper cone attached to the coil moves with it and sets up sound waves in the surrounding air.

Generators

When a coil is rotated between the poles of a magnet, the conductor cuts the magnetic field lines and an e.m.f. is induced. The size of the e.m.f. generated changes with the orientation of the coil and alternates in sign during the course of each rotation. This process is used in the large generators in power stations to produce an alternating (a.c.) electricity supply.

Electric generators are essential devices that convert mechanical energy into electrical energy, operating on the principle of electromagnetic induction. They do not create electricity; instead, they harness energy from an external source, such as motion or fuel, to generate electrical power. The core components of a generator include an engine, an alternator, and a fuel source. The engine provides the mechanical energy needed to rotate the alternator, which contains magnets and coils of wire. As the engine turns the alternator, the movement induces an electrical current in the coils, effectively transforming mechanical energy into electrical energy. Generators are widely used in various applications, from powering homes during outages to supplying energy for industrial operations.



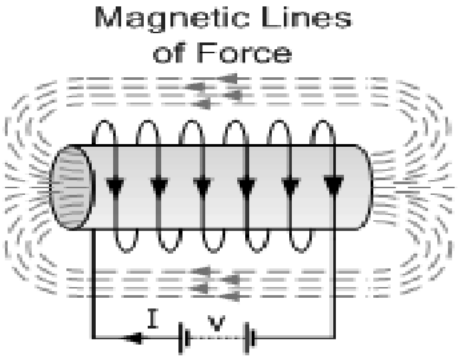
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Electromagnetic induction

Electromagnetic induction uses the relationship between electricity and magnetism whereby an electric current flowing through a single wire will produce a magnetic field around it. If the wire is wound into a coil, the magnetic field is greatly intensified producing a static magnetic field around itself forming the shape of a bar magnet giving a distinct North and South pole.

Air-core Hollow Coil

The magnetic flux developed around the coil being proportional to the amount of current flowing in the coils windings as shown. If additional layers of wire are wound upon the same coil with the same current flowing through them, the static magnetic field strength would be increased. Therefore, the magnetic field strength of a coil is determined by the *ampere turns* of the coil. With more turns of wire within the coil, the greater the strength of the static magnetic field around it. But what if we reversed this idea by disconnecting the electrical current from the coil and instead of a hollow core we placed a bar magnet inside the core of the coil of wire. By moving this bar magnet "in" and "out" of the coil a current would be induced into the coil by the physical movement of the magnetic flux inside it.

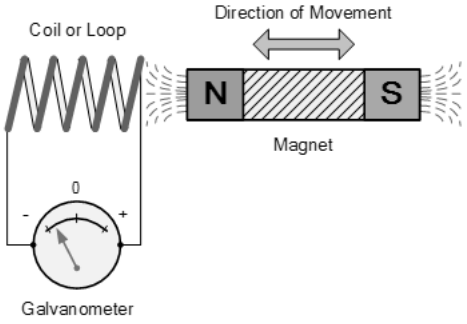


If we kept the bar magnet stationary and moved the coil back and forth within the magnetic field an electric current would be induced in the coil. Then by either moving the wire or changing the magnetic field we can induce a voltage and current within the coil and this process is known as **Electromagnetic Induction** and is the basic principle of operation of transformers, motors and generators.

Electromagnetic Induction by a Moving Magnet

Faraday's Law of Electromagnetic Induction.

When the magnet is moved "**towards" the coil**, the pointer or needle of the Galvanometer, which is basically a very sensitive centre zeroed moving-coil ammeter, will deflect away from its centre position in one direction only. When the magnet stops moving and is held stationary with regards to the coil the needle of the galvanometer returns back to zero as there is no physical movement of the magnetic field.



When the magnet is **moved "away" from the coil** in the other direction, the needle of the galvanometer deflects in the opposite direction with regards to the first indicating a change in polarity. Then by moving the magnet back and forth towards the coil the needle of the galvanometer will deflect left or right, positive or negative, relative to the directional motion of the magnet.

If the **magnet is now held stationary and ONLY the coil** is moved towards or away from the magnet the needle of the galvanometer will also deflect in either direction. Then the action of moving a coil or loop of wire through a magnetic field induces a voltage in the coil with the magnitude of this induced voltage being proportional to the speed or velocity of the movement.

The faster the movement of the magnetic field the greater will be the induced emf or voltage in the coil, Faraday's law to hold true there must be "**relative motion"** or movement between the coil and the magnetic field and either the magnetic field, the coil or both can move.

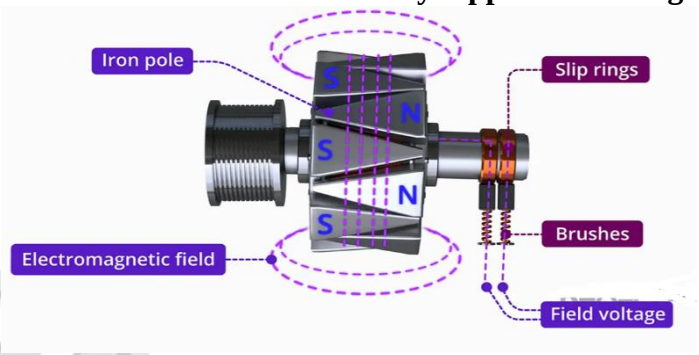
Faraday's Law of Induction

From the above description, there is a relationship between an electrical voltage and a changing magnetic field to which Faradays law of electromagnetic induction states: "**that a voltage is induced in a circuit whenever relative motion exists between a conductor and a magnetic field and that the magnitude of this voltage is proportional to the rate of change of the flux".**

Electromagnetic Induction is the process of using magnetic fields to produce voltage, and in a closed circuit, a current.

But a changing magnetic flux produces a varying current through the coil which itself will produce its own magnetic field as we saw in the Electromagnets tutorial. This self-induced e.m.f opposes the change that is causing it and the faster the rate of change of current the greater is the opposing e.m.f. This self-induced e.m.f will, by Lenz's law oppose the change in current in the coil and because of its direction this self-induced e.m.f is generally called a back-e.m.f.

Lenz's Law states that:" **the direction of an induced e.m.f is such that it will always oppose the change that is causing it".** An induced current will always OPPOSE the motion or change which started the induced current in the first place and this idea is found in the analysis of Inductance.



Types of generators

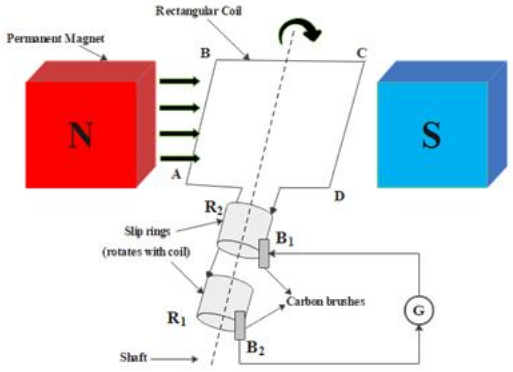
The simple A.C motor

Alternating Current (AC) generators are essential devices that convert mechanical energy into electrical energy, producing an alternating current output. The simplest form of an AC generator consists of a rectangular coil rotating within a uniform magnetic field, typically provided by permanent magnets. This rotation induces an electric current in the coil due to electromagnetic induction. AC generators are particularly advantageous because they can transmit electricity over long distances with minimal energy loss, making them more efficient than their DC counterparts. They are widely used in various applications, from powering homes to supplying electricity for industrial operations.

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The ac generator / the alternator

The simplest alternating current (a.c.) generator (**alternator**) consists of a rectangular coil between the poles of a C-shaped magnet. The ends of the coil are joined to two **slip rings** on the axle and against which *carbon brushes* press. When the coil is rotated it cuts the field lines and an e.m.f. is induced in it. The e.m.f. varies over one complete rotation. As the coil moves through the vertical position with **AB** uppermost, **AB** and **CD** are moving along the lines (**BC** and **DA** do so always) and no cutting occurs. The induced e.m.f. is zero.

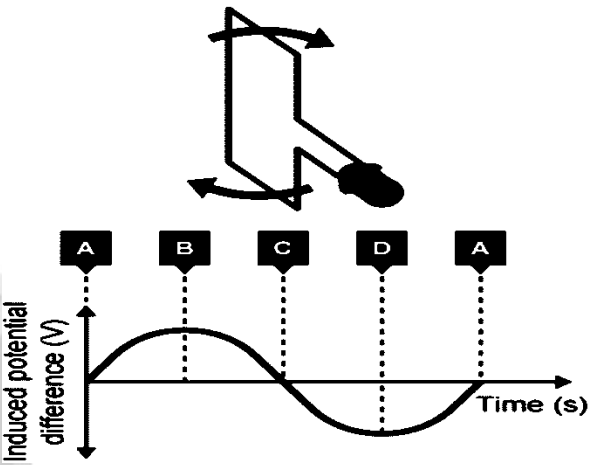


During the first quarter rotation the e.m.f. increases to a maximum when the coil is horizontal. Sides **AB** and **DC** are then cutting the lines at the greatest rate. In the second quarter rotation the e.m.f. decreases again and is zero when the coil is vertical with dc uppermost. After this, the direction of the e.m.f. reverses because, during the next half rotation, the motion of **AB** is directed upwards and **DC** downwards.

An alternating e.m.f. is generated which acts first in one direction and then the other; it causes a.c. to flow in a circuit connected to the brushes. The frequency of an a.c. is the number of complete cycles it makes each second and is measured in hertz (Hz), i.e. 1 cycle per

second = 1Hz. If the coil rotates twice per second, the a.c. has frequency 2Hz. The mains supply is a.c. of frequency 50Hz. An alternating current (ac) generator is a device that produces a potential difference. A simple ac generator consists of a coil of wire rotating in a magnetic field. Cars use a type of ac generator called an alternator to keep the battery charged and to run the electrical system while the engine is working.

Action of a.c. generator: The slip rings maintain constant contact with the same sides of the coil. As one side of the coil moves up through the magnetic field, a potential difference is induced (created) in one direction. As the rotation continues and that side of the coil moves down, the induced potential difference reverses direction. This means that the alternator produces a current that is constantly changing. This is alternating current or ac.



Alternator output on a graph

The output of an alternator can be represented on a potential difference-time graph, with potential difference on the vertical axis and time on the horizontal axis. The graph shows an alternating sine curve. The maximum potential difference or current can be increased by: *increasing the rate of rotation, increasing the strength of the magnetic field, and increasing the number of turns on the coil.* The diagram shows four different positions of the coil in an alternator, and the corresponding potential difference produced.

The potential difference-time graph for an alternator

A - The coil is at 0°. The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.

B - The coil is at 90°. The coil is moving at 90° to the direction of the magnetic field, so the induced potential difference is at its maximum.

C - The coil is at 180°. The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.

D - The coil is at 270°. The coil is moving at 90° to the direction of the magnetic field, so the induced potential difference is at its maximum. Here, the induced potential difference is in the opposite direction to what it was at B.

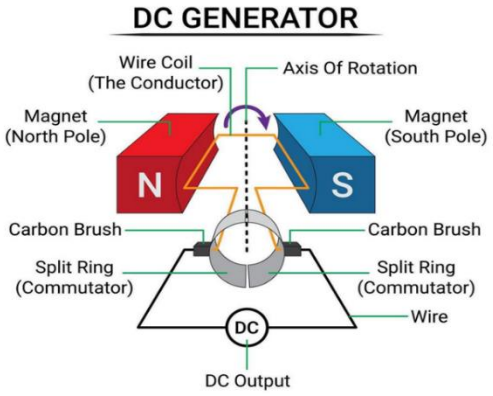
A - The coil is at 360°, ie it is back at its starting point, having done a full rotation. The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.

Practical generators (The rotor and stator of a power station Alternator)

In power stations several coils are wound in evenly spaced slots in a soft iron cylinder and electromagnets usually replace permanent magnets. The electromagnets rotate (the rotor) while the coils and their iron core are at rest (the stator). The large e.m.f. and currents (25 kV at several thousand amps) induced in the stator are led away through stationary cables, otherwise they would quickly destroy the slip rings by sparking. Instead the relatively small power required by the rotor is fed via the slip rings from a small generator (the exciter) which is driven by the same turbine as the rotor.

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Simple D.C. electric motor / Generator



A simple motor to work from direct current (d.c.) consists of a rectangular coil of wire mounted on an axle which can rotate between the poles of a C-shaped magnet.
Each end of the coil is connected to half of a split ring of copper, called a **split-ring commutator**, which rotates with the coil. Two carbon blocks, the **brushes**, are pressed lightly against the commutator by springs. The brushes are connected to an electrical supply.
If Fleming's left-hand rule is applied to the coil in the position shown, we find that side **AB** experiences an upward force and side **CD** a downward force. (No forces act on **AD** and **BC** since they are parallel to the field.) These two forces rotate the coil in a clockwise direction until it is vertical.
The brushes are then in line with the gaps in the commutator and the current stops. However, because of its inertia, the coil overshoots the vertical and the commutator halves change contact from one brush to the other. This reverses the current through the coil and so the directions of the forces on its sides. A downward force on the right now, acts Side AB on, while **CD** is on the left with an upward force. The coil thus carries on rotating clockwise.

Practical motors

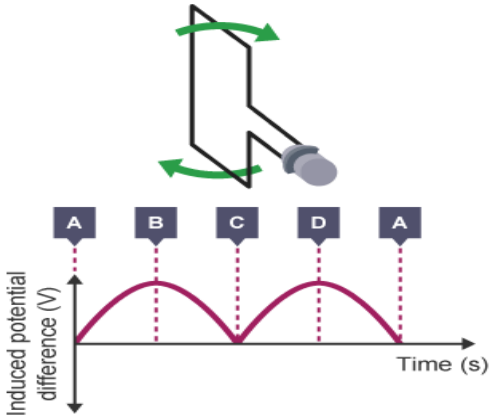
Practical motors have the following features:
(i) A coil of many turns wound on a soft iron cylinder or core, *which* rotates with the coil. This makes it more powerful. The coil and core together are called the **armature**.
(ii) Several coils each in a slot in the core and each having a pair of commutator segments. This gives increased power and smoother running.
(iii) An electromagnet (usually) to produce the field in which the armature rotates. Most electric motors used in industry are **induction motors**. They work off a.c. (alternating current) on a different principle from the D.C. motor.

The Dynamo

In a dynamo, a split ring commutator changes the coil connections every half turn. As the induced potential difference is about to change direction, the connections are reversed. This means that the current to the external circuit is always in the same direction.

Dynamo output on a graph

The output of a dynamo can be shown on a potential difference-time graph. The graph shows a curve that stays in the same direction all the time. The shape of the curve can be thought of as a **sine curve,** with the negative part reflected in the time axis. The maximum potential difference or current can be increased by: increasing the rate of rotation, increasing the strength of the magnetic field, and increasing the number of turns on the coil.
The diagram shows four different positions of the coil in a dynamo, and the corresponding potential difference produced.

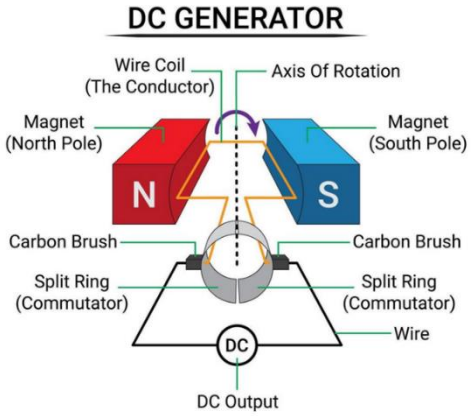


The potential difference-time graph for a dynamo

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A - The coil is at 0°. The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.
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D - The coil is at 270°. The coil is moving at 90° to the direction of the magnetic field, so the induced potential difference is at its maximum. Here, the induced potential difference is in the **same** direction as at B.
A - The coil is at 360°, ie it is back at its starting point, having done a full rotation. The coil is moving parallel to the direction of the magnetic field, so no potential difference is induced.

Working Principle of A DC Generator or Dynamo



- ✓ When the D.C. motor is connected to a power source, current flows through the brushes into the commutator and then into the rotor windings.
- ✓ The current flowing through the rotor creates a magnetic field around the rotor. This field interacts with the magnetic field of the stator (from the permanent magnets or field coils).
- ✓ The interaction between the rotor's magnetic field and the stator's magnetic field produces a torque on the rotor, causing it to rotate.
- ✓ As the rotor turns, the commutator periodically reverses the direction of the current in the rotor windings.
- ✓ This reversal ensures that the magnetic forces continue to push the rotor in the same direction, allowing it to keep spinning.
- ✓ The rotor continues to spin as long as current is supplied. The speed of the motor can be controlled by varying the voltage or current supplied.

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Applications of D.C. Motors

- ✓ They are used as centrifugal pumps, lifts, and weaving machines, cranes and elevators.
- ✓ In the automotive sector, DC motors power electric vehicles and are essential in systems like Powering windshield wipers, electric windows, and seat adjustments and electric traction.
- ✓ In household appliances, including hair dryers, fans and vacuum cleaners, displaying their adaptability in both industrial and domestic settings.
- ✓ Industrial Equipment like in conveyor belts, hoists, and machine tools, Brushed DC motors are increasingly utilized in robotics arms and mobile robots, where precise control and responsiveness are crucial.

Advantages of A.C over D.C

- ✓ There is little or no power losses
- ✓ A.C can easily and cheaply be stepped up and stepped down
- ✓ Frequency of the supply can be precisely controlled
- ✓ Thinner cables can be used since voltage can be stepped up and down.

Moving-coil galvanometer

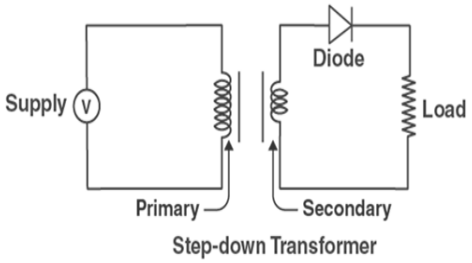
A galvanometer detects small currents or small p.d.s, often of the order of milliamperes (mA) or millivolts (mV). In the moving-coil pointer-type meter, a coil is pivoted between the poles of a permanent magnet. Current enters and leaves the coil by hair springs above and below it. When there is a current, a pair of forces act on the sides of the coil (as in an electric motor), causing it to rotate until stopped by the springs. The greater the current, the greater the deflection which is shown by a pointer attached to the coil.
The soft iron cylinder at the centre of the coil is fixed and along with the concave poles of the magnet it produces a radial field, i.e. the field lines are directed to and from the centre of the cylinder. The scale on the meter is then even or linear, i.e. all divisions are the same size.

Rectifiers and Inverters
A rectifier is an essential electronic device that converts alternating current (AC) into direct current (DC). Rectifiers typically utilize one or more P-N junction diodes, which allow current to flow in one direction while blocking it in the opposite direction, effectively transforming the oscillating AC into a steady DC output.

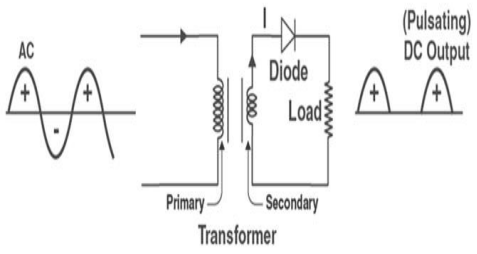
There are several types of rectifiers, including half-wave and full-wave rectifiers.
Half-wave rectifiers only utilize one-half of the AC cycle, while full-wave rectifiers use both halves, resulting in a more efficient conversion.
Inverters are essential electronic devices that convert direct current (DC) into alternating current (AC), enabling the use of DC power sources to operate household appliances and electronic equipment.

This conversion is crucial for integrating renewable energy systems, such as solar panels, into the electrical grid, as most household devices require AC power.
They also manage the speed and torque of electric motors, making them vital in various applications, from industrial machinery to electric vehicles.
As the demand for renewable energy solutions grows, inverter manufacturers are adapting to technological shifts and market dynamics, facing challenges in production and innovation.
In addition to their role in renewable energy, inverters are increasingly popular in automotive applications, allowing users to power devices while on the road.

Half-wave rectifiers transform AC voltage to DC voltage.
A half-wave rectifier circuit uses only one diode for the transformation.
A half-wave rectifier is defined as a type of rectifier that allows only one-half cycle of an AC voltage waveform to pass while blocking the other half cycle.



Half Wave Rectifier Circuit
A half-wave rectifier is the simplest form of the rectifier and requires only one diode for the construction of a half wave rectifier circuit. A half wave rectifier circuit consists of three main components as follows: A diode, a transformer, and a resistive load



Working of Half Wave Rectifier

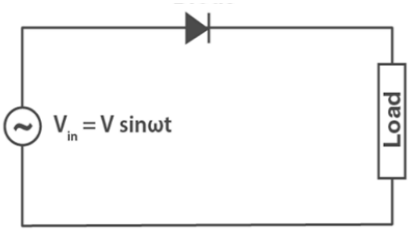
A high AC voltage is applied to the primary side of the step-down transformer. The obtained secondary low voltage is applied to the diode. The diode is forward biased during the positive half cycle of the AC voltage and reverse biased during the negative half cycle. The final output voltage waveform:

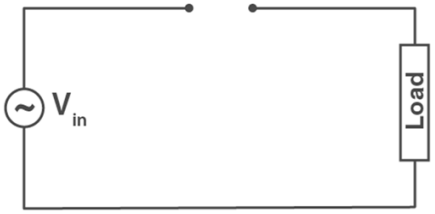
For better understanding, let us simplify the half-wave circuit by replacing the secondary transformer coils with a voltage source as shown below:

For the positive half cycle of the AC source voltage, the circuit effectively becomes as shown below in the diagram:



When the diode is forward biased, it acts as a closed switch. However, during the negative half cycle of the AC source voltage, the equivalent circuit becomes as shown in the figure below

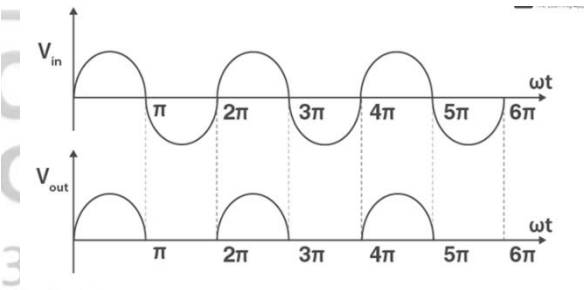




When a diode is reverse biased, it acts as an open switch. Since no current can flow to the load, the output voltage is equal to zero.

Half Wave Rectifier Waveform

The half wave rectifier waveform before and after rectification is shown below in the figure.



Half Wave Rectifier Capacitor Filter

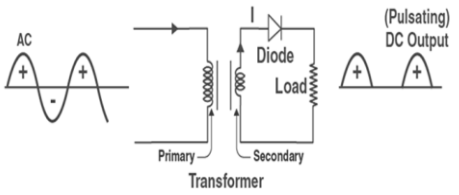
The output waveform of a half wave rectifier is a pulsating DC waveform. Filters in half wave rectifiers are used to transform the pulsating waveform into constant DC waveforms. A capacitor or an inductor can be used as a filter.

The circuit diagram below shows how a capacitive filter is used with half wave rectifier to smoothen out a pulsating DC waveform into a constant DC waveform.

Applications of Half Wave Rectifier

Here are a few common applications of half wave rectifiers:

- ✓ They are used for signal demodulation purpose
- ✓ They are used for rectification applications
- ✓ They are used for signal peak applications



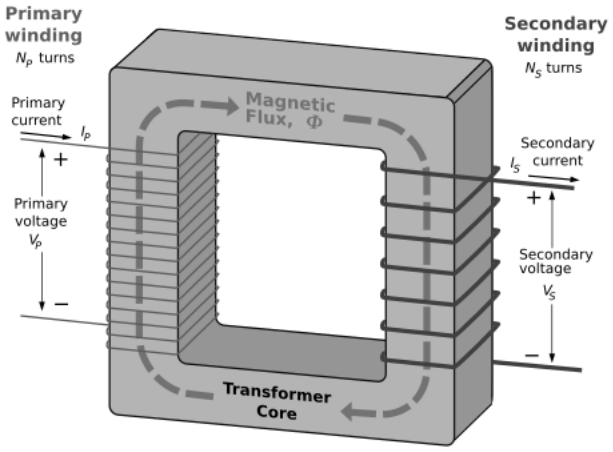
Disadvantages of Half Wave Rectifier

- ✓ Power loss
- ✓ Low output voltage
- ✓ The output contains a lot of ripples

Transformers

Many household devices such as electronic keyboards, toys, lights and telephones require a lower voltage than is provided by the mains supply and a transformer is needed to reduce the mains voltage. When two coils lie in a magnetic field, variations in the current in one coil induce a current change in the other. The voltage transformation depends on the ratio of the number of turns of wire in each coil. Alternating current generated in a power station is transformed into a very high voltage for long-distance electrical transmission. This reduces the size of the current flowing in the transmission cables and minimizes the energy lost to thermal energy due to the resistance of the cables.

A **transformer** transforms (changes) an *alternating* voltage from one value to another of greater or smaller value. It has a primary coil and a secondary coil consisting of insulation-coated wires wound on a complete soft iron core, one either on top of the other or on separate limbs of the core.



The **transformer**, in a simple way, can be described as a device that Procedures up or Procedures down voltage. The transformer works on the principle of Faraday's law of electromagnetic induction and mutual induction. There are usually two coils – primary coil and secondary coil – on the transformer core. The core laminations are joined in the form of strips. The two coils have high mutual inductance.

When an alternating current passes through the primary coil, it creates a varying magnetic flux. This change in magnetic flux induces an EMF (electromotive force) in the secondary coil, which is linked to the core having a primary coil by is mutual induction.

When a transformer is working, a primary potential difference drives an alternating current through the primary coil, the primary coil current produces a magnetic field, which changes as the current changes, the iron core increases the strength of the magnetic field, the changing magnetic field induces a changing potential difference (voltage) in the secondary coil, and the induced potential difference produces an alternating current in the external circuit.

Mutual induction

When the current in a coil was switched on, off or changed, in a simple iron-cored transformer, a voltage was induced in a neighboring coil. If Coil A is the ***primary*** and coil B the ***secondary,*** then, A changing current in a primary coil (A) induces a current in a secondary coil (B).

Switching on the current in the primary sets up a magnetic field and as its field lines grow outwards from the primary, they cut the secondary. A P. D. is induced in the secondary until the current in the primary reaches its steady value. When the current is switched off in the primary, the magnetic field dies away and we can imagine the field lines cutting the secondary as they collapse, again inducing a p.d. in it. Changing the primary current by ***quickly*** altering the rheostat has the same effect. The induced p.d. is increased by having a soft iron rod in the coils or, better still, by using coils wound on a complete iron ring. More field lines then cut the secondary due to the magnetization of the iron.

Transformer equation

An alternating voltage applied to the primary induces an alternating voltage in the secondary.

The value of the secondary voltage can be shown, for a transformer in which all the field lines cut the secondary, to be given by $\frac{\text{Primary voltage}}{\text{Secondary voltage}} = \frac{\text{Primary turns}}{Secondary\ turns}$

In symbols, $\frac{V_p}{V_s} = \frac{N_p}{N_s}$.

A step-up transformer has more turns on the secondary than the primary and V_S is greater than V_P. For example, if the secondary has twice as many turns as the primary, V_S is about twice V_P. In a step-down transformer, there are fewer turns on the secondary than the primary and V_S is less than V_P. Symbols for a transformer: a) step-up ($V_S > V_P$); b) step-down ($V_P > V_S$).

Efficiency of Transformer

The efficiency of a transformer is also known as **commercial efficiency**. It is represented by the letter 'η'. The efficiency of a Transformer is described as the ratio of power output (in W or kW) to input (in W or kW). Hence, the efficiency of transformer may be expressed as follows:

$$Efficiency\ (\eta)\ = \frac{Power\ Output}{Power\ Input}\ x100 Efficiency\ (\eta)\ = \frac{Power\ Output}{Power\ Input}\ x100$$

The power input and output will be equal if the transformer is perfect or 100 percent efficient (no energy losses).

$IpVp\ =\ IsVs$ …… (1),

And for an ideal transformer, $\varepsilon_p = V_p$

By approximation, if the secondary is an open circuit or the current drawn from it is modest, $\varepsilon_s = V_s$.

The voltage across the secondary coil is V_s. $\frac{V_s}{V_p} = \frac{N_s}{N_p}$…… *(2)*

Combining Equations (1) and (2), we have $\frac{I_S}{I_P} = \frac{V_S}{V_P} = \frac{N_S}{N_S} = K$

$$Efficiency\ (\eta) = \frac{I_S V_S}{I_P V_P}\ x100\% Efficiency\ (\eta) = \frac{I_S V_S}{I_P V_P}\ x100\%$$

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Energy Losses in a Transformer

If the p.d. is stepped up in a transformer, the current is stepped down in proportion. This must be so, if we assume that all the energy transferred by the current to the primary appears in the secondary, i.e. that energy is conserved and the transformer is 100% efficient or 'ideal' (many approach this efficiency).

Then; power in primary = power in secondary, $I_P V_P = I_S V_S$, where I_P and I_S are the primary and secondary currents, respectively. $\therefore \frac{I_S}{I_P} = \frac{V_P}{V_S}$. So, for the ideal transformer, if the p.d. is doubled the current is halved.

In practice, it is more than halved, because of small energy losses in the transformer arising from the following causes.

However, some energy losses do occur in actual transformer for the following reasons:

Flux Leakage: Because some flux leaks from the core, not all flux generated by the primary coil make it to the secondary coil. This occurs as a result of the core's inadequate design or the presence of air holes in the core. It is possible to lower it by wrapping the primary and secondary coils over each other. It can also be lowered if the core is well-designed.

Resistance of windings: Because the wire used for the windings has some electrical resistance, energy is wasted as a result of the heat generated in the windings. These are mitigated in high current, low voltage

windings by utilizing thick wire with a high conductive substance. Large transformers have to be oil-cooled to prevent overheating

Eddy Currents: The iron core is in the changing magnetic field of the primary and currents, called eddy currents, are induced in it which causes heating. These are reduced by using a laminated core made of sheets, insulated from one another to have a high resistance.

Hysteresis Loss: In each AC cycle, the alternating magnetic field reverses the magnetization of the core. The loss of energy in the core occurs as heat owing to hysteresis loss, which is minimized by employing a magnetic material with a low hysteresis loss.

Application of Transformer

The following are some of the most common uses for transformer:

a) Increasing or reducing the voltage level in an AC circuit to ensure the correct operation of the circuit's various electrical components,
b) It stops DC from flowing from one circuit to another,
c) It separates two separate electric circuits,
d) Used in radio and TV receivers, which require several different voltages

Examples

A transformer has 600 turns of the primary winding and 20 turns of the secondary winding. Determine the secondary voltage if the secondary circuit is open and the primary voltage is 140 V. Given Total number of turns of the primary coil (N_1) = 600 turns, Total number of turns of the secondary coil (N_2) = 20 turns, and Primary voltage (V_1) = 140 V

Solution:

The voltage on the primary coil = 140V, N turns =600

The voltage on the secondary coil = $V_{2,\ Turns}$ =20

From the formula, $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ **V_s= 4.67 V**

2. A transformer has a primary coil with 1600 loops and a secondary coil with 1000 loops. If the current in the primary coil is 6 Ampere, then what is the current in the secondary coil?

Given: Primary coil (N_1) = 1600 loops, Secondary coil (N_2) = 1000 loops, The current in the primary coil (I_1) = 4 A

From the formula, $\frac{I_s}{I_p} = \frac{N_s}{N_p}$ **I_P = 6.4 A**. The current on the secondary coil is 6.4 Ampere.

3), A transformer steps down the mains supply from 230V to 10V to operate an answering machine. a). What is the turn's ratio of the transformer windings? b). How many turns are on the primary if the secondary has 100 turns?

a) Primary Voltage, V_p=230, Secondary Voltage, Vs=10V

Turns ratio; $\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{230V}{10V} = \frac{23}{1}$; 23:1

Secondary turns, N_S=100 turns; From, (a), $\frac{N_P}{N_S} = \frac{23}{1}; N_P = 23xN_S = 23x100 = 2300turns$

Activity

1). A transformer has 1000 turns on the primary coil. The voltage applied to the primary coil is 230Va.c. How many turns are on the secondary coil if the output voltage is 46Va.c?

2). A transformer steps down the mains supply from 240 V to 12 V to operate a doorbell.
(a) What is the turns ratio of the transformer windings?
(b) How many turns are on the primary if the secondary has 80 turns?

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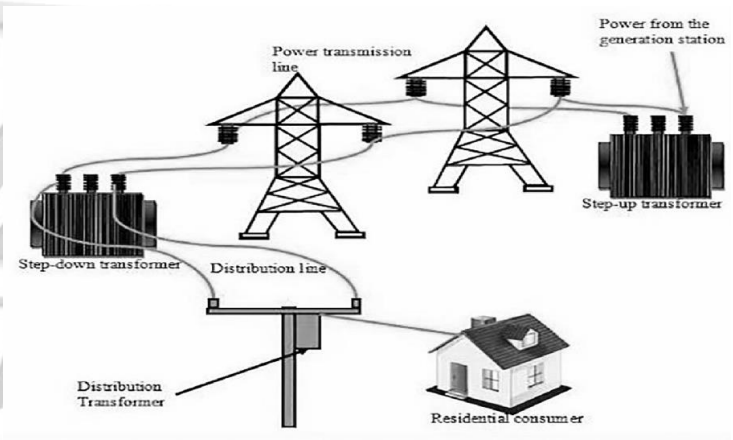
3). A transformer steps up an a.c. voltage of 240 V to 960 V.
(a) Calculate the turns ratio of the transformer windings.
(b) How many turns are on the secondary if the primary has 500 turns?

4). A transformer steps down a voltage from 240V to12V for a radio. If the primary windings are 300 turns, how many turns on the secondary windings?
5). An electric power generator produces 24kW at 240V. The voltage is stepped up to 4000V. If the transformer is 100% efficient, calculate the current in the secondary coil
6). A transformer 80% efficient is connected to a 240V A.C supply to operate a heater of resistance 240Ω. If the current flowing in the primary circuit is 5A, calculate the potential difference across the heater.

4.3 ELECTRIC ENERGY DISTRIBUTION AND CONSUMPTION

Learning Outcomes

a) Understand the distribution of electricity from the source to consumer units(u)
b) Understand the energy transformations in common domestic electrical devices and how energy can be saved(u)
c) Understand how to use mains electricity safely and know the insulation colour codes used in domestic wiring (u, k,s)
d) Know the dangers of mains electricity and understand how these may be minimised by safety devices, and by sensible precautions (k, u,v/a)
e) Know how to read a domestic electricity meter and its significance (k, u,s)
f) Appreciate the importance of the use of energy saving appliances (u, s,v/a)



Introduction

Electrical energy is the work done by electric charges, calculated by multiplying power by the time the current flows. This energy is derived from the potential or kinetic energy of charged particles. The rate at which this energy is transferred within a circuit is known as electric power, measured in watts. One watt is defined as one joule per second, illustrating the relationship between energy and time. Understanding the distinction between energy and power is crucial. Energy represents the total work done, while power indicates how quickly that work is performed. For instance, a light bulb may consume a certain amount of energy over time, but its power rating tells us how much energy it uses per second. As global electricity consumption continues to rise, with figures exceeding 25 terawatt-hours, the efficient use of electrical energy and power becomes increasingly important for sustainable development and energy management.

The mains electricity supply

Grid system

The **National Grid** is a network of cables, mostly supported on pylons, that connects all the power stations in a country to consumers. In the largest modern stations, electricity is generated at 25000V (25kilovolts = 25kV) and stepped up in a transformer to a higher p.d. to be sent over long distances. Later, the p.d. is reduced by substation transformers for distribution to local users. At the National Control Centre, engineers direct the flow of electricity and re-route it when breakdown occurs. This makes the supply more reliable and cuts costs by enabling smaller, less efficient stations to be shut down at off-peak periods.

Advantages of high-voltage transmission

The efficiency with which transformers step alternating p.d.s up and down accounts for the use of a.c. rather than d.c. in power transmission.

Power cables have resistance and so the electric current causes heating of the cable during the transmission of electricity from the power station to the user. In order to reduce energy losses, the current in the cables should be kept low.

Higher voltages are used in the transmission of electric power so that smaller currents can be used to transfer the energy.

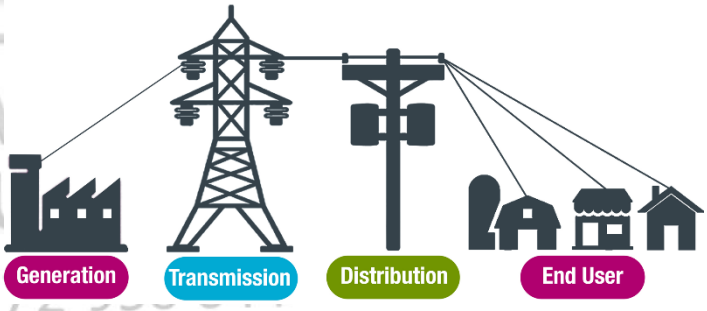
Advantages of high-voltage transmission of electricity *include:*

(i) Reducing the amount of energy lost as thermal energy in the transmission cables

(ii) Allowing wires with small cross-sectional areas to be used; these are cheaper and easier to handle than the thicker wires required carrying large currents. High p.d.s requires good insulation but is readily produced by a.c. generators.

(iii) Lower currents in cables so thinner/cheaper cables can be used.

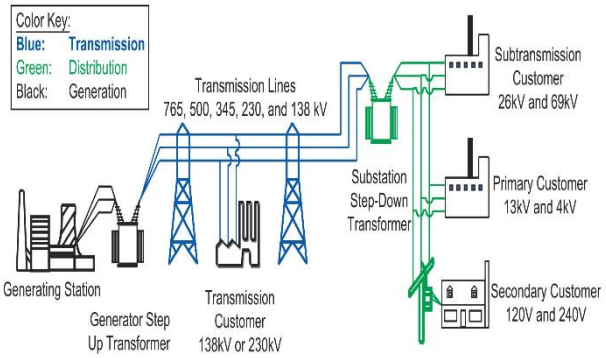
Transmission and Distribution of Electricity



Transmission refers to the high-voltage movement of electricity over long distances, akin to motorways transporting vehicles quickly across the country. This system connects power plants to substations, where the voltage is reduced for safe distribution. Once electricity reaches substations, the distribution phase begins. This involves lower-voltage power lines that deliver electricity to homes and businesses. The distribution network is essential for providing reliable access to electricity, adapting to local demand and ensuring that power is available where it is needed most. As the energy landscape evolves, particularly with the rise of renewable sources, the transmission and distribution systems face new challenges. Utilities and system operators must continuously balance supply and demand, integrating advanced technologies to enhance efficiency and reliability in delivering electricity to consumers.

The grid system

Uganda's electricity sector is primarily powered by hydroelectric sources, contributing 1,023.59 MW, followed by thermal (100 MW), cogeneration (63.9 MW), and grid-connected solar (60 MW). Despite these resources, only about 42% of the population had access to electricity by 2021, highlighting a significant gap in energy availability. To address this, isolated grid systems are emerging as a viable solution, particularly in rural areas where traditional grid expansion is challenging. The Twaake integrated energy minigrid project has gained recognition for its innovative approach to delivering clean and economical energy, showcasing the potential of decentralized energy solutions. Furthermore, Uganda's participation in the Eastern Africa Power Pool (EAPP) aims to enhance regional power trade and improve electricity access. As the country explores alternative technologies, including solar photovoltaic systems, the potential for increased electricity access remains promising, paving the way for a more sustainable energy future.



Electricity is transmitted at high voltages primarily to enhance efficiency and minimize energy losses. When electrical power travels over long distances, resistance in the transmission lines can lead to significant energy loss. By increasing the voltage, the current flowing through the wires is reduced, which directly decreases the power loss due to resistance. This principle is rooted in Ohm's Law, where power loss is proportional to the square of the current. High-voltage transmission systems utilize transformers to step up the voltage for long-distance travel and then step it down for safe distribution to consumers. This method not only conserves energy but also allows for the transmission of larger amounts of power over vast distances, making it essential for modern electrical grids. In summary, high-voltage transmission is a critical strategy for efficient energy distribution, ensuring that electricity can be delivered effectively while minimizing waste and maintaining system reliability.

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Domestic Electricity

Domestic electricity in Uganda is governed by specific tariffs aimed at making power more accessible to households. Customers consuming up to 100 units per month can purchase the first 15 units at a subsidized rate of UGX250 per kilowatt-hour. This lifeline tariff is designed to support low-income households, allowing them to manage their energy costs effectively. Despite the availability of electricity, many Ugandans still rely on solid fuels like firewood and charcoal for cooking, highlighting a significant gap in energy access. The demand for electricity is growing rapidly, with household consumption increasing at an annual rate of 13%. Appliances account for a significant portion, approximately 64.7% of total electricity usage. This highlights the importance of understanding energy consumption patterns to manage costs and promote efficiency. Domestic electric circuits are designed to supply power safely throughout homes. These circuits consist of various components, including switches, wires, and safety devices like fuses and circuit breakers.

Power rating on each appliance

Understanding the power ratings of common household appliances is essential for managing energy consumption and costs. For instance, dishwashers typically consume between 1200 to 1500 watts, while electric clothes dryers can use a significant amount of energy, ranging from 1800 to 5000 watts. In

contrast, gas-heated dryers are more efficient, requiring only 300 to 400 watts. When planning for energy efficiency, it's crucial to consider the wattage of all appliances. For example, a coffee maker generally uses about 600 to 1200 watts, while a clothes washer consumes around 350 to 500 watts. These figures can help homeowners make informed decisions about their energy use and potential savings. By being aware of these power ratings, individuals can optimize their energy consumption, potentially leading to lower utility bills and a reduced environmental impact.

The Meaning of 5kWh Appliance

A 5 kWh appliance refers to the energy consumption of an appliance that uses five kilowatt-hours of electricity. The term "kWh" stands for kilowatt-hour, which is a unit of energy that quantifies how much power an appliance uses over time. For example, if an appliance operates at a power level of 1 kW for 5 hours, it will consume 5 kWh of energy. Understanding kWh is essential for managing energy costs. The cost of electricity is typically calculated based on kWh usage, meaning that a 5 kWh appliance will contribute to your monthly electricity bill depending on your local rates. For instance, if your electricity costs UGX0.10 per kWh, running a 5 kWh appliance would cost you UGX0.50 for one hour of use. In practical terms, a 5 kWh appliance can power various household devices, such as a refrigerator or a washing machine, for a limited time. Knowing the kWh rating of your appliances helps in making informed decisions about energy consumption and efficiency.

Electricity Meters



Electricity meters are essential devices that measure the amount of electrical energy consumed by a residence or business. They operate with a high level of accuracy, ensuring that consumers are billed correctly for their energy usage. Traditional analog meters have largely been replaced by digital meters, which utilize electronic components to provide precise readings. These digital meters not only record energy consumption but also transmit data directly to utility companies, streamlining the billing process. Digital meters come in various types, including single-phase and three-phase meters, catering to different energy needs. Three-phase meters are commonly used in commercial settings, measuring the power of three-phase electrical supplies.
The transitions to smart meters have further enhanced energy management, allowing users to monitor their consumption in real-time and make informed decisions about their energy use.

Calculating the Cost of Electricity

ELECTRICAL ENERGY: Electrical energy is the work done in moving an electric charge by an electric force. The SI unit of electrical energy is the Joule (J)**.** This electrical energy is accompanied with a rise in temperature so this energy may be given out as heat energy. This explains why wires become hot when electricity passes through them.

Calculating electrical circuits

Find the total or effective resistance in the circuit. When finding current through a resistor in parallel, first find the potential difference (voltage) across the parallel connection. Power dissipated in any resistor is $P = I^2R$. Power expended in the whole circuit is $P = IV$

ACTIVITY

1. In the diagram below, a battery of e.m.f 12V and internal resistance 0.6Ω is connected resistors. Determine; (i) Current through the circuit, (ii) Current through the 4Ω and 6Ω resistor, (iii)Power dissipated in the 4Ω resistor, (iv) Power expended in the circuit.

2. A dry cell of e.m.f, E and internal resistance, r drives a current of 0.25A through a resistor of 5.5Ω and drives a current of 0.3A through a resistor of 4.5Ω. Determine the E.m.f, E and internal resistance, r., and the power developed in 5.5ohms resistor.

Commercial Electricity

Electricity and its Units

Power is the rate of electricity used while electricity is the actual energy consumption. Imagine a 100-feet pipe, filled with water. When you open a valve on one end, the water immediately flows out the other end. The pressure wave has traveled to 100 feet of pipe. Likewise, electricity is the flow of electrons through a conductor. $\boldsymbol{Electricity\ (Energy) = Power * Time}$

The unit of electricity is kilowatt hour or kWh. This is the actual amount of energy used in one hour. Suppose you use 1000W power in 1 hour then you consume 1 unit or 1 kWh of electricity. So, if a 100W bulb lit up for 5 hours then the total electricity it consumes:

$\boldsymbol{Electricity = 100W * 5h = 500WH = 0.5\ kWh\ or\ 0.5\ unit}$

Power Consumption and its Units

Power consumption is the amount of energy used per unit of time to operate something. Consider an office building, it needs 4-watt power energy to function and the availability of the power is always required to work properly. Power is always measured in watts (W) or kilowatt (kW). There are 1000 watts in 1 kilowatt. Let's say, your washing machine has a power rate of 1.5kW which means it consumes electricity at the rate of 1500 watts. Similarly, if you buy a 100W bulb, it does not mean it consumes 100 watts of electricity. It means it consumes at the rate of 100W.

In Uganda, electricity boards such as UMEME sell electricity. They use our meters to estimate the electrical energy consumed. The energy consumed is measured in kilowatt-hours (kWh).

$\boldsymbol{Energy\ Consumption\ (kWh) = Power\ Rating\ (kW) \times Usage\ Time\ (hours)}$.

$\boldsymbol{Base\ Charge = Energy\ Consumption\ (kWh) \times Rate\ per\ kWh}$

A kilowatt-hour is the amount of electrical energy consumed by a device of power 1000W in one hour. All electrical appliances are marked (rated) showing the power rating in Watts and voltage in Volts. An electrical appliance rated 240V, 60W means that the appliance supplies or consumes 60J every second when connected to a 240V mains supply.

Example

An electric kettle labelled 5kW is connected to an electric power supply for 20 minutes. Determine the amount of energy consumed and the cost of electricity used during the time if each kWh costs UGX780/=

Solution

Energy consumed =power*time=$5x\frac{20}{60} = 1..67kWh.$

Cost =electrical energy x rate of electricity=1.67x780=UGX1302.6/=

ACTIVITY

1. How much will it cost to run four bulbs rated at 40W each for 2 days, if the cost of each unit of electricity is UGX750?

2. Find the cost to run two bulbs rated at 60W each and an electric iron rated at 120W for 35 minutes, if the unit is UGX420/=.
3. An electrical heater is rated at 3000W, 240V. Find the total number of units it consumes in 1.5 hours and the cost of electricity if each unit costs UGX10, 000/= after using the heater for 3hours every day for a month.
4. An electrical heater supplies or consumes 3000J every second when connected to a 240V mains supply. Janelle paid an electricity bill of UGX2800/= after using two identical bulbs for 2 hours every day for 20 days at a cost of 2600shs per unit. Determine the power consumption by each of the bulbs.
5. Find the cost of running five 60W lamps and four 100W lamps for 8 hours if the electrical energy costs UGX500/= per unit.
6. Mr. Peter uses 5 kettles of 800W each, a flat iron of 1000W, 4 bulbs of 60W each and 2 bulbs of 75W each. If they are used for 6hours every day for 30 days and one unit of electricity costs
200shs, find the total cost of running the appliances.
7. A television is rated 240V, 600W.
(a) What do you understand by the statement above?
(b) Calculate the current flowing through the TV.
(c) Calculate the resistance of the television.
(d) Calculate the cost of running the television for 600 minutes if the unit cost is 600shs.

Energy Transmission in common of Electric Devices

Energy transmission is a fundamental concept in the operation of electric devices, where electrical energy is transformed into various other forms. Common household appliances such as flat irons, electric toasters, and stoves convert electrical energy into thermal energy, enabling cooking and heating. Similarly, televisions transform electrical energy into sound and light, providing entertainment and information. The process of energy transfer in electric circuits is crucial for understanding how these devices function. The energy transferred to a resistor, for instance, is calculated by multiplying electric power by time, illustrating the relationship between energy consumption and device operation. Various energy transformation devices play a significant role in our daily lives, converting electrical energy into light, heat, sound, and mechanical energy. This transformation is essential for the functionality of appliances like light bulbs, heaters, and fans, showcasing the versatility and importance of energy transmission in modern technology.

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Safety Measures

Electrical safety is crucial in both workplace and home environments to prevent accidents and injuries. Here are some essential safety measures to consider. First, always keep electrical equipment away from water to avoid electrocution. Ensure that all equipment is unplugged safely after use, and avoid overloading outlets, which can lead to fires. In the workplace, maintain a safe distance from power lines, ideally staying at least 10 feet away. Use protective gear, such as non-conductive gloves and goggles, when working with electrical equipment. Regularly inspect electrical tools and cords for damage, and ensure that all equipment is properly grounded. At home, follow appliance instructions carefully and utilize fuses and circuit breakers to protect against power surges. By adhering to these safety tips, you can significantly reduce the risk of electrical hazards and create a safer environment for everyone.

Transmission of electricity

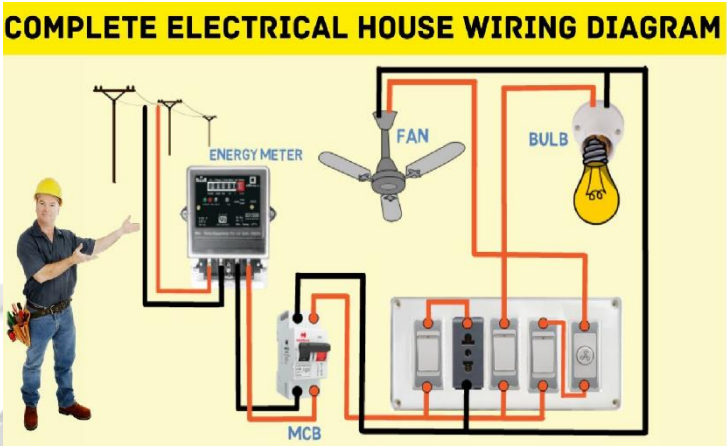
Electricity generated at power stations is stepped up to higher voltages before transmission using step transformers. The power transmitted is usually alternating current and it is stepped down as it reaches

factories, industries, towns and homes using step down transformers. Transmission can be either overhead or underground.

How power losses are reduced during transmission of electricity:

Electricity is transmitted at high voltages to reduce power loss due to the heating effect in the transmission cables. The transmission cables are made thick to reduce its resistance hence minimizing power loss.

House wiring (domestic electrical installation)



Electricity is connected in a house by thick cables called the mains from the electricity poles to the meter box or fuse box and then to the main distribution box. From here, electricity is supplied to the electrical appliances. The electricity supply cables in a house consist of the following wires. Domestic electrical installation involves a systematic approach to distributing energy throughout a home, powering everything from lights to appliances. Key considerations include selecting the right wire types, understanding circuit layouts, and adhering to safety standards.

When wiring a house, several essential components must be included to ensure safety and functionality. The circuit breaker panel serves as the heart of the electrical system, distributing power through various circuits to different areas of the home. Standard residential wiring consists of wires, cables, outlets, switches, and electrical panels, all of which must comply with local codes. In kitchens, for instance, it is crucial to have a minimum of eight circuits, with kitchen lighting on a separate circuit rated for 15 or 20 amps.

Ground Fault Circuit Interrupter (GFCI) outlets are also required in areas prone to moisture, such as kitchens and bathrooms, to prevent electrical shocks. Additionally, using the correct gauge wire is vital; 14-gauge wire is typically used for lighting circuits, while 12-gauge is suitable for general-purpose outlets. Following these guidelines ensures a safe and efficient electrical system in your home.

Precautions taken when wiring a house

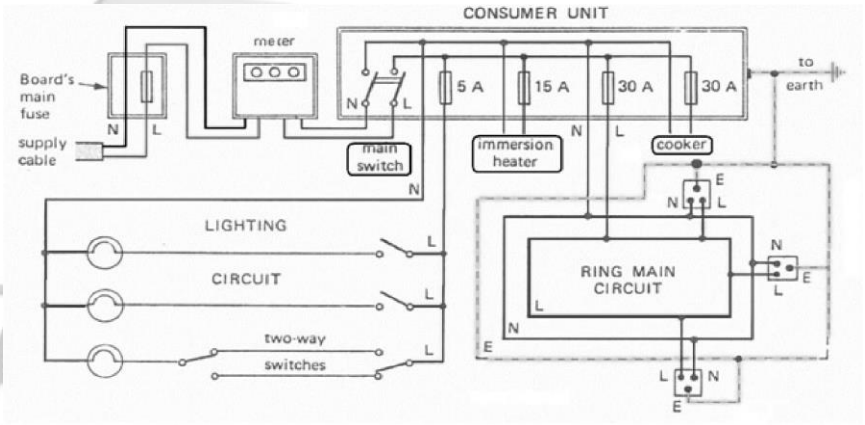
When wiring a house, safety should always be the top priority. Here are ten essential tips to ensure safe residential electrical wiring. First, always turn off the power at the circuit breaker or fuse box before starting any work. This simple step can prevent serious accidents. Additionally, using insulated tools is crucial to protect against electrical shocks. Wearing safety glasses and protective clothing is another important precaution. These items can shield you from debris and potential electrical hazards. Always test the wires with a voltage tester before touching them, ensuring they are not live. Having the right tools on hand can also make the process smoother and safer. Finally, ensure that all wiring complies with local codes and regulations. Proper grounding of electrical systems is essential to prevent shocks and fire hazards. By following these guidelines, you can significantly reduce the risks associated with electrical wiring in your home.

Dangers of mains electricity

Mains electricity poses significant dangers, including electric shocks, fires, and electrical burns. The high voltage, typically around 220-240 V, makes contact with live wires particularly hazardous. Surges in electricity can lead to severe consequences, such as fires or electric shocks, emphasizing the importance of safety measures. To mitigate these risks, built-in safety features like fuses and earth wires are essential. Fuses work by melting when a high current flows through them, effectively cutting off the electricity supply to the appliance and making it safe to touch. This mechanism is crucial in preventing potential accidents. Common hazards include overloaded sockets and faulty appliances, which can exacerbate the dangers of mains electricity. Awareness and adherence to safety guidelines are vital for preventing electrical accidents in homes and workplaces. Always engage licensed professionals for electrical installations and repairs to ensure safety.

Mains Electricity Safety

Start by following appliance instructions carefully to ensure proper usage. Avoid overloading outlets, as this can lead to electrical fires. If you encounter exposed voltages, keep the device turned off and maintain a safe distance from other objects to prevent accidental contact. In addition, always keep electrical equipment away from water to reduce the risk of electrocution. Unplug devices safely and ensure that cords are installed properly and kept tidy to avoid tripping hazards. Familiarize yourself with the electrical systems in your home or workplace, and engage only licensed professionals for any installation or repair work. Lastly, always consider using safety signs and tags to identify electrical hazards.



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Domestic Wiring in Mains Electricity

A typical home electrical system consists of two 240-volt wires and one neutral wire, which deliver power to various appliances and lighting fixtures. The three primary types of electrical wires include live (hot) wires, neutral wires, and grounding wires. Live wires are typically red or blown, neutral wires are white/black, and grounding wires are either bare yellow or green.

Earthing

A ring main has a third wire which goes to the top socket on all power points and is earthed by being connected either to a *metal* water pipe entering the house or to an earth connection on the supply cable.
This third wire is a safety precaution to prevent electric shock should an appliance develop a fault. The earth pin on a three-pin plug is connected to the metal case of the appliance which is thus joined to earth by a path of almost zero resistance. If then, for example, the element of an electric fire breaks or sags and touches the case, a large current flows to earth and 'blows' the fuse. Otherwise the case would become 'live' and anyone touching it would receive a shock which might be fatal, especially if they were 'earthed' by, say, standing in a damp environment, such as on a wet concrete floor.

Sample item

A family is downtown slums in in Uganda uses 2kW heater for 10 hours and a 100W lamp for 8 hours each day for 2 months. At the same the time, an electric immersion heater was immersed in 0.05 kg of oil placed in a lagged copper calorimeter. The temperature of oil rose from 20^{o}C to 80^{o}C in 100seconds. If the specific heat capacity of oil is 2000Jk^{-1} and that od calorimeter is 400Jk^{-1}. As a physics student; help to determine the (a) Power supplied by the heater, (b) The cost of running the heater for 100s for 2 months' period if used every day. **HINT: ERA Cost of unit UGX780.5**/=

Insulation and Color Codes

Color coding in insulation and control cables is essential for ensuring safety and compliance in electrical installations. By using standardized color codes, manufacturers and technicians can easily identify and connect cables correctly, reducing the risk of hazardous mistakes. Common wire colors include **black, red/blown, white, green/yellow, and blue**, each serving a specific purpose in electrical wiring. In addition to safety, proper insulation and color coding contribute to the efficiency of electrical systems, ensuring that installations meet local codes and regulations.

Double insulation

Appliances such as vacuum cleaners, hairdryers and food mixers are usually double insulated. Connection to the supply is by a two-core insulated cable, with no earth wire, and the appliance is enclosed in **a non-conducting plastic case**. Any metal attachments that the user might touch are fitted into this case so that they do not make a direct connection with the internal electrical parts, such as a motor. There is then no risk of a shock should a fault develop.

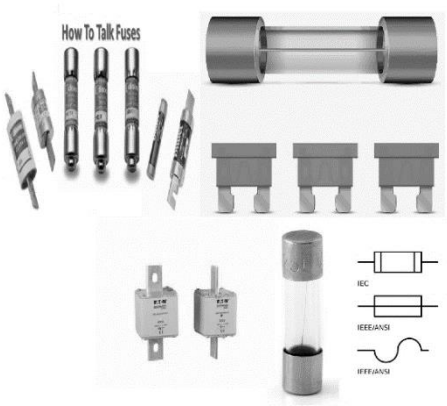
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Circuit breakers / Trip Switches:

Trip switches (also known as **circuit breakers**) are now used instead of fuses in consumer units. They contain an electromagnet which, when the current exceeds the rated value of the circuit breaker, becomes strong enough to separate a pair of contacts and break the circuit Like fuses, circuit breakers are always placed in the live wire. In the design, when the current is large enough in an electromagnet, an adjacent iron bolt is attracted far enough for a plunger to be released, which allows a push switch to open and contact to the rest of the circuit to be broken. Circuit breakers operate much faster than fuses and have the advantage that they can be reset by pressing a button. As for a fuse, the trip switch setting should be chosen to be a little higher than the value of the current in the device being protected.

The Residual Current Circuit Breaker (RCCB), also called a Residual Current Device (RCD), is an adapted circuit breaker which is used when the resistance of the earth path between the consumer and the substation is not small enough for a fault-current to blow the fuse or trip the circuit breaker. It works by detecting any difference between the currents in the live and neutral wires; when these become unequal due to an earth fault (i.e. some of the current returns to the substation via the case of the appliance and earth) it breaks the circuit before there is any danger. They have high sensitivity and a quick response. An RCD should be plugged into a socket supplying power to a portable appliance such as an electric lawnmower or hedge trimmer. In these cases, the risk of electrocution is greater because the user is generally making a good earth connection through their feet. They serve as a resettable fuse, automatically cutting off power when necessary, thus safeguarding both people and property from electrical hazards.

FUSE



A **fuse** protects a circuit; it is always placed in the live wire. It is a short length of wire of material with a low melting temperature, often 'tinned copper', which melts and breaks the circuit when the current in it exceeds a certain value. Two reasons for excessive currents are 'short circuits' due to worn insulation on connecting wires and overloaded circuits. Without a fuse the wiring would become hot in these cases and could cause a fire. **A fuse should ensure that the current-carrying capacity of the wiring is not exceeded.** In general, the thicker a cable is, the more current it can carry, but each size has a limit. Always switch off before replacing a fuse, and always replace with one of the same value as recommended by the manufacturer of the appliance. A 3A (red) fuse will be needed for appliances with powers up to 720W, or 13A (brown) for those between 720W and 3kW. Calculation of the current in a device allows the correct size of fuse to be chosen.

Example

An electric heater has a power rating of 2 kW. If the supply voltage is 240 V, determine the current in the Heater. Should a 3 A or 13 A fuse or trip switch setting be chosen to protect the heater?

Response:

$Power;\ P = IV$: Rearrange the equation to give $I = \frac{P}{V} = \frac{2000W}{240V} = 8.3A$

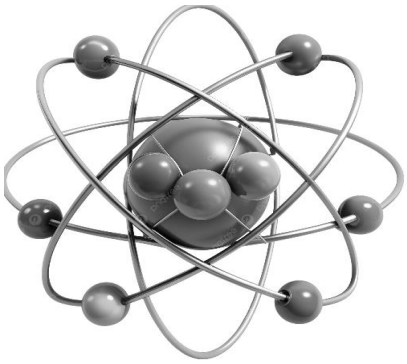
The fuse/trip switch setting should have a higher rating than the current in the heater, so a 13 A fuse/trip switch setting should be chosen.

Activity

a) An electric heater has a power rating of 1.5 kW. If the supply voltage is 240 V, determine the current in the heater. Should a 3 A, 13 A or 30 A fuse be used to protect the heater?
b) A television has a power rating of 100 W. If the supply voltage is 240 V, determine the current in the television. Should a 3 A, 13 A or 30 A fuse be chosen to protect the television?
c) An electric cooker has a power rating of 6.4 kW. If the supply voltage is 240V, determine the current in the cooker. Should a 3 A, 13 A or 30 A trip switch setting be chosen to protect the oven?

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4.5 ATOMIC MODELS



Learning Outcomes

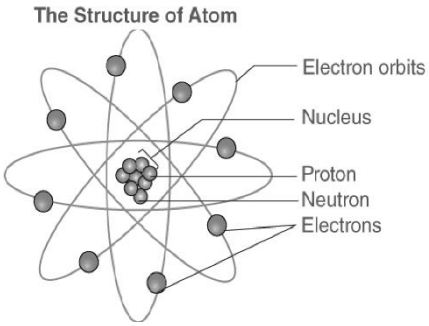
a) Understand the structure of an atom in terms of a positive nucleus and negative electrons(u)
b) Understand the terms: atomic number, mass number, and isotopes, and use them to represent different nuclides (k,u)
c) Understand the methods by which electrons are ejected from /matter atoms and how these electrons are useful (u, v/ a)

Introduction

Atomic models are essential in understanding the structure and behavior of atoms, the fundamental building blocks of matter. The nucleus of an atom is composed of positively charged protons and uncharged neutrons of very similar mass. The number of protons determines the properties of an atom, but the number of neutrons can vary to give different isotopes of the same element. Some heavy nuclei are unstable and break up into multiple parts in nuclear fission. Light nuclei may combine in nuclear fusion. Both processes emit substantial amounts of energy.

STRUCTURE OF AN ATOM

The structure of an atom can be described as consisting of two main regions: a positively charged nucleus at the center and negatively charged electrons surrounding the nucleus.



The Nucleus (Positive): The nucleus is a small, dense core located at the center of the atom. It contains protons and neutrons: Protons are positively charged particles. Neutrons have no charge (they are neutral). The overall charge of the nucleus is positive due to the presence of protons. The number of protons in the nucleus is called the atomic number, which defines the element (e.g., hydrogen has 1 proton, carbon has 6 protons). The nucleus accounts for almost all of the atom's mass, but it occupies only a tiny fraction of the atom's volume.

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Electrons (Negative): Surrounding the nucleus are electrons, which are negatively charged particles. Electrons are much lighter than protons and neutrons. Electrons are arranged in regions of space called electron shells or energy levels. These shells orbit around the nucleus. The number of electrons in a neutral atom equals the number of protons, which balances the atom's overall charge.

Protons and neutrons

We now believe as a result of many experiments, in some of which α- and other high-speed particles were used as 'atomic probes', that atoms contain three basic particles – protons, neutrons and electrons.

A proton is a hydrogen atom minus an electron, i.e. a positive hydrogen ion. Its charge is equal in size but opposite in sign to that of an electron, but its mass is about 2000 times greater.

A neutron is uncharged with almost the same mass as a proton.

Protons and neutrons are in the nucleus and are called nucleons. Together they account for the mass of the nucleus (and most of that of the atom); the protons account for its positive charge.

Particle	Relative Mass	Relative Charge	Location
Proton	1836	+1	In nucleus

Neutron	1839	+0	In nucleus
Electron	1	-1	Outside nucleus

In a neutral atom the number of protons equals the number of electrons surrounding the nucleus. Hydrogen is simplest with one proton and one electron. Next is the inert gas helium with two protons, two neutrons and two electrons. The soft white metal lithium has three protons and four neutrons.

	Hydrogen	Helium	Lithium	Oxygen	Copper
Protons	1	2	3	8	29
Neutrons	0	2	4	8	34
Electrons	1	2	3	8	29

Electrostatic Forces: The negatively charged electrons are attracted to the positively charged nucleus by the electrostatic force (Coulomb force), which holds the atom together. Despite this attraction, electrons do not "fall" into the nucleus because they occupy specific energy levels or orbital's, which are governed by the principles of quantum mechanics.

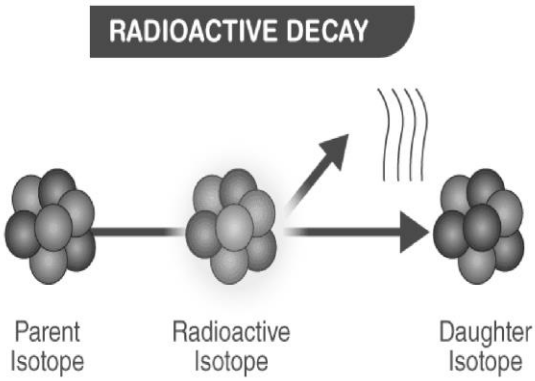
Atomic Number (Z): The atomic number is the number of protons in the nucleus of an atom.
It is represented by the symbol Z. The atomic number determines the identity of the element. For example: Hydrogen (H) has an atomic number of 1 because it has 1 proton. Carbon (C) has an atomic number of 6, meaning it has 6 protons. The atomic number also equals the number of electrons in a neutral atom, since protons and electrons balance each other's charge.
The atomic or proton number Z of an atom is the number of protons in the nucleus. The proton number is also the number of electrons in the atom. The electrons determine the chemical properties of an atom and when the elements are arranged in order of atomic number in the Periodic Table, they fall into chemical families.

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Mass Number (A): The mass number is the total number of protons and neutrons in an atom's nucleus. It is represented by the symbol A. Mass number = Protons (Z) + Neutrons (N). For example, carbon-12 (C-12) has a mass number of 12 because it has 6 protons and 6 neutrons. Unlike the atomic number, which is unique to each element, the mass number can vary among atoms of the same element, depending on the number of neutrons.
The mass or nucleon number A of an atom is the number of nucleons in the nucleus.
In general, the number of neutrons in the nucleus = A – Z. Atomic nuclei are represented by symbols. Hydrogen is written as ${}_{1}^{1}H$, helium as ${}_{2}^{4}He$ and lithium as ${}_{3}^{7}Li$. In general, atom X is written in nuclide notation as ${}_{Z}^{A}X$, where A is the nucleon number and Z the proton number.

Isotopes and nuclides

These are atoms of the same element with the same atomic number but different mass numbers.
Therefore, isotopes of an element have the same number of protons and electrons and different number of neutrons.
Isotopes are atoms of the same element (same number of protons) that have different numbers of neutrons. Isotopes have the same atomic number (Z) but different mass numbers (A). Because the number of neutrons varies, isotopes of an element may have different physical properties, such as different masses, but they behave chemically in the same way. For example, carbon has three naturally occurring isotopes:



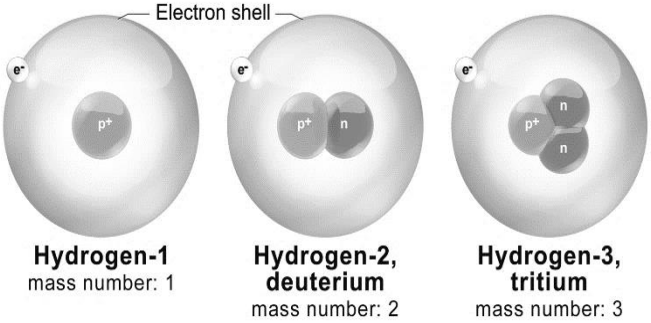
Isotopes of an element are atoms that have the same number of protons but different numbers of neutrons. That is, their proton numbers are the same but not their nucleon numbers. An element may have more than one isotope.

Isotopes have identical chemical properties since they have the same number of electrons and occupy the same place in the Periodic Table. Few elements consist of identical atoms; most are mixtures of isotopes. Chlorine has two isotopes; one has 17 protons and 18 neutrons (i.e. Z = 17, A = 35) and is written $^{35}_{17}Cl$, the other has 17 protons Worked example 37 17 and 20 neutrons (i.e. Z = 17, A = 37) and is written Cl . They are present in ordinary chlorine in the ratio of three atoms of $^{35}_{17}Cl$ to one atom of $^{35}_{17}Cl$, giving chlorine an average atomic mass of 35.5.
Hydrogen has three isotopes: $^{1}_{1}H$, with one proton, deuterium $^{2}_{1}H$ with one proton and one neutron and tritium $^{3}_{1}H$ with one proton and two neutrons. Ordinary hydrogen consists of 99.99 % $^{1}_{1}H$ atoms. Water made from deuterium is called heavy water: it has a density of 1.108 gcm^{-3}, it freezes at 3.8°C and boils at 101.4°C. Each form of an element is called a nuclide. Nuclides with the same Z number but different A numbers are isotopes. Radioactive isotopes are termed radioisotopes or radionuclides; their nuclei are unstable

Carbon-12 (C-12): 6 protons and 6 neutrons.
Carbon-13 (C-13): 6 protons and 7 neutrons.
Carbon-14 (C-14): 6 protons and 8 neutrons.
All three isotopes have 6 protons (atomic number = 6) but different mass numbers due to varying numbers of neutrons.

Representing Nuclides

Nuclides are represented using their atomic and mass numbers. The standard notation is $^{Z}_{A}X$; Where A is the mass number (protons + neutrons), Z is the atomic number (number of protons), X is the chemical symbol of the element.
Examples of Nuclide Representation:
Carbon-12: A = 12 (6 protons + 6 neutrons), Z = 6 (6 protons). Carbon-14: A = 14 (6 protons + 8 neutrons), Z = 6 (6 protons). Uranium-238: A = 238 (92 protons + 146 neutrons), Z = 92 (92 protons).



Charged atoms

A charged atom, commonly referred to as an ion, occurs when an atom gains or loses electrons, resulting in a net electric charge. Ions can be positively charged, known as cations, or negatively charged, called anions. This charge imbalance is crucial in various chemical reactions and physical processes, as charged atoms interact through Coulomb forces, attracting or repelling each other based on their charges. Charged atom" often lead to answers like "**ion," "anion," or "proton.**" These terms reflect the fundamental nature of ions in chemistry. For instance, "**ion**" is a three-letter answer with a high confidence rating, while "**anion" and "proton"** are also common responses.

Applications of Isotopes

- ✓ In medicine, radioactive isotopes are integral to nuclear medicine, providing diagnostic information and treatment options for diseases such as cancer and cardiovascular conditions. These isotopes, found in radiopharmaceuticals, allow for targeted therapies and precise imaging of organ functions.
- ✓ In agriculture, isotopes are utilized to improve crop yields and manage pest control. They help trace nutrient uptake in plants and monitor the effectiveness of fertilizers.
- ✓ Isotopes are employed in food processing to ensure safety and extend shelf life through radiation. Beyond health and agriculture, isotopes are valuable in environmental studies, where they trace pollution sources and study ecological processes.
- ✓ Carbon-14 is used in carbon dating to determine the age of archaeological finds, providing insights into historical timelines.
- ✓ Carbon-14 is used in radiocarbon dating to determine the age of ancient biological materials. Isotopes like Iodine-131 are used in medical imaging and treatment, especially in cancer therapy. Uranium-235 is used as fuel in nuclear reactors.

A nuclide

A nuclide is a specific type of atom defined by its unique combination of protons (Z), neutrons (N), and the energy state of its nucleus. Each nuclide represents a distinct nuclear configuration, which can influence its stability and behavior. For instance, isotopes are nuclides of the same element that differ in neutron count, leading to variations in mass and stability. The most stable nuclide is nickel-62, which possesses the lowest binding energy per nucleon, making it particularly resilient against decay. Nuclide symbols are used to represent these atomic species, incorporating the atomic number and mass number.

Electron Emission

Electron emission is defined as the ejection of electrons from the surface of a material. This process can be stimulated by various factors, including temperature elevation, radiation, and electric fields. The emitted electrons are used in vacuum tubes, cathode ray tubes, and advanced energy conversion systems. There are several types of electron emission, including thermionic emission, where electrons are released due to thermal energy, and photoemission, which occurs when electrons absorb photon energy. Field emission, another significant type, involves the emission of electrons induced by an external electrostatic field. Each of these processes has unique characteristics and applications, making them essential in fields like electronics and materials science.

Electron Emission and Its Types

Electron emission is the ejection of an electron from the surface of matter. We know that the electrons are attracted to the protons in the nucleus of an atom. This attraction holds the electrons in place. But if the electrons gain sufficient energy from an external source, the electrons can escape the metal surface. In this article, we will explore the definition and the types of electron emission.

Electron Emission

Electrons are negatively charged sub-atomic particles responsible for the generation of electricity and magnetism. Metals have free electrons that can move from one atom to the other within the metal. It's responsible for electrical conductivity, and unable to escape the metal surface. This is because when these negatively charged particles (electrons) try to leave the metal, the surface of the metal acquires a positive charge. Due to the attraction between the negative and the positive charges, the electrons are pulled back

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into the metal. There exist no forces to pull them forward. The electrons are thus forced to stay inside the metal due to the attractive forces.

This barrier provided by the metal surface to prevent escaping of free electrons is called the **surface barrier.** However, the surface barrier can be broken by providing a certain minimum amount of energy to the free electrons, which increases their kinetic energy and consequently help them escape the metal surface. This minimum amount of energy is known as the **work function** of the metal. When the work function is provided to the metal, the consequent liberation of electrons from the metal surface is known as **electron emission.**

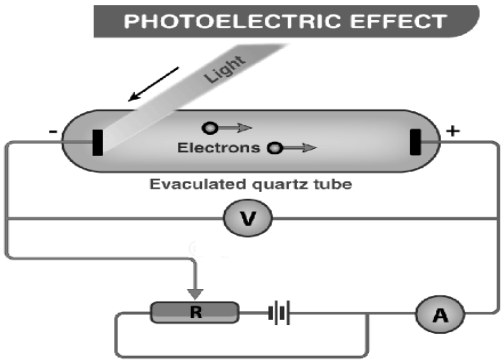
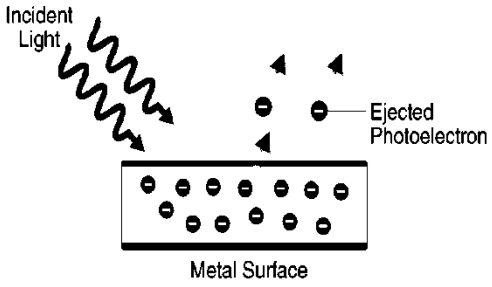


Photo-Electric Emission / Effect

The photoelectric effect is where electrons are emitted from a material when it is exposed to electromagnetic radiation, such as ultraviolet light. This effect occurs when light waves strike a metal surface, causing the ejection of electrons. The process is contingent upon the frequency of the incident light; only light with a frequency above a certain threshold can initiate electron emission. Einstein's explanation of the photoelectric effect demonstrated that light could behave both as a wave and as a particle, leading to the development of solar cells and digital cameras.

PHOTOELECTRIC EFFECT

The **photoelectric effect** is a phenomenon in which electrons are ejected from the surface of a metal when light is incident on it. These ejected electrons are called **photoelectrons**. It is important to note that the emission of photoelectrons and the kinetic energy of the ejected photoelectrons is dependent on the frequency of the light that is incident on the metal's surface. The process through which photoelectrons are ejected from the surface of the metal due to the action of light is commonly referred to as **photoemission**. The photoelectric effect occurs because the electrons at the surface of the metal tend to absorb energy from the incident light and use it to overcome the attractive forces that bind them to the metallic nuclei.



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Applications of the Photoelectric Effect

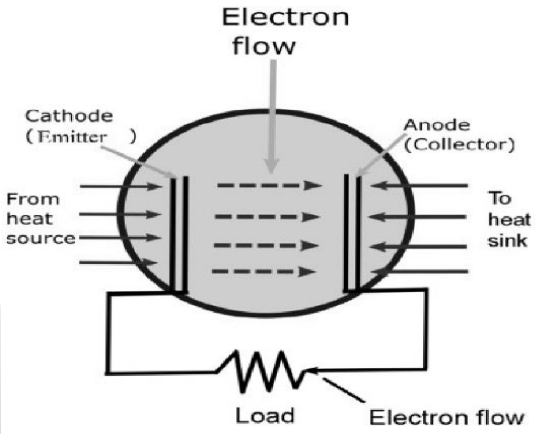
Used to generate electricity in solar panels. These panels contain metal combinations that allow electricity generation from a wide range of wavelengths. Motion and Position Sensors: In this case, a photoelectric material is placed in front of a UV or IR LED. When an object is placed in between the Light-emitting diode (LED) and sensor, light is cut off, and the electronic circuit registers a change in potential difference.

Lighting sensors, such as the ones used in Smartphones, enable automatic adjustment of screen brightness according to the lighting. This is because the amount of current generated via the photoelectric effect is dependent on the intensity of light hitting the sensor. Digital cameras can detect and record light because they have photoelectric sensors that respond to different colours of light.

X-Ray Photoelectron Spectroscopy (XPS): This technique uses X-rays to irradiate a surface and measure the kinetic energies of the emitted electrons. Important aspects of the chemistry of a surface can

be obtained, such as elemental composition, chemical composition, the empirical formula of compounds and chemical state. Photoelectric cells are used in **burglar alarms**. Used in photomultipliers to detect low levels of light. Used in video camera tubes in the early days of television.
Night vision devices are based on this effect. The photoelectric effect also contributes to the study of certain nuclear processes. It takes part in the chemical analysis of materials since emitted electrons tend to carry specific energy that is characteristic of the atomic source.

Thermionic emission

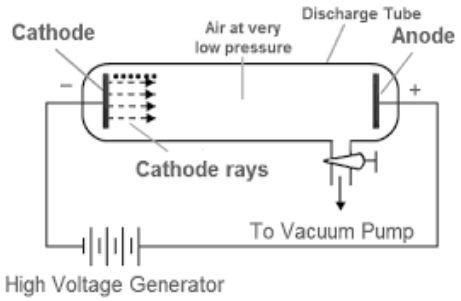


Thermionic emission is the process by which charged particles, primarily electrons, are released from a heated electrode. When a metal, typically a cathode, is heated to high temperatures around 1,000 °C (1,800 °F) or more its thermal energy provides sufficient kinetic energy for some electrons to overcome the work function of the material and escape into the surrounding vacuum. This phenomenon, historically known as the Edison effect, has significant applications in various technologies, including vacuum tubes and electron guns. In these devices, thermionic emission is harnessed to create a flow of electrons, which can be manipulated for various purposes, such as amplification and signal processing. Thermionic emission is used in structured materials, such as super lattices of elemental metals and compound semiconductors, enhancing our understanding of electron behavior and potential applications in energy conversion processes.

Applications of thermionic emission

Thermionic emission refers to the release of electrons from heated materials, a phenomenon that plays a vital role in various electronic applications. This process is fundamental to the operation of traditional electron tubes, which serve as sources of electrons in devices like vacuum tubes and cathode ray tubes. These tubes are essential in amplifying signals and generating images in older television and computer monitors. In addition to electron tubes, thermionic emission is utilized in power electronics and high frequency vacuum transistors, which are crucial for modern communication technologies. Furthermore, thermionic converters leverage this emission for electricity generation, converting heat directly into electrical energy, making them valuable in energy-efficient systems. Moreover, thermionic emission devices are lightweight and resilient, making them suitable for use in spacecraft, where they can withstand the harsh conditions of space travel.

Cathode Rays



Cathode rays, or electron beams, are streams of electrons emitted from the negative electrode (cathode) in a vacuum tube. When a high voltage is applied across two electrodes in a low-pressure gas environment, these electrons travel towards the positively charged anode, creating a visible beam. Cathode rays are also fundamental to the operation of cathode-ray tubes (CRTs), which were widely used in early television sets and computer monitors, where they produced images by directing electron beams onto a fluorescent screen.

A cathode-ray tube (CRT) is a vacuum tube in which an electron beam, deflected by applied electric or magnetic fields, produces a trace on a fluorescent screen. In a cathode ray tube, electrons are accelerated from one end of the tube to the other using an electric field.

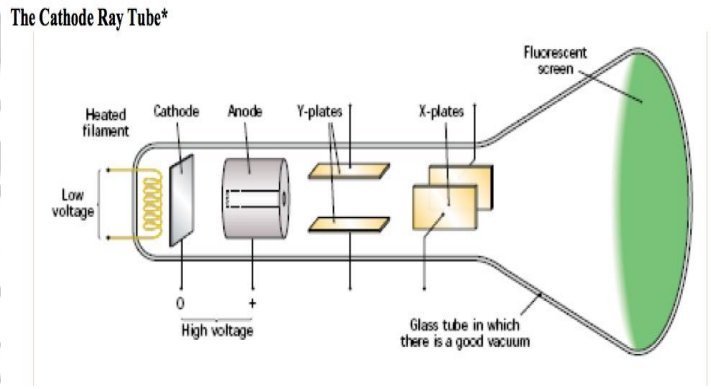
When the electrons hit the far end of the tube they give up all the energy they carry due to their speed and this is changed to other forms such as heat. A small amount of energy is transformed into X-rays. The cathode ray tube (CRT), is an evacuated glass envelope containing an electron gun a source of electrons and a fluorescent light, usually with internal or external means to accelerate and redirect the electrons. Light is produced when electrons hit a fluorescent tube. The electron beam is deflected and modulated in a manner that allows an image to appear on the projector. The picture may reflect electrical wave forms (oscilloscope), photographs (television, computer monitor), echoes of radar-detected aircraft, and so on.

Uses of Cathode Ray Tube

Used as a most popular television (TV) display. X-rays are produced when fast-moving cathode rays are stopped suddenly. The screen of a cathode ray oscilloscope, and the monitor of a computer, is coated with fluorescent substances. When the cathode rays fall off the screen pictures are visible on the screen.

Properties of Cathode Rays

Cathode rays consist of electrons, so they carry a negative charge. In a vacuum, cathode rays travel in straight lines from the cathode to the anode. Cathode rays can be deflected by electric and magnetic fields, further proving they carry charge. When cathode rays strike certain surfaces, they transfer energy and may produce light or heat. The study of cathode rays led to the discovery of the electron as a fundamental particle, a major milestone in atomic physics and the foundation for various technologies, including the cathode-ray tube (CRT) used in early televisions and oscilloscopes.



THE C.R.O (Cathode Ray Tube)

The electron gun, this consists of the following parts, the cathode – used to emit electrons, the control grid – this is connected to low voltage supply and is used to control the number of electrons passing through it towards the anode.

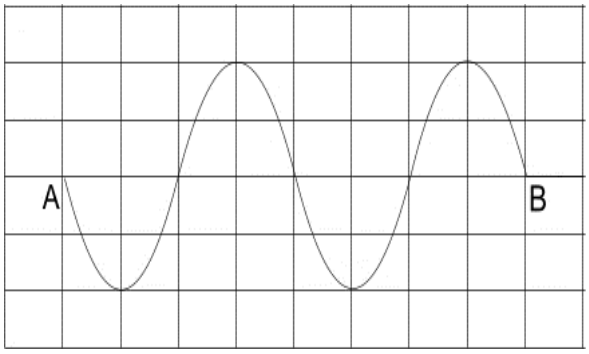
The anode – the anode is used to accelerate the electrons and also focus the electrons into a fine beam.

Since the grid control the number of electrons moving towards the anode. It consequently controls the brightness of the spot on the screen. As the grid control is made more negative, it repels most of the electrons, allowing a few to reach the screen hence screen appears dark. When it is made more positive, it attracts the electrons hence brightening the screen.

Deflecting system: This consists of the x and y plates. They are used to deflect the electron beam horizontally and vertically respectively.

Fluorescent: This is where the electrons beam is focused to form a bright spot. The zinc sulphide coating on the fluorescent screen converts kinetic energy in light and produces a bright spot when the electrons beam is focused on it.

Get unknown p.d, connect it to y-plate, and then compare the deflection by counting the number of cm deflected. This means that we can measure unknown p.d. Used to study wave forms of current and voltage. Used in manufacture of T.V.



Example

A C.R.O with time base switch on is connected across a power supply; the wave form shown below is obtained. Distance between each line is 1cm (i) identify the type of voltage generated from the power source (ii). Alternating current, (iii). find the amplitude of voltage generated if voltage gain is 5V per cm.

Amplitude = 2cm, 1cm = 5V, 2cm is equivalent to (5 x 2) = 10V

Calculate the frequency of power source is the time base setting on the C.R.O is

Time for 2 cycles = 8 x 5.0 x 10^{-3}. Time for 1 cycle = 0.02s. Frequency = 50HZ

Uses of an oscilloscope

Learning outcome

Explain how an oscilloscope can be used to display waveforms and measure p.d. and intervals of time.

Introduction

The discovery of the electron led to great technological advances in electronics. Electrons moving at high speed in a vacuum are called **cathode rays**, and twentieth century televisions and computer screens all contained a cathode ray tube. The cathode ray oscilloscope (CRO) is an important scientific instrument that works in a similar way. The oscilloscope allows rapidly changing electrical signals to be analysed by plotting a voltage–time graph on a screen. When a microphone is used to convert a sound wave into an electrical signal, the waveform can be viewed directly on the oscilloscope screen. An oscilloscope can be used as a voltmeter, to measure varying PDs, and also to measure intervals of time, enabling the frequency of a signal to be found.

Oscilloscope settings

Cathode ray oscilloscope (CRO)

The vertical axis on an oscilloscope screen provides a measurement of p.d. and the horizontal axis is a measure of time. The signal to be displayed or measured is connected to the Y-input terminal of the oscilloscope. The **Y-gain** control amplifies the input p.d. to make it large enough to appear a suitable size on the screen. The Y-gain setting in volts per division or V/div allows the size of the input p.d. to be measured.

The **time-base** controls how fast the bright spot (the input signal) moves from left to right. The distance moved by the spot is directly proportional to time and so the horizontal axis becomes a time axis. The time base setting in milliseconds per division or ms/div allows time intervals in a varying p.d. to be measured.

When preparing the oscilloscope for use, set the X-shift and Y-shift controls (which allow the spot to be moved 'manually' over the screen in the X and Y directions, respectively) to their mid-positions. The time base and Y-gain controls can then be adjusted to suit the input.

Key definitions
Y-gain controls the amplification of the input p.d.
Time-base controls the time interval displayed on the horizontal axis of the screen

With the time-base switched on, the display on an oscilloscope screen (called traces) for three different input p.d.s. When the p.d. applied to the Y-input is zero, and there is a straight line across the centre of the screen. When the Y-input is a constant D.C. signal, the trace is a horizontal line displaced upwards by an amount determined by the Y-gain setting. When the Y-input is an a.c. signal, the p.d. is alternately positive and negative.

Oscilloscope traces with time base on
When the time base is switched off, the trace is concentrated to a spot that does not move from left to right. Figure 4.6.3 shows how the display appears for different inputs. In Figure 4.6.3a, the input p.d. is zero and the spot remains at the centre of the screen. When the input p.d. is a constant d.c. signal and the spot is displaced upwards. When the Y-input is an a.c. signal, so the p.d. is alternately positive and negative and the trace appears as a continuous vertical line whose length increases when the Y-gain is increased.

Oscilloscope traces with time base off
A concentrated spot can damage the screen so the time-base should be set to produce an extended line when possible.

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Uses of an oscilloscope
Measuring p.d.s
An oscilloscope can be used as a d.c. /a.c. voltmeter by connecting the p.d. to be measured to the Y-input terminals; the displacement of the trace in the vertical direction is proportional to the p.d. For example, if the Y-amp gain control is set on 1V/div, a vertical displacement of one whole division on the screen would be given by a 1V d.c. input.
A vertical line one division long (time base off) would be produced by an a.c. input of 1V peak to trough (amplitude =0.5V).
The vertical displacement can be measured with the time base either on or off. To find the value of a d.c voltage, count the number of whole divisions the trace (horizontal line or spot) is displaced vertically and multiply that number by the V/div setting. For an a.c. input, count the number of divisions occupied by the vertical line (time base off) or vertical peak-to-trough distance (time base on).
The amplitude of the a.c. voltage can then be found by multiplying the V/div setting by half the number of vertical divisions counted.

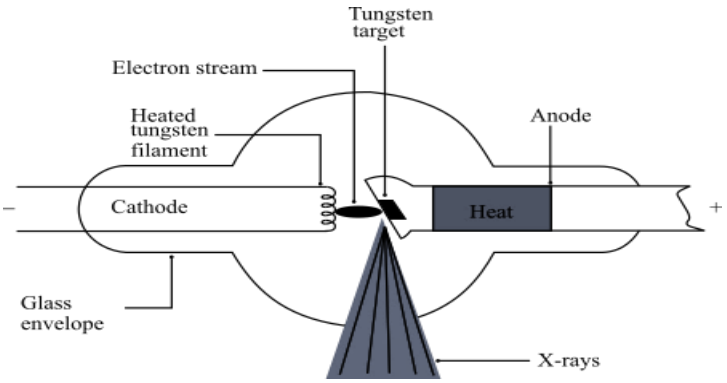
Displaying waveforms
When the time base is on, the oscilloscope acts as a 'graph-plotter' to show the waveform, i.e. the variation with time, of the p.d. applied to its Y-input. The displays in Figure 4.6.4 are of alternating p.d.s with sine waveforms. When time base frequency equals that of the input and one complete wave is obtained. For the trace, half are formed. If the traces are obtained with the Y-amp gain control on, say, 0.5V/ div, the

vertical peak-to-trough voltage of the a.c. = 3.0 divs × 0.5V/div, that is, 1.5V, and the amplitude of the signal = 0.75V.
Sound waveforms can be displayed if a microphone is connected to the Y-input terminals

Measuring time intervals and frequency
These can be measured if the oscilloscope has a calibrated time base. For example, when the time base is set on 10ms/div, the spot takes 10milliseconds to move one division horizontally across the screen.
If this is the time base setting for the waveform then, since one complete wave occupies two horizontal divisions, we can say;
time for one complete wave $= \ 2.0divs \ \times \ 10ms/div \ = \ 20ms = \frac{20}{1000} = \frac{1}{50}s$
∴number of complete waves per second = 50
∴frequency of a.c. applied to Y-input = 50Hz

Activity
1). An oscilloscope is used to measure a d.c. voltage. Calculate the value of the voltage if the trace on the oscilloscope is displaced (from zero).
a) by 3.0 divisions when the Y-gain setting is 0.5 V/div
b) by 4.2 divisions when the Y-gain setting is 2.0 V/div.
2). An oscilloscope is used to display an a.c. signal. Calculate the amplitude of the a.c. signal if the length of the vertical line obtained on the display when the time-base is turned off is 8.6 divisions and the Y-gain setting is 1.0 V/div.
3). One wavelength of an input signal occupies 4.0 horizontal divisions on the screen of an oscilloscope. If the time base setting is 1 ms/div, calculate the frequency of the signal
4). An oscilloscope is used to measure a d.c. voltage. Calculate the value of the voltage if the trace on the oscilloscope is displaced (from zero) by 2.8 divisions when the Y-gain is set at 0.1V/div.

X – RAYS
X-rays are a form of high-energy electromagnetic radiation, characterized by their ability to penetrate various materials, including human tissue. This unique property allows X-ray imaging to create detailed pictures of the inside of the body, making it an invaluable tool in medical diagnostics. Commonly used to examine bones and joints, X-rays help healthcare providers identify fractures, infections, and other conditions. The process of obtaining X-ray images is quick and painless, utilizing invisible energy beams that produce images on film or digital media. Advancements in technology have expanded the applications of X-rays, including their use in space exploration. X-rays play a crucial role in both medical and scientific fields, enhancing our understanding of the human body and the cosmos. X-Rays are radiations of electromagnetic wave that are produced when first moving electrons are stopped by dense matter.



In the X - ray tube, electrons from the hot cathode are accelerated across the vacuum by a large potential difference. On reaching the Anode, the first moving electrons hit the target of tungsten which decelerates them resulting into the production of X– rays. The target should be of a high melting point because during the hitting of the target, very high

temperatures build up, so the high melting point is to make the target able to withstand the high temperatures.

Characteristics of X-Rays

X-rays have enough energy to pass through most objects, including human tissue. This makes them valuable for medical imaging and security scans.

X-rays are ionizing, meaning they have enough energy to remove tightly bound electrons from atoms, thus ionizing them. This property is both useful in applications like cancer treatment and potentially harmful, as it can damage or destroy living tissue.

Production

X-rays are produced through the acceleration of electrons in an X-ray tube, where a potential difference is applied. This process begins with thermionic emission, where a current heats the cathode filament, releasing electrons. These electrons are then accelerated towards a target material, typically tungsten, within the tube anode. Upon collision with the tungsten nuclei, the high-energy electrons undergo rapid deceleration, resulting in the emission of X-rays. There are two primary types of radiation generated during this interaction: characteristic radiation, which occurs when electrons displace inner-shell electrons in the target, and Bremsstrahlung radiation, produced when electrons are deflected by the electric field of the nuclei. The production of X-rays is crucial in various fields, particularly in medical imaging, where they allow for the visualization of internal structures.

Applications of X-rays

X-rays are extensively used in radiography to create images of the inside of the body, helping in the diagnosis and monitoring of conditions such as fractures, infections, and tumors. Techniques like computed tomography (CT) use X-rays to create detailed cross-sectional images. Dentists use X-rays to inspect teeth and jaw structures for cavities, bone loss, and other issues. X-ray machines are used in airports and other secure areas to scan luggage and packages for dangerous items.

X-rays are employed in non-destructive testing to inspect the integrity of materials and structures, such as pipelines, aircraft, and buildings. X-ray crystallography is a technique used to determine the atomic and molecular structure of a crystal by scattering X-rays on the crystal and analyzing the diffraction pattern.

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Safety and Risks

While X-rays are invaluable in many fields, exposure to high doses or prolonged exposure to X-rays can be harmful, increasing the risk of cancer and other health issues. Therefore, safety protocols are essential to minimize exposure, such as using lead aprons in medical settings and maintaining adequate shielding in industrial applications.

Types of X – rays

X-rays are a form of electromagnetic radiation that can penetrate various materials, making them invaluable in medical imaging. There are several types of X-rays, each serving a specific purpose in diagnosing health conditions. The most common types include plain radiography, which captures static images of the body, and computed tomography (CT) scans, which provide detailed cross-sectional images. Fluoroscopy is another type that produces real-time moving images, allowing doctors to observe the function of organs and systems. Other specialized X-rays include abdominal, chest, and dental X-rays, each targeting specific areas for evaluation. For instance, abdominal X-rays help diagnose issues in the digestive system, while chest X-rays are crucial for assessing lung conditions.

X-rays are a crucial part of the electromagnetic spectrum, categorized into two main types: hard and soft X-rays. Hard X-rays possess higher energies, typically above 10 keV, and shorter wavelengths, making them ideal for penetrating dense materials. This characteristic allows hard X-rays to be extensively used in medical imaging, such as CT scans and cancer treatments, where detailed images of bones and tumors are required. In contrast, soft X-rays have lower energies and longer wavelengths, generally ranging from 0.1 to 10 keV. These properties make soft X-rays particularly effective for imaging softer tissues, such as those found in biological samples. Researchers are increasingly utilizing soft X-rays in advanced imaging techniques, allowing for the observation of living cells and tissues without causing significant damage.

Applications of x-rays

X-rays are a vital tool in both medical and non-medical fields, with diverse applications that significantly impact health and safety. In medicine, X-rays are primarily used for diagnostic purposes, helping to identify conditions such as broken bones, infections, and tumors. They play a crucial role in cancer treatment, where high-energy X-rays are employed in radiation therapy to target and destroy cancerous cells by damaging their DNA. Beyond healthcare, X-rays have important applications in security and industrial settings. They are utilized in security systems to scan luggage and cargo, ensuring safety in transportation. Additionally, X-rays are employed in research and industrial imaging, allowing for non-destructive testing of materials and components. Advancements in X-ray imaging technology, such as those developed by researchers promise to enhance the precision and effectiveness of X-ray applications, paving the way for improved diagnostics and treatment options in the future.

Health hazards of X – rays

X-rays are invaluable in medical imaging, aiding in the diagnosis of various conditions. However, exposure to ionizing radiation from X-rays poses significant health risks. High levels of radiation can lead to acute effects such as skin reddening, hair loss, and even severe tissue damage. These effects are rare but can occur with excessive exposure. Long-term exposure to X-rays is particularly concerning, as it has been linked to an increased risk of cancer. The dose-dependent nature of these risks means that the likelihood of adverse effects varies based on the amount of radiation absorbed and the specific body part being imaged. For instance, radiation to the head and neck can result in complications like dry mouth and swallowing difficulties. While X-rays are essential for diagnosing serious health issues, it is crucial to balance their benefits against potential health hazards. Patients should discuss their imaging needs with healthcare providers to minimize unnecessary exposure.

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Safety precautions of X – rays

X-rays are a valuable diagnostic tool, but they come with safety considerations due to their potential to cause DNA mutations, which can lead to cancer. Patients should be informed about the risks, especially pregnant women, as radiation can harm a developing fetus. It is crucial to communicate these risks before undergoing any X-ray procedure. To minimize exposure, healthcare professionals must adhere to strict safety protocols. This includes using protective equipment such as lead aprons and collars for patients, and ensuring that no personnel routinely hold or support animals or film during X-ray procedures. Proper structural shielding, including lead-lined walls and floors, is essential to protect both patients and staff from unnecessary radiation exposure. Patients should also be advised to remove any metal objects, such as jewelry and eyeglasses, before the procedure.

4.6 NUCLEAR PROCESSES

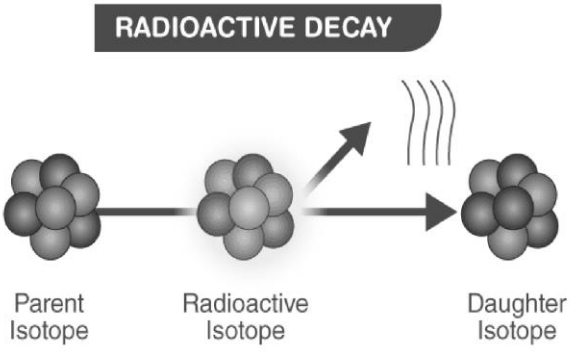
Learning Outcomes

a) Understand the processes of nuclear fission and fusion and the associated energy changes(u)
b) Understand the spontaneous and random nature of nuclear decay and interpret decay data in terms of half-life (k, u,s)
c) Know the applications of radioactivity and the dangers associated with exposure to radioactive materials. (k,u)
d) Understand and appreciate that there are significant social, political, and environmental dimensions associated with use of nuclear power. (u,v/a)

Introduction

Nuclear processes encompass a variety of reactions that involve the interaction of atomic nuclei. A nuclear reaction occurs when two nuclei collide or when a nucleus interacts with a subatomic particle, resulting in the formation of new nuclides. The two primary types of nuclear reactions are fission and fusion. In fission, a heavy nucleus, such as uranium, splits into smaller nuclei upon neutron collision, releasing significant energy in the form of heat and radiation. Fusion involves the merging of two light nuclei to form a heavier nucleus, a process that powers stars, including our Sun. Both fission and fusion yield millions of times more energy than conventional energy sources, making them crucial for energy production. Understanding these nuclear processes is essential for advancements in energy technology and medical applications, as they hold the potential for sustainable energy solutions and innovative treatments.

RADIOCTIVITY



Radioactivity is the phenomenon where unstable atomic nuclei lose energy by emitting radiation, a process known as radioactive decay. This decay can result in the release of various types of radiation, including alpha and beta particles. Materials that contain these unstable nuclei are classified as radioactive, and their emissions can have significant implications for health and safety. The applications of radioactivity are vast, spanning medical, industrial, and research fields. Radioisotopes are crucial in medical diagnostics and therapies, allowing for targeted treatments and imaging techniques.

Radioactivity

Due to nuclear instability, an atom's nucleus exhibits the phenomenon of Radioactivity. Energy is lost due to radiation that is emitted out of the unstable nucleus of an atom. Two forces, namely the force of repulsion that is electrostatic and the powerful forces of attraction of the nucleus, keep the nucleus together. These two forces are considered extremely strong in the natural environment. The chance of encountering instability increases as the size of the nucleus increases because the mass of the nucleus becomes a lot when concentrated. That is the reason why atoms of Plutonium, Uranium are extremely unstable and undergo the phenomenon of radioactivity.

The three types of nuclear emission

Certain isotopes can decay into a more stable state with emission of radiation in the form of discrete particles (α- and β-particles) or high-frequency electromagnetic waves (γ-radiation). The emission of the

radiation is random in direction. An α-particle is a doubly positively charged helium ion and a β-particle is a negatively charged electron. Owing to their electric charge both α-particles and β-particles are deflected by electric and magnetic field; γ-radiation is deflected by neither.

Alpha, beta and gamma radiation
Experiments to study the penetrating power, ionizing ability and behaviour of radiation in magnetic and electric fields show that a radioactive substance emits one or more of three types of radiation – called alpha (α-), beta (β-) and gamma (γ-) radiation. The emission of radiation from a nucleus is a spontaneous and random process in direction; we will consider this again later lead sheet with 1mm hole to prevent overloading of GM tube.

Alpha Decay (α)
In alpha decay, the nucleus emits an alpha particle, which consists of two protons and two neutrons (like a helium nucleus). This emission reduces the mass of the nucleus and transforms the atom into a different element with a lower atomic number. Example: Uranium-238 decays to Thorium-234 through alpha emission. An alpha particle is a helium atom, which has lost 2 electrons. An alpha particle has mass 4 and atomic number 2, which is positively charged. Alpha particles (α) are a type of ionizing radiation that consists of two protons and two neutrons bound together. They are identical to the nucleus of a helium-4 atom and carry a +2 charge.

An alpha particle is made up of two protons and two neutrons, giving it a relatively large mass. Since it has two protons, it carries a positive charge of +2. Alpha particles are relatively heavy compared to other types of radiation, such as beta particles or gamma rays. Their mass is about 4 atomic mass units. They typically have kinetic energies in the range of 4-9 MeV (mega-electron volts), which is quite high in energy compared to other forms of radiation.
Alpha particles have **low penetrating power**. They can be stopped by a few centimeters of air, a sheet of paper, or even the outer dead layer of human skin. This limited range means alpha radiation is generally not harmful when outside the body but can be very dangerous if alpha-emitting materials are inhaled, ingested, or enter the bloodstream.
Alpha particles have **high ionizing power** because of their large mass and charge. As they travel through matter, they create many ion pairs by knocking electrons off atoms, causing strong ionization in a short distance. This ionization capability makes alpha particles effective at damaging biological tissues if they come into direct contact with living cells.
Due to their mass, **alpha particles travel relatively slowly** compared to beta particles and gamma rays. Their speed is usually around 5-10% the speed of light. Emission of an alpha particle from a radioactive nucleus reduces the atomic number of the element by 2 and the atomic mass by 4. This process transforms the original atom into a different element, typically shifting it down two places in the periodic table (Uranium-238 decaying to Thorium-234).
Due to their high ionizing power, alpha particles can be detected with devices sensitive to ionization, such as Geiger-Müller tubes and scintillation counters.

Properties of alpha particles:
- ✓ Alpha particles are helium nuclei hence are positively charged,
- ✓ Deflected by both magnetic and electric fields because of their large mass,
- ✓ Have the greatest ionizing power,
- ✓ Have the least penetrating power,

- ✓ Stopped by a thick sheet of paper,
- ✓ Have a very short range in air,
- ✓ Affect the photographic films,
- ✓ Have speed less than the speed of light, and
- ✓ They cause fluorescence when incident on fluorescent substance.

When an unstable nucleus emits an alpha particle, the mass reduces by 4 and atomic number by 2, a radioactive substance ${}^{238}_{92}X$ undergoes decay and emits an alpha particle to form Y.
Write an equation for the process ${}^{238}_{92}X \rightarrow {}^{x}_{y}Y + {}^{4}_{2}He$
238 =x + 4 x =234 92 = y + 2 y = 90
${}^{238}_{92}X \rightarrow {}^{234}_{90}Y + {}^{4}_{2}He$

What are some uses of alpha particles?
Alpha particles have low penetrating power but this still provides a range of useful applications:

- ✓ Smoke detectors – americium-241 is commonly used in ionising smoke detectors. Smoke that enters the detector reduces the amount of alpha particles that are detected and triggers the alarm
- ✓ Static eliminators typically use alpha particles from polonium-210 to remove static charges from equipment
- ✓ Radioisotope thermoelectric generators use alpha particle decay from plutonium-238 to generate heat which is converted to electricity, commonly used in space probes
- ✓ Some alpha emitters are being investigated for their potential use in unsealed source radiotherapy to treat cancer.
- ✓ Alpha radiation is utilized in thickness gauges to ensure quality control in manufacturing processes.

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Beta Decay (β)
In beta decay, a neutron in the nucleus transforms into a proton, releasing a beta particle (which is an electron or positron) and an antineutrino or neutrino. This process increases the atomic number by one without changing the atomic mass, turning the atom into a different element. Example: Carbon-14 decays into Nitrogen-14 through beta emission.
Beta particles are fast moving electrons. When radioactive nuclei decay by emitting a beta particle, mass number is not affected but the atomic number increases by one.

A beta-minus particle is an electron, carrying a negative charge (-1). A beta-plus particle, or positron, is the antimatter counterpart of an electron, carrying a positive charge (+1). Beta particles are much lighter than alpha particles, with a mass approximately 1/1836th of a proton's mass. This small mass allows them to travel faster than alpha particles. The energy of beta particles can vary widely, generally in the range of a few keV (kilo-electron volts) to several MeV (mega-electron volts), depending on the specific decay process. Beta particles have moderate penetrating power. They can penetrate several millimeters into human tissue or a few centimeters of air.

Unlike alpha particles, materials like plastic, glass, or a thin sheet of metal, such as aluminum foil, can stop beta particles. Beta radiation can cause burns or radiation damage to skin if in close contact, and it

can penetrate superficial tissue layers. Beta particles have moderate ionizing power, less than alpha particles but greater than gamma rays. They can ionize atoms and molecules as they pass through matter, but since they are lighter, they tend to spread their energy over a greater distance. Due to their low mass, beta particles travel at relatively high speeds, often close to the speed of light, depending on their energy level.

Properties of beta particles:

A beta-minus particle is an electron, carrying a negative charge (-1).

- ✓ They are negatively charged,
- ✓ Lighter since they have negligible mass,
- ✓ Easily deflected by both magnetic and electric fields,
- ✓ Have greater penetrating power than alpha particles because of their high speed,
- ✓ Less ionizing power than alpha particle,
- ✓ Stopped by a thin sheet of aluminum,
- ✓ Have a greater range in air than alpha particles,
- ✓ Cause fluorescence when incident on fluorescent substance

Beta particles can be detected using Geiger-Müller counters, scintillation detectors, and other radiation-detecting devices that measure ionization. Beta particles are light, high-speed particles with moderate ionizing power and penetrating ability. They can travel through air and penetrate shallow materials but are stopped by denser materials like metal or plastic. Beta radiation is useful in medical applications and scientific research but requires shielding to prevent tissue damage.

E.g. unstable nuclei ${}^{226}_{86}X$ decays to form a stable nuclei Y by emitting a beta particle

${}^{226}_{88}X \rightarrow {}^{n}_{m}Y + {}^{0}_{-1}e;$

$226 = n + 0 \qquad n = 226, 88 = m - 1 = 89$

${}^{226}_{88}X \rightarrow {}^{226}_{89}Y + {}^{0}_{-1}e;$

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What are some uses of beta particles?

The medium penetrating power of beta particles provides a range of useful applications, which include:

- ✓ Thickness detectors for the quality control of thin materials i.e. Paper
- ✓ Treatment of eye and bone cancers, strontium-90 or strontium-89 are commonly used
- ✓ Tritium is used in some phosphorescent lighting typically for emergency lighting as it requires no power
- ✓ Fluorine-18 is commonly used as a tracer for positron emission tomography (pet).

Gamma Decay (γ)

In gamma decay, the nucleus emits a gamma ray, a high-energy form of electromagnetic radiation. Gamma emission usually occurs after alpha or beta decay when the nucleus remains in an excited energy state and needs to release excess energy to stabilize. Example: Cobalt-60, after beta decay, emits gamma rays as it stabilizes.

GAMMA RAYS

These are electromagnetic radiation with the shortest wavelength. When unstable nuclei decay by emitting gamma rays, the mass and atomic number are not affected. Gamma radiation (γ) is a form of high-energy electromagnetic radiation emitted by the nuclei of radioactive atoms. Unlike alpha and beta particles, gamma rays have no mass and no charge, which gives them unique properties. Gamma rays are photons

packets of electromagnetic energy similar to visible light but with much higher energy. They carry no electrical charge, meaning they are neutral. Mass: Gamma rays are massless, which allows them to travel at the speed of light. Gamma radiation can be detected with instruments sensitive to high-energy photons, such as Geiger-Müller counters, scintillation detectors, and gamma spectrometers.

Properties of gamma rays:
Gamma ray is an electromagnetic radiation with a very short wave length, have no mass number and carry no charge. They are produced when an excited atomic nucleus loses energy and the energy is given out as gamma rays

- ✓ They are not charged,
- ✓ Travel at a speed of light since they are electromagnetic radiations,
- ✓ Not deflected by both magnetic and electric fields since they are not charged,
- ✓ Have the least ionizing power,
- ✓ Have the greatest penetrating power,
- ✓ Undergo interference and diffraction,
- ✓ Cause fluorescence when incident on fluorescence substances,
- ✓ Have the greatest range in air, and
- ✓ Stopped by thick block of lead

What are some uses of gamma ray emitters?
Gamma emitting radionuclides are the most widely used radiation sources. The penetrating power of gamma rays has many applications. However, while gamma rays penetrate many materials, this does not make them radioactive. The four radionuclides that are by far the most useful are cobalt-60, caesium-137, technetium-99m and americium-241.
Uses of cobalt-60:

- ✓ sterilization of medical equipment in hospitals
- ✓ pasteurization, via irradiation, of certain foodstuffs
- ✓ levelling or thickness gauges (i.e. food packaging, steel mills)
- ✓ Industrial radiography.

Uses of caesium-137:

- ✓ measurement and control of the flow of liquids in industrial processes
- ✓ investigation of subterranean strata (oil, coal, gas and other mineralisation)
- ✓ measurement of soil moisture-density at construction sites
- ✓ Levelling gauges for packaging of food, drugs and other products.

Uses of technetium-99m:

- ✓ Tc-99m is the most widely used radioactive isotope for medical diagnostic studies
- ✓ Different chemical forms are used for brain, bone, liver, spleen and kidney imaging. It is also used for blood flow studies.

Uses of americium-241:

- ✓ smoke detectors for households
- ✓ fluid levelling and density gauges
- ✓ thickness gauges for thin materials (paper, foil, glass)
- ✓ aircraft fuel gauges

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- ✓ When mixed with beryllium, americium-241 produces a 241AmBe neutron source with uses in well logging, neutron radiography and tomography.

Radioactive decay

Radioactive decay is the emission of an α-particle or a β-particle from an unstable nucleus. During α- or β-decay, the nucleus changes to that of a different element, this may itself be unstable. After a series of changes a stable element is formed. These changes are spontaneous and random and cannot be controlled; also it does not matter whether the material is pure or combined chemically with something else.

α-decay

An α-particle is a helium nucleus, having two protons and two neutrons, and when an atom decays by emission of an a-particle, its nucleon number decreases by 4 and its proton number by 2. For example, when radium of nucleon number 226 and proton number 88 emits an α-particle, it decays to radon of nucleon number 222 and proton number 86.

We can write the following radioactive decay equation using nuclide notation: ${}^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$. The values of A and Z must balance on both sides of the equation since nucleons and charges are conserved.

β-decay

In β–-decay a neutron changes to a proton and an electron. neutron → proton + electron

The proton remains in the nucleus and the electron is emitted as a β–-particle. The new nucleus has the same nucleon number, but its proton number increases by one since it has one more proton.

Radioactive carbon, called carbon-14, decays by β–-emission to nitrogen: ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

Note that a β–-decay is often just referred to as a β-decay.

In β-decay a neutron turns into a proton and an electron so that the number of neutrons in the nucleus decreases; this increases the stability of a nucleus that has an excess of neutrons. The factors affecting the stability of nuclei are considered in more detail opposite.

γ-emission

After emitting an α-particle, or β-particle, some nuclei are left in an 'excited' state. Rearrangement of the protons and neutrons occurs and a burst of γ-emissions is released.

Other particles

Positrons are subatomic particles with the same mass as an electron but with opposite (positive) charge. They are emitted in some decay processes as β+- particles. Their tracks can be seen in bubble chamber photographs. The symbol for a positron is b+. In β+- decay a proton in a nucleus is converted to a neutron, and a positron as, for example, in the reaction: ${}^{64}_{29}Cu \rightarrow {}^{64}_{28}Ni + {}^{0}_{+1}e$

A neutrino (ν) is also emitted in β+-decay. Neutrinos are emitted from the Sun in large numbers, but they rarely interact with matter so are very difficult to detect. A particle called an antineutrino ( ) υ , with no charge and negligible mass, is emitted in β–-decay. Antineutrinos and positrons are the 'antiparticles' of neutrinos and electrons, respectively. If a particle and its antiparticle collide, they annihilate each other and energy is transferred to γ-radiation.

Example

Polonium ${}^{218}_{84}Po$ decays by emission of an α-particle to an isotope of lead (symbol Pb). Write down the decay equation.

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An α-particle consists of two protons and two neutrons so when polonium decays by a-emission, Z decreases by 2 and A decreases by 4: $\mathbf{^{218}_{84}Po \rightarrow {}^{214}_{82}Pb + {}^{4}_{2}He}$

Strontium $^{90}_{38}Sr$ decays by emission of a β-particle to an isotope of yttrium (symbol Y). Write down the decay equation.

A β-particle is an electron so when strontium decays by β-emission, A remains constant but a proton changes to a neutron so Z increases by 1: $\mathbf{^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + {}^{0}_{-1}e}$

ACTIVITY

1). Americium $^{241}_{95}Am$ decays by emission of an α-particle to an isotope of neptunium (Np). Write down the decay equation.

2). Yttrium $^{91}_{39}Y$ decays by emission of an α-particle to an isotope of zirconium (Zr). Write down the decay equation.

Half-life

Learning outcomes

a) Know what is meant by the half-life of a particular isotope, and use this in calculations.
b) Calculate the half-life when background radiation has not been subtracted.
c) Understand why certain isotopes are used for particular applications, based on the type of radiation emitted and the half-life of the isotope.

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Expected outcomes

When an α- or β-particle is emitted from a nucleus, a different element is formed. The emission is random for any individual atom, but occurs at a constant rate known as the half-life, whose value depends on the isotope. Half-lives can be calculated from decay data.

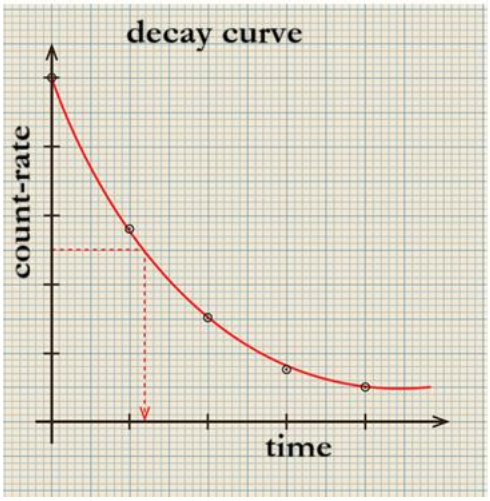
Accurate calculation of the half-life of a radioactive isotope requires the background radiation to be taken into account. Radioisotopes find many applications. They are used as tracers in medicine to detect tumors, in industry to measure fluid flow, and in agriculture to detect the uptake of nutrients. Other applications range from radiotherapy to smoke alarms to dating objects in archaeology.

Radioactive atoms have unstable nuclei which change or decay into atoms of a different element when they emit a- or b-particles. The rate of decay is unaffected by temperature but every radioactive element has its own definite decay rate, expressed by its half-life.

Radioactivity

The half-life of a particular isotope is the time taken for half the nuclei of that isotope in a given sample to decay. It is difficult to know when a substance has lost its entire radioactivity, but the time for its activity to fall to half its value can be found more easily.

Half-life the time taken for half the nuclei of a particular isotope in any sample to decay



Decay curve

The average number of disintegrations (decaying atoms) per second of a sample is its activity. If it is measured at different times (by finding the count-rate using a GM tube and rate-meter), a decay curve of activity against time can be plotted. The ideal curve for one element shows that the activity decreases by the same fraction in successive equal time intervals.

Half-life from the graph:

- ✓ The graph of amount of an element N against time is plotted
- ✓ Draw a horizontal line from half of the original amount to meet the curve
- ✓ Draw a vertical line from the point on the curve to meet the time axis
- ✓ Read the half-life from where the vertical line meets the time axis

Half-Life of a Radioactive Material

The half-life of a radioactive material is the time required for half of the radioactive atoms in a sample to decay. During this time, the amount of the original radioactive substance decreases, while the amount of decay products increases. Each type of radioactive material has a characteristic half-life, which can range from fractions of a second to millions of years.

Understanding the decay curve

Radioactive decay follows an exponential decay model, meaning that the amount of substance does not decrease by a fixed amount each time but rather by a fixed percentage. After each half-life, 50% of the remaining radioactive atoms decay, reducing the sample amount progressively but never completely to zero. If a sample has a half-life of 10 years, then after 10 years, half of the original material will remain. After 20 years (two half-lives), only a quarter (25%) of the original material will remain, and so on. A longer half-life generally indicates greater stability, as the material decays more slowly. Equally, a short half-life suggests the material is less stable and decays quickly.

Suppose we have 100 grams of a radioactive substance with a half-life of 5 years: After 5 years: 50 grams remain, after 10 years: 25 grams remain, and after 15 years: 12.5 grams remain. This pattern continues, with each interval of 5 years reducing the remaining amount by half. When a graph of account rate against time or radioactive nuclei is drawn, the half-life of the radioactive nuclei can be determined;

It falls from 80 to 40 disintegrations per second in 10 minutes, from 40 to 20 in the next 10 minutes, from 20 to 10 in the third 10 minutes and so on. The half-life is 10 minutes. Half-lives vary for different isotopes from millionths of a second to millions of years. For radium it is 1600 years. The information in Figure may also be represented in table form.

Time/min	0	10	20	30
Counts/s	80	40	20	10

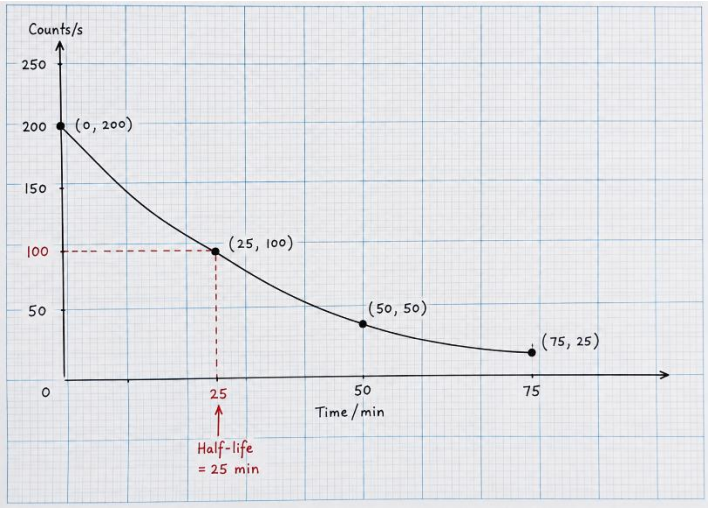
Example

In an experiment to find the half-life of radioactive iodine, the following results were obtained.

Time/min	0	25	50	75

Counts/s	200	100	50	25

i What is the half-life of the iodine?
The count-rate drops by half every 25 minutes.
The half-life of iodine is 25 minutes.
ii What fraction of the original material is left after 75 minutes?



Responses
75 minutes corresponds to 3 half-lives.
After 25 minutes, fraction left = 1/2
After 50 minutes, fraction left = 1/2 × 1/2 = 1/4
After 75 minutes, fraction left = 1/2 × 1/4 = 1/8
Therefore, $\boldsymbol{Fraction = \frac{1}{2^n}}$**, where n is the number of half-lives**

$\frac{M}{M_0} = \left(\frac{1}{2}\right)^n$, Where, $M_0 = original\ mass$, and M is the remaining mass, and **n is the number of half-lives.**

b) Carbon-14 has a half-life of 5700 years. A 10 g sample of woodcut recently from a living tree has an activity of 160 counts/minute. A piece of charcoal taken from a prehistoric campsite also weighs 10 g but has an activity of 40 counts/minute. Estimate the age of the charcoal.

Responses
After 1 × 5700 years the activity will be 160/2 = 80 counts per minute.
After 2 × 5700 years the activity will be 80/2 = 40 counts per minute.
The age of the charcoal is 2 × 5700 = 11 400 years.

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Alternatively, $\frac{original\ mass}{remaining\ mass} = \frac{total\ time}{halflife\ time} = 2^n; n = \frac{total\ time}{halflife\ time} = number\ of\ halflives$

$\frac{M_0}{M} = 2^{(\frac{total\ time}{halflife\ time})}$; Where, $M_0 = original\ mass$, and M is the remaining mass.

1) In an experiment to find the half-life of a radioisotope the following results were obtained.

Time/min	0	10	20	30	40	50
Counts /s	200	133	88	59	39	26

a) Estimate the half-life of the radioisotope from the graph data.

Estimation:
Initial count rate = 200 counts/s
Half of 200 = 100 counts/s

From the data, 100 counts/s lies between:

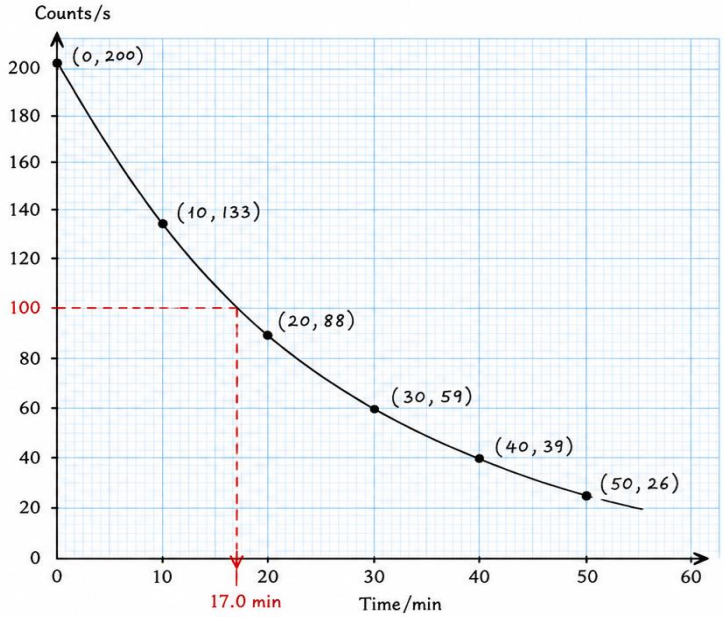
- 133 counts/s at 10 min
- 88 counts/s at 20 min

Use linear interpolation:
Drop from 133 to 100 = 33 counts
Total drop from 133 to 88 = 45 counts
Fraction of interval = 33/45 = 0.733

Time for drop to 100 counts/s
= 10 + 0.733 × 10
= 17.33 min

Estimated half-life ≈ 17 minutes

b) Determine the half-life of the radioisotope by plotting a graph.



From the graph, the time corresponding to 100 counts/s is about 17 minutes.

Half-life from graph ≈ 17 minutes

2).In an experiment to determine the half-life of a radioactive material, its count-rate falls from 140 counts/minute to 35 counts/minute in an hour. Calculate the half-life of the material.

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Responses
Initial count rate = 140 counts/min
Final count rate = 35 counts/min
Time elapsed = 1 hour = 60 minutes
A half-life means that half reduce the count rate.
140 counts/min → 70 counts/min → 35 counts/min
Therefore, the count rate has been halved twice. Hence, 2 half-lives have elapsed in 60 minutes.
$2T_{1/2} = 60min,$
$T_{1/2} = \frac{60min}{2} = 30min$
$T_{1/2} = 30min,$
The half-life of the radioactive material is 30 minutes.

Carbon-14 has a half-life of 5700 years. A 5 g sample of woodcut recently from a living tree has an activity of 80 counts/minute. A 5 g piece of wood taken from an ancient dugout canoe has an activity of 20 counts/minute. Estimate the age of the canoe.

Responses
Half-life of Carbon-14 = 5700 years
Activity of living wood = 80 counts/min
Activity of ancient wood = 20 counts/min
The activity decreases by half after each half-life:
80 counts/min → 40 counts/min → 20 counts/min
Therefore, the activity has decreased by half twice, meaning that 2 half-lives have elapsed.
Age of canoe = 2 × 5700 years
Age of canoe = 11,400 years
The estimated age of the canoe is approximately 11,400 years.

Activity 1
In a certain town, people are concerned about the waste disposal from the factory into the nearby lake, which is their source of water for home use. They raised this issue to the chairperson Local Council 1 (LC1) who directed the management of the factory to stop disposing waste into the lake. A scientist was contacted to investigate the presence of radioactive material in the water. The scientist found out that the water was indeed radioactive as shown in Table 1 and Table 2.

Time/days	0	5	10	15	20	25	30
Activity/counts per minute	1200	740	440	260	160	90	60

Although the water from the lake remains radioactive for a long time, the scientist recommended that water will be safe for use again when the activity is less than 38 counts per minutes.
Task: As a student of physics;
(a) Advise the chairperson LC1 about the time the community will wait for the water to be safe for use again. Sensitize the members of the community about the risks associated with radioactive materials and how such materials should be handled.
(b) Sensitive the members of the community about the risks associated with radioactive materials and how such materials should be handled.

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Activity 2
The following values were obtained from the readings of a rate meter from a radioactive isotope of iodine as shown in the table 2 for radioactive iodine.

Time (Hour)	0	2500	5000	7500	1000	12500	17250	20000
Disintegrations/min	15	11	8	5	4.0	3.2	1.6	1.2

Estimate the half-life of iodine and suggest the possible precautions to undertake.

Applications of Half-Life / Uses of Radioactivity

Radioactivity has many important applications in medicine, industry, agriculture, archaeology, and scientific research. The half-life of a radioactive isotope is particularly important because it determines how long the isotope remains useful and how long it remains hazardous.

1. Medical applications

- ✓ Cancer treatment (radiotherapy): Radioactive sources such as cobalt-60 are used to destroy cancer cells.
- ✓ Medical diagnosis: Radioisotopes such as technetium-99m are used to examine organs and detect abnormalities.
- ✓ Sterilisation: Gamma radiation is used to sterilise medical equipment.
- ✓ Tracing body processes: Radioactive tracers can be used to study the functioning of organs.

2. Carbon dating

Carbon-14 is used to determine the approximate age of ancient organic materials such as: Wood, Bones, Charcoal, and Ancient cloth

This works because carbon-14 has a known half-life of about 5,700 years.

3. Archaeology and geology

Radioactive dating is used to estimate the age of: Fossils, Rocks, Archaeological remains, and Ancient artefacts

Different isotopes are selected depending on the age of the material.

4. Smoke detectors

A small amount of americium-241 is used in some smoke detectors. Its radiation ionises air inside the detector, allowing the device to detect smoke.

5. Industrial thickness control

Radioactive sources are used to measure and control the thickness of materials during manufacture, such as Paper, Plastic sheets, Aluminium foil, and Steel plates

The amount of radiation reaching a detector changes when the thickness changes.

6. Detecting leaks in pipes

Radioactive tracers can be introduced into pipelines. Radiation detectors can then help locate leaks or determine the movement of fluids through the system.

7. Food preservation

Gamma radiation can be used to:

- ✓ Kill harmful microorganisms
- ✓ Control insects
- ✓ Delay sprouting of crops such as potatoes
- ✓ Extend the shelf life of some foods

8. Electricity generation

Radioactive materials, especially uranium, are used as fuel in nuclear reactors. Energy released during nuclear fission is converted into electrical energy.

9. Scientific research

Radioisotopes are used as tracers to follow chemical and biological processes, for example:

- ✓ Movement of substances through plants
- ✓ Chemical reactions
- ✓ Metabolism in living organisms

10. Agricultural applications

Radiation is used in agriculture to:

- ✓ Develop improved crop varieties through mutation breeding
- ✓ Control insect pests

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- ✓ Study the absorption of fertilisers by plants
- ✓ Investigate plant nutrient requirements

Importance of half-life
The half-life determines the rate at which a radioactive substance decays. It is useful for selecting isotopes for particular purposes:

Application	Suitable radioactive property
Medical diagnosis	Short half-life
Cancer treatment	Appropriate penetrating radiation and controlled half-life
Carbon dating	Long half-life
Smoke detectors	Long-lasting source
Industrial tracers	Half-life long enough for the measurement
Nuclear fuel	Controlled radioactive decay/fission properties

A short half-life means rapid decay, while a long half-life means slow decay. Therefore, the half-life of a radioactive isotope determines how suitable it is for a particular application.

Dangers of radioactivity/ Dangers of nuclear radiation
Nuclear radiation can be harmful because ionising radiation has enough energy to damage living cells and DNA. The severity of the effect depends mainly on the type of radiation, dose received, exposure time, and distance from the source.
1. Damage to body cells: Radiation can ionise atoms and molecules in body tissues, causing damage or death of cells.

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2. Cancer: Long-term or high exposure to ionising radiation can damage DNA and increase the risk of cancers such as Leukemia, Thyroid cancer, Lung cancer, and Bone cancer

3. Radiation burns: A high dose of radiation can cause serious burns and damage to the skin and underlying tissues.

4. Radiation sickness: Exposure to a very high dose over a short period can cause acute radiation sickness, with symptoms such as Nausea and vomiting, Weakness and fatigue, Hair loss, Damage to blood-forming tissues, Internal bleeding
In severe cases, death

5. Genetic mutations: Radiation can damage DNA. If reproductive cells are affected, mutations may potentially be passed to future generations.

6. Damage to reproductive organs: High radiation doses can damage the ovaries or testes and may cause Infertility, Reduced fertility, and Damage to reproductive cells

7. Effects on an unborn baby: Exposure during pregnancy can damage a developing foetus, potentially causing developmental abnormalities, Growth problems, Brain development problems, and Increased risk of childhood cancer

8. Damage to internal organs: If radioactive materials enter the body through breathing, eating, drinking, or wounds, they can irradiate tissues from inside the body.
For example, radioactive iodine can concentrate in the thyroid gland.

9. Environmental contamination: Radioactive substances released into the environment can contaminate as Soil, Water, Plants, Animals, and Food
Some radioactive materials remain hazardous for many years because of their long half-lives.

10. Death: Extremely high doses of ionising radiation can cause severe organ and tissue damage and may result in death.

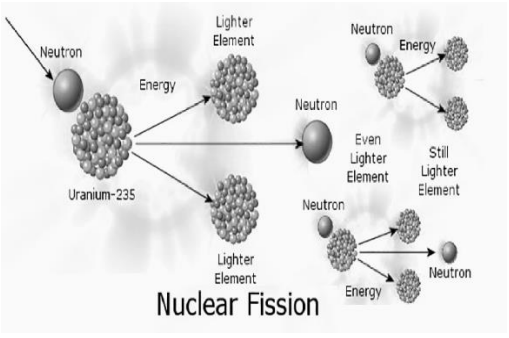
The three basic principles of radiation protection are:
1. Reduce exposure **TIME** — spend as little time as possible near the source.
2. Increase **DISTANCE** — stay as far away from the radioactive source as possible.
3. Use **SHIELDING** — place suitable shielding between the person and the source, such as lead, concrete, or other appropriate materials.

Danger	**Possible effect**
Cell damage	Cell death or malfunction
DNA damage	Mutations
Prolonged exposure	Increased cancer risk
Very high dose	Radiation sickness
Radiation to skin	Burns
Reproductive-cell damage	Infertility/genetic effects
Foetal exposure	Developmental abnormalities
Internal contamination	Irradiation of internal organs
Environmental contamination	Long-term ecological effects
Extremely high exposure	Death

Nuclear radiation is dangerous mainly because it is ionising and can damage cells and DNA. The risk can be greatly reduced through proper radiation protection and controlled exposure.

Nuclear Fission and Fusion

Nuclear fission:

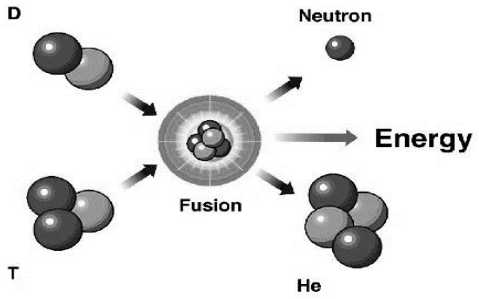


This is the splitting of nucleus of heavy atoms into two lighter nuclei. This process can be started by bombardment of a heavy nucleus with a neutron. The products of the process are two light atoms and more neutrons, which can make a process, continue. Nuclear fission is a powerful reaction in which the nucleus of an atom, typically uranium-235, splits into two or more smaller nuclei, releasing a significant amount of energy. This process occurs when a neutron collides with a heavy nucleus, causing it to become unstable and break apart. The fission reaction not only produces smaller atoms, known as fission products, but also emits gamma photons and additional neutrons, which can trigger further fission events in a chain reaction. Nuclear fission is the process that powers nuclear reactors, providing a reliable source of energy for

electricity generation. Most nuclear power plants utilize uranium as fuel, capitalizing on the energy released during fission to produce steam that drives turbines. As the demand for energy continues to grow, advancements in nuclear technology, including Generation IV reactors, aim to enhance safety and efficiency in harnessing this energy source.

Nuclear Fusion:

Nuclear fusion is a process where two light atomic nuclei combine to form a heavier nucleus, releasing vast amounts of energy in the process. This reaction is the fundamental energy source of stars, including our Sun, where hydrogen atoms fuse to create helium. The mass difference between the reactants and the product results in energy release, as described by Einstein's equation, $E=mc^2$.



Nuclear energy

Nuclear energy is a vital clean energy source, providing around 9% of the world's electricity and supporting climate goals and national security. It is generated through nuclear fission, where the nucleus of an atom is split to release energy. This process not only produces electricity but also contributes significantly to low-carbon energy production, accounting for about one-quarter of the world's low-carbon electricity. As global demand for energy rises, nuclear power is experiencing resurgence, with projections indicating record production levels by 2025. Increased investment and advancements in technology are driving this growth, positioning nuclear energy as a key player in the clean energy transition. Uganda is on a promising path towards harnessing nuclear energy, with plans to begin power generation by 2031. The journey began with the enactment of the Atomic Energy Act in 2008, which established a regulatory framework for nuclear energy use. The government aims to generate at least 1,000 megawatts (MW) from nuclear sources, diversifying its energy portfolio to meet growing demands. In 2024, Uganda hosted an International Atomic Energy Agency (IAEA) review to assess its uranium production capabilities, a crucial step in its nuclear ambitions. The first nuclear project is planned for Buyende, located about 150 km from Kampala, marking a significant milestone in the country's energy strategy. Uganda is exploring potential partnerships, including a nuclear deal with Russia, to bolster its nuclear infrastructure.

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Fission

The heavy metal uranium is a mixture of isotopes of which $^{235}_{92}U$, called uranium-235, is the most important. Some atoms of this isotope decay quite naturally, emitting high-speed neutrons. If one of these hits the nucleus of a neighbouring uranium-235 atom (as it is uncharged the neutron is not repelled by the nucleus), the nucleus may break (fission of the nucleus) into two nearly equal radioactive nuclei, often of barium and krypton, with the production of two or three more neutrons. The energy released is large and appears mostly as kinetic energy of the fission fragments. These fly apart at great speed, colliding with surrounding atoms and raising their average kinetic energy, i.e. their temperature. The fission fragments are called daughter nuclei and the original uranium atom is called the parent nucleus. Other isotopes can undergo fission; those such as plutonium-239 that can sustain a chain reaction are termed nuclear fuels. If the fission neutrons split other uranium-235 nuclei, a chain reaction is set up. In practice, some fission neutrons are lost by escaping from the surface of the uranium before this happens. The ratio of those causing fission to those escaping increases as the mass of uranium-235 increases. This must exceed a certain critical value to sustain the chain reaction.

Chain reaction/ Nuclear reactor

In a nuclear power station, heat from a nuclear reactor produces the steam for the turbines.

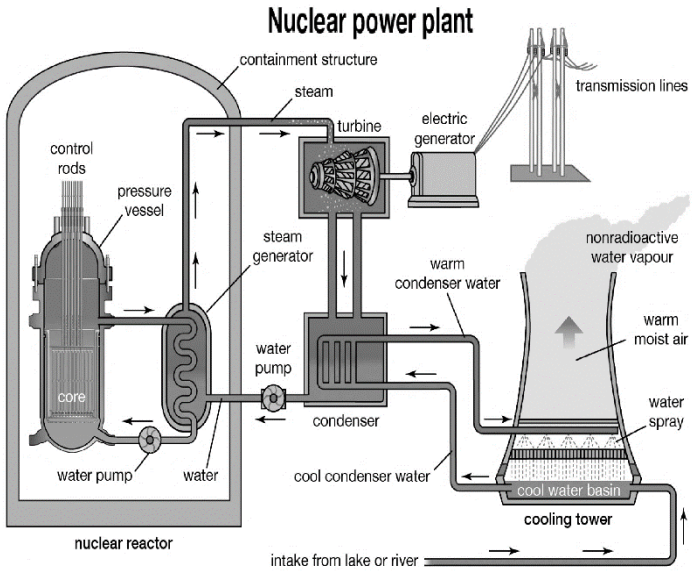
Simplified diagram of one type of reactor

The chain reaction occurs at a steady rate, which is controlled by inserting or withdrawing neutron absorbing control rods of boron among the uranium rods. The graphite core is called the moderator and slows down the fission neutrons: fission of uranium-235 occurs more readily with slow than with fast neutrons. Carbon dioxide gas is pumped through the core as a coolant. In the heat exchanger the heated gas transfers energy to pipes containing cold water so that the water boils to produce steam. The concrete shield gives workers protection from γ-emissions and escaping neutrons. The radioactive fission fragments must be removed periodically if the nuclear fuel is to be used efficiently.

In an atomic bomb, an increasingly uncontrolled chain reaction occurs when two pieces of uranium-235 come together and exceed the critical mass.

Nuclear reactors

Nuclear reactors are essential devices that initiate and control nuclear fission, a process where atoms split to release energy. This energy is harnessed for various applications, including commercial electricity generation and marine propulsion. By August 2023, the United States operated 93 commercial nuclear reactors across its 54 power plants, highlighting the significance of nuclear energy in the national energy landscape. Recent discussions have emerged regarding the extension of the operational life of nuclear reactors, such as those in Heysham, where opinions diverge between supporting the extension for energy needs and concerns over safety and environmental impact. Meanwhile, Canada is exploring the commercialization of small reactor designs, which could revolutionize energy production with a 15-year fuel cycle. Mobile nuclear reactors are gaining attention for their potential to provide reliable energy solutions for military operations, addressing the growing demand for portable power sources in various industries.



Nuclear Reactions

Nuclear reactions cause changes in the nucleus of atoms, which in turn leads to changes in the atom itself. Nuclear reactions convert 1 element into a completely different element. Suppose if a nucleus interacts with any other particles and then separates without altering the characteristics of other nuclei then the process is called as **nuclear scattering rather** than specifying it as a nuclear reaction. This does not imply radioactive decay. One of the most evident nuclear reactions is the nuclear fusion reaction that occurs in fissionable materials producing induced nuclear fission.

A nuclear chain reaction occurs when a single nuclear reaction causes one or more subsequent reactions, leading to a self-sustaining series of reactions. This process is fundamental to both nuclear reactors and nuclear weapons. The most common type of nuclear chain reaction involves nuclear fission, where a heavy nucleus, such as uranium-235 or plutonium-239, splits into smaller nuclei, releasing energy and neutrons.

These released neutrons can then initiate further fission reactions in nearby nuclei, perpetuating the chain reaction.

Procedures in a Nuclear Chain Reaction

A neutron collides with a heavy atomic nucleus (e.g., uranium-235), causing it to become unstable and split into two smaller nuclei (fission products) along with a release of energy and additional neutrons. This fission releases a large amount of energy in the form of kinetic energy and gamma radiation. The fission event releases two or three neutrons, which can then collide with other nearby fissile nuclei, causing them to undergo fission as well. If each fission event leads to at least one more fission, the reaction becomes self-sustaining, creating a chain reaction. A sufficient amount of fissile material (critical mass) is required to sustain the chain reaction, as too few atoms would make it difficult for neutrons to continue colliding with nuclei. In nuclear reactors, the rate of the chain reaction is regulated using control rods that absorb excess neutrons, allowing the reaction to proceed at a steady rate to produce energy safely. In nuclear weapons, the chain reaction is uncontrolled, leading to an explosive release of energy within a fraction of a second.

Nuclear Reactions -Types

Inelastic scattering: This process takes place when a transfer of energy occurs. It occurs above threshold energy called the inelastic threshold energy and is the energy of the first excited state.

Elastic Scattering: It occurs when there is energy transfer between a particle and intends nuclei. It is the most vital process for slowing down neutrons. In the case of an elastic scattering total kinetic energy of any system is conserved.

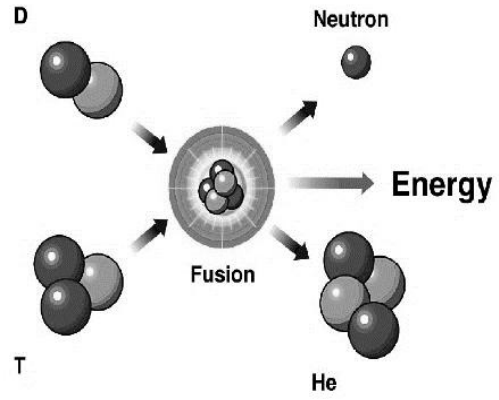
Transfer Reactions: The absorption of a particle followed by discharge of 1 or 2 particles is referred as transfer reactions.

Capture Reactions: When nuclei capture neutral or charged particles followed by discharge of γ-rays, it is termed as capture reactions. Radioactive nuclides are produced by neutron capture reactions.

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Fusion

If light nuclei join together to make heavier ones, this can also lead to the release of energy. Such a fusion reaction has been achieved in the hydrogen bomb. Fusion can only occur if the reacting nuclei have enough energy to overcome their mutual electrostatic repulsion. This can happen if they are raised to very high temperature pump cold water (over 100 million °C) so that they collide at very high speeds. If fusion occurs, the energy released is enough to keep the reaction going; since heat is required, it is called thermonuclear fusion.



The source of the Sun's energy is nuclear fusion. The temperature in the Sun is high enough for the conversion of hydrogen into helium to occur, in a sequence of thermonuclear fusion reactions known as the 'hydrogen burning' sequence.

The nuclear model of the atom

Thermonuclear reactions

The following thermonuclear reactions occur in the Sun

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + positron\ |{}^{0}_{+1}e| + neutrino\ (v)$$

$^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{1}H + \gamma - ray$
$^{3}_{2}H + {}^{3}_{2}H \rightarrow {}^{4}_{2}H + {}^{1}_{1}H + {}^{1}_{1}H$
Each of these fusion reactions results in a loss of mass and a release of energy. Overall, tremendous amounts of energy are created that help to maintain the very high temperature of the Sun.

Nuclear Fusion Reaction
This is the union of two light atomic nuclei to form a heavy atom. It involves the release of energy.
$^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{1}He + energy$, $^{2}_{1}H + {}^{2}_{1}H \uparrow\rightarrow {}^{4}_{1}He + {}^{2}_{1}n + energy$

Social, Political, and Environmental Dimensions of Nuclear Power Use
Many communities have concerns about nuclear safety, often influenced by past nuclear accidents (e.g., Chernobyl, Fukushima). Ensuring transparency and safety is crucial to gaining public support. The dual-use nature of nuclear technology (for power generation and weaponry) raises concerns about the spread of nuclear weapons. Treaties such as the Non-Proliferation Treaty (NPT) regulate nuclear technology and promote peaceful use. Long-lived radioactive waste requires secure, stable storage to prevent environmental contamination over thousands of years. Nuclear energy has low greenhouse gas emissions compared to fossil fuels, making it attractive for reducing climate impact.

Nuclear and radiation accidents and incidents
Nuclear and radiation accidents have raised significant safety concerns since the inception of nuclear power. As of 2014, over 100 serious incidents have been recorded, with 57 classified as severe. The Chernobyl disaster in 1986 remains the most catastrophic, resulting in widespread radiation exposure and long-term health effects. In contrast, the Fukushima accident in 2011, while serious, did not lead to the same level of health threats for workers as seen in Chernobyl. The Three Mile Island incident in the United States also marked a pivotal moment in nuclear safety, where a partial meltdown resulted in a minor radiation release. These events have prompted international organizations like the IAEA to enhance emergency preparedness and response strategies.

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Safety precautions
To reduce exposure to ionising radiations:
(i) Exposure time to the radiation should be minimised
(ii) the distance between a source and a person should be kept as large as possible
(iii) People should be protected by the use of shielding which absorbs the radiation.
In industry, sources are handled by long tongs and transported in thick lead containers. Workers are protected by lead and concrete walls, and wear radiation dose badges that keep a check on the amount of radiation they have been exposed to over a period (usually one month). The badge contains several windows which allow different types of radiation to fall onto a photographic film; when the film is developed it is darkest where the exposure to radiation was greatest.

The increasing use of radioisotopes in medicine and industry has made it important to find safe ways of transporting and using radioactive materials and of disposing of radioactive waste. In using and transporting radioactive materials the effects of ionising radiation need to be minimised with thick lead containers and remote handling where possible.
Varieties of methods are used for radioactive storage. Waste with very low levels of radioactivity

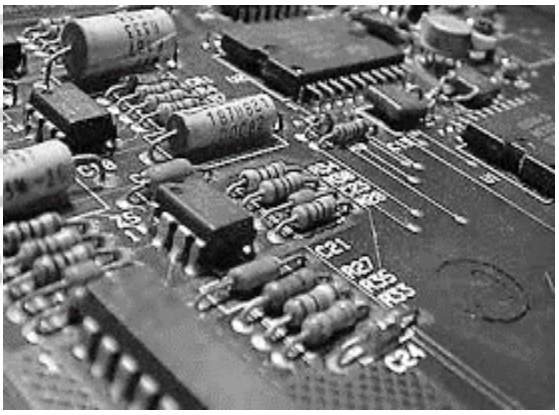
is often enclosed in steel containers which are then buried in concrete bunkers; possible leakage is a cause of public concern, as water supplies could be contaminated allowing radioactive material to enter the food chain. Waste with high levels of radioactivity is immobilised in glass or synthetic rock and stored deep underground.

The weak sources used at school should always be:
(i) lifted with forceps
(ii) held away from the eyes and
(iii) kept in their boxes when not in use

Activity

1. Explain the meaning of the term isotope. An isotope of helium can be written in nuclide notation as ${}_{2}^{3}He$. Describe how an atom of ${}_{2}^{3}He$ one of ${}_{2}^{4}He$differs from
2. An atom of calcium can be written in nuclide notation as ${}_{20}^{40}Ca$. State the values of the nucleon number A and the proton number Z for an atom of calcium. When a calcium atom loses an electron it becomes an ion. State whether the ion is negatively or positively charged.
3. Describe the importance of Geiger and Marsden's experiment on the scattering of α-particles by a thin metal film to understanding the structure of the atom. State the charge on (i) a proton, (ii) a neutron and (iii) a helium nucleus.
4. Explain what is meant by nuclear fission and nuclear fusion, and outline the processes that occur in each of them. Outline the processes that occur in a nuclear reactor, and explain how a chain reaction is controlled in a nuclear reactor.

4.5 DIGITAL ELECTRONICS



Learning Outcomes

a) Understand how resistors are used to make potential dividers in control and logic circuits (u,s)
b) Understand elementary logic and memory circuits that exploit devices such as bistable and a stable switches, logic gates and resistors as potential dividers (u,s)
c) Know that logic circuits are able to store and process binary information and that this can be exploited in an increasingly wide variety of digital instruments (k, u,s)

Introduction

Digital electronics is a vital field that focuses on the study and application of digital signals. It encompasses the design and engineering of devices that utilize these signals, which are essential for modern computing and communication systems. Digital electronics operates on binary data, allowing for efficient processing and manipulation of information, such as numbers and text. The discipline includes various components, such as logic gates, combinational and sequential circuits, which form the backbone of digital systems. Recent advancements in materials science are pushing the boundaries of digital electronics, particularly in high-temperature applications. Innovations beyond traditional silicon technologies are being explored to enhance the resilience and performance of electronic devices, ensuring that digital electronics continues to evolve and meet the demands of modern technology.

Potential Divider

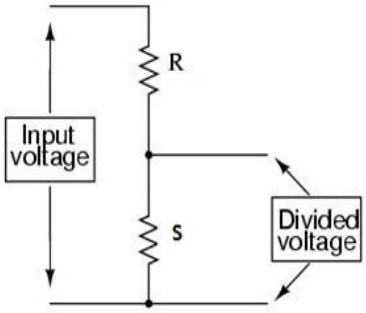
A potential divider, also known as a voltage divider, is a fundamental electronic circuit that reduces a higher voltage to a lower voltage. This is achieved by using resistors in series, where the output voltage is a fraction of the input voltage, determined by the resistor values. This simple yet effective design is widely utilized in various applications, including sensor circuits and signal processing. In practical terms, a potential divider allows for the adjustment of voltage levels, making it essential in electronic devices. For instance, it can be used to calibrate sensor outputs or to create reference voltages for operational amplifiers. It is based on the principle that the potential drop across a segment of a wire of uniform cross-section carrying a constant current is directly proportional to its length. It is used in the volume control knob of music systems. Sensory circuits using light-dependent resistors and thermistors also use potential dividers. They can be used as audio volume controls, to control the temperature in a freezer or monitor changes in light in a room. Two resistors divide up the potential difference supplied to them from a cell. The proportion of the available p.d. that the two resistors get depends on their resistance values.

- V_{in} = p.d. supplied by the cell
- V_{out} = p.d. across the resistor of interest
- R_1 = resistance of resistor of interest R_1
- R_2= resistance of resistor R_2

Potential Divider

A potential divider consists of two resistors (R_1 and R_2=S) in series. The current *I* through both the resistors are the same. The potential across resistor R_1 is V_1 and R_2=S is V_2. The potential difference across the resistors can be mathematically written using Ohm's law.

From ohms law, $V_1 = IR_1, and\ V_2 = IR_2,\ dividing\ \ both\ sides\ yields\ \frac{V_1}{V_2} = \frac{R_1}{R_2}$



Using the above equation, it can be understood that the total potential difference (V) is divided between the two resistors according the ratio of their resistances. By choosing the appropriate resistor values, the potential difference across the resistances can be varied. A potential divider (or voltage divider) is a simple circuit used to divide an input voltage into smaller output voltages.

This is achieved by connecting two or more resistors (or other components) in series across a voltage source. The divided voltage is taken from the junction between these components, and its value depends on their relative resistances.

Applications of Potential Dividers



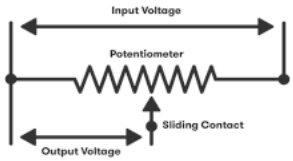
Adjustable Voltage Supplies (Variable Voltage Sources): A variable resistor (potentiometer) can be used in a potential divider to produce a range of output voltages. They are used in power supplies to adjust the output voltage according to specific requirements. For example, in lab equipment where different voltages are needed for testing circuits.

Volume Control in Audio Equipment: A potentiometer is used as a potential divider to adjust the voltage that controls sound intensity. In radios, speakers, and other audio devices, the volume control knob is essentially a variable potential divider that adjusts the audio signal level reaching the speaker.

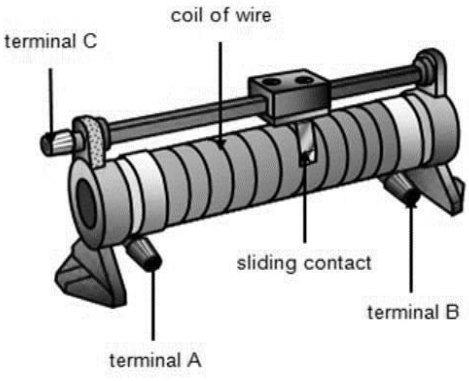
Sensors and Transducers: Many sensors, such as thermistors (temperature sensors) and light-dependent resistors (LDRs), are connected in a potential divider circuit to produce an output voltage that varies with environmental conditions. In light-sensitive or temperature-sensitive circuits, potential dividers provide a varying voltage output that can be used in control systems, like adjusting brightness in automatic lighting or regulating temperature.

Battery Level Indicators: A potential divider can scale down the voltage of a battery to a safer, readable level for a microcontroller or ADC (Analog-to-Digital Converter). Used in battery-operated devices to monitor and display battery voltage levels. For example, in mobile phones, laptops, and electric vehicles, battery indicators often rely on a potential divider to measure the state of charge.
Reference Voltage for Comparators: A potential divider can create a fixed reference voltage for a comparator circuit. In control systems, such as thermostats, this reference voltage is compared with an input signal to trigger an action, like turning a heater on or off based on temperature levels.
Signal Conditioning: Potential dividers can be used to scale down higher voltages to a level that's compatible with low-voltage circuitry or sensitive input devices. Common in digital electronics, where signals need to be scaled to safe levels for microcontrollers or analog-to-digital converters without damaging sensitive components.
Level Shifting: In some digital circuits, a potential divider adjusts signal voltages to match different logic levels. Essential in interfacing components that operate at different voltage levels, such as connecting 5V and 3.3V logic circuits in integrated systems like microcontrollers, sensors, and communication modules.

Variable Resistor / Rheostat



A variable resistor (rheostat) can be used to control current in a circuit. A variable resistor consists of a length of resistance wire and an adjustable sliding contact. Without switching off the circuit, the resistance can be varied using a sliding contact. A rheostat is made using a resistance wire, which is wound around circular insulation. A sliding contact is placed in the wire to change the length of the resistor. An end of the wire and sliding contact is connected to the circuit. As the length of the resistance wire is changed, the resistance also changes. The resistance can be set to any value from nearly zero to the total resistance of the wire in the variable resistor. A rheostat is used in car lighting systems to change the brightness of the lights.



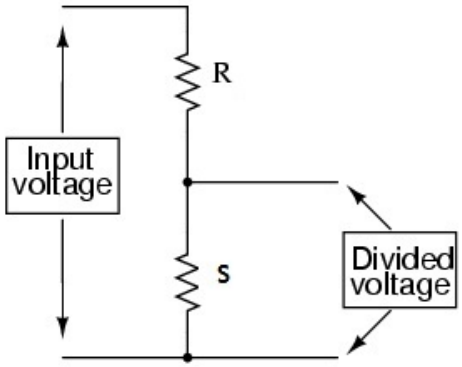
Potentiometer

Variable resistors are used in electronics (and are then called potentiometers) as volume and other controls. These consist of a coil of constantan wire (an alloy of 60% copper, 40% nickel) wound on a tube with a sliding contact on a metal bar above the tube.
The design of a potentiometer is similar to that of a variable resistor. All the three points, both the ends of resistance wire and the adjustable contact, are connected to the circuit. Two terminals and the contact are connected to the circuit. The length of the wire can be changed by the sliding contact. The resistance increases as the length of the wire increases. The resistance can be set to any value from zero to the total resistance of the wire. Potentiometers are often used, for example, to change the volume in a speaker system.

Application of Potential Dividers

Potential dividers are widely used in sensory circuits. The change in the physical property of a sensor has to be processed before it can be displayed or measured. Light-dependent resistors and thermistors are two examples of sensory devices whose resistances vary with light and temperature respectively. The resistance of a light-dependent resistor decreases as the light intensity increases. The resistance of the thermistor decreases with rise in temperature. A potential divider can be used to process the information obtained from these sensory devices.

Let us consider a potential divider circuit with a sensory device can be placed in the position of S.



Potential Divider in Sensory Circuits

The voltage across sensory device (Vs) can be mathematically written as:

$$V_s = \frac{S}{S+R} \times Input\ voltage$$

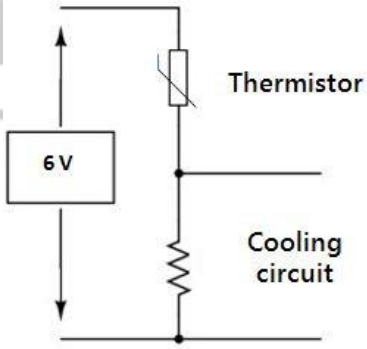
The magnitude of Vs depends on the relative resistance of R and S. We can note that, as the resistance of sensory device (S) increases, the voltage also increases.

Example

A potential divider circuit can be used inside a refrigerator to switch on the cooling circuit when the temperature is high (more than 3°C).

Potential Divider Using a Thermistor

The characteristics of the thermistor are given in the table below. Let the voltage across the cooling circuit be VCC and the resistance of cooling circuit is 5kΩ. In order for the cooling circuit to operate, it needs a potential difference of 5 V or more.

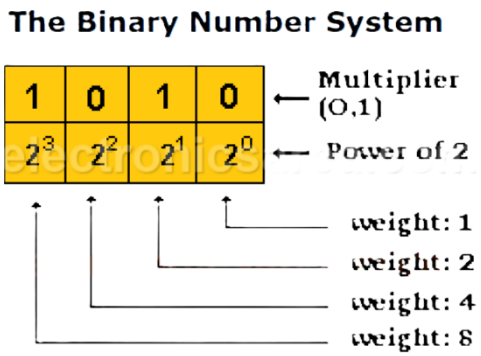


Temperature	Resistance of Thermistor
2°C	1500 Ω
3°C	1000 Ω
4°C	500 Ω

Hence, this potential divider meets the requirements of the refrigerator. These circuits can be further modified to suit different applications. For example: switching off a heater when the temperature is above a certain temperature. This circuit can also be used for switching off lights in the daytime and switching them on at night (**LDR**).

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Binary systems and logic gates



The binary number system is fundamental to digital electronics, utilizing only two digits: 0 and 1. This base-2 system is ideal for representing digital signals, as it aligns perfectly with the two states of electronic components—on and off. Each binary digit, or bit, can represent a true or false condition, making it essential for data processing and storage in computers. In digital applications, binary numbers are used to perform various operations, including arithmetic and logical functions. The simplicity of the binary system allows for efficient encoding and decoding of information, which is crucial in modern computing. For instance, complex data structures and algorithms rely on binary representations to function effectively. Moreover, the conversion between binary and other number systems, such as decimal, is a common task in digital electronics. Understanding binary is vital for anyone working in technology, as it forms the backbone of all digital systems.

Logic gates

Logic gates are fundamental components in digital electronics, designed to perform Boolean functions through various electronic components like diodes, transistors, and resistors. These gates process binary inputs to produce a single binary output, enabling complex computations and decision-making processes in digital systems. The primary types of logic gates include AND, OR, NOT, XOR, NAND, NOR, and XNOR. Each gate has distinct functions: for instance, the AND gate outputs a high signal only when all inputs are high, while the OR gate outputs high if at least one input is high. Understanding these gates is crucial for designing and analyzing digital circuits, as they form the building blocks of more complex systems.

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Digital electronics

Digital electronics is a vital branch of electronics focused on the study and application of digital signals, which are represented as discrete binary values (0s and 1s). This field encompasses the design and engineering of devices that utilize these signals, making it essential for modern technology. Digital electronics is foundational in various applications, from computers to communication systems, where information is processed and manipulated efficiently. One of the key advantages of digital electronics is its ability to handle information that is inherently digital, such as numbers and text. This allows for precise and reliable data processing, which is crucial in today's digital age. The use of logic gates, which form the basis of digital circuits, enables the creation of complex systems that can perform a variety of functions. Digital electronics is a type of electronics that deals with the digital systems, which processes the data/information in the form of binary (0s and 1s) numbers, whereas analog electronics deals with the analog system, which processes the data/information in the form of continuous signals.

Understanding Discrete, Analog and Digital Signals in Industrial Instrumentation

Subject Area	Instrumentation and Automation
Main Focus	Discrete, Analog and Digital Signals
Key Control Systems	PLC, DCS and Field Communication Systems
Main Application	Monitoring, measurement, control and data transmission in process plants

In chemical plant instrumentation and general industrial automation, field devices such as sensors, switches, transmitters, relays and actuators must communicate with control systems. The most common control systems include Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCS). The communication between field devices and controllers is mainly carried by three types of signals: discrete signals, analog signals and digital signals.
Although these signal types are sometimes confused, each one has a distinct meaning and role. Discrete signals are used mainly for status indication, analog signals are used for continuously varying measurements, and digital signals are used for encoded data communication and logical processing.

Learning Objectives

a) Define discrete, analog and digital signals clearly.
b) Distinguish the key features and applications of the three signal types.
c) Relate signal types to real industrial devices such as valves, motors, flow meters and temperature sensors.
d) Explain why 4-20 mA current loops are widely used for analog signal transmission in industry.
e) Appreciate the role of signals in PLC, DCS and modern plant automation systems.

Signal Types Explained
Discrete Signal (Binary Contact Signal)

A discrete signal, also called a binary signal, represents only two possible states. These may be ON or OFF, TRUE or FALSE, OPEN or CLOSED, and 1 or 0. It is the simplest signal used in industrial control because it communicates whether a device is in one condition or another.
A limit switch may show whether a valve is open or closed.
A contactor may show whether a motor is running or stopped.
A thermal relay may show whether a motor has overheated or tripped.
A pressure switch may show whether pressure is above or below a set limit.
Discrete signals may be passive or active. Passive contacts do not supply their own voltage and are usually powered by the PLC input circuit. Active discrete signals supply a step voltage or pulse, commonly 24 V DC, which the controller interprets as logic 1 or logic 0.

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Type of Discrete Signal	Meaning	Typical Industrial Example
Passive contact	No internal voltage; the PLC supplies sensing voltage.	Valve limit switch or relay contact.
Active signal	Has a voltage or pulse output interpreted as 1 or 0.	24 V DC proximity sensor or electronic switch.

Analog Signal (Continuously Variable Signal)

An analog signal represents a physical quantity that changes continuously. It is used when a system needs an actual measured value rather than only an ON/OFF condition. Common analog measurements include pressure, temperature, flow rate, level, voltage and current.
A pressure transmitter may send a signal showing the actual pressure in a pipe.
A temperature transmitter may send a signal showing the actual temperature of a reactor or tank.

A flow meter may send a signal showing the rate of liquid or gas flow.
Common analog standards include 0-10 V and 4-20 mA.
A PLC analog input module receives an analog signal and converts it into a digital value through sampling and quantization. This allows the PLC or DCS to process the measurement, display it, trend it and use it for control decisions.

Digital Signal (Encoded Binary Data)

A digital signal is made up of binary data, meaning sequences of 0s and 1s. Unlike a simple discrete signal that communicates only one ON/OFF state, a digital signal can carry more detailed information using many bits. It may carry measurement values, diagnostic messages, calibration data, device identification and control commands.
Smart sensors may transmit encoded data to a control system.
Communication networks such as Modbus, Profibus and HART use digital information.
A measured analog value can be converted into digital form for processing.
A threshold condition may be represented digitally as over-limit or normal.

Comparison of Discrete, Analog and Digital Signals

Attribute	Discrete Signal	Analog Signal	Digital Signal
Basic form	Binary: 0 or 1	Continuous value	Binary-coded data using multiple bits
Main purpose	Status indication	Measurement and control	Data transmission, logic and diagnostics
Examples	Valve open/closed, motor ON/OFF	Temperature, pressure, flow rate, level	Modbus data, calibration data, smart sensor data
PLC/DCS interface	DI/DO modules	AI/AO modules	Communication modules or digital interfaces
Signal behaviour	Changes between two states	Varies gradually with process value	Transmits coded information
Noise performance	Generally low susceptibility	Voltage analog signals can be affected by noise; current loops are stronger	Good if properly shielded and terminated

Why 4-20 mA Is Widely Used for Analog Signals

Industrial automation commonly uses 4-20 mA current loops for analog signal transmission. This standard is preferred because it is reliable over long cable distances, less affected by electrical noise and easier to diagnose when a fault occurs.

Better Noise Immunity

Voltage signals such as 0-10 V can lose accuracy when cables are long or when electromagnetic interference is present. In contrast, a current signal remains more stable because the same current flows around the loop. This makes 4-20 mA suitable for noisy industrial environments such as chemical plants, motor control rooms and processing lines.

Easier Fault Diagnosis

In a 4-20 mA system, 4 mA represents the zero-level measurement, while 20 mA represents the full-scale measurement. A reading of 0 mA usually suggests a fault such as broken wiring, failed transmitter supply or open circuit. This makes fault detection easier than in a 0-20 mA system, where 0 mA could mean either a true zero reading or a wiring failure.

Current Reading	Meaning in a 4-20 mA Loop
4 mA	Zero-level process measurement, not a fault.
20 mA	Full-scale process measurement.
0 mA	Abnormal condition such as open circuit, broken wire or device failure.
Below 4 mA or above 20 mA	Out-of-range or instrument fault.

Industrial Applications

Device or Process	Likely Signal Type	Reason
Valve limit switch	Discrete	It reports whether the valve is open or closed.
Motor overload relay	Discrete	It reports normal or trip condition.
Temperature transmitter	Analog	Temperature changes continuously and requires measurement.
Flow transmitter	Analog	Flow rate varies continuously with process conditions.
Smart pressure transmitter with HART	Digital and analog	It can transmit a 4-20 mA value and digital diagnostic information.
PLC-to-DCS communication	Digital	It transfers coded data, alarms, values and commands.

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Application Questions

A valve in a water treatment plant has a limit switch that indicates whether it is open or closed. Identify the type of signal produced and explain your answer.

A temperature transmitter sends a changing value to a PLC as a chemical mixture is heated. State the type of signal and explain why this type is suitable.

A smart flow meter sends calibration data and diagnostic messages to a control system. Identify the type of signal used for this information.
Explain why a 4-20 mA signal is preferred to a 0-10 V signal when the instrument is far from the control room.
A transmitter gives 0 mA on a 4-20 mA loop. Explain why this reading is treated as a fault rather than a zero process value.

Conclusion

Discrete, analog and digital signals form the basic communication language of industrial instrumentation. Discrete signals show two-state conditions, analog signals represent continuously changing measurements, and digital signals carry encoded data. Understanding these signal types helps technicians, engineers and learners design, operate and troubleshoot reliable automation systems in modern industries.

BOOLEAN ALGEBRA, LOGIC GATES, APPLICATIONS AND SCENARIO EXAMINATION QUESTIONS

Digital Electronics and Logic Circuits

Meaning of Boolean Algebra

Boolean algebra is a branch of mathematics used to deal with logical values. It is widely applied in digital electronics, computer systems, calculators, mobile phones, automatic control systems, security systems, traffic lights, industrial machines and communication systems.

Unlike ordinary algebra, Boolean algebra uses only two values: 0 and 1. These two values are used to represent two possible states such as OFF and ON, false and true, low and high voltage, or no and yes.

Truth Table:

The truth table is a table that gives all the possible values of logical variables and the combination of the variables. It is possible to convert the Boolean equation into a truth table. The number of rows in the truth table should be equal to 2^n, where "n" is the number of variables in the equation. For example, if a Boolean equation consists of 3 variables, then the number of rows in the truth table is 8. ($2^3 = 8$)

Boolean Value	Logical Meaning	Electrical Meaning	Real-Life Meaning
0	False	OFF / LOW voltage	No / Open / Inactive
1	True	ON / HIGH voltage	Yes / Closed / Active

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For example, a school security door may open only when the identity card is valid and the correct PIN is entered. This decision can be represented using Boolean algebra.

Basic Logic Operations

Boolean algebra is mainly based on three basic logic operations: AND, OR and NOT. Logic gates represent these operations electronically.

AND Operation

The AND operation gives an output of 1 only when all the inputs are 1. It is represented by A * B or simply AB, and is read as A AND B.



A	B	Output Y = AB
0	0	0
0	1	0
1	0	0
1	1	1

Example:
A computer laboratory door opens only when a learner has a valid identity card and enters the correct PIN. If A represents a valid identity card and B represents the correct PIN, then Door = A * B.

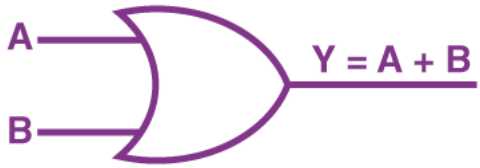
OR Operation

The OR operation gives an output of 1 when at least one input is 1. It is represented by A + B and is read as A OR B.

A	B	Output Y = A + B
0	0	0
0	1	1
1	0	1
1	1	1

OR Gate Diagram

Example:
A fire alarm rings when smoke is detected or when heat is detected. If A represents smoke detected and B represents heat detected, then Alarm = A + B.



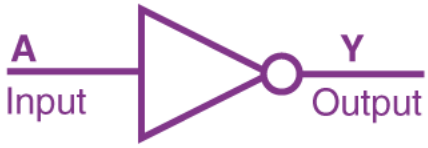
NOT Operation

The NOT operation reverses the input value. It is represented by A' or A-bar and is read as NOT A.

A	Output Y = A'
0	1
1	0

NOT Gate Diagram

Example:
An automatic street light turns ON when it is not daytime.
If A represents daytime, then Light = A'.



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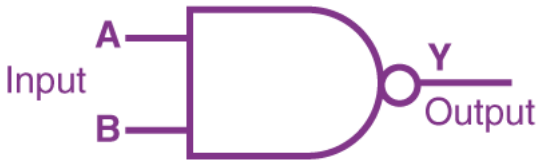
Other Important Logic Gates

NAND Gate

A NAND gate is an AND gate followed by a NOT gate. Its output is the opposite of an AND gate. Its Boolean expression is Y = (AB)'.

A	B	AB	Output Y = (AB)'
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

Using De Morgan's theorem, (AB)' = A' + B'.

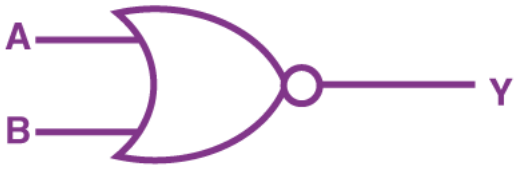


NOR Gate

A NOR gate is an OR gate followed by a NOT gate. Its output is the opposite of an OR gate. Its Boolean expression is Y = (A + B)'.

A	B	A + B	Output Y = (A + B)'
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

Using De Morgan's theorem, (A + B)' = A'B'.



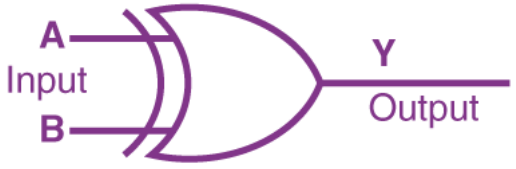
XOR Gate

The XOR gate gives an output of 1 when the inputs are different. It is called the exclusive OR gate. Its expression is Y = A'B + AB'.

A	B	Output Y
0	0	0
0	1	1
1	0	1
1	1	0

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Example: An XOR gate can be used in a two-way lighting system where a light changes state depending on the positions of two switches.

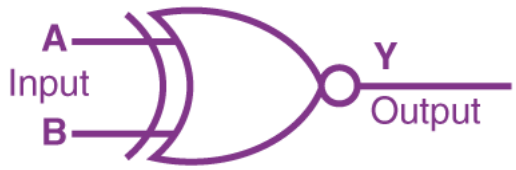


XNOR Gate

The XNOR gate gives an output of 1 when the inputs are the same. Its expression is Y = AB + A'B'.

A	B	Output Y
0	0	1
0	1	0
1	0	0
1	1	1

Example:
An XNOR gate can be used in comparison circuits to check whether two binary values are equal.



Boolean Algebra Rules and Properties

Boolean algebra has special rules used to simplify logic expressions and reduce the number of gates needed in a circuit.

Identity Laws

The identity laws show that a variable remains unchanged when combined with a special value.

OR Form	AND Form
A + 0 = A	A * 1 = A

OR-ing a variable with 0 or AND-ing it with 1 does not change the variable.

Null Laws or Domination Laws

These laws show that some values dominate the entire expression.

OR Form	AND Form
A + 1 = 1	A * 0 = 0

In an OR operation, the presence of 1 makes the output 1. In an AND operation, the presence of 0 makes the output 0.

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Idempotent Laws

These laws show that repeating the same variable does not change the output.

OR Form	AND Form
A + A = A	A * A = A

Repeating the same condition does not create a new condition.

Complement Laws

A complement is the opposite of a Boolean variable.

OR Form	AND Form
A + A' = 1	A * A' = 0

A switch is either ON or OFF, but it cannot be ON and OFF at the same time.

Involution Law

The involution law states that complementing a variable twice gives the original variable.

OR Form	AND Form
(A')' = A	(A')' = A

The opposite of the opposite is the original value.

Commutative Laws

These laws show that the order of variables does not affect the result.

OR Form	AND Form
A + B = B + A	AB = BA

A OR B gives the same result as B OR A, and A AND B gives the same result as B AND A.

Associative Laws

These laws show that grouping does not affect the result.

OR Form	AND Form
(A + B) + C = A + (B + C)	(AB)C = A(BC)

Brackets can be moved without changing the output when the same operation is used.

Distributive Laws

The distributive laws are used when one operation is spread over another.

OR Form	AND Form
A + BC = (A + B)(A + C)	A(B + C) = AB + AC

These laws help in expanding and simplifying Boolean expressions.

Absorption Laws

Absorption laws help remove unnecessary terms.

OR Form	AND Form
A + AB = A	A(A + B) = A

A larger expression is absorbed by a simpler part of itself.

De Morgan's Theorems

These theorems simplify expressions with brackets and complements.

OR Form	AND Form
(A + B)' = A'B'	(AB)' = A' + B'

The complement of OR becomes AND of complements, and the complement of AND becomes OR of complements.

Summary Table of Boolean Algebra Laws

Law	OR Form	AND Form
Identity Law	A + 0 = A	A * 1 = A
Null Law	A + 1 = 1	A * 0 = 0
Idempotent Law	A + A = A	A * A = A
Complement Law	A + A' = 1	A * A' = 0
Involution Law	(A')' = A	(A')' = A
Commutative Law	A + B = B + A	AB = BA
Associative Law	(A + B) + C = A + (B + C)	(AB)C = A(BC)

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Distributive Law	A + BC = (A + B)(A + C)	A(B + C) = AB + AC
Absorption Law	A + AB = A	A(A + B) = A
De Morgan's Law	(A + B)' = A'B'	(AB)' = A' + B'

Circuit Simplification Using Boolean Algebra

Boolean algebra is useful because it helps reduce complicated digital circuits into simpler ones. Suppose a circuit has the expression Y = A + AB.

Original Circuit

The Boolean expression is Y = A + AB. Using the absorption law, A + AB = A.

Universal gates are NAND and NOR gates.

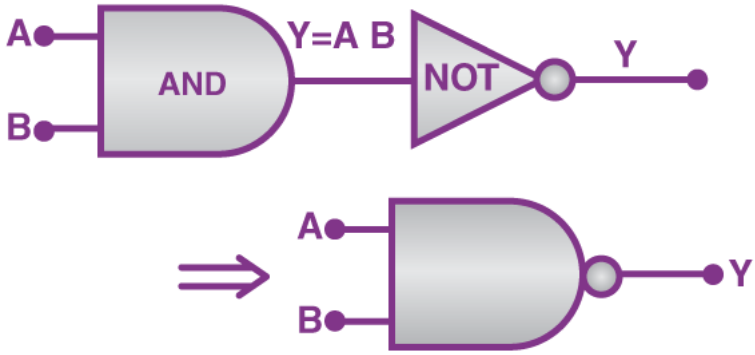
Because NOT gate is an inverter. As a result, if 0 is used as an input, the output will be 1.

An inverter is also known as a NOT gate. The obtained output is the inverse of the input.

If A and B are the input, then the OR gate output can be given as Y=A+B.

If A and B are the input, then the XNOR gate output can be given as Y=A.B+A'B'.

Realize the following Boolean expression using only NAND gates. Y = AB + BC + AC



Logic diagram: Step-1: Replace basic gates by NAND equivalents

Step-2: Eliminate two single inputs NAND gates are connected in series.

Step-3: Draw the resultant logic circuit.

Applications of Boolean Algebra

Computer Systems: Computers use Boolean algebra to process data. Every operation in a computer is based on 0s and 1s. Logic gates are combined to form processors, memory circuits, arithmetic circuits and control units.

Calculators: Calculators use logic gates to perform addition, subtraction, multiplication and division. Boolean algebra helps design the internal circuits that process numbers.

Mobile Phones: Mobile phones use digital circuits for calling, messaging, camera control, fingerprint detection, charging control and network communication.

School Security Systems: A school door can be designed to open only when a valid card and correct PIN are used. Door = Card * PIN.

Fire Alarm Systems: A fire alarm may ring when smoke is detected or when temperature becomes too high. Alarm = Smoke + Heat.

Automatic Street Lights

A street light can turn ON when it is not daytime. Light = Daytime'.

Water Pump Control

A water pump may operate only when the tank is empty and electricity is available. Pump = TankEmpty * PowerAvailable.

Traffic Light Systems

Traffic lights use logic circuits to control red, amber and green lights. Sensors detect vehicles and pedestrians, and the control system decides which light should turn ON.

Industrial Machines

Factories use Boolean logic to improve safety. A machine may start only when the power switch is ON, the emergency button is not pressed, and the safety guard is closed. Machine = Power * GuardClosed * Emergency'.

Examination Processing Systems

A school system may promote a learner if the learner passes Mathematics or Science. Promotion = Mathematics + Science.

Importance of Boolean Algebra

Boolean algebra is important because it helps engineers, technicians and students to design and simplify digital systems. It helps reduce the number of gates used in a circuit, which reduces cost, saves power and improves speed.

Boolean algebra also helps in troubleshooting faulty digital circuits. By understanding the expected output from a Boolean expression, a technician can identify where a circuit has failed. In modern technology, Boolean algebra forms the foundation of computers, robots, automatic machines, communication systems, calculators, mobile phones and digital control systems.

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Examination Questions

1. A secondary school installs a computer laboratory security system. The door opens only when a learner presents a valid school identity card and enters the correct PIN. The alarm rings when the wrong PIN is entered or when the emergency button is pressed. At night, the security light turns ON when it is not daytime.

a) State the Boolean operation used for the door-opening system.
b) Write the Boolean expression for the door-opening system.
c) Write the Boolean expression for the alarm system.
d) Write the Boolean expression for the night security light.
e) Draw a logic gate diagram for the door-opening system.

2. A school uses an automatic water pump to fill an overhead tank. The pump should operate only when the tank is empty and electricity is available. The pump should stop when the tank is full. An alarm should sound when the tank is empty but electricity is not available.

a) Write the Boolean expression for the pump to operate.
b) Write the Boolean expression for the pump to stop because the tank is full.
c) Write the Boolean expression for the alarm to sound when the tank is empty but electricity is not available.
d) Draw a logic gate diagram for the pump-operating system.
e) Explain why Boolean algebra is useful in designing automatic water systems.

3: A dormitory is fitted with an automatic fire detection system. The alarm rings when smoke is detected or when the temperature becomes too high. The emergency light turns ON when the alarm rings and power is available.

a) Write the Boolean expression for the alarm system.
b) Write the Boolean expression for the emergency light.
c) Identify the logic gates needed for the alarm system.
d) Construct a truth table for the alarm system.
e) Explain how this system improves safety in a school dormitory.

4 A workshop machine should start only when the main switch is ON, the safety guard is closed, and the emergency stop button is not pressed.

a) Write the Boolean expression for the machine to start.
b) Identify the logic gates required.
c) Explain the purpose of the NOT operation in the system.
d) Draw a logic gate diagram for the machine-starting circuit.
e) State two advantages of using Boolean logic in industrial safety systems.

5. At a road junction, a traffic light system uses sensors to detect vehicles and pedestrians. The green light turns ON when a vehicle is detected and no pedestrian is crossing. The pedestrian warning light turns ON when a pedestrian button is pressed.

a) Write the Boolean expression for the green light.
b) Write the Boolean expression for the pedestrian warning light.
c) Identify the logic gates used in the green light system.
d) Draw a logic gate diagram for the green light system.
e) Explain how Boolean logic can reduce accidents at road junctions.

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1. A bell rings when the time switch is ON or when the teacher presses a manual switch. Write the Boolean expression for the bell system.
2. A machine starts only when the power switch is ON and the safety guard is closed. Write the Boolean expression for the machine.
3. A security light turns ON when it is not daytime and motion is detected. Write the Boolean expression for the system.
4. A fan turns ON when the room is hot or when the manual switch is pressed. Write the Boolean expression for the fan system.

Conclusion

Boolean algebra is a very important part of digital electronics. It uses only two values, 0 and 1, to represent logical states such as OFF and ON, false and true, or low and high voltage. The main Boolean operations are AND, OR and NOT, and these are represented by logic gates.

Boolean algebra rules such as identity laws, null laws, idempotent laws, complement laws, commutative laws, associative laws, distributive laws, absorption laws and De Morgan's theorems are used to simplify logic expressions. Simplification helps reduce circuit size, cost and power consumption.

Logic gates are used in many real-life systems, including computers, calculators, mobile phones, security systems, water pumps, fire alarms, street lights, traffic lights and industrial machines. Therefore,

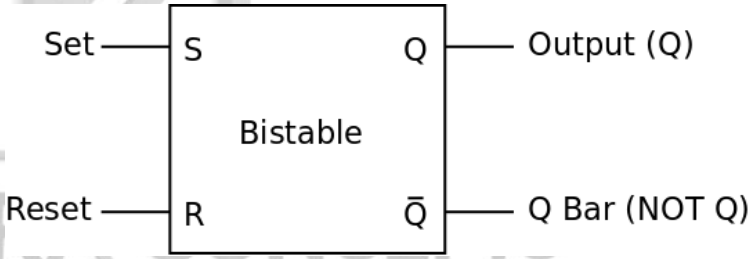
understanding Boolean algebra helps learners connect classroom knowledge to modern technology and real-life problem solving.

BISTABLE CIRCUITS

A Bistable is a digital circuit that has two inputs and a digital output.
The SET input makes the output Logic 1 (HIGH) and the output will stay in this state until forced to change. The RESET input makes the output Logic 0 (LOW) and the output will also stay in this state until forced to change. The output of a Bistable circuit is stable in both states - it can remain as either Logic 1 or Logic 0 indefinitely until either the SET or RESET initiate a change of state. The name means that the circuit has two stable states.

The terms **Bistable, Latch and Flip-Flop** are sometimes used interchangeably to describe Bistable circuits. However, each of these terms does have a specific meaning.
A bistable circuit is the most basic circuit with SET and RESET inputs and the output immediately responds to a change in the inputs.
A latch is very similar to the basic bistable circuit but includes an ENABLE to control the state of the output.
A flip-flop is a bistable circuit where the output changes on the rising (usually) edge of a clock pulse.

BISTABLE BASICS



A Bistable has two inputs called **Set (S)** and **Reset (R**).
The output is called **Q**. There is often a second output, which is the opposite of Q or, in logic terms, **NOT Q**($\bar{Q}$). In the most common bistable, **Set** and **Reset** are usually **LOW** and must go **HIGH** to change the output.

NOTE
1. In normal operation, SET and RESET are usually both held LOW
2. Q is always the opposite of Y
3. SET and RESET should not both be high at the same time - if they are the state of the outputs is undecided
4. There are also bistable where SET and RESET are usually HIGH and go LOW to change the output.

Meaning of Bistable Circuits

A bistable circuit is an electronic circuit that has two stable states. It can remain in either of these two states until an external input signal changes it. The word bistable means two stable or steady conditions.
In digital electronics, the two states are represented by 0 and 1, LOW and HIGH, or OFF and ON. A bistable circuit is also called a flip-flop or a latch, depending on how it is controlled.
A bistable circuit is important because it can store one bit of information. One bit is the smallest unit of digital information and can have only one of two values: 0 or 1.

Basic Principle of Operation

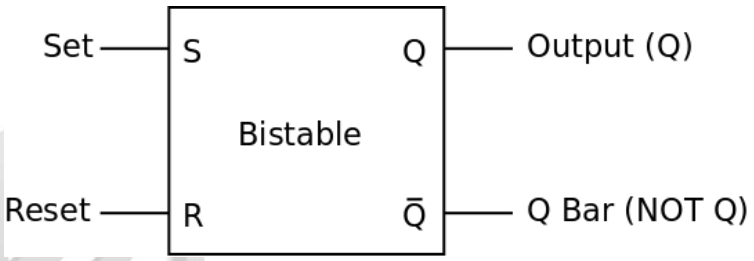
A bistable circuit works by using feedback. Feedback means that part of the output signal is connected back to the input. This feedback enables the circuit to remember its previous state even when the original input signal is removed.

The circuit commonly has two outputs, Q and Q′. The output Q′ is the complement of Q. This means the two outputs are normally opposite. When Q is 1, Q′ is 0. When Q is 0, Q′ is 1.

State	Q	Q′	Meaning
Set state	1	0	Circuit stores 1
Reset state	0	1	Circuit stores 0

Why Bistable Circuits are Called Memory Circuits

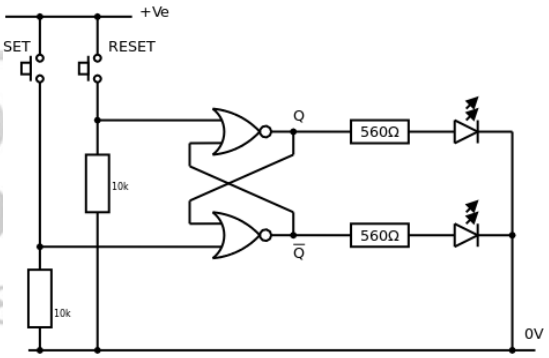
A bistable circuit is called a memory circuit because it remembers its previous output state.



When a SET signal is applied, the output becomes Q = 1 and remains in that state even after the SET signal is removed. It changes only when a RESET signal is applied. This makes bistable circuits useful in computers, counters, digital clocks, registers and automatic control systems.

Bistable Circuit Using Cross-Coupled Transistors

A simple bistable circuit can be built using two transistors. The two transistors are connected so that the output of one transistor controls the input of the other transistor. When one transistor is ON, the other transistor is OFF. The circuit can remain permanently in either of these two conditions.



Operation of the Transistor Bistable Circuit

When transistor Q1 is ON, current flows through it and the collector voltage of Q1 becomes LOW. This LOW voltage is fed to the base of Q2, keeping Q2 OFF. Since Q2 is OFF, its collector voltage becomes HIGH, and this HIGH voltage is fed back to the base of Q1, keeping Q1 ON.

The opposite condition is also stable: Q1 may be OFF while Q2 is ON. This explains why the circuit has two stable states.

Bistable Circuits Using Logic Gates

Bistable circuits can also be constructed using logic gates. The common types include SR latches made from NOR gates, SR latches made from NAND gates, clocked SR flip-flops, D flip-flops, JK flip-flops and T flip-flops.

SR latch using NOR gates, SR latch using NAND gates, Clocked SR flip-flop, D flip-flop, JK flip-flop, and T flip-flop

S′	R′	Q(next)	Operation
1	1	Previous state	Hold / Memory
0	1	1	Set
1	0	0	Reset
0	0	Invalid	Not allowed

Clock	D	Q(next)
Active edge	0	0
Active edge	1	1
No active edge	X	Previous state

SR Latch Using NOR Gates

An SR latch is one of the simplest bistable circuits. The letters SR stand for Set and Reset. The circuit has two inputs, S and R, and two outputs, Q and Q′.

Input/Output	Meaning
S	Set input
R	Reset input
Q	Main output
Q′	Complement output

When S = 1 and R = 0, the circuit is SET and Q becomes 1. When S = 0 and R = 1, the circuit is RESET and Q becomes 0. When S = 0 and R = 0, the circuit holds the previous output. When S = 1 and R = 1, the condition is invalid because Q and Q′ may fail to remain opposite.

SR Latch Using NAND Gates

An SR latch can also be made using NAND gates. In this type, the inputs are active LOW. This means the circuit responds when the input is 0 rather than 1. The inputs are usually written as S′ and R′.

Feature	NOR SR Latch	NAND SR Latch
Type of input	Active HIGH	Active LOW
Hold condition	S = 0, R = 0	S′ = 1, R′ = 1
Set condition	S = 1, R = 0	S′ = 0, R′ = 1
Reset condition	S = 0, R = 1	S′ = 1, R′ = 0
Invalid condition	S = 1, R = 1	S′ = 0, R′ = 0

Clocked Bistable Circuit

A clocked bistable circuit changes state only when a clock signal is applied. A clock signal is a regular pulse that controls when the circuit is allowed to change state. This prevents the circuit from changing randomly or at the wrong time.

D Flip-Flop

The D flip-flop is a bistable circuit with one main input called D. The letter D means Data. The D flip-flop stores the value present at the D input when the clock signal is applied.
D flip-flops are widely used in registers and memory circuits because they store data in a controlled way.

JK Flip-Flop

The JK flip-flop is an improved version of the SR flip-flop. It removes the invalid condition found in the SR latch. J acts like SET, while K acts like RESET.

T	Q(next)	Operation
0	Previous state	Hold
1	Opposite of previous state	Toggle

Toggle means changing to the opposite state. JK flip-flops are useful in counters because they can change state on every clock pulse when both J and K are 1.

T Flip-Flop

The T flip-flop is a bistable circuit that changes state when the input T is 1 and a clock pulse is applied. T means Toggle.

A T flip-flop can divide the frequency of a signal by 2. For example, if the clock input frequency is 1000 Hz, the output frequency becomes 500 Hz.

Comparison of Bistable Circuits

Type	Inputs	Main Function	Common Application
SR NOR latch	S and R	Set and reset storage	Simple memory circuits
SR NAND latch	S′ and R′	Active-low set/reset storage	Digital control circuits
Clocked SR flip-flop	S, R and clock	Controlled storage	Sequential circuits
D flip-flop	D and clock	Stores data	Registers and memory
JK flip-flop	J, K and clock	Set, reset and toggle	Counters
T flip-flop	T and clock	Toggles output	Frequency division

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Applications of Bistable Circuits

Computer memory

Bistable circuits are used to store binary information in computers. Since one bistable circuit stores one bit, many bistable circuits are combined to form memory units.

Registers

Registers are temporary storage units in the processor. They store binary data during processing. An 8-bit register uses 8 flip-flops.

Counters

Counters use flip-flops to count pulses. They are used in digital clocks, calculators, speed counters, production counters and school attendance counting systems.

Digital clocks

Digital clocks use bistable circuits to count seconds, minutes and hours.

Alarm systems

In an alarm system, a bistable circuit can keep the alarm ON after a sensor detects danger. The alarm remains ON until a reset button is pressed.

Start-stop motor control

A bistable circuit can control a motor. Pressing START sets the circuit and switches the motor ON. Pressing STOP resets the circuit and switches the motor OFF.

Switch debouncing

Mechanical switches may produce many unwanted pulses when pressed. A bistable circuit can remove these unwanted pulses and produce a clean digital signal.

Traffic light systems

Traffic lights use bistable and sequential circuits to remember which light is currently ON and when to change to the next light.

Water pump control

A school water pump may be controlled using a bistable circuit. The START button sets the pump ON, while a tank-full sensor resets it OFF.

Electronic calculators

Calculators use flip-flops in storage and counting circuits to process numbers.

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Worked Example: Alarm Memory Circuit

A smoke detector in a laboratory sends a SET signal to a bistable circuit when smoke is detected. The alarm remains ON until a teacher presses a RESET button.

Condition	Input State	Result
Smoke detected	S = 1, R = 0	Alarm turns ON
Reset button pressed	S = 0, R = 1	Alarm turns OFF
No new input	S = 0, R = 0	Alarm remains in previous state

This example shows how a bistable circuit provides memory in an alarm system. The alarm does not depend only on the present smoke condition; it remembers that smoke was detected until a responsible person resets it.

Advantages of Bistable Circuits

- They store one bit of information.
- They remember previous states.
- They are used in memory systems, counters and registers.
- They can control machines and keep alarms ON until reset.
- They can clean noisy switch signals.

- They help in frequency division.
- They are building blocks of sequential logic circuits.

Limitations of Bistable Circuits

Some bistable circuits, especially SR latches, have invalid input conditions. If invalid inputs are applied, the output may become unpredictable. Bistable circuits may also be affected by electrical noise if poorly designed. In high-speed circuits, timing problems may occur if inputs change at the wrong time. For this reason, practical digital systems often use clocked and edge-triggered flip-flops.

Difference Between a Latch and a Flip-Flop

Feature	Latch	Flip-Flop
Control signal	Enable signal	Clock signal
Triggering	Level-triggered	Edge-triggered
Response	Responds while enabled	Responds at clock edge
Complexity	Simpler	More controlled
Example	SR latch	D flip-flop
Application	Simple storage	Sequential digital systems

Important Terms

Term	Meaning
Set	making the output Q = 1
Reset	making the output Q = 0
Hold	keeping the output unchanged
Toggle	changing the output to the opposite state
Clock	a pulse signal that controls when a flip-flop changes state
Feedback	connecting part of the output back to the input

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Examination Questions

Scenario 1: School Water Pump Control System

A school uses an automatic water pump to fill an overhead tank. The pump is switched ON by pressing a START button. It remains ON even after the START button is released. When the tank becomes full, a sensor sends a RESET signal and the pump stops.

a) Identify the electronic circuit that can be used to remember the ON state of the pump.
b) Explain why the pump remains ON after the START button is released.
c) State the function of the RESET signal.
d) Draw a labelled block diagram of the pump control system.
e) Give two advantages of using a bistable circuit in this system.

Scenario 2: Laboratory Fire Alarm System

A school laboratory has a smoke detector connected to an alarm system. When smoke is detected, the alarm turns ON and remains ON until the laboratory technician presses a reset button.

a) Explain why a bistable circuit is suitable for this alarm system.

b) Identify the SET input in the system.
c) Identify the RESET input in the system.
d) State the two stable states of the alarm system.
e) Explain why the alarm should not switch OFF automatically when the smoke clears.

Scenario 3: School Gate Digital Counter

A school installs a digital counter at the gate to count learners entering the compound. Each learner passing through a sensor produces one pulse. The counter uses flip-flops to store and update the number counted.

a) State why flip-flops are useful in counters.
b) Name the type of flip-flop commonly used for toggling.
c) Explain the meaning of toggle.
d) Describe what happens to the output of a T flip-flop when T = 1 and clock pulses are applied.
e) Give two other applications of flip-flops apart from counters.

Scenario 4: Computer Memory System

A computer stores data using electronic memory cells. Each memory cell can store either 0 or 1.

a) Name the circuit that can store one bit of information.
b) State the two possible values stored by the circuit.
c) Explain why many bistable circuits are needed in computer memory.
d) State one difference between a latch and a flip-flop.
e) Give one reason why bistable circuits are important in computers.

Scenario 5: Workshop Machine Control System

A workshop machine has a START button and a STOP button. When START is pressed, the machine starts and continues running. When STOP is pressed, the machine stops immediately.

a) Explain how a bistable circuit can be used in this machine.
b) Which input acts as the SET signal?
c) Which input acts as the RESET signal?
d) State the two stable states of the machine control system.
e) Explain one safety advantage of having a RESET or STOP function.

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Scenario 6: School Bell Timing System

A school bell system uses a digital timer. The timer contains flip-flops that count pulses from a clock circuit. When the correct number of pulses is reached, the bell rings.

a) Explain why flip-flops are used in digital timers.
b) State the role of clock pulses in the timing system.
c) Name one flip-flop that can be used for counting.
d) Explain how a T flip-flop can divide frequency.
e) Give one advantage of using digital timing systems in schools.

Conclusion

Bistable circuits are essential building blocks in digital electronics because they can store one bit of information. They have two stable states, represented by 0 and 1. The circuit remains in one state until an external input changes it.

Bistable circuits can be made using transistors, NAND gates, NOR gates and flip-flops. Common types include SR latches, clocked SR flip-flops, D flip-flops, JK flip-flops and T flip-flops.

They are widely used in computer memory, counters, registers, digital clocks, alarm systems, traffic lights, motor control systems, water pump control systems and calculators. Understanding bistable circuits helps learners understand how digital systems store information, remember previous states and perform sequential operations.

The first time SET (Red line) goes HIGH it makes the OUTPUT (Green line) go HIGH. Making the SET go HIGH again has no further effect - the OUTPUT stays HIGH. Making the RESET (Blue line) go HIGH makes the OUTPUT go LOW.
Making the RESET go HIGH again has no further effect - the OUTPUT stays LOW. The SET and RESET pulses can be momentary pulses as shown by the final RESET pulse which is just a very narrow, short pulse.

BUFFER

A buffer is a simple circuit where the input value is the same as the output value. This means if the input is off the output will be off. If the input is on the output will be on. There are many reasons why a buffer may be added to the circuit. In most cases, it is to ensure a strong output signal. The input voltage or current may be a low value and running the input through the buffer helps ensure a consistent output level. There is more than one way to make a buffer so check out the buffer article for more information.

INVERTER

The inverter uses one transistor to take an input signal and make the output signal the opposite. This means if the input is off the output will be on. If the input is on the output will be off. Many people say that a NAND gate is an AND gate with an inverter. These gates do have inverted logic but a NAND gate is not an AND gate with an inverter. In fact, the NAND gate can be made with two transistors and the AND gate requires three transistors when sending an output. The AND gate is basically a NAND gate with an inverter. However, the LED in the circuit is also flipped as the current is flowing through the circuit in a two-transistor AND gate. The current is flowing toward the second ground and can be used as an output signal in a three-transistor AND gate.

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EXAMINATION ITEMS

MODERN PHYSICS

The government has discovered a precious and rare mineral in a certain part of the country. A team of men picked samples and kept them in a store of one of the hospitals where photographic plates are also stored. The mineral was checked on regularly and they made the following observations;
All photographic plates had darkened. Its mass reduced spontaneously with time as shown below

Mass (g)	200	150	70	35	25
Time (days)	0	4	16	28	30

Task: As a physics learner,

(a) Use the graph to estimate its half-life;
(b) Support the view that the mineral is radioactive.
(c) Explain the best way of storing this rare mineral.
(d) What are the dangers of exposing this mineral to the public?

A government has constructed an underground pipe to transport its oil over long distances. When tested, the pipe is suspected to leak in a 100 m section and the leakage point is not easy to identify since the pipe is underground. An engineer has proposed mixing some radioactive substance of short half-life in the oil and using a detector to find the spot where the oil is leaking. The radioactive substance to be used should diminish activity to less than 10 s^{-1} within 1 hour. The engineer has identified one substance to be used and found out that its activity when mixed with the oil, reduced from 480 s^{-1} to 60 s^{-1} in 30 minutes. The engineer has not yet drawn conclusions about this choice of substance and may need your help.

Task: Assist the engineer to:

a) Determine the half-life of the radioactive substance he is about to use.
b) the substance should now be mixed in the oil and start tracing the leakage.
c) Explain how the leakage is traced using this method.
d) Explain why the substance to be used should have a short half-life.

A factory uses a gamma ray source to inspect the quality of manufactured metal castings. The management has however received reports of the need to protect workers from the radiations using aluminum but are not so sure of how thick the aluminum sheets should be. They are also wondering how else the workers can be protected.

Below is a table showing the relationship between thickness of aluminum and gamma ray intensity detected by a radiation counter.

Aluminum thickness(mm)	0	2	4	6	8	10
Gamma ray intensity (units)	280	150	70	40	18	10

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Hint; ***Gamma radiators are safe if intensity is below 25 units.***

Use your knowledge in physics to;

(a) Explain to the management why the workers need to be protected.
(b) Suggest other ways in which the workers could be protected.
(c) Determine the ideal thickness of the aluminum sheets.
(d) Identify other uses of the gamma rays.

In a certain hospital, an X-ray machine is used for many purposes. A cancer patient was told the doctors were going to use radiotherapy to treat cancerous cells in his body.

Since the X-ray machine in the hospital could be adjusted to produce X-rays of wave length 0.01 *nm* and 10 *nm*. The patient wondered which wave length would be used on him and how it would be done safely. The patient also wondered how else the X-rays can be used. Use your knowledge of physics;

(a) To explain to the patient how the X-ray machine will be safely used.
(b) To explain to the patient how x rays can be used for other purposes in life and precautions that should be taken to ensure safety.

In a S3 class, students are required to identify how to use radioactive materials to make electricity. They proposed the use of Uranium-235 whose half-life is 705 million years instead of materials with short lives. They also suggested the nuclear plants should be located in an isolated area but

couldn't tell why. All the workers would also be required to wear Personal protective equipment. The student however couldn't tell how the radioactive materials are used to produce electricity. In addition, they were to be given 2kg of a radioactive material of half-life 4 months. They did not know when more radioactive materials would be required. Since the nuclear plant would produce sufficient energy when more than 100 g of radioactive materials are present.
Use your knowledge of physics to;
(a) Explain why materials with long half-lives are required and why the nuclear plant should be in such a location.
(b) Explain why the workers should wear Personal protective equipment.
(c) Help the learners understand how electricity can be produced using such materials.
(d) Determine when more nuclear materials would be needed.

SATTELLITES AND COMMUNICATION

An article in the newspaper gave information that on 02 / December 2024, Ugandan engineers with the help of Japanese engineers launched a satellite. The literature teacher who picked interest in the article found new words like artificial and natural satellites. He developed a number of unanswered questions which could be answered by a physics learner like you.
(a) Explain the difference between the two types of satellites in the article.
(b) With reasons, justify why Uganda should spend all that much money to launch its own satellite.
(c) Incase Uganda is to develop a super rocket capable of reaching different planets. List with reasons the planets it can land on and planets it cannot land on.

A soldier who travelled to another continent was surprised that his watch (still set to his home country time) read 10:00 am while it was 9:00 pm in the country he had gone to. He also noticed that the country he had gone to was covered in snow which he had never seen in his home country. In fact, his home area had been in a dry season for about two months prior to his trip. After a month he observed that the appearance of the moon kept on varying. This made him wonder. After trying to contact his relatives through a letter, he was told he could make a telephone call to his relatives. This surprised him as he thought a person could only make calls to a country, he is in.

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Task: Use your knowledge of physics;
(a) Explain why there was a difference in time
(b) Explain why the country he was in covered with snow yet there was a long period of drought in his home area.
(c) Help the soldier understand why the appearance of the moon kept on changing
(d) Help the soldier understand how telephone calls like the one he made one possible.

A tourist who went to a coastal town was surprised by a number of things he encountered. He checked into his hotel room at about 11:00am when the coastline was about 100m away. On getting out of his room after about two hours, the coastline had shifted and about 10m away from where he stood when checking into his hotel room. This greatly surprised him. At night, the sky was filled with so many stars of different colors and brightness, he wandered how these stars came into existence and why they appear in that way. He decided to drive around the town in the evening. After turning on the engine without fastening his seat belt and starting on his journey, an alarm went off. The tourist wondered what made the alarm to go off.
Task: Use your knowledge of physics to;
(a) Explain why the coastline changed position

(b) To help the tourist understand how the stars were formed and why they are different in appearance.
(c) To explain to him how alarm system works.

LIGHT AND WAVES

During a science fair held in a school main hall of size of hall is 40m by 30 m, a number of complaints and observations were made;
The speakers in the hall produced sound which was loud and distorted. Many of the attendees thought it would damage their ears.
Despite the fact that all the lights in the hall were switched on, the hall appeared dimly lit. A mirror that had been intended to be used for magnification of objects surprised everyone when it formed diminished images despite the position of the object. Later, a laser light was made incident on a semicircular prism. Initially, the light rays followed the path as shown in (i) above. However, as the angle I increased to 45°, the ray changed path to the one in (ii).

Hint: Wavelength of waves produced by speaker = 8.0cm, Speed of sound = 330 ms^{-1}, Refractive index of air = 1.00, and Refractive index of glass =1.5
Task: Use your knowledge of physics to;
(a) Explain the cause of the distortion of sound, how it can be reduced and determine if the sound was dangerous.
(b) Explain how the dimness of light can be improved.
(c) Identify a better mirror for the desired purpose.
(d) Help observers understand why the light behaved the way it did.

Soldiers who went for a training camp made a number of observations during a one month stay. On a certain hot day, they noticed pools of water on the tarmac road. The pools of water however disappeared as they came close to them. On a certain rainy day, there was lightening followed by a loud thunder. The soldiers were surprised by the occurrence. The soldiers were told that one month before their camp started, the area became totally dark at about 1:00pm. Light was however restored after about 80 minutes which scared people in the area. One of the soldiers wanted to explain the occurrence using a slide projector. He intended to place a slide 20cm from a convex lens the focal length 10cm with an intention of producing an image of magnification 4 but was not sure if it would work.
Hint; Speed of light in a vacuum = 3 x 10^8 ms^{-1}, Speed of sound = 330ms^{-1}
Task: Use your knowledge of physics to:
a. Explain to the soldiers what the pools of water on the road were.
b. Explain to the soldiers why the lightening was seen before the sound from the sky.
c. Help the soldiers understand why there was darkness during day time.
d. Help the soldier determine if the projector would produce the desired magnification

The students in a particular class visited a laboratory with a white bulb and a red one, to observe a glass tank filled with water with a white base at the bottom. Modifications were made to create a shallow end on one side of the tank using glass material. To their surprise, when they struck the water's surface at the shallow end with a long rectangular rod at a frequency of 80 Hz, they noticed that the spacing between successive crests changed from 2.5cm to 5cm. Additionally, they were disturbed by the distortion of ripples as they struck the tank walls. They were also surprised to see the base turning black when it was replaced with a yellow sheet and the red lights switched on.

Hint; the glass tank would break if the velocity of the waves that hit it is greater than 20ms^{-1}

Task: Use your knowledge of physics to:

a. Determine if the ripple tank will break.
b. Explain the reason for the change in the distance between the ripples and its impact on the velocity of the ripples.
c. Explain what distorted the waves and how it could have been reduced.
d. Explain why the yellow sheet changed color when the red lights were switched on.

During the construction of a multipurpose hall of size 70m by 40m in a school, the students have been asked to raise challenges that could arise after the hall's construction. They are listed below;

- There could be a distortion of sound as a result of two sounds being heard.
- The hall could be dimly lit because of the paint color used to paint the walls.
- There could be disturbance of the neighbors in the community. During the day, the neighbors that would be disturbed wouldn't be very far but at night, even those outside the school would be disturbed.
- Complaints could arise from the wrong type of mirrors installed in the bathrooms.
- Complaints would have arisen from fears due to insecurity from not checking under cars.

Task: Use your knowledge of Physics to;

a) Identify the cause of the distortion of sound and structural adjustments that can be made to ensure the distortion is minimized.
b) Identify the paint color to use to increase the amount of light in the room.
c) Establish how the sound would reach the community, how it can be reduced, and the difference in the distance that the sound from the hall reaches.
d) Identify the type of mirrors that should be installed in the bathrooms and those that should be used to check under the cars.

One hot afternoon some learners walked along a tarmac road in the west ward direction to check on a new swimming pool. On the road, they saw a speeding car at a distance and its engine sounds kept on reducing as it moved further away. They also saw what looked like water near the car; but the water disappeared when they reached the spot where they had seen it and it reappeared to another spot ahead. Later on, the weather changed and there was a light drizzle though the sun was still bright. In the Eastern direction, they observed a semi-circular distribution of colours in the sky. They finally reached the swimming pool; however, the pool-attendant warned them to be careful when they are to use the swimming pool because it may appear shallow when filled with water. The adventure ended in arguments because the learners had different views about the observations and experiences, they had that day.

Task: Use your knowledge of physics to assist the learners to understand:

(a) Why the sounds they heard from the car kept on reducing?
(b) The process that leads to what they observed on the tarmac road.
(c) The process that leads to what they observed in the sky.
(d) Why swimming pool appears the way the attendant told them?

During the music gala in a hall, one of the adjudicators observed the following;
On entering the stage, the colour of dress of one presenter changed from a yellow dress with red dots to a red dress with black dots. The sound from the nearest loud speaker reached him after 0.05s. She kept on hearing voices of two people singing on stage, yet there was only one person on the stage.

Hint: *Speed of sound in air =320 ms^{-1}*

Task: Using the knowledge of Physics, help the adjudicator to understand;
(a) Why the colour of the dress changed.
(b) Why the sound was reaching her after 0.05s.
(c) The origin of the second voice and how it can be minimized.

A tycoon is to construct a first-class hotel and as he consulted from the technical personnel, the following guidelines on facilities he wanted to set up were given:

- The swimming pool should have a label of its depths at different points to avoid relying on a deceptive look.
- The multipurpose hall must have a soft wall or it must use curtains along the walls.
- Each entrance should strictly have white lights as the inside of the hall may have other LED lights for decoration.
- The security personnel should have devices to check under the cars entering the hotel, as a way of ensuring hotel security.
- The tycoon is not knowledgeable about the importance of such guidelines in his upcoming investment and is seeking for explanations.

Task: Using the knowledge of physics, help the business man understand;
(a) The cause of deceptive look.
(b) The reason behind multipurpose hall having a soft wall and curtains.
(c) Why the entrance must have white lights and how decoration on individuals is attained from inside the hall.
(d) Which kind of ***materials*** are needed in making the devices to be used while checking ***under*** the cars entering the hotel.

In a town, there is a woman who uses loud horn speakers to broadcast various information to the community. She has received the following concerns from the members of her community;

- Listeners at different locations have noticed a difference in time in which the sound reaches them.
- People who are at far distances are unable to receive the information broadcast by the speakers.
- People are complaining about too much noise from the speakers, some of whom are not interested at all in what is being broadcast.

Because of those concerns, the town council leadership has advised the woman to set up a radio broadcasting station and the broadcasting authorities allocated her a radio frequency of 87.8 MHz's She is ready to take up the advice, only that she lacks enough knowledge to guide her more. **HINT:**
Speed of light in air = 3×10^8 ms^{-1}

Task: Using your knowledge of Physics, assist the woman to;
(a) Differentiate between the type of waves produced by her current system and those to be produced in the system proposed by the town council leadership.
(b) Understand why the new method of broadcasting will not cause a problem of noise pollution.
(c) Understand why the new system of broadcasting is able to reach those who are far away and they get the broadcast almost instantly.
(d) Determine wavelength of the waves used in broadcasting in the new system.

MECHANICS AND HEAT

Workers at a construction site are meant to raise pieces of scrap of mass 6 kg through a height of 15m. Their boss always complains that the workers who carry the pieces of metal do the work slowly, especially

in the afternoon when the temperatures are high and in the morning when it is cold. In response, the workers claim their hands are burnt by the hot metals which slows them down. One of the workers suggested they use a pulley of velocity ratio 4 and an efficiency of 80%.

Task: Use your knowledge of physics to:

a. Explain why the metals are very cold in the morning and hot in the afternoon.
b. Draw a design of the required pulley and explain how it can be used to solve their problem.
c. Determine the minimum force required to ensure an 80% is achieved.

The string they used had a mass of 120g and a specific heat capacity of 2510 $JKg^{-1}K^{-1}$, and the work done to lift the load would be converted to heat energy in the string at the contact point of the pulley.

Hint; The string would break if its temperature reaches by 28^{o}C.

d. Determine if the string suggested above would be suitable for the purpose.
e. Suggest ways in which the efficiency of the pulley system can be improved.

During a party, 2 liters of water at 24 ^{o}C were served to a man and a woman. They complained that it was warm and were given 50g of ice at -10 ^{o}C blocks. They mixed the water and blocks in a wooden container with a negligible specific heat capacity. They were surprised by the ice cubes disappearing in the water. The man put his mixture in a plastic container (SHC = 2800 $JKg^{-1}K^{-1}$) while the woman put her mixture in a metallic container (SHC= 800 $JKg^{-1}K^{-1}$). They were surprised to find their water at different temperatures after some time. *HINT: Specific Heat capacity of water = 4200 $JKg^{-1}K^{-1}$, Latent heat of fusion of ice = 340000 JKg^{-1}*

Task: Use your knowledge of Physics to:

a. Determine if the water cooled when mixed with ice.
b. Why do the ice cubes disappear when mixed with water?
c. Explain why there was a difference in temperatures in the water kept in the plastic and the metallic container.

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Students who visited a bridge at a dam were told a number of measures followed in the construction of a dam above a bridge.

The walls of the dam are made thick at the bottom than they are at the top. Reinforced concrete is preferred to normal concrete on the bridge.

Gaps are left on the upper part of the bridge and not the lower one. Steel cables with a maximum breaking stress of $5x10^{8}Nm^{-2}$ and cross sectional $6.0x10^{-4}$ m^{2}. The students were curious to know if the truck of mass 20,000kg could safely pass over the bridge

TASK: Using your knowledge of physics;

(a) Explain to the students why the walls of the dam are made thicker at the bottom.
(b) To explain what would happen if the concrete used is not rein enforced.
(c) To help the learners understand the importance of the gaps left.
(d) To determine if the truck could safely pass over the bridge.

A driver of a certain vehicle intended to determine the average velocity covered during a section of a journey where the speed limit is 40kmh^{-1}. He started at rest and accelerated to 20ms^{-1} in five minutes. He maintained this velocity for another 5 minutes before suddenly coming to rest after being stopped by a policeman. As the car came to rest, he jerked forward which worried him. The policeman told him he was over speeding which he denied. He also told him his tyres were worn

out which posed a very big risk to his life. Just before starting the engine, he went to check the water levels in the engine and noticed it was low. In addition, he noticed the radiator had very small black tins which surprised him as he thought the bigger tins would be better. After packing the car, he noticed that a white car of similar make that had been packed in the same spot like he was cooler on the inside than his black one.

TASK: Use your knowledge of physics to;

(a) Determine if the car breached the speed limit.
(b) Explain how the driver can avoid jerking forward again.
(c) Explain why the tyres being worn out presented a risk the man driving the car.
(d) To explain the relevance of water in the engine and why the radiator tins were black and thin.
(e) Explain why the inside of the black car was hotter than the white car.

On a sports day held in a wet muddy field, athletes were told to wear shoes with sharp spikes in order to be able to run successfully. After the race, the athletes were given thick black woolen jackets instead of white ones. Some athletes who wanted to drink water between 10 0C to 15 0C were told the only water available was hot (at 100°C) that had been kept in a vacuum flask. This surprised the athletes as they wondered how it was possible to keep water hot for such a long time. Also available were 2kgs of ice cubes and a steel pan of mass 0.6kg in which to mix them. They wondered if the water would cool to the desired temperature after the ice was put in it.

TASK: Use your knowledge in physics to;

(a) Explain why the athletes were advised to use shoes with spikes.
(b) Help the athletes understand why they were given black thick jackets.
(c) Explain how the flask is able to keep water hot for a long time
(d) Determine if the water attained the desired temperature.

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ELECTRICITY AND MAGNETISM

During a science project, learners are told that electricity at a substation is transmitted at 13 kV with a current of 0.05A using thick aluminum wires for use inside a house at a voltage of 240 V. The house has two television sets (TVs) that operate on direct current but should be connected such that they receive maximum current and function properly. The learners, however, couldn't get an explanation of the issues mentioned.

Task: Use your knowledge of Physics to;

a. Understand how the voltage is changed from 13 kV to 240 V.
b. Why thick aluminium wires are used during power transmission.
c. Determine the current in the house if 20% of the electrical energy is lost during voltage change.
d. Account for the energy losses as the voltage changes and how those losses can be reduced.
e. Understand how the current used in the TV is changed from alternating current (AC) to direct current (DC).
f. How the Television Sets should be connected to ensure they receive maximum current and function properly?

An electromagnet as shown in Figure below is constructed by winding a wire around an iron nail of resistance 0.5Ω, connecting it to a battery of four cells of EMF 1.5V each, and then placing it above a tin containing iron fillings, some of which are attracted to the nail. Upon disconnecting the battery, most iron fillings fall off. However, when the iron nail is replaced with an identical steel nail of the same size,

the pins are attracted slower. Surprisingly, when the EMF source is disconnected, just a few of the iron fillings fall off.

Task: Use your physics knowledge to:

a. Explain how the electromagnet operates.
b. Use domain theory to explain how the nail becomes a magnet.
c. Elaborate on the difference in the time taken before the steel and iron nails start attracting small pins.
d. Explain what would happen if a battery of 2 cells of the same EMF was used instead of one of 4 cells.
d. Identify other factors that could contribute to an increase in the number of nails being attracted. f. Suggest ways in which the magnetized nails can be made to lose their magnetism.

A certain household has a set of appliances as listed in the table below.

Appliance	**Power rating**	**Time of use**
4 bulbs	**20 W each**	13 hours every day
Cooker	**2500 W**	4 hours every day
Flat iron	**1500 W**	5 hours each week
Electric fence of low resistance wire	**2200 W**	10 hours every day

The owner of the household while making a budget for how much money would be required every week to cater for the electricity bill. He also wondered how the sockets for those appliances should be connected to ensure high current flows and why low resistance instead of high resistance wire is used. *Hint; The owner only intends to spend sh.50000 on electricity every week.*

Task: Use your knowledge of Physics to;

a. Determine if sh. 50000 would be enough to cater for the electricity bill for a week.
b. Explain how the sockets of the appliances should be connected to ensure maximum current flows
c. Explain why low-resistance wires are used for the electric fence.
d. Suggest measures on how to reduce the electricity bill.

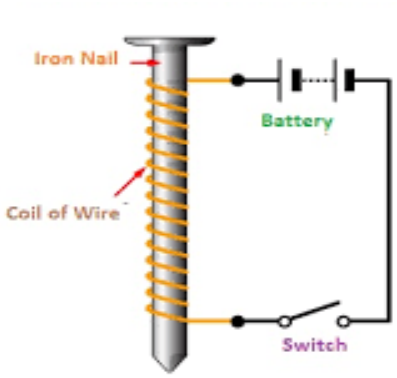
A model farm uses a windmill to generate electricity to run a water pump that is rated 240V, 1500W. People who went to visit the farm were told the wind mill is connected to a generator whose operation they didn't know. They also wondered how the pump is able to work when there is no wind yet water is required and how the efficiency of the generator can be improved. They also spoke to a technician who told them the pump needs to be connected to a fuse as a safety measure. One of them wondered how it works and what its specifications should be.

TASK: Use your knowledge of physics to;

(a) Explain how the generator works.
(b) Help the people understand how the wind mill is able to supply power when there is no wind.
(c) To identify ways in which the efficiency of the generator can be improved.

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(d) To help them understand how the fuse works and determines its power rating.



Students visited a busy scrap yard and noticed that metallic scrap was packed in metallic boxes. The work was however tedious. They suggested since the area is connected to electricity; they could provide a solution to solve the problem. They provided the circuit in **Figure** as a solution. The owner of the yard could not understand how the set-up works. Many students believed a set up like that would work however some disagreed.

The ones who disagreed said it would only be effective if the circuit was connected to a direct current source. This presented a challenge as the only power source available is at the yard was alternating current. They also wondered how the set up could be improved to help it carry heavier items. One suggested this could be done by replacing the coil of 10 Ω with another 4 Ω.

TASK: Use your knowledge of physics to;

(a) Explain to the scrapyard owner how the set up will help in solving the problem.
(b) Explain how the current source can be changed to the desired one.
(c) To determine if a change in the coils would make work easier.
(d) To identify other ways of making the work easier.

A home has a solar panel and a 12 V battery. The solar panel generates 52 V of d.c power but only 14V in needed to charge the battery. The home owner wants to install a bulb that automatically comes on when night falls. He is in possession of the following electronic components; an AND gate; an OR gate, a NOT gate, a light dependent resistor L, which conducts when light falls on it, a 200 ohms resistor R and a 600 ohms resistor. So far, he has connected some of the components. He is not sure if his system will function as required and he has failed to position the remaining the components.

Task: As a learner who has studied physics, help the home owner to:

(a) Make necessary calculations to find out whether the charger circuit will be able to efficiently charge the battery.
(b) Identify the type of gate, X; giving reasons for your response.
(c) (i) Identify the gate to be connected at a, b and c so that the light bulb is automatically switched on only when night falls.
(ii) Draw the circuit symbol for the gate chosen in (c) (i). (iii)Draw the truth table for the gate chosen in (c)(i).

During charity work in the hospital by Red Cross Society of one school, a certain liquid containing a radioactive material spilled on one student accidentally, having been placed on an open place by a medical intern. The hospital authorities immediately took the student for a mandatory self-isolation within the hospital premises. The parents accused the hospital of negligence and demanded to see their child in a weeks' time.

Hint:

- The liquid had an activity of 250 counts per second when tested immediately, with a half-life of 2 days.
- The back ground count rate in the laboratory was 50 counts per second.
- The student can be safe to re-join the public if the count rate falls below 10 counts per second.

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Task: Use your knowledge of physics to:-
(a) Determine how long the student will be self-isolated.
(b) Enlighten the parents on the dangers of having their child at home without medical monitoring. (c) Explain to the medical intern how such materials should be handled.

In a certain family, a child got an accident while playing with his friends and it was suspected to be broken leg. The family was referred by nearby health facility to go for X-ray radiography. The family already had some false information about how X-rays are produced and the related dangers to their child, therefor they were unwilling to go for it. The X-ray machine requires a voltage of about 4 kV to operate but the available main voltage supply is 10 kV. ***Hint: Available resistors are 300 Ω and 200 Ω***
Task: As physics learner, Help the family to:

a. Clear the false information about the X-rays.
b. Understand how X-rays can be used to solve the problem of the family.
c. Using the knowledge of digital electronics, help your friends understand how a 10 kV voltage would be used to operate the machine.

As a man in Uganda was watching an educative TV show at 11:00 am, the program was interrupted to bring a live broadcast of some educative night time events in South Mexico. The live broadcast showed some children that who were viewing a dark sky on a cloudless, clear night. The dark sky had greyish areas and many bright twinkling spots of different extents of brightness and colours. Some of the bright spots appeared to be moving. The TV presenter reported that unlike night time, there was only one outstanding bright object in the sky during day time and that it is part of a continuously evolving universe. The man was unable to understand this TV production and wished to have a clear explanation.
Task: As physics student, help the man to understand:
(a) (i) what the observed grey areas that the learners saw represent.
(ii) what the artificial bright spots represent and their significance in the universe.
(b) why there are outstanding bright objects that the TV presenter mentioned, and their significance in the universe.
(c) why there existed:
(i) different levels of brightness of the bright spots. (ii) differences in colour of the bright spots.

After research work, your group has presented the following article that was collected from a journal on nuclear science….
At the end of your presentation, some classmates have not understood the ideas in it, and have requested you on behalf of the group to give them more details.
Task: As a learner of Physics assist them by:
(a) (i) explaining how the discoveries on radioactivity have played a great role in enhancing the different sectors.
(ii) explaining how harmful the discoveries can be, in the field of medicine.
(b) showing, using a well-balanced equation, how uranium reduced to thorium.
(c) determining the time taken by the uranium isotope to reduce to half its original size.

In some southern part of South Africa, people were ordered to vacate their areas and relocate to other parts of the country in anticipation of the heavy rains in the coming months, that are likely to cause flooding

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and landslides. The Local authorities have been requested by the Ministry of Disaster Preparedness to sensitize the people about the issues. However, they are finding difficulties in explaining to the people: -
• Why rains will be experienced in their area while other parts of the continent are experiencing dry season.
• How it is possible to predict accurately weather patterns before they occur.
• Why there are two seasons threatening them with high rainfall in a period of just a year.

Task: As a student of physics, help the Local authorities to understand: -

(a) The variations in seasons as realized by the locals at the same time of the year. (b) How the weather is always accurately predicted before it happens.
(c) Why the community is experiencing that challenge twice in the same year.

In recent times Uganda joined a number of countries that have launched an artificial satellite. When the satellite is in orbit, the sun is the major source energy needed for operation of devices on the satellite. Some Ugandans think that the government is wasting resources in such activities and are planning to make a protest. You have been invited to make a presentation that can answer these Ugandans.

Task: In your presentation:

(a) Explain (i) why it is important for a country to have that type of technology. (ii) why that object is called "artificial".
(b) (i) Inform them about other bodies that are kept in this type of motion. (ii) Explain why such bodies have this kind of motion.
(b) (i) Explain how the major source of energy produces energy.
(ii) Explain the other roles of the major source of energy, on earth.

An elder in a certain village was narrating to his family members his experience of a visit to London. He said that in London, day time was longer than night time with 16 hours of day and 8 hours of night, this was unique to family. He also added that stars were rare organisms that died at day time and resurrected at night. Furthermore, he stated that the shape of the moon kept changing over a month's cycle.
The family members, in comparison, said that some of the elder's experiences were equally observed in their village but unfortunately did not understand these occurrences.

Task: As a student of physics, help the elder and his family to understand;

a) how the unique observation in London came about. b) the observation of stars at day time and night time.
c) why the shape of the moon keeps on changing over that period.

A rider who has been using a simple bicycle has purchased a new and improved one. The total mass of the rider and this new improved bicycle is 80 kg. The rider uses this bicycle to go up a hill of height 5 m in 20 seconds and he is 75% efficient. On the other hand, the simple bicycle has two toothed wheels are connected by a chain, with 48 teeth in the big toothed wheel and 16 teeth in the smaller toothed wheel. The rider is looking for more explanations to convince his brother that he is not just wasting money by buying the improved Bicycle.

Task: Using your Physics knowledge, help the brother to:

(a) (i) determine the velocity ratio of the simple bicycle.
(ii) explain the advantages and disadvantages of having a high velocity ratio in the connected toothed wheels.
(b) determine the power used by rider to move up the hill using the improved bicycle.

(c) understand why the rider preferred to use the improved bicycle for riding up a hill.
(d) Explain why it is important for the rider to sweat.

A S.4 child and her mum have gone to buy some cooking utensils. The mum explains to the shop attendant that she usually gets problems in cooking beans since they take long to get ready when being boiled in water, leading to wastage of energy and time. The attendant shows her an appliance claiming it cooks fast due to its features. The lady is not convinced about the appliance and wishes to get more information before buying it; so she asks the child to explain more.

Task: Assuming that the lady is your parent or guardian, use knowledge of Physics to educate her on:

(a) Why the appliance makes the beans get ready faster.
(b) Why the steel pan should have a plastic handle.
(c) Why the steel pan should have a thick body.
(d) Why steel is an important property in this appliance.
(e) Why the bottom of the pan and its sides are made of different colours respectively.
(f) The different means by which heat from the heat source can reach the beans.

A business woman intends to install a storage gravity water tank in his home which should supply pressure at 10 kPa. She also needs her tank to have a ladder with steps each of height 40 cm for climbing up to clean his tank. Due to extreme weather conditions the tank may burst as a result of the expansion and contraction of the pipes used. To avoid this, the business woman has been advised to buy a pipes made of a suitable material and get a person who will fit them well. Unfortunately, she does not have enough knowledge about such installation works and is looking for further assistance. Hint: Density of water = $1gcm^{-3}$. Acceleration due to gravity = $10ms^{-2}$

Task: Using the knowledge of physics to help the business woman to;

(a) Determine the height the tank must be raised to, and the number of steps to be put in the ladder.
(b) Understand how the pipes would be connected to the tank, and the suitable material of the pipes to be used would be determined.

Your friend travelled in an old ramshackle vehicle for an appointment. The first 60 km they covered were on a rough road and the journey turned out to be bumpy and she felt like she was being carried in a wheel barrow. This made her recall Hooke's law which they learnt in Physics at school. After the bumpy section, the road was now smooth for the remaining 20 km where they moved at a speed of 80 kmhr-1, which is the traffic speed limit for that road. For the entire journey she spent 1 hour on the road and unfortunately missed the appointment. She has been given a new appointment at the same time tomorrow. As she narrates this story to you, she is not sure if she will be able to make it for the appointment, and is seeking for you advice and help in this matter.

Task: Help your friend to:

(a) Differentiate between a wheelbarrow and the car, with reference to her experience.
(c) (i) Describe the important property of materials that is useful and applied in the vehicle for a better experience.
(ii) State the law that applies to materials as referred to in your friend's experience.
(d) Determine the speed at which she moved on the bumpy section of the road.
(e) Determine and advise her on how much earlier she should start the journey if she is to be on time for the new appointment, given that she is to use the same vehicle on the same road.

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A business lady operates a restaurant which serves food and drinks. In the morning as she was driving her car to his restaurant, it developed a problem. There was a lot of steam coming from the bonnet and the engine stopped working. The mechanic she invited told her that the engine had overheated because there was little water in the radiator. After filling the radiator with water the car started working. When she reached her restaurant, she prepared 0.02 kg ice cubes for customers who wish to add them to their drinks. She then steamed the matooke for lunch and proceeded to make her special drink that she serves out in plastic glasses that hold 0.5 kg of the drink.

Task: Assist the business lady to;

(a) (i) understand the features that make her car radiator efficient for its purpose. (b) (i) identify the various states of water that she used that day.

(ii) explain why each of the states of water works very well for the purpose it served that day.

(d) determine the specific heat capacity of the special drink, given that a customer needed four ice cubes to reduce the temperature from 30 ^{o}C to 10 ^{o}C. *Hint: Specific latent heat of fusion of ice is 336000 Jkg^{-1}, Specific heat capacity of water is 4200 Jkg^{-1}K^{-1}*

A class intends to undertake a physics project of making a thermometer to be used in a physics laboratory. At the planning stage, the following questions have come up; how to select the suitable liquid to be used; and how to come up with the graduation on the thermometer. They have approached you for some ideas to help them produce a working product.

Task: As a physics learner help your friends to, understand;

(a) (i) What they should consider when choosing a suitable liquid for this project.

(ii) How their thermometer should be graduated.

(b) Determine the density of the liquid to be used in the absence of a measuring cylinder or any other apparatus for measuring volume.

Hint: the volume of the liquid required is 5cm^{3}. Knowledge of principles of moments to determine density.

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Your parents operate a diary business and buy five jerry cans daily. Before buying milk from any farmer, its purity is tested using a hydrometer. One evening the hydrometer accidentally fell down and stopped working yet the milk had to be tested. You advised them to keep the milk into a refrigerator which automatically switches off when the temperature of the milk has dropped from room temperature to a temperature of 10 ^{0}C. The parents were worried that their milk would get spoilt and hence make losses; they wanted you to explain and assure them if your advice would really work. ***Hint: Volume of each jerry can of milk is 20 litres, Room temperature = 24 ^{0}C, Specific heat capacity of milk = 3.14 Jkg^{-1}K^{-1}, Density of pure milk = 1035 kgm^{-3}, and Materials to use include; beam balance, measuring cylinder and beaker***.

Task: Using the knowledge of physics, assist your parents to;

(a) determine the purity of the milk in absence of a hydrometer.

(b) understand how much heat energy is withdrawn by the refrigerator from the milk.

(c) understand how the features of the device you proposed, are able to save the milk from getting spoilt.

In a certain home, it is the children's responsibility to draw water for cooking and also to boil it for drinking. They draw the water from an underground well using a rope and a bucket. The children have raised a complaint to their father that pulling water using a rope and a bucket is tiresome and are suggesting that a simple machine for drawing water be designed for them. Every day, they use an aluminium saucepan

of mass 2 kg to boil 10 litres of water from a temperature of 24 0C to 90 0C. The father is planning to address his children's concern but is not certain of how to solve it, and is looking for guidance.

Task: Using the knowledge of physics, help the father to;

(a) (i) design the simple machine that can be used and explain how it works.
(ii) understand how to improve on efficiency of the machine designed in (a)(i).
(b) understand how much heat energy is used daily by the family to boil drinking water.

Hint: Specific heat capacity of aluminum = 900JKg-^{1}K^{-1},
Specific heat capacity of water = 4200 JKg^{-1}K^{-1}
Density of water = 1000 kgm^{-3}

A S.4 boy has researched about a certain device that produces rotation when connected to a source of electricity and is found in appliances such as fans, cassette players and disc players. The boy has removed such a device from an old music cassette player at home and according to his research it can be converted into a dynamo to light his bicycle's headlamp. The boy is looking for assistance on how this can be done.

Task: Help the boy to:

(a) describe the construction and working of the device to produce rotation.
(b) describe how the device is to be converted into a dynamo, and how it will work to light the head lamp.
(c) improve the efficiency of the device.

Your neighbour bought an electric kettle and connected it the first time to a power socket to boil 2 kg of water. Immediately, the neighbour heard a small explosion in the kettle and it stopped working. The neighbour called you for help and on inspecting the kettle, it had the following features; a two-pin plug connected to the kettle's cable. The cable had three wires in it, one with red insulation connected to the first pin, the second with blue insulation, connected to the second pin and the third had green insulation but not connected to any pin, also, the heating element had blown. The label on the kettle read 2 kW, 110 V, 50Hz.

Task: Assist your neighbor to:

(a) know the name given to each of the wires in the cable.
(b) (i) understand explain the meaning of quantities written on the label.
(ii) determine the resistance of the element of the kettle.
(c) (i) understand the cause of blowing of the kettle.
(ii) understand what could have been done to prevent blowing of the kettle.
(iii) know other precautions that should always be taken in proper use of the kettle.

A community has started a project to generate electricity from a nearby water fall. They have installed a generator that produces 50,000 W of a.c. electricity at 500 V. They hope to transmit this electricity to the village that is 10 km away. They have erected the poles and connected the necessary wires all the way from the water fall to the village. The wires have a total resistance 4 □. The appliances the community hopes to use work on 240 V. An engineer has advised the leaders in the project not to connect this power to the users because it will cause problems. The leaders have disagreed with the engineer, saying that he is using this as a trick to get more money from him, else they need clear explanations.

Task: Help the engineer to convince the leaders by;

(a) Explaining the problems that will arise if the electricity is used as it is.
(b) Determining the percentage power loss that is likely to occur along the way, when the power is used directly as it is.

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(c) Explaining the working of the devices that must be installed in the transmission system to enable safe use of the electricity with minimum power loss.
(d) Giving the advantages that the community is to attain by generating a.c. instead of d.c.

A certain home is failing to manage electricity bills and thinks the electricity board is cheating them. They recently bought 60 units of electricity which got used up in less than a week, even when they stopped using electricity for cooking food. They also complain that when the lights are switched on, the rooms in the house become too hot. You inspected their home and found out that they had 6 filament bulbs of 100 W each that worked 5 hours a day and 3 security lamps of 200 W each that worked 10 hours a day. They were boiling water twice a day with a heating coil of power 2000 W and it was taking 15 minutes each time to boil water. They wish to get more information from you after your inspection.

Task: Assist the members of the home to:
(a) Understand the meaning of the number of units they bought.
(b) Make necessary calculations to determine whether they were cheated, and give them any relevant advice.
(c) understand why the rooms get hot when their lights are switched on.
(d) come up with ways of reducing the electricity bill, even when they are still using it for same purposes.

During a physics study tour to an electricity generation substation, learners were guided on the processes of electricity generation and consumption. From the information the substation engineer provided, learners made the following observations which were however not fully explained because of limited time;

- Electricity at the substation is transmitted at 13 kV in alternating current of 0.05 A.
- The voltage used for home consumption units is 240 V with a little higher direct current.
- Workers in the substation are all required to wear personal protective equipment (PPE).

Task: Using the knowledge of physics, help the learners to:
(a) Understand why the power is transmitted at a value different from the one consumed.
(b) Determine the exact current supplied to a given home, for consumption.
(c) How the voltage changes.
(d) Understand why the substation workers use the PPE?

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A man constructed his house near a high-power line of 15 KV with 0.08 A. He wanted to connect the house to the power and use some electrical appliances. He consulted a local electrician who assured him that they can connect the power line direct to the house in order to reduce costs. The man was warned by his colleagues that he risks burning down his house if he continues with the electricians' plan. Hint: The man wants to start up with the following appliances in the house:

Item	Number of items	Power rating	Time of use (hours)
Inside bulbs	4	60 W	8
Security bulbs	2	100 W	14
A television	1	120 W	20
A speaker	1	300 W	20
A fridge	1	600 W	4

Task: Using the knowledge of physics, help the man to:
(a)(i) Understand why his house can easily burn down and explain what he can do to get power safely.
(ii) the recommended connection of the bulbs in the house, and why?

(b) Determine his weekly expenditure on electricity if the appliances are used daily, taking the unit cost of the electricity unit as UGX550.
(c) Know the appropriate practices he needs to adapt which ensure his safety, basing on the location of his house.

On a rainy day, a certain house was struck by lightning, instantly destroying the fuse in the meter box. The family members were all safe but were advised always to take precautions while it is raining. The house owner didn't understand why they needed to take precautions after all no harm came to them that day.
Hint: Power supplied to the house through the metre box is 240 V and the fuse is made of a material of resistance 480 Ω.
Task: Using the knowledge of Physics;
(a) Explain to the house owner how he can safe-guard his house from such occurrences in the future.
(b) Suggest precautions the family members should always take to be safe when such a situation arises.
(c) Determine the rating of the fuse and the current above which may have caused it to burn.

A land-lady was recently told that electricity from a power substation is transmitted at 12 kV using thick aluminium cables and is to be used in her house at 240 V. She got confused by how the electricity changes voltage from one value to another and said that the thick cables are a waste of money. Inside the house are two sets of appliances of resistance 20 Ω and 30 Ω but the land-lady is not sure of how they should be connected to ensure that they will work effectively.
Task: Use your knowledge of physics to help the land-lady to understand;
a) The system through how the electricity changes from one value to another.
b) Why such cables are used.
c) How the appliances should be connected to ensure that they work effectively with a high amount of current.

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