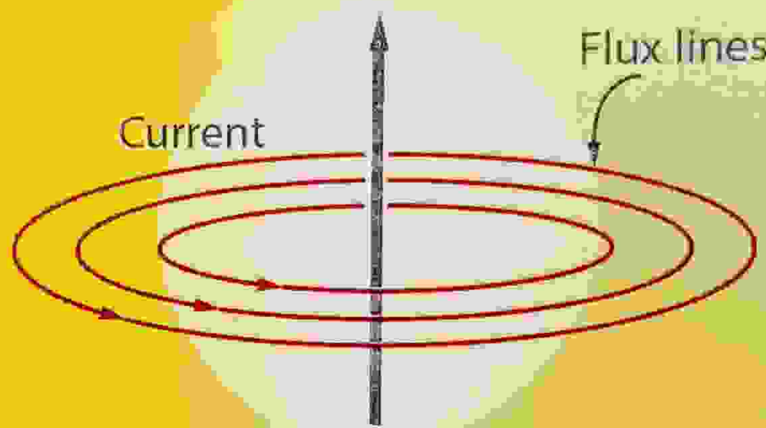
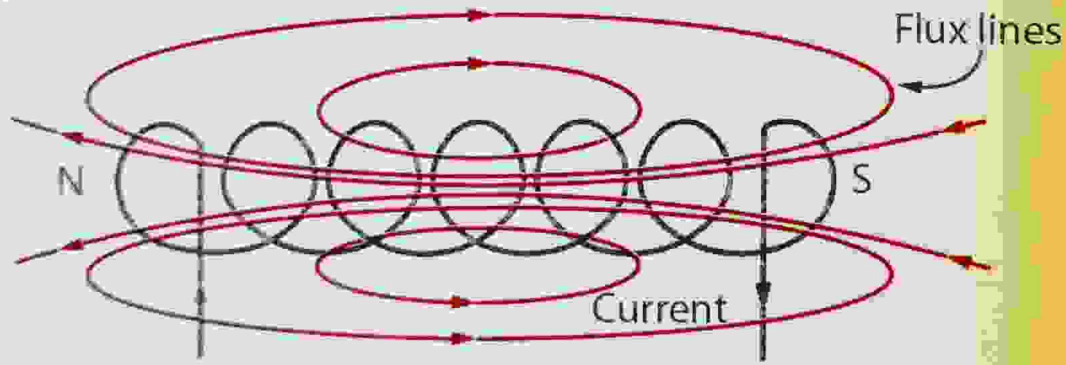
Extreme Series

PHYSICS

GRADE 9 - 10





Based on Common Currently Used National and International Curriculum

Extreme Series

2016 E.C

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Extreme

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UNIT 1

1. Physics and Human Society

1 . 1 What is Physics ?

1 . 2 Branches of Physics

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1. Physics and Human Society

Wel Come to this fascinating unit where you will be able to define physics describe branches of physics, explain the relation of physics to other fields of study, appreciate the application of physics in the every day life and get to know the prominent contributors to the advancement of physics. Enjoy !

1.1 What is physics ?

The word physics is thought to have come from the Greek word *phusis* meaning nature. so, we can define it as a field that studies the laws of nature.

Physics : Is a branch of natural science that studies about matter, energy and their interaction

Physics, not only describes the basic principles that make the universe behave the way it does, but also helps us to understand the working manner of Cars, airplanes, rockets, radios, computors, smart phones and so much more simple and complex devices.

- A person who studies physics is called *physicist.*

1.2 Branches of Physics

Physics do have many branches some of them are the following

- **Mechanics :** Deals with the motion of bodies with or without considering the cause of motion that is force.

Mechanics is further divided into two as classical and quantum mechanics

- Classical or Newtonian mechanics deals with motion and interaction between bodies.

In classical mechanics, we do not study a body that moves with a speed in an appreciable fraction of speed of light or phenomena on the atomic scale.

- Quantum mechanics deals with behavior of molecules and particles such as electrons, protons and neutrons

- **Acoustics :** Deals with the study of sound, its transmission, production and effects.
- **Optics:** Deals with the behavior, propagation and properties of light.
- **Thermodynamics:** Deals with the concept of heat, temperature and the inter convertion of heat and other forms of energy.
- **Electromagnetism:** Deals with the electric field, magnetic field and their interaction
- **Nuclear Physics:** Deals with the structure, property and interaction of nuclei of atoms
- **Astrophysics:** Deals with the space objects and space phenomena exploration.

Illustrative Examples

1. Physics studies about
   A) Living Things C) Chemical Reaction
   B) Matter and Energy D) Politics
2. A person who studies physics is called
   A) Physicist C) Chemist
   B) Physician D) Pilote
3. The branch of physics that studies sound is
   A) Optics C) Mechanics
   B) Acoustics D) Thermodynamics
4. The branch of physics that studies light is
   A) Optics C) Mechanics
   B) Acoustics D) Thermodynamics
5. Geophysics studies the
   A) Earth B) Space C) Ocean D) Moon
6. Astrophysics studies the
   A) Earth B) Space C) ocean D) Wave
7. _____ Studies motion and interaction between bodies

A) Thermodynamics
B) Optics
C) Mechanics
D) Electromagnetism

8. _____ Deals with the forces that occur between charged particles.

A) Optics
B) Electromagnetism
C) Mechanics
D) Acoustics

9. Heat, temperature and energy conversion studied via

A) Optics
B) Thermodynamics
C) Acoustics
D) Mechamics

10. The structure, property and interaction of nuclei is the concern of

A) Thermodynamics
B) Electromagnetism
C) Mechanics
D) Nuclear physics

Answers

1. B	4. A	7. C	10. D
2. A	5. A	8. B	
3. B	6. B	9. B	

1.3 Related Fields to Physics

Physics is the foundation of many disciplines. Some of them are discussed below

- **Engineering :** The design and analysis of civil, electrical, mechanical, computer, electronics and other engineering structures rely on the principles and concepts of physics.
- **Biophysics :** Makes use of the principles and methods of physics to study living things.
- **Geophysics :** Uses the principles and concepts of physics to study the Earth.
- **Medical physics :** Diagnostics and medical therapy such as x - rays, magnetic resonance imaging (M R I), ultrasound etc use principles of physics,

11. Why is Physics considered to be the basic science ?

Explanation

Because, the concepts of physics reach up more complicated sciences.

1.4 Historical Issues and Contributors

As science and technology advanced, physics evolved from classical to modern over the centuries

Classical Physics : Evolved from the renaissance to the end of the 19^{th} century.

Modern Physics : Starts from the begining of the 20^{th} century and modified many laws of classical physics.

Modern physics caused dramatic changes in technology, way of life and our view of the universe.

The most famouse physicists whose thoughts and contributions revolutionized physics are given below

Physicist	Contributions
Galileo Galilei  Italian physicist and Engineer	Studied the solar - system and the universe using a telescope known as "father of physics"

Isaac Newton  English mathematician, physiscist	Developing calculus, formulated laws of motion and gravitation Greatest mathematical and physicist of all time
Micheal Faraday  English scientist	Discovered the electromagnetic induction and benzene Studied electrolysis
James Prescott Joule  English physictst and brewer	Studied the nature of heat and its relation to mechanical energy
Marie Curie Curie  Polish - French physicist	The first woman to win a Nobel prize for the discovery of the elements polonium and radium

Albert Einstein  German - American physicist	Best known for the general and special theory of relativity and the concept of mass - energy eqivalence, $E = m c^2$ Known to be the greatest physicist of all time.

End of unit Questions

I. Give Short Answer to the following Questions

1. What is Physics ?
2. What are the branches of Physics ?
3. Name fields related to Physics
4. List some Physicist Contributed to advance Physics
5. Who Studied the rate of Energy transfer ?

i. Match items in Column "A" with those in Column "B"

A	B
6. Isaac Newton	A. Heat
7. Albert Einstein	B. Electric Lamp
8. Thomas Edison	C. Radium
9. J. J Thomson	D. Neutron
10. Ernest Rutherford	E. $E = m c^2$
11. James Chadwick	F. $F = ma$
12. Wilhelm Conrad	G. Electron
13. Marie Curie	H. Proton
14. Joule Prescott	I. X - ray
	J. Telephone

Answer to the End of unit Questions

II. Short Answers.

1. Physics is the study of matter, energy and their interaction
2. Mechanics, optics, Acoustics, Thermodynamics, Electromagnetism
3. Biophysics, Geophsics, Engineering, medecine
4. Galilio, Newton, Einstein, Edison, Watt, Joule
5. James Watt

III. Matching Item Answers

6. F	8. B	10. H	12. I	14. A
7. E	9. G	11. D	13. C	

UNIT -2

2 . Physical Quantities

2 . 1 Scales, Scientific Notation, Significant, Figures and Prefixes Data Measuring Scales

2 . 2 Measurement and Safety

2 . 3 Physical Quantities

2 . 4 Fundamental and Derived Quantities

2 . 5 Scalar and Vector Quantities

2 . 6 Vector Resolution

2 . 7 Addition of Vectors

2 . 8 Graphical Method of Vector Addition

2. Physical Quantities

We are very happy to meet you in this wonderful unit where you will get to know measuring scales, scientific notation, significant figures, prefixes and define physical quantities, differentiate basic quantities from derived quantities and distinguish scalar quantities from vector quantities. We hope, you will love it.

2.1 Scales, Scientific Notation, Significant Figures and Prefixes

What are Data Measuring Scales?

Studying natural phenomena involves quantifying events and observations. For this purpose, we use levels of measurement called *scales*.

Scale: Is a set of number or variables used to categorize, classify, compare or measure the level of something.

In physics, the most common types of data measuring scales are four. Those are, nominal, ordinal, interval and ratio scales.

Nominal Scale: Classifies or categories data without asigning number value and without ordering or ranking

For example, gender (male, female), religion (Islam, Christian), martial status (single, married), eye colour (blue, brown), subject (Physics, maths), residence area (urban, rural)...etc

- It is a least precise method of quantification.

Ordinal Scale: Classifies data into categories that can be ordered or ranked

For example, students rank (1^{st}, 2^{nd}, 3^{rd},), body size (Small, medium, large), judging (poor, good, excellent), grades (A, B, C)

- Precise measurement of differences does not exist since measured values are not equally spaced.

Interval Scale: Ranks data but has no true zero value.

For example, temperature (36 °C, 37°c), IQ (109,110), SAT Score

- Precise differences between units exist but there is no true zero.

Ratio Scale: Ranks data and has a true zero value

For example , height (1.75m, 1.78m), weight (550N, 600N), time (second, minute, hour) length (millimetre, centimeter, meter)

- It is precise, has true zero, can be added, subtracted, divided or multiplied.

Conceptual Examples

1. Why do we say there is no precision in an ordinal scale?

Explanation

Because, when we rank observation as 1st, 2nd or small, large or poor, good etc... There is no fixed interval between the data. That is, the difference between 1st and 2nd , 2nd and 3rd may not be same. And, we can not tell how much small is small and how much large is large !

2. In an interval scale, there is no true zero. Why? Defend your answer.

Explanation

For example, IQ tests do not measure people who have n[illegible] intelligence. And 0°c temperature does not mean no heat at all.

3. A ratio scale has a true point. Does this necessary mea[illegible] can be observed for a quantity?

Explanation

No! for some quantities, a value of zero will never be observed. For example, we can never have a temperature of zero kelvin, a man of zero height, ... etc.

4. Are scales involving division of two ratio scale also themselves ratio

scales? Explain

Explanation

Yes. Ratio scales obey the four basic operations of mathematics

Illustrative Examples

5. Which scale of measurement allows the four basic operations of mathematics?

   A) Nominal B) Ordinal C) Ratio D) Interval

6. _____Scale has the capacity to indicate the complete absence of a quantity.

   A) Nominal B) Ordinal C) Interval D) Ratio

7. Which scale of measurement is least precise?

   A) Nominal B) Ordinal C) Interval D) Ratio

8. 5 gram is one - half of 10gram, and 15gram is 3 time of 5 gram is the measure of __ scale

   A) Nominal B) Ordinal C) Interval D) Ratio

Answers

5. C 6. D 7. A 8. D

What is Scientific Notation?

In physics, we may face numbers that are too large or too small which are inconvenient to write or to read. To avoid such difficulties scientists devised a simple method called the *scientific notation.*

Scientific Notation: Is a simple way of, writing numbers that are too small or too large using the power of ten in the form

$$d \times 10^n$$

Where: d is decimal number between 0 and 10

n is an integer exponent.

In the general form of the scientific notation, $d \times 10^n$,

- d is a decimal number with only one digit to the left of the decimal point

- $n > 0$ represents the number of times the decimal point in d moved to the right. And,
- $n < 0$ represents the number of times the decimal point in d moved to the left.

For example; $2.5 \times 10^3 = 2500$m, and

2.5×10^{-3}m = 0.0025m

Illustrative Example

9. Write the following numbers using a scientific notation
   a) 300000000 m/s
   b) 0.0000075m
   c) 6371000m
   d) 0.0002517m

Solution

a) 3.0×10^8 m/s
b) 7.5×10^{-6} m
c) 6.4×10^6m
d) 2.5×10^{-4}m

What are Significant Figures?

Not all digits are meaningful in a measurement

Significant Figures: Are reliable digits in a measurement

We use the following rule of thumb to determine significant figures

Rules to Determine the Number of Significant Figures

- None zero digits are considered as significant

  Example: 3456m has four significant figures
- Zeroes are not considered as significant

  Example: 345000 has three significant figures
- Zeroes between none zeroes are considered as significant

  Example: 34005m has five significant figures

- Zeroes after a decimal point are taken as significant

  Example: 340.0m has four significant figures

- Zeroes indicating decimal places alone are not significant

  Example: 0.0034m has two significant figures.

- Numbers in front of a power of ten are considered as significant.

  Example: 2000 has one significant figure

  2.0×10^4 has two significant figure

  2.00×10^4 has three significant figure

Note: The numbers like 20000, 3500, 12000....etc are called *ambiguou* since they can have different number of significant figures.

Illustrative Example

10. Determine the number of significant figures for the following values.

a) 314000m	e) 3.400kg	i) 20.0×10^3m
b) 21 005kg	f) 314.201m	j) 200×10^2m
c) 10.00m	g) 0.000134m	k) 30.04×10^4m
d) 31.005m	h) 2.0×10^3 kg	

Answers

a) 3	c) 4	e) 4	g) 3	i) 3	k) 4
b) 5	d) 5	f) 6	h) 2	j) 3	

What are Prefixes?

Scientists not only used the scientific notation to write very large or very small values, but also used symbols in front of units to replace the power of ten.

Prefix: Is a symbol or a letter used in front of units replacing the power of ten

Some of the commonly used prefixes are given below

Prefix	Symbol	Exponent	Description
Yotta	Y	10^{24}	Septillion

Zetta	Z	10^{21}	Sextillion
Ext	E	10^{18}	Quintillion
Peta	P	10^{15}	Quadrillion
Tera	T	10^{12}	Trillion
Giga	G	10^{9}	Billion
Mega	M	10^{6}	Million
Killo	K	10^{3}	Thousand
hecto	h	10^{2}	Hundred
deca	da	10^{1}	Ten
base	b	10^{0}	One
deci	d	10^{-1}	Tenth
centi	c	10^{-2}	Hundredth
milli	m	10^{-3}	Thousandth
micro	μ	10^{-6}	Millionth
nano	n	10^{-9}	Billionth
pico	p	10^{-12}	Trillonth
Femto	f	10^{-15}	Quadrillionth
Atto	a	10^{-18}	Quintillionth
Zepto	Z	10^{-21}	Sextillionth
Yocto	y	10^{-24}	Septillionth

Conceptual Example

11. Do all pre fixes exist in front of SI units? Explain

Explanation

Not all. For example, kilogram (kg) is the SI unite of mass. Here, even if kilo (K) is a prefix,gram (g) is not an SI unit. ok!

Illustrative Examples

12. Write the following values using an appropriate prefixes
   a) The radius of the Earth is 6,371,000m
   b) The diameter of hair is 0.000,0075m
   c) The speed of light in vacuum is 300,000,000m/s

d) The distance of the sun from the earth is 150,000,000,000m

Answers

a) 6.4Mm b) 7.5μm c) 0.3G m/s d) 0.15Tm

2.2 Measurement and Safety

Our daily life is engaged in measuring things for different reasons. We say a kilo of sugar, banana, coffee, a litter of water, milk, nafta, a meter of cloth, string, cable and an hour, a day, a month and, year etc

Measurement: Is a process of comparing an unknown quantity with a known and internationally accepted standard unit of that quantity

For example, if we say 5kg of banana, it means that, the amount of banana, we are talking about is 5times large as the kilogram which is the standard unit of mass.

In a measuring process, there are three key common elements

- The quantity to be measured
- The measuring instrument
- The standard unit of measurement

For example, we have the following measurements

Physical Quantity	Measuring Instrument	Standard Unit
Time	Clock	Second
Length	Meter Tape	Meter
Mass	Balance	Kilogram

Laboratory Safety Rules

In a laboratory where experiment is done, since toxic chemicals and hazardions materials exist, students should follow safety rules so that physics laboratory can be a safe and enjoyable place for learning and discovery.

Some of the common laboratory safety rules are:

- Wear a laboratory safety goggles, shoes, cloths ...... etc
- Avoid wearing baggy clothing, bulky jewelry, dangling bracelets, sandals.... etc

- Do not eat, drink, chew gum in the laboratory
- Never taste or smell chemicals
- Wash hands thoroughly after laboratory work
- Do not touch bare wires if not insulated
- Stand by hazard reducing materials like fire extinguisher

Illustrative Example

13. What is an SI unit? Explain

Explanation

SI unit standard for system international is a world wide accepted standard unit of measurement. As an example, the SI unit of time is second (S), the SI unit of length is meter (m) and the SI unit of temperature is kelvin (K)

2.3 What are Physical Quantities?

Quantities that can be measured directly or indirectly are known as physical quantities . The measured value of a physical quantity is described using a number and a unit.

Physical Quantity: Is anything that can be measured and expressed using number and unit

For example, if you have 3kg of banana,then the quantity measured is mass with a magnitude of 3 and a unit of kilogram.

Physical quantities are classified into two major categories as,

- Fundamental and Derived
- Scalar and Vector

So, now let's define and explain them one by one

2.4 Fundamental and Derived Quantities

Based on wheather a physical quantity is measured directly or not, we classify it as fundamental or as a derived quantity.

Fundamental Physical Quantity: Is a quantity that can be measured and defined directly.

A fundamental physical quantity is also called a *basic physical quantity* and its unit is called *basic unit*.

- A basic unit is a directly defined unit and it does not depend on other units.

The seven fundamental physical quantities and their basic units are given below

Basic Quantity	Symbol	Basic unit	Symbol
Length	ℓ	meter	m
Mass	m	kilogram	kg
Time	t	second	S
Temperature	T	kelvin	K
Electric Current	I	Ampere	A
Amount of substance	n	Mole	mol
Luminous Intensity	I_v	Candela	Cd

As an example, let's see how the quantities time, length and mass are directly defined.

Time: Is the duration between the beginning and end of an event.

The SI unit of time is the second (S)

- Second is defined as 9192631770 times the period of vibration of cesium - 133 atom.

None SI units of time are minute (min), hour (hr), day, month and year.

The Units of Time are Related as Shown Below

1 minute	60 seconds
1 hour	60 minutes
1 day	24 hours
1 week	7 days
1 month	30 days
1 year	365.25 days

Illustrative Example

14. Express the following durations in seconds

a) 3 hours
b) 0.2 hours
c) 2/5 hours
d) 45 minutes
e) 2.5 hours
f) 30.5 minutes

15. Express the result of the following durations in seconds

a) 2 hours + 0.3 hours
b) 3 hours + 0.4 hours + 20 minutes

Solutions

14. a) 3 hours = (3) (60) (60) = 10800 seconds

b) 0.2 hours = (0.2) (60) (60) = 720 seconds

c) $\frac{2}{5}$ hours $= \left(\frac{2}{5}\right)(60)(60) = 1440$ seconds

d) 45 minutes = (45) (60) = 2700 seconds

e) 2.5 hours = (2.5) (60) (60) = 9000 seconds

f) 30.5 minutes = (30.5) (60) = 1830 seconds

15.

a) 2 hours + 0.3hours = (2) (60) (60) + (0.3) (60) (60) = 8280 seconds

b) 3 hours + 0.4 hours + 20minutes

= (3) (60) (60) + (0.4) (60) (60) + (20) (60) = 13440 seconds

Length: Is the distance between two points

The SI unit of length is the meter (m)

- Meter (m) is defined as a distance travelled by light in vacuum in a time of $\frac{1}{299792458}$ second.

None SI unit of length are millimetre (mm), centimeter (cm) and kilometer (Km)

The Units of Length are Related as Shown Below

I centimeter	10 millimeter
I meter	100 centimeter
I kilometer	1000 meter

Illustrative Examples

16. If the distance between two bus stations is 500m, then what is this distance in
    a) Millimeter b) Centimeter c) Kilometer
17. Express the sum of the distance given below in meter
    a) 0.2km + 500cm + 2500mm
    b) $\frac{1}{4}$ km + 3.5km + 45000mm + 2500cm

Solutions

16. a) 500m = (500) (100) (10) = 500,000 mm
    b) 500m = (500) (100) = 50,000 cm
    c) $500\text{m} = (500)\left(\frac{1}{1000}\right) = 0.5\text{km}$

17. a) 0.2km + 500cm + 2500mm

$$= (0.2)(1000) + (500)\left(\frac{1}{100}\right) + 2500\left(\frac{1}{1000}\right)$$

$$= 200 + 5 + 2.5 = 207.5\text{m}$$

b) $\frac{1}{4}$ km + 3.5km + 45000mm + 2500cm =

$$\left(\frac{1}{4}\right)(1000) + (3.5)(1000) + (45000)\left(\frac{1}{1000}\right) + 2500\left(\frac{1}{100}\right)$$

$$= 250 + 3500 + 45 + 25 = 3820\text{m}$$

Mass: Is the amount of matter contained in a body

The SI unit of mass is the kilogram (kg)

- Kilogram is defined as the mass of a particular platinum - iridium alloy cylinder in paris, France.

None SI unit of mass are gram (g), milligram (mg) quintal. and tonne.

The Units of Mass are Related as Shown Below

1 gram	1000 milligram
1 kilogram	1000 gram
1 quintal	100 kilogram
1 tonne	10 quintal

Illustrative Examples

18. If you buy 3 kilogram of banana, what is this amount in
    a) Gram b) Milligram c) Quintal d) Tonne
19. Express the sum of the masses given below in kilogram
    a) 0.2 ton + 0.5 quintal + 5000 gram
    b) $\frac{1}{5}$ ton + 2.5 quintal + 2500 gram

Solutions

18. a) 3kilogram = (3) (1000) = 3000 gram
    b) 3kg = (3) (1000) (1000) = 3,000,000 milli gram
    c) $3kg = (3)\left(\frac{1}{100}\right) = 0.03$ quintal
    d) $3kg = (3)\left(\frac{1}{100}\right) = 0.003$ tonne.

19. a) 0.2 ton + 0.5 quintal + 5000gram

$$= (0.2)(1000) + (0.5)(100) + (5000)\left(\frac{1}{1000}\right)$$

$$= 255kg$$

b) $\frac{1}{5}$ ton + 2.5 quintal + 2500gram

$$= \left(\frac{1}{5}\right)(1000) + (2.5)(100) + (2500)\left(\frac{1}{1000}\right)$$

$$= 452.5kg$$

More over, physical quantities that can not be defined or measured directly are called *derived quantities*.

Derived Physical Quantity: Is a quantity that can be obtained by combining, that is dividing or multiplying two or more basic quantities.

For example, Area, Speed, density, force, pressure e.t.c are derived quantities

➡ The unit of derived quantities are called *derived units*.

Some of the derived quantities along with their units are give below;

Derived Quantity	Symbol	Formula	Unit	Symbol
Speed	v	$\frac{\text{Distance}}{\text{Time}}$	$\frac{\text{meter}}{\text{Second}}$	m/s
Density	ρ	$\frac{\text{mass}}{\text{volume}}$	$\frac{\text{kilogram}}{\text{meter cube}}$	kg/m^3
Acceleration	a	$\frac{\text{veloccity change}}{\text{Time}}$	$\frac{\text{meter}}{\text{second square}}$	m/s^2
Force	F	(Mass) (Acceleration)	Newton	$IN = \frac{1kgm}{s^2}$
Work	W	(Force) (Displacement)	Joule	$I J = \frac{1kgm^2}{S^2}$
Pressure	P	$\frac{\text{Force}}{\text{Area}}$	Pascal	$I Pa = \frac{Ikg}{ms^2}$

Illustrative Examples

20. Which of the following is basic quantity?

A) Work B) Density C) Mass D) Pressure

21. Identify the basic unit

A) Kelvin B) Pascal C) Joule D) Newton

22. All pairs represent derived quantities, except

A) Work, speed
B) Mass, time
C) Density, volume
D) Area, speed

23. Which of the following is a derived quantity?

A) Current B) Speed C) Length D) Temperature

24. Identify the derived unit

A) Kelvin B) Mole C) Ampere D) Newton

25. All pairs represent basic units, Except

A) Kelvin, kilogram
B) Ampere, Joule
C) Ampere, kelvin
D) Kelvin, Candela

26. All pairs represent derive units, Except

A) Candela, Joule
B) Pascale, Newton
C) Joule, Newton
D) Tesla, Weber

Answers

20. C 21. A 22. B 23. B 24. D 25. B 26. A

2.5 Scalar and Vector Quantities

Some physical quantities can be described by a number and a unit, that is magnitude alone, and some others are expressed using a magnitude and direction.

Scalar Quantity: Is a quantity that can completely be described by magnitude alone.

For example, time, mass, temperature, density, volume ...... etc are scalar quantities

Conceptual Examples

27. Why do we say that quantities such as time, mass and temperature are scalar quantities? Explain

Explanation:

Because, they do not require direction for their description. For example, it is expressive to say 3 hours, 2kg or 37^{0}c. You do not need to say 3 hours to the east, 2kg due west or 37^{0}c towards the south ..... etc. ok!

28. Can we conclude that, all the fundamental quantities are also scalar quantities

Explanation

Yes. All the seven basic quantities are scalar quantities

Vector Quantity: Is a quantity that requires both magnitude and direction for its complete description

For example; displacement, velocity, acceleration, force, ... etc are vector quantities.

Conceptual Example

29. Why do we say quantities such as velocity and force are vector quantities? Explain

Explanation

Because they require direction for their complete description. For example, saying a force of 500N is acting towards north and a car is moving at 30km/n due East makes sense.

30. Can we conclude that, all the derived quantities are also vector quantities?

Explanation

No. Not all. For example, area, volume, density, speed, pressure.... etc are derived quantities. But, are not vector quantities.

Illustrative Example

31. Which of the following is a vector quantity?

A) Current B) Temperature C) Force D) Pressure

32. Which Pairs are scalars?

A) Speed, Force C) Velocity, Force

B) Acceleration, pressure D) Density, pressure

33. All pairs are vector quantities except

A) Speed, distance C) Acceleration, velocity

B) Velocity, force D) Force, velocity

34. Which of the following is a scalar quantity?

A) Acceleration C) Velocity

B) Pressure D) Force

35. All pairs are scalars except

A) Acceleration,speed C) Temperature,speed

B) Current, mass D) Density,volume

Answers

31. C 32. D 33. A 34. B 35. A

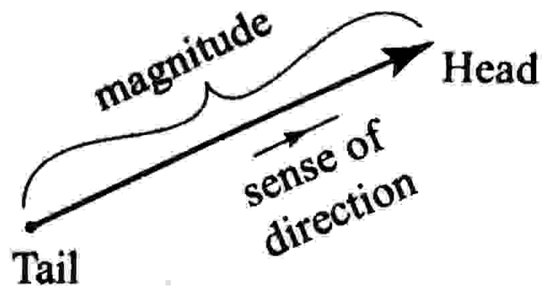
A Vector Quantity can be Represented Either Algebraically or Geometrically

- Algebraically, a vector is represented by a bold face letter or a letter with an arrow over its head.

For example, a force vector can be represented as **F** or $\vec{F}$ and the magnitude of the vector is represented by a light face letter or a letter in the absolute value notation as F or $|F|$.

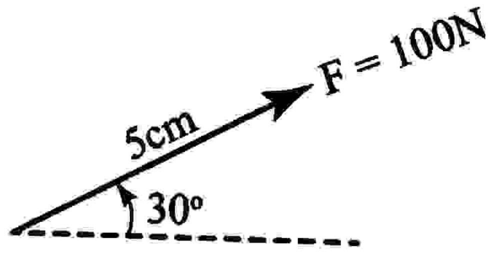
- Geometrically, a vector is represented by an arrow that is drawn to an appropriate scale.

The initial point of the arrow is a tail and its final point is a head. If the arrow is drawn to scale, then its length represents the magnitude and its head indicates the direction of the vector as shown below



While expressing a vector geometrically, we use an appropriate scale to draw its magnitude and a protractor to determine its direction.

For example, to represent a force of 100N that is acting at an angle of 30° from the horizontal, we may let 1cm = 20N, hence 5cm = 100N, use a ruler and draw 5 cm at an angle of 30° from the horizontal using a protractor as shown

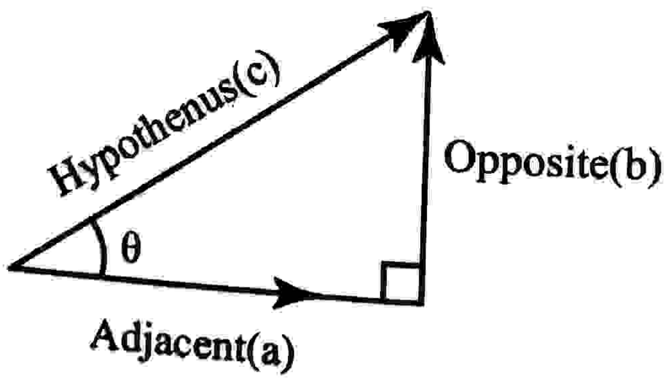


2.6 What is Vector Resolution?

A vector can be decomposed into parts, and this process is called *resolution*

Vector Resolution: Is the process of splitting a vector in to components.

To resolve a vector into horizontal or x - component and vertical or y - component, we need to use the basic trigonometric relations as defined below.



$$\text{Sin}\,\theta = \frac{\text{Opposite}}{\text{Hypothenus}} = \frac{b}{c} \Rightarrow b = C\sin\theta$$

$$\text{Cos}\,\theta = \frac{\text{Adjacent}}{\text{Hypothenus}} = \frac{a}{c} \Rightarrow a = C\cos\theta$$

$$\tan\theta = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{b}{a} \Rightarrow \theta = \tan^{-1}\left(\frac{b}{a}\right)$$

And, to combine the components, into one magnitude, we use Pythagora's theorem as follows;

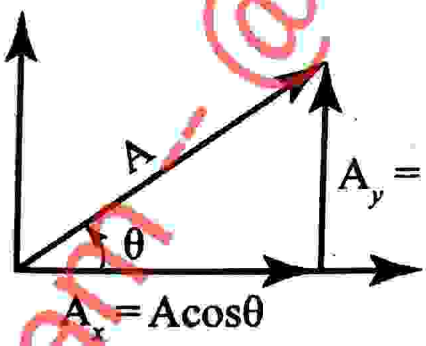
$$c^2 = a^2 + b^2$$

$$c = \sqrt{a^2 + b^2}$$

And, the angle that **c** makes from **a** is obtained from

$$\tan\theta = \frac{b}{a}$$

Now, suppose we want to decompose vector $\vec{A}$ into a horizontal Component, $\overrightarrow{A_x}$ and a vertical component, $\overrightarrow{A_y}$ such that, $\vec{A} = \overrightarrow{A_x} + \overrightarrow{A_y}$



We Know;

$$\text{Cos}\,\theta = \frac{A_x}{A} \Rightarrow A_x = A\cos\theta$$

$$\text{Sin}\,\theta = \frac{A_y}{A} \Rightarrow A_y = A\sin\theta$$

Where: θ is the angle that vector A makes with the x - axis, and the magnitude of vector A is obtained by:

$A = \sqrt{A_x^2 + A_y^2}$, and its direction is;

$$\tan\theta = \frac{A_y}{A_x} \Rightarrow \theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)$$

Illustrative Examples

36. An automobile moved a distance of 4000m at an angle of 37^0 north of east. What are the x and y components of the displacement of the automobile?

37. If a bus moved 5km due east and then 10km at 53^0 from the horizontal, then what is the over all displacement of the bus.

Solution

36. $S_x = S\cos\theta = (4000)\cos(37^0) = (4000)(0.8) = 3200\text{m}$

$S_y = S\sin\theta = (4000)\sin(37^0) = (4000)(0.6) = 2400\text{m}$

37. $S_x = 5\text{km} + 10\cos(53^0) = 5 + 6 = 11\text{km}$

$S_y = 0 + 10\sin(53^0) = 0 + 8 = 8\text{ km}$

$S = \sqrt{S_x^2 + S_y^2}$

$S = \sqrt{11^2 + 8^2}$

$S = 13.6\,km$

2.7 Addition of Vectors

When we add vector quantities, we need to consider both their magnitude and their directions. And, the sum or difference of two or more vectors is called *resultant*.

Resultant Vector: Is a single vector obtained by adding two or more vectors and whose effect is the same as the individual vectors acting together.

To add scalars, we use ordinary algebra while, to add vectors we make use of vector algebra.

Conceptual Examples

38. Can we add a scalar quantity to vector quantity? Explain

Explanation

Never! For example, no quantity exists being the sum or difference of force and velocity, acceleration and displacement...... etc.

39. Can we add vectors of different kind? Explain

Explanation

No. That is not possible. For example, we get nothing if we try to add force and velocity or acceleration and displacement.

40. If we have force of 4N and 6N, Can we conclude that their result is 10N? Explain

Explanation

No! Depending on their directions, the resultant of a 4N and a 6N force varies from 2N to 10N. For example, when they are acting in the same direction, their resultant is 10N, when they are acting at right angle to each other, their resultant is 7.21N and when they are acting in opposite directions, the magnitude of their resultant is 2N

The resultant of two vector $\vec{A}$ and $\vec{B}$ can be denoted by $\vec{R}$, and let's consider three cases one by one

Addition of Parallel Vectors

The magnitude of the resultant of two vectors acting in the same direction is equal to the sum of the magnitude of the two vectors and its direction is in the direction of the two vectors.

That is, if we have two force vectors, $\vec{F_1}$ and $\vec{F_2}$ as shown

Then their resultant is

$\vec{R} = \vec{F_1} + \vec{F_2}$ =

Addition of Antiparallel Vectors

The magnitude of the resultant of two vectors acting in opposite directions is the difference of the magnitude of the two vectors and its direction is in the direction of the bigger vector

The is, if we have two force vectors $\vec{F_1}$ and $\vec{F_2}$ as shown

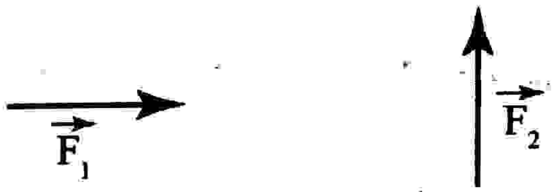
Then their resultant

$$\vec{R} = \vec{F_1} - \vec{F_2} =$$

Addition of Perpendicular Vectors

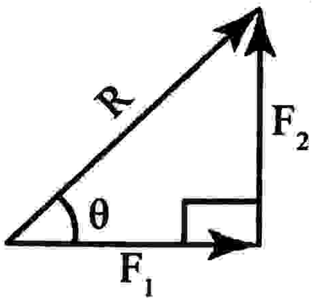
The magnitude of the resultant of two vectors acting at right angle to each other is obtained by using pythagora's theorem and its direction is determined using the basic trigonometric relations.

That is, if we have two force $\vec{F_1}$ and $\vec{F_2}$ as shown



Then their resultant

$$\vec{R} = \sqrt{F_1^2 + F_2^2}$$



$$\tan\theta = \frac{F_2}{F_1} \Rightarrow \theta = \tan^{-1}\left(\frac{F_2}{F_1}\right)$$

Illustrative Example

41. Given two forces:; $F_1 = 6N$ and $F_2 = 8N$. Find their resultant when
    a) $F_1 = 6N$, East and $F_2 = 8N$ East
    b) $F_1 = 6N$, East and $F_2 = 8N$ West

c) $F_1 = 6N$, East and $F_2 = 8N$ North

Solution

a) The two forces are parallel

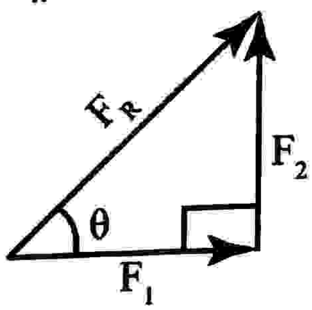
$$F_R = F_1 + F_2 = 6 + 8 = 14N, \text{ East}$$

b) The two forces are anti parallel

$$F_R = F_1 - F_2 = 6 - 8 = -2N, \text{ East} = 2N, \text{ west}$$

c) The two forces are perpendicular

$$F_R = \sqrt{F_1^2 + F_2^2} = \sqrt{6^2 + 8^2} = \sqrt{100} = 10N$$



$$\sin\theta = \frac{F_2}{F} = \frac{8}{10} = 0.8$$

Then, using scientific calculater, $\theta = \sin^{-1}(0.8) = 53^0$

Hence, the resultant is 10N at 53^0 North of East.

- The resultant of two vectors is maximum when they are acting in the same direction or parallel, and it is minimum when they are acting in opposite directions or anti parallel

2.8 Graphical Method of Vector Addition

To add vectors graphically, we use a ruler to determine their magnitude and a proteractor to determine their direction. Here under, we define the triangle law, the parallelogram law and the polygon law of vector additions. Enjoy!

Triangle Law of Vector Addition

It is used to find the resultant of two non-parallel vectors graphically. And, it is stated as follows.

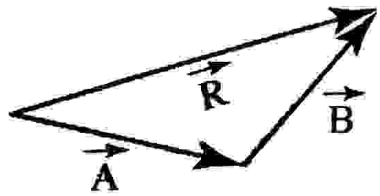
Triangle law, states that:

"Join the two vectors head to tail and then draw the resultant vector from the tail of the first vector to the head of the second vector."

For example, if we have two vectors $\vec{A}$ and $\vec{B}$ as shown,

Then, their resultant is

$\vec{R} = \vec{A} + \vec{B}$



➥ The final geometry we get in the triangle law triangle three - sided figure

Parallelogram Law of Vector Addition

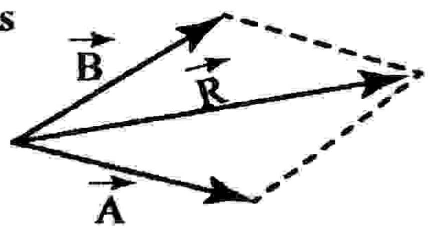
It is also used to find the resultant of two non-parallel vectors graphically.

Parallelogram Law, states that: "Join the two vectors tail to tail and form a parallelogram and then draw the diagonal of the parallelogram as resultant vector."

For example, if we have two vectors, $\vec{A}$ and $\vec{B}$ as shown

Then, the resultant is

$\vec{R} = \vec{A} + \vec{B}$



➥ The final geometry in the parallelogram law is a four sided figure

Polygon Law of Vector Addition

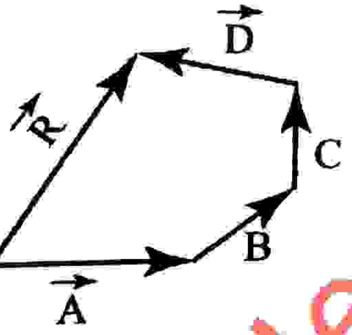
It is used to find the resultant of more than two vectors and states that.

"Join the vectors head to tail and then draw the resultant vector from the tail of the first vector to the head of the last vector."

For example, if we have vectors $\vec{A}$, $\vec{B}$, $\vec{C}$ an $\vec{D}$ then their resultant can be obtained as follow then their resultant

Then their resultant

$$\vec{R} = \vec{A} + \vec{B} + \vec{C} + \vec{D}$$



➥ The final geometry in the polygon law is a many sided figure

Conceptual Examples

42. If two vectors have equal magnitudes, what will be the maximum and the minimum value of their magnitude
43. What does $\vec{A} - \vec{B}$ mean? Explain
44. If three vectors have unequal magnitudes, can their resultant be zero? Explain
45. What can you say about the resultant of three or more vectors, if they form a polygon when joined head to tail. Explain
46. If we have two vectors $\vec{A}$ and $\vec{B}$ as shown, then graphically find:

    i. $\vec{A} + \vec{B}$

    ii. $\vec{A} - \vec{B}$

Explanation

42. Assuming a veotor has a magnitude of A

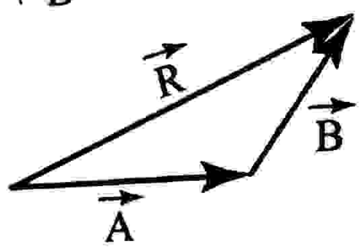
    maximum = 2A, minimum = 0

43. It means, the sum of $\vec{A}$ and $-\vec{B}$, $\vec{A} + (-\vec{B})$, we reverse the direction of vector $\vec{B}$

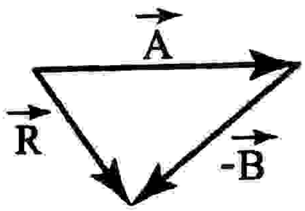
44. Yes! for example, $\vec{A}$ = 4m, East, $\vec{B}$ = 3m, west $\vec{C}$ = 1m, west

45. It is zero

46. i) $\vec{R} = \vec{A} + \vec{B}$



ii) $\vec{R} = \vec{A} - \vec{B} = \vec{A} + \left(-\vec{B}\right)$



47. Which combination of basic quantities can define force?

A) Acceleration and mass

B) Mass time and velocity

C) Acceleration, length and time

D) Time, length and mass

Hint:- F = ms

$$IN = 1kg\, {m}/{s}^2 = M\frac{L}{T^2}$$

Answer: D

48. Which property of vectors is possible?

A) Vector addition is associative

B) Vector subtraction is commutative

C) The resultant of perpendicular vectors is zero

D) The resultant of parallel vectors is zero.

Hint:- $\vec{C} + \left(\vec{A} + \vec{B}\right) = \vec{B} + \left(\vec{A} + \vec{C}\right)$

$\vec{A} - \vec{B} = -\vec{B} + \vec{A}$

$/A - B/ \leq R \leq /A + B/$

Answer: A

49. The resultant of vectors $\vec{A}$ and $\vec{B}$ is 12units if the magnitide of $\vec{A}$

is 6 units, then that of $\vec{B}$ is

A) Greater than 18 units

B) $6 \leq B \leq 18$

C) Less than6 units

D) Less that 12 units

Hint:- $/A - B/ \leq 12 \leq /A + B/$

$6 - B \leq 12$ or $12 \leq 6 + B$

$B \leq 18$ $B \geq 6$

Answer: B

50. The magnitude of the resultant of two vectors is minimum then the vectors are

A) Parallel to each other

B) Perpendicular to each other

C) Opposite to each other

D) At 450 to each other

Hint: $|\vec{A} - \vec{B}| \leq R \leq |\vec{A} + \vec{B}|$

(Opposite) (parallel)

Answer: C

51. The *x* component of a vector of magnitude 25 units is 15 units what is the Y component of the vector?

A) 10 units B) 20 units C) 40 units D) 35 units

Hint: $A = \sqrt{A_x^2 + A_y^2}$

$(25)^2 = (15)^2 + A_y^2$

$A_y = 20$ unit

Answer: B

52. The magnitude of the resultant of two vectors is 20 when they are parallel and 4 when they are opposite to each other. Their magnitudes must Be?

A) 8 and 12 units

B) 6 and 14 units

C) 24 and 16 units

D) 10 and 6 units

Hint: $A + B = 20$

$\underline{A - B = 4}$

$A = 12$ and $B = 8$

Answer: A

53. A bird flies 4km East and 3km North. What is the resultant displacement of the bird?

A) 5km, 370 East of North
C) 5km, 370 North of East
B) 7 km, 370 East of North
D) 1km, East

Hint: $S = \sqrt{S_1 2 + S_2 2} = \sqrt{3^2 + 4^2}$

$S = 5Km, \tan\theta = \frac{3}{4}$

$\theta = \tan^{-1}(0.75) = 37^0$

Answer: C

54. The resultant of two forces that are perpendicular to each other is 130N. If one of the vectors is 120N, what is the magnitude of the other vector?

A) 10N B) 250N C) 125N D) 50N

Hint: $130^2 = 120^2 + F^2$

$F = 50N$

Answer: D

55. A cart is pulled by a rope making an angle of 45^0 by a force of 100N. What is the magnitude of the vertical component?

A) 45N B) 70N C) 60N D) 100N

Hint: $F_y = F \sin\theta = 100 \sin(450) = 100(0.7) = 70N$

Answer: B

56. A vector of magnitude 10 units has components of Ax equal to 6 unit. What angle does the vector make with the positive x - axis?

A) 37^0 B) 45^0 C) 53^0 D) 60^0

Hint: $\sin\theta = \frac{Ay}{A} = \frac{8}{10}$

$\theta = \sin-1(0.8)$

$\theta = 53^0$

Answer: C

57. Two forces act together on an object. The magnitude of their resultant is least when the angle between them is ?

A) 0^0 B) 45^0 C) 60^0 D) 180^0

Hint: $|A - B| \leq R \leq |A - B|$

least maximum

$\theta = 180^0$ $\theta = 0^0$

Answer: D

58. Which of the following pairs of vectors will not produce a resultant of 15

A) 5 and 12 units C) 10 and 15 units

B) 6 and 8 units D) 10 and 6 units

Hint: $/A - B/ \leq R \leq /A + B/$

Answer: B

End of unit Questions and Problems

I. Give Short Answers to the following Questions

1. What is physics?
2. List branches of physics
3. A person who studies physics is known as?
4. What is unit?
5. What is measurement ?
6. What are significant figures?
7. What is a scientific notation?
8. What are prefixes?
9. What are physical quantities
10. Mention the data measuring scales
11. What is vector resolution?
12. How many seconds are there in one day?
13. If two vectors have equal non-zero magnitudes, can their resultant be zero? Explain

14. In which graphical rule we connect vectors head to tail?

15. Write 0.000005m using
   a) Scientific notation
   b) Prefix

16. The volume of the earth is on the order of $30 \times 10^{21} m^3$. Write this value using prefix

17. Read and write using prefixes the following numbers
   i. 1000,000,000
   ii. 1000,000,000,000
   iii. 1000,000.000,000,000,
   iv. 1000,000,000,000,000,000
   v. 1000,000,000,000,000,000,000
   vi. 1000,1000,000,000,000,000,000,000

II. Match the items in column "A" with those in column "B"

A	B
18. No ranking	A) Ratio
19. Ranking, No precision	B) Interval
20. Precise, No true zero	C) Nominal
21. Has true zero	D) Ordinal
22. 10^0	E) Yotta, yocto
23. $10^1, 10^{-1}$	F) Zetta, zepto
24. $10^2, 10^{-2}$	G) Exa, atto
25. $10^3, 10^{-3}$	H) Peta, femto
26. $10^6, 10^{-6}$	I) Tera, pico
27. $10^9, 10^{-9}$	J) Giga, nano
28. $10^{12}, 10^{-12}$	K) Mega, micro
29. $10^{15}, 10^{-15}$	L) Killo, milli
30. $10^{18}, 10^{-18}$	M) hecto,centi
31. $10^{21}, 10^{-21}$	N) deca, deci
32. $10^{24}, 10^{-24}$	O) base

P) Micto, Macta

Answers to End of unit Questions

I. Short Answer and Explanations

1. Physics is a branch of natural science that studies about matter, energy and interaction.
2. Mechanics, Thermodynamics, optics, Acoustics ...... etc
3. Physicist
4. SI unit is an internationally accepted standard unit of measurement and stands for system international
5. Measurement is a process of comparing an unknown quantity with a standard one of the same type.
6. Significant figures are reliable digits obtained in a measurement
7. Scientific notation is a simple way of writing very small or very large numbers using a power of ten.
8. Prefixes are symbols used in place of power of ten in front of units
9. Physical quantities are quantities that can measured directly or indirectly
10. Nominal, ordinal, interval and ratio
11. Vector resolution is a process of splitting vector in to components
12. 1 day = 24 house = (24) (60) (60) = 86400 seconds
13. Yes when they act in opposite directions
14. Triangle and polygon laws
15. 0.0000005m is
    i. 5×10^{-6}m, scientific notation
    ii. 5μm , prefix
16. 10^{21} is zetta, 30 Zm^2
17.
    i. Billion, Giga = 10^9
    ii. Trillion, Tera = 10^{12}

iii. Quadrillion, Peta = 10^{15}

iv. Quintillion, Exa = 10^{18}

v. Sextillion, Zetta = 10^{21}

vi. Septillion, yotta = 10^{24}

II. **Matching Item**

18.C	22.O	26.K	30.G
19.D	23.N	27.J	31.F
20.B	24.M	28.I	32.E
21.A	25.L	29.H	

UNIT -3

3. Motion in a Straight Line

3.1 Position Distance and Displacement

3.2 Speed, Velocity and Acceleration

3.3 Equations of Motion with Constant Acceleration

3.4 Graphical Description of Uniformly Accelerated motion

3.5 Relative velocity in one dimension

3. Motion in a Straight Line

Hello there! How do you do? We are very happy to meet you in this fascinating unit where you will be able to define motion, describe motion parameters such as distance, displacement speed, velocity, acceleration and plot their graphs against time and solve problems related to motion of bodies in a straight line. You will Love it.

3.1 Position, Distance and Displacement

Motion of a body can only be explained by considering its position from a give point as time passes. Hence, to define motion, first we need to be clear about the concept of position and reference frame.

Position: Is the location of a body from a specific reference point.

For example, as you move from home to school, your initial position is home your final position is school.

Conceptual Example

1. Can the position of a body be negative? Explain

Explanation:

Yes, when the body moves or located to the left side or down side of the origin.

☑ The motion of a body is expressed using a particular reference point called the *frame of reference*

Frame of Reference: Is a point that is used to determine position of body.

☑ A point of reference, that is, a reference frame may be at rest or in motion.

Now, let's see how motion of a body is defined,

Motion: Is a continuous change in position of a body with respect to a fixed point as time passes.

Therefore, a body is said to be in motion only if it changes its position relative to some fixed reference frame as time goes.

Conceptual Example

2. If a body is observed moving in one reference frame, can we conclude that the body is also moving in all other reference frames? Explain

Explanation:

No! For example, if you are in a car that is moving at 100km/hr, then you are moving at that speed when observed by a person standing by the road but you are not moving as seen by a person sitting next to you in the car.

As a body moved from one point to the other, it covers some distance.

Distance (S) : Is the actual path length travelled by a moving body

Distance, is a scalar quantity and its SI unit is meter (m).

And, depend-ling on the path length to be measured, we may use non - SI units such as micrometer (Nm), millimetre (mm), centimetre (cm), kilometre (km) .... etc.

Conceptual Examp

3. Can the distance covered by a body be negative ? Explain.

Explanation:

Never. A moving body covers non-zero and non-negative distance. When a body moves, it changes its position as time passes

Displacement ($\vec{S}$) **:** Is the change in position of a body in a specific direction

Displacement, is a vector quantity and its SI unit is meter (m)

☑ Displacement of a body tells us how far and in which direction the body is now from its starting point.

Therefore, displacement of a body is the shortest or short cut distance of the body between its initial and final positions.

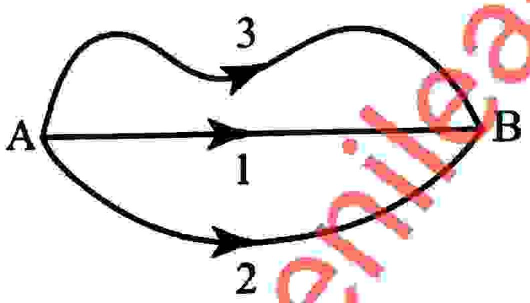
Conceptual Example

4. Can displacement of a body became negative or zero? Explain

Explanation:

Yes, It became negative when the body moves to the left or down ward from the origin and it became zero when the body returned to its starting point.

5. If a body moved from point A to point B along three different paths as shown, which path represent displacement of the body? And why?



Explanation:

Path -1 Because, it is the shortest path length of the body from its initial position to its final position.

The difference between distance and displacement is given in the following table.

Distance	Displacement
☑ Actual path length	☑ Shortest path length
☑ Scala quantity	☑ Vector quantity
☑ Depends on path followed	☑ Depends on initial and final position
☑ Always positive	
☑ Greater than or equal to displacement	☑ Can be zero, negative or positive
	☑ Less than or equal to distance

☑ Distance and displacement have the same SI unit, meter (m)

Illustrative Example

6. If a bus moved 800m due east along a straight road and then 300m due west along the same road, then what are the distance and displacement of the bus?

7. Suppose your school is 1km away. If you return home after class along the same rout. What is your entire trip?

   A. Distance

   B. Displacement for the

8. If a body moved 300m due east and then 400m due north, then what are the distance and displacement of the body?

9. If an athlelete runs once along circular track of radius 400m, then what are the distance and displacement of the athelete?

Solution

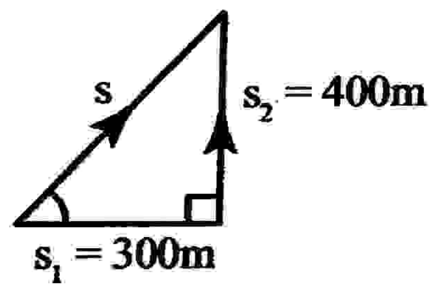
6. Distance = 800m + 300m = 1100m, and

   Displacement = 800m - 300m = 500m due East

7. Distance = 1km + 1km = 2km = 2000m, and

   Displacement = 1km - 1km = Zero

8. The path of the body can be visualized as follows.



   A. Distance = $s_1 + s_2 = 300m + 400m$

   B. Displacement = $\sqrt{S_1^2 + S_2^2} = \sqrt{(300)^2 + (400)^2} = \sqrt{250000}$

   $S = 500m$, North of East

9. Distance = $2\pi r = 2\ (3.14)\ (400) = 2512m$

   Displacement = 0, zero

3.2 Speed, Velocity and Acceleration

As a body move, it may be faster or slower and the quantity that describes how fast a body is moving is called *speed.*

Speed: Is the rate at which a body changes its location

Mathematically, speed of a body is calculated as follows;

$$\text{Speed} = \frac{\text{Distance Travelled}}{\text{Time Taken}}$$

$$\boxed{V = \frac{s}{t}}$$

Speed is a scalar quantity and its SI unit is meter per second (m/s). other non - SI unite of speed include kilo meter per hour (km/h) and miles per hour (mi/h).

For different reasons, a body may not move at constant speed through out its journey history. At one time the body may move faster and at another time, it may move slower. Therefore, we need to consider average speed to talk about the over all speed of the body during its entire trip.

Average Speed: Is the speed that a body attained to cover the total distance.

Mathematically, average speed of a body is obtained by.

$$\text{Average Speed} = \frac{\text{Total Distance Travelled}}{\text{Total Time Taken}}$$

$$V_{av} = \frac{S_T}{t_T}$$

Conceptual Example

10. What does the speedometer of a car measure?

Explanation:

Speedometer in a car measures instantaneous speed of the car, that is the speed of the car at a specific instant of time

11. Can the average speed of a moving body ever be zero? Explain

Explanation:

Never! Average speed of a body can not be zero. But, at some instants of time, the body may have zero speed during the moments it stooped in its journey history.

Illustrative Examples

12. If a car travelled 81 km in 1hour and 30 minutes, what is its average speed?

13. A boy walked a distance of 400m in 5minutes and run a distance of 800m for 3minutees. What is the average speed of the boy?

14. Amotor-cycle moved a distance of 200m at a speed of 10m/s and a distance of 600m at a speed of 20 m/s. What is the average speed of the motor ?

15. A cheetah can run at 30m/s. How far will it travel in 12 seconds?

16. An athlete runs a rectangular field of side 100m by 80m in one minute. What is average speed?

17. If a car moved a distance of 500m at a speed of 400 km/n and returned, at a speed of 60km/n to its initial position along the same road, what is its average speed of the athlete?

Solution

12. $Vav = \frac{S_T}{t_T} = \frac{81\text{ km}}{1\text{ hour} + 0.5\text{hour}} = \frac{81000\text{m}}{5400\text{sec.}} = 15\text{m/s}$

13. $Vav = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t_1 + t_2} = \frac{400 + 800}{5(60)+3(60)} = \frac{1200}{480} = 2.5\text{m/s}$

14. $Vav = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t_1 + t_2},$

$$t_1 = \frac{S_1}{V_1} = \frac{200}{10} = 20\text{sec}$$

$$t_2 = \frac{S_2}{V_2} = \frac{600}{20} = 30\text{sec}$$

$$Vav = \frac{800}{50} = 16\text{m/s}$$

15. $S = vt = (30)12 = 360\text{m}$

16. $Vav = \frac{S_T}{t_T} = \frac{2(100+80)}{60} = \frac{360}{60} = 6\text{m/s}$

17. $Vav = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t_1 + t_2} = \frac{S_1 + S_2}{\frac{S_1}{V_1} + \frac{S_2}{V_2}}$

$$= \frac{2S}{\frac{S(v_1s + v_2)}{v_1 v_2}} = \frac{2v_1v_2}{v_1 + v_2}$$

$$Vav = \frac{2(40)(60)}{40 + 60}$$

$$= \frac{4800}{100} = 48km/h$$

For a moving body, its speed alone may not give complete description about the nature of its motion. Therefore, to answer the question, how fast and in which direction a body is moving, we use a concept called *velocity*.

Velocity: Is the rate of change of displacement in a unit time

Mathematically, velocity of a body is calculated as :

$$\text{Velocity} = \frac{\text{change in Displacement}}{\text{Time Taken}}$$

$$\boxed{\vec{V} = \frac{\Delta\vec{S}}{\Delta t}}$$

Velocity is a vector quantity and its SI unit is meter per second (m/s). It can also be expressed using km/h or mi/h.

➥ The magnitude of velocity is speed of the body.

Conceptual Examples

18. Can a body have a constant velocity and varying speed at time? Explain

Explanation:

No! Constant velocity means steady speed in a specific direction.

19. Can a body have a Constant Speed and a Varying Velocity at the same time? Explain

Explanation:

Yes! This is possible when a body moves in a circular path at steady speed.

20. A man leaves his house for a cycle ride, and comes back to his house

after half an hour, covering a total distance of 5km. What can you say about the average velocity of the man?

Explanation:

$$\vec{V}au = \frac{\Delta\vec{S}}{\Delta t} = 0, \text{Zero}$$

Illustrative Example

21. A car moved 500m due east in 15 seconds and then 300m due west in 5 seconds. What is the cars
    A. Average speed
    B. Average velocity
22. A boy walks 400m East and then 300m north in just 20 seconds. Find the boy's
    A. Average speed
    B. Average velocity
23. An athlete runs a circular track of radios 400m in just in 40 seconds. What is the athlet's
    A. Average speed
    B. Average velocity

Solution

21. A) $Vav = \frac{S_1 + S_2}{t_1 + t_2} = \frac{500 + 300}{15 + 5} = \frac{800}{20} = 40 \, m/s$

B) $\vec{V}av = \frac{\Delta S}{\Delta t} = \frac{S_2 - S_1}{15+5} = \frac{300-500}{20} = -10 \, m/s$, West

$\vec{V}av = 10 \, m/s,$ East

22. A) $Vav = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t} = \frac{400+300}{20} = 35 \, m/s$

B) $\vec{V}av = \frac{\Delta S}{\Delta t} = \frac{\sqrt{s_1^2 + s_2^2}}{t} = \frac{\sqrt{(400)^2 + (300)^2}}{20} = 25 \, m/s,$ North of East.

23. A) $Vav = \frac{S_T}{t_T} = \frac{2\pi r}{t} = \frac{2(3.14)(400)}{40} = 62.8 \, m/s$

B) $\vec{V}av = \frac{\Delta S}{\Delta t} = 0$, zero.

Conceptual Examples

24. Is there any difference between average velocity and instantaneous velocity of a body? Explain

Explanation:

Yes there is! Average Velocity is the over all velocity of a body for its entire trip. While, instantaneous velocity is the velocity of the body at a particular instant of time.

$$\text{In symbol, } \vec{V}av = \frac{\overrightarrow{\Delta S}}{\Delta t}$$

$$\vec{V}inst = \frac{\overrightarrow{\Delta S}}{\Delta t} \text{ as } \Delta t \text{ approaches zero,}$$

25. If the average velocity of a body is found to be zero, can we conclude that its instantaneous velocity is also zero ? Explain

Explanation:

No! A moving body can have zero average velocity when it returns to its initial position, but during its journey history, it might have been moving faster, slower or might have stopped at some instants of time.

When a body changes its velocity, that is speeds up, slows down or changes its direction of motion, we say, the body is *accelerating*.

26. If the average velocity of an object is zero in some time interval, what can you say about the displacement if the object for the interval?

Answer: The displacement is **zero,** since the displacement is proportional to average velocity.

Acceleration Is the rate of change of velocity per unit time.

Mathematically, acceleration of a body is calculated as

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time taken}}$$

$$\vec{a} = \frac{\Delta \vec{V}}{\Delta t} = \frac{V - u}{t}$$

Acceleration is a vector quantity and its SI unit is meter per second square (m/s^2)

A body is said to accelerate when there is change in its speed, in its direction or in both. A body at rest has zero initial velocity and a body coming to rest has zero final initial velocity. Moreover, when a body slows down, its acceleration became negative and we call the body is *decelerating*.

Conceptual Examples

27. Can a body of zero velocity accelerate? Explain

Explanation:

Yes, For example, a body thrown up ward has zero velocity at its maximum height but is still accelerating.

28. If the acceleration of a body is zero, does it mean that its velocity is also zero? Explain

Explanation:

No! For example, when a body moves at constant speed in a straight line, its acceleration is zero but its velocity is none - zero constant.

29. Can the acceleration of a body has opposite direction to its velocity? Explain

Explanation:

Yes! When a body slows down, its acceleration has opposite direction to its velocity.

30. When a body decelerates, that is slows down, will it have necessary a negative acceleration? Explain

Explanation:

No. Not necessary! For example, if a body that moves in the negative

x - direction slows down, then its acceleration is positive that points to the positive x- direction.

The acceleration of a body at a specific instant of time is called instantaneous acceleration. Mathematically, instantaneous acceleration is obtained by

$$\vec{a}\,\text{inst.} = \frac{\Delta \vec{V}}{\Delta t} \text{ as } \Delta t \text{ approaches zero}$$

31. What does it mean when we say the acceleration of a body is $3m/s^2$? Explain

Explanation:

It means, the velocity of the body is increasing by 3m/s every second. There fore, the body has 3m/s in the first second, 6m/s in the next second, 9 m/s in the third second, ... etc

Illustrative Examples

32. What is the acceleration of a train if it speeds up from 20m/s to 50m/s in 5 seconds?

Solution

$$a = \frac{v-u}{t} = \frac{50-20}{5}$$

$$= 6m/s^2$$

33. If a car accelerates at a rate of $4m/s^2$ starting from rest, how long will it take the car to reach a speed of 12m/s?

Solution:

From, $a = \frac{v-u}{t}$

$$t = \frac{v-u}{a} = \frac{12-0}{4}$$

$$= 3 sec.$$

34. An ambulance moving at 144 km/h takes 10 seconds to slow down to 10m/s . What is its acceleration?

Solution

$$a = \frac{v-u}{t}, \; u = 144\, km/h = 40\, m/s$$

$$a = \frac{10-40}{10} = -3\,m/s^2$$

☑ The minus sign tells us, the acceleration is opposite in direction to the velocity.

35. If a taxi moving at 10m/s accelerate at 2m/s². What will be its velocity after 5 seconds?

Solution

$$\text{We know, } a = \frac{v-u}{t}$$

$$v = u + at = 10 + (2)(5)$$

$$= 20\,m/s$$

36. If a car moving at constant acceleration of 3m/s² attained velocity of 20m/s in 4seconds, what was its initial velocity?

Solution

$$\text{From, } a = \frac{v-u}{t}$$

$$u = v - at = 20 - (3)(4)$$

$$= 8\,m/s$$

In actual cases, a moving body may speed up, slow down or change its direction of motion. But, in some ideal and rare case, a body may travel at constant speed through its journey history. In such cases, the body is said to be in *uniform motion.*

Uniform Motion: Is the motion of a body at a constant speed.

☑ A body in a uniform motion covers equal distance in equal intervals of time and has zero acceleration. More over if the body is moving in a straight line, its average and instantaneous velocities have the same values at all times.

Illustrative Example

37. If a body has the following journey history, in a straight line, then find,

A. The instantaneous velocity for each time internal

B. The average velocity

C. The acceleration of the body

D. Is the body under uniform motion? Why?

Distance (m)	0	10	20	30	40	50
Time (s)	0	1	2	3	4	5

Solution

A) $V_1 = \frac{S_1}{t_1} = \frac{10}{1} = 10\,m/s$

$V_2 = \frac{S_2}{t_2} = \frac{20}{2} = 10\,m/s$

$V_3 = \frac{S_3}{t_3} = \frac{30}{3} = 10\,m/s$

$V_4 = \frac{S_4}{t_4} = \frac{40}{4} = 10\,m/s$

$V_5 = \frac{s_5}{t_5} = \frac{50}{5} = 10\,m/s$

B) $V_{av} = \frac{S_T}{t_T} = \frac{50}{5}\ 10\,m/s$

C) $a = \frac{\Delta V}{\Delta t} = \frac{10-10}{1} = 0$, zero

D) *Yes, the body is in a uniform motion since its speed is constant.*

3.3 Equations of Motion with Constant Acceleration

If the velocity of a body increase or decreases by equal amounts in equal intervals of time, then the acceleration of the body be came constant and the body is said to be in a *uniform acceleration motion.*

The motion parameters such as velocity, acceleration displacement and time taken of a body in a uniform motion are related by simple set of equations known as *the equations of motion.*

Now let's derive the equations of motion using the definition of acceleration and average velocity.

Acceleration, $a = \frac{V-u}{t}$, then the final velocity is

$V = u + at$ ------ (1)

Average Velocity, $V_{av} = \frac{s}{t}$, $V_{av} = \frac{V+u}{2}$

$S = \left(\frac{v+u}{2}\right)t$ ------ (2)

Substitute, $v = u + at$, in to equation (2), we get,

$$S = \left[\frac{(u+at)+u}{2}\right]t$$

$S = ut + \frac{1}{2}at^2$ ------- (3)

Again, substiting, $t = \frac{v-u}{a}$, in to eqution (2), we obtain,

$$s = \left(\frac{v+u}{2}\right)\left(\frac{v-u}{a}\right)$$

$v^2 = u^2 + 2as$ ------- (4)

Illustrative Examples

38. A car accelerates at $2m/s^2$ starting from rest, what will be its velocity after 10 seconds?

Solution

$V = u + at = 0 + (2)(10)$

$= 20m/s$

39. An automobile accelerates at $4m/s^2$ starting from rest. What distance will it cover in 10 seconds?

Solution

$S = vt + \frac{1}{2}at^2 = (0)10 + \frac{1}{2}(4)(10)^2$

$= 200m$

40. An airplane moving at 100m/s decelerates uniformly at $6m/s^2$. What will be its speed as it moved 800m along the run - way?

Solution

$$V^2 = u^2 + 2as = (100)^2 + (2)(-6)(800) = 400$$

$$V = 20\ m/s$$

41. A racing car is travelling at 10m/s. It accelerates uniformly and covers a distance of 725m in 10 sec. Calculate the acceleration of the car

Solution

$$S = ut + \frac{1}{2}at^2 \Rightarrow 725 = (10)(10) + \frac{1}{2}a(10)^2$$

$$a = 12.5\ m/s^2$$

42. A truck gradually starts off from rest with a uniform acceleration of 2m/s² and reaches a velocity of 16m/s. Calculate the distance it covered.

Solution

$$V^2 = u^2 + 2as$$

$$S = \frac{v^2 - u^2}{2a} = \frac{(16)^2 - (0)^2}{2(2)}$$

$$= 64m$$

43. A car moving with constant acceleration covers the between two points 100m apart in 10 seconds. If its speed as it passes the second point is 15m/s. Then, what is

A. Its speed at the first point

B. Its acceleration

Solution

A) $S = \frac{(V+u)}{2}t \Rightarrow u = \frac{2(s)}{t} - v = \frac{2(100)}{10} - 15 = 5\ m/s$

B) $a = \frac{V-u}{t} = \frac{15-5}{10} = 1\ m/s^2$

44. A Volkswagen and a Cadillac are driven on the same 120km trip. The Volkswagen travels at 80km/h all the time. The cadillac driving at 100km/n stops for ten minutes after travelled for half an hour: Which car is the first to arrive at the destination?

Solution

The volkswagen takes, $t_v = \frac{S}{V_v} = \frac{120}{80} = 1.5h$, and the cadillac

takes, $t_c = \frac{S}{Vc} = \frac{120}{100}$

$= 1.2h$. And, slince it was not moving

For 10 minutes, the total time it was on the road is then $t_c = 1.2h + 10min = 1.4h$ since $t_c < t_v$, it is the cadillac that arrived first at the destination.

45. A cyclist starts from rest and accelerates at 1m/s for 20 second. He then travels at a constant speed for 1minute and finally decelerates at $2m/s^2$ until he stops. Find:

A. His maximum speed

B. The total distance he covered

Solution

First Phase, $V = u + at = 0 + (1)\ (20) = 20 \, m/s$

$$S_1 = ut + \frac{1}{2}at^2 = (0)(20) + \frac{1}{2}(1)\ (20)^2 = 200m$$

Phase Two, $S_2 = Vt = (20)(60) = 1200\,m$

Phase Three, $S_3 = \frac{V^2 - u^2}{2a} = \frac{0 - (20)^2}{2(-2)} = 100m$

A. $V = 20m/s$

B. $S = s_1 + s_2 + s_3 = 1500m$

46. A taxi moving at 30m/s is forced to stop in 5 seconds due to an electric pole blocking the road 85m ahead. If the drivers reaction time is 0.3 second, could he manage avoiding collision with the pole?

Solution

Total stopping distance is reaction distance plus braking distance

$$S = S_r + S_b = ut_r + \left(\frac{V + u}{2}\right)t = (30)\ (0.3) + \left(\frac{0+30}{2}\right)5$$

$= 84m$

47. A bus initially at rest accelerates to a speed 25m/s in 4 seconds. What is the distance covered by the bus in the fourth second?

Solution

$$S_n^{th} = u = + \frac{a}{2}(2t-1),$$

$$a = \frac{v-u}{t} = \frac{25-0}{4} = 6.25 \, m/s^2$$

$$S_n^{th} = 0 + \frac{6.25}{2}[2(4)-1] = 21.9m$$

48. A car is a accelerating uniformly at it passes two checkpoints that are 30m apart, The time taken between checkpoints is 4 second and the car's speed at the first checkpoint is 5m/s. Find.

A. The acceleration of the car

B. Its speed at the second checkpoint

Solution

A) $S = ut + \frac{1}{2}at^2 \Rightarrow 30 = \frac{1}{2} a(4)^2 \Rightarrow a = 1.25 \, m/s^s$

B) $V = u + at = 5 + (1.25)(4) = 10 \, m/s$

49. The velocity of a train reduces form 15m/s to 7m/s while travelling a distance of 80m. How much further will the train travel before coming to rest provided the acceleration is constant.

Solution

$S_1 \frac{V_1^2 - u_1^2}{2a}$ and $S_2 = \frac{V_2^2 - u_2^2}{2a}$, Taking Ration

$$\frac{S_2}{S_1} = \frac{V_2^2 - u_2^2}{V_1^2 - u_1^2}$$

$$\frac{S_2}{80} = \frac{0-(7)^2}{(7)^2 - (15)^2}$$

$$S_2 = 22m$$

50. A body moving with constant deceleration of 5m/s² covers a 30m distance in 3seconds. How far will the body travel before coming to rest?

Solution

$$S_1 = V_1 t - \frac{1}{2}at^2 \Rightarrow$$

$$V_1 = \frac{2S_1 + at^2}{2t} = \frac{(2)(30)+(-5)(3)^2}{2(3)} = 2.5 \,m/s$$

$$S_2 = \frac{V_2^2 - u_2^2}{2a} = \frac{0-(2.5)^2}{2(-5)} = 0.625m$$

51. If a body moving with uniform acceleration covers 15m in the third second and 25m in the eight second. How much will it travel in the tenth second?

Solution

$$S_n^{th} = u + \frac{a}{2}(2t-1)$$

$$15 = u + \frac{a}{2}(2(3)-1) ----(1)$$

$$25 = u + \frac{a}{2}(2(8)-1) ----(2)$$

Solving the two equations simultaneously, we get, $a = 2m/s^2$, $u = 10m/s$

Hence, $S^{th}_{10} = 10 + 2/2 \; (2(10) - 1) = 29m$

52. A car starting from rest moves with constant acceleration and reached a velocity of 20m/s. What was the velocity of the car at the middle of the trip?

Solution

$$S = \frac{V^2 - u^2}{2a}, \text{and at the middle}$$

$$\frac{S}{2} = \frac{(V^*)^2 - u^2}{2a}, V^* \text{ is velocity at mid-point}$$

$$V^* = 10\sqrt{2} \,m/s$$

53. Two cars A and B, at the same initial position accelerate uniformly form rest. After 5 second, A is 2m ahead of B. What will be their separation after 8 seconds?

Solution

$$\text{First case}, S_A = \frac{1}{2} a_A t^2 \text{ and } S_B = \frac{1}{2} a_A t^2$$

$$\text{And}, S_A - S_B = \frac{1}{2} t^2 (a_A - a_B) \Rightarrow a_A - a_B = 0.25 m/s^2$$

$$\textit{Second case}, S_A - S_B = \frac{1}{2} t^2 (a_A - a_B) = \frac{1}{2}(8)^2 [0.25]$$

$$S_A - S_B = 8m$$

54. A car starting from rest accelerates at $4m/s^2$. If it travelled 40m in the last second, what is the total distance covered by the car?

Solution

$$S_n^{th} = u + \frac{a}{2}(2t_n - 1) \Rightarrow 40 = 0 + \frac{4}{2}(2t_n - 1) \Rightarrow t = 10.5 \sec$$

$$S = ut + \frac{1}{2}at^2 = 0(10.5) + \frac{1}{2}(4)(10.5)^2$$

$$= 220.5m$$

55. A careless Motorist travelling at 90km/h passes a police car moving at 50km/h. Immediately, the police car starts accelerating at $3m/s^2$. At what distance will the police catch the motorist?

Solution

$$Vt = ut + \frac{1}{2}at^2$$

$$V = u + \frac{1}{2} at$$

$$t = 7.4 \sec$$

$$S = Vt = (25)(7.5) = 18m$$

56. Two sport cars start from rest and move one after the other in 1 minute interval with an acceleration of $0.4m/s^2$ each. How long after the first car starts moving will the distance between them be 4200m?

Solution

$$S_1 - S_2 = \frac{1}{2} at_1^2 - \frac{1}{2} at_2^2, t_2 = t_1 - 60$$

$$4200 = \frac{1}{2}(0.4)\left[t_1^2 - (t_1 - 60)\right]^2$$

$$t_1 = 145 \text{ seconds}$$

57. A bullet moving with a speed 200m/s can penetrate a 4cm thick block. What should be the speed of the bullet to penetrate a 10cm thick block of the same material?

Solution

From, $V^2 = u^2 + 2as \; u \propto \sqrt{s}$

$$\frac{u_2}{u_1} = \frac{\sqrt{S_2}}{\sqrt{S_1}} \Rightarrow u_2 = u_1\sqrt{\frac{S_2}{S_1}} = 200\sqrt{\frac{10}{4}}$$

$$u_2 = 316\,m/s$$

58. A bus is beginning to move with an acceleration of $1m/s^2$. A boy who is 48m behind the bus starts running at 10m/s. After what time will he catch the bus?

Solution

Distance moved by the body Distance moved by the bus

$$S_1 = S_2$$

$$Vt = 48 + \frac{1}{2}(a)\,t^2$$

$$10t = 48 + \frac{1}{2}t^2$$

$\Rightarrow t^2 - 20t + 96 = 0$ using the quadratic equation

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$t = 8sec$ or $t = 12sec$

Earlier time, $t = 8sec$

59. The motion of a body is given by the equation, $V = mt + n$ where m is $5m/s^2$ and n is 10m/s. How far will it travel in the first 2 seconds?

Solution

$V = mt + n = 5t + 10 = u + at$

Hence, $u = 10m/s$ and $a = 5m/s^2$

$$\Rightarrow S = ut + \frac{1}{2}at^2 = (10)^2 + \frac{1}{2}(5)(2)$$

$$= 30m$$

60. Show that the distance moved by a body in the n^{th} second is obtained by: $S_n^{th} = u + \frac{a}{2}(2t_n - 1)$

$$S_n^{th} = S_n - S_{n-1}$$

$$= \left[ut_n + \frac{1}{2}at_n^2\right] - \left[u(t_n - 1) + \frac{1}{2}a(t_n - 1)^2\right]$$

$$= ut_n + \frac{1}{2}at_n^2 - \left[ut_n - u + \frac{1}{2}a(t_n^2 - 1)^2\right]$$

$$= ut_n + \frac{1}{2}at_n^2 - ut_n + u - \frac{1}{2}at_n^2 + \frac{2t_n a}{2} - \frac{1}{2}a$$

$$= u + \frac{2t_n^a}{2} - \frac{1}{2}a$$

$$= u + a\left[t_n - \frac{1}{2}\right]$$

$$= u + \frac{a}{2}(2t_n - 1)$$

Warning: The equations of motion we used so far are applicable only for a body that is uniformly accelerating.

Typical example of a body in uniform acceleration is free fall. A body thrown or released in air move to wards the centre of the earth at a constant acceleration called *acceleration due to gravity.*

Free Fall: Is a body that move in air due to the influence of gravity alone.

Near the surface of the earth, a freely falling body moves at a constant gravitational acceleration of $g = 9.81\ m/s^2$.

The equations of motion for a free fall are the same as those used for a uniformly accelerated motion in a straight line except some symbol and sign modifications.

So here, we use 'g' for 'a' and 'y' or 'h' for 's' and in this book we use positive sign for 'g' when the motion is downward and negative sign for an upward motion. There fore, we can have the following cases.

For a body dropped $u = 0$	For a body thrown down ward $u \neq 0$	For a body thrown up ward $u \neq 0$
$V = gt$	$V = u + gt$	$V = u - gt$
$y = \frac{1}{2}gt^2$	$y = ut + \frac{1}{2}gt^2$	$y = ut - \frac{1}{2}gt^2$
$V^2 = 2gy$	$V^2 = u^2 + 2gy$	$V^2 = u^2 - 2gy$

☑ A body is in free fall as soon as it is released in to the air weather it is dropped, or thrown in any direction and in the absence of air resistance, all bodies fall with the same acceleration regardless of their mass.

Conceptual Example

61. What will happen to the velocity and acceleration of a body that is thrown upward when it reached the maximum height? Explain

Explanation:

At the maximum height, the velocity of the body is zero but its acceleration remains 9.81 m/s^2.

Illustrative Example

62. A ball is kicked upward with an initial speed of 20m/s from the ground, use $g = 10m/s^2$ and calculate,

A. The speed of the ball at t = 2 second
B. The maximum height reached by the ball
C. The time the ball takes to return to the ground

Solution

A. $V = u - gt = 20 - (10)(2) = 0$, zero

B. $V^2 = u^2 - 2gh_{max}$, $V = 0$ at h_{max}

$$h_{max} = \frac{u^2}{2g} = \frac{(20)^2}{2(10)} = 20m$$

C. $Y = ut - \frac{1}{2}gt^2$, $y = 0$

$$0 = ut - \frac{1}{2}gt^2$$

$$t = \frac{2u}{g} = \frac{2(20)}{10} = 4\text{second}$$

63. At the time a ball is dropped from the top of a 20m building, a stone is thrown up ward from the ground. If they both hit the ground at the same time, what was the initial velocity of the stone?

Solution

For the ball, $Y = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2(20)}{10}} = 2\,\text{sec}$

For the stone, $Y = ut - \frac{1}{2}gt^2 = 0$

$$u(2) = \frac{1}{2}(10)(2)^2$$

$$u = 10\text{m/s}$$

64. From what height did a body fall if its speed as it strikes the ground is 30m/s?

Solution

$$V^2 = u^2 + 2gy,\ u = o$$

$$Y = \frac{V^2}{2g} = \frac{(30)^2}{2(10)}$$

$$= 45\text{m}$$

65. A stone is released from the top of 180m cliff. If one second later a ball is thrown down and both hit the ground at the same time, with what speed was the ball thrown?

Solution

For the stone, $Y = ut_s - \frac{1}{2}gt_s^2, \Rightarrow t_s = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2(180)}{10}} = 6$

For the ball, $Y = ut_b + \frac{1}{2}gt_b^2, t_b = t_s - 1 = 6 - 1 = 5\text{sec}$

There fore, $180 = 5u + \frac{1}{2}(10)(5)^2$

$u = 61 m/s$

66. An object is thrown down ward with initial speed of 12m/s from a 20m high building. Describe how the height of the object varies with time.

Solution

The height of the object from the ground at any time is

$$Y = 20 - (ut + \frac{1}{2}gt^2)$$

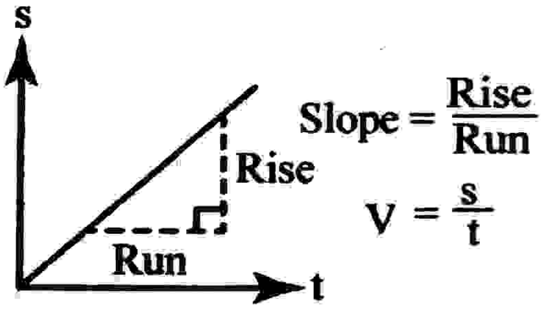
$$Y = 20 - ut - \frac{1}{2}gt^2$$

3.4 Graphical Description of Uniformly Accelerated Motion

A graphical description of motion of a body is a powerful means that help us to easily visualize the nature of motion of a body under consideration. To plot a motion graph, we label the independent variable that is time along the *x*-axis and the dependent variable such as displacement, velocity and acceleration along the y - axis with the appropriate scales.

Distance - Time Graph (s - t) Graph

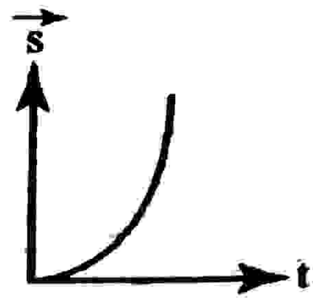
For a uniform motion in a straight line, the s - t graph is a straight line that passes through the origin.



☑ Slope of the distance - time graph represents *speed* of the body

Displacement - Time Graph, $(\vec{s} - t)$ Graph

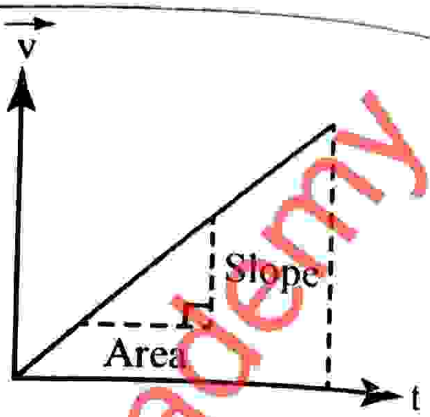
For a uniformly accelerated motion, the $\vec{V}$-t graph is half - parabolla as shown in the sketch.



☑ Slope of displacement - time graph represent *velocity* of the body

Velocity - Time Graph, ($\vec{V}$ - t) Graph

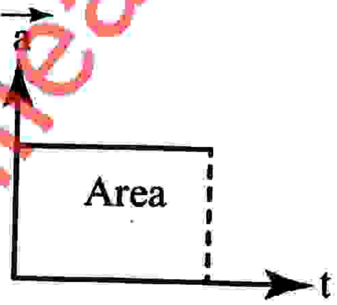
For a uniformly accelerated motion, the $\vec{V}$ - t graph is a straight line that passes through the origin, if the body started from rest.



☑ The slope of a velocity - time graph represents *acceleration* of the bod and the area under the velocity - time curve represents *displacement* o the body.

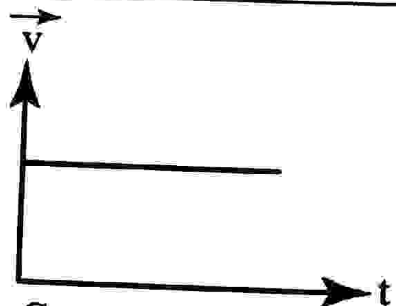
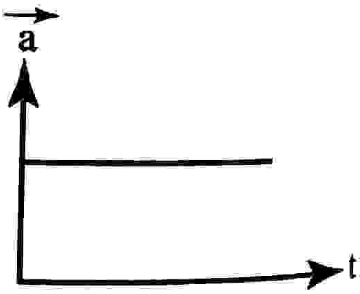
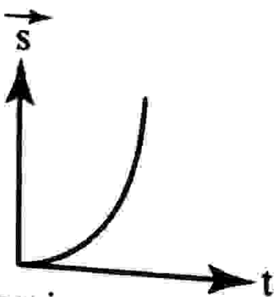
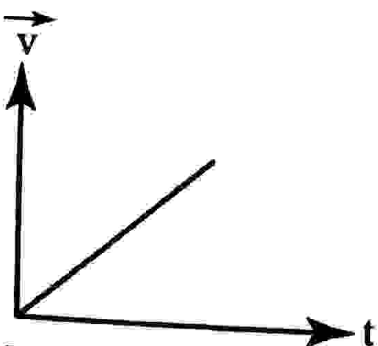
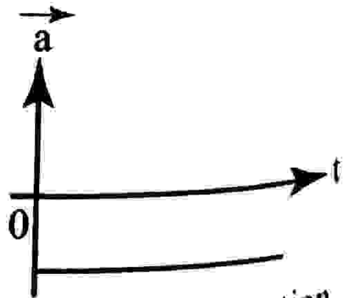
Acceleration - time Graph, ($\vec{a}$ - t) graph

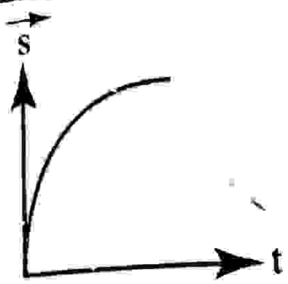
For a uniformly accelerated motion, the $\vec{a}$ - t graph is a horizontal line parallel to the time axis as shown



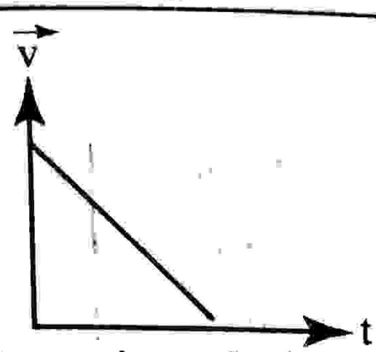
☑ The area under the acceleration - time graph represents the *change in velocity* of the body.

Some of the typical motion graphs are the following.

Displacement - Time Graph	Velocity - Time Graph	Acceleration - Time Graph
 Constant velocity	 Constant velocity	 Postive acceleration
 Increasing velocity	 Increasing velocity	 Negative acceleration



Decreasing velocity



Decreasing velocity

Conceptual Example

67. Is there any difference between uniform motion and uniformly accelerated motion? Explain

Explanation

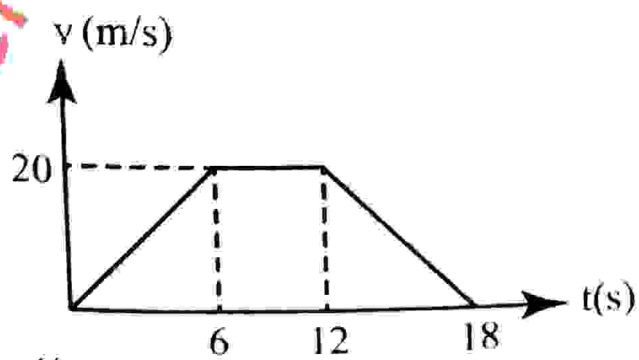
Yes! In a uniform motion in a straight line, the velocity is constant and the acceleration is zero. But, in a uniformly acceleration motion, the velocity changes and the acceleration is constant.

68. Why is the distance - time graph straight while, the displacement - time graph is parabollic? Explain

Explanation

Because, in a uniform motion, the speed is constant, and distance is obtained by, s = vt, 1st degree linear. While in a uniformly accelerated motion, the speed varies and displacement is obtained by $s = ut + \frac{1}{2}at^2$, 2nd degree quadratic.

69. Describe the nature of motion of a car whose velocity varies with time as shown below



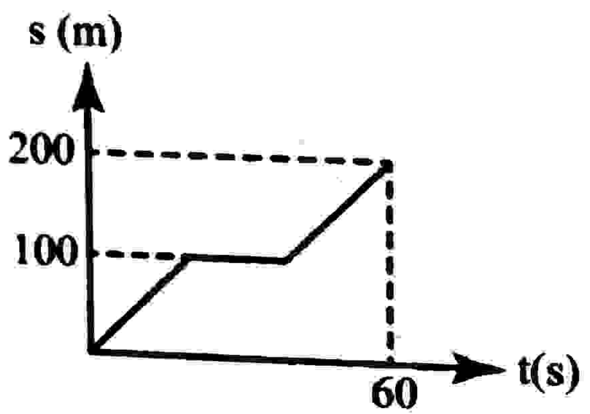
Explanation

The car starts from rest and reached a velocity of 20m/s in 6 seconds and moved at this rate for another 6 seconds and then slows down uniformly and comes to rest in 6 seconds.

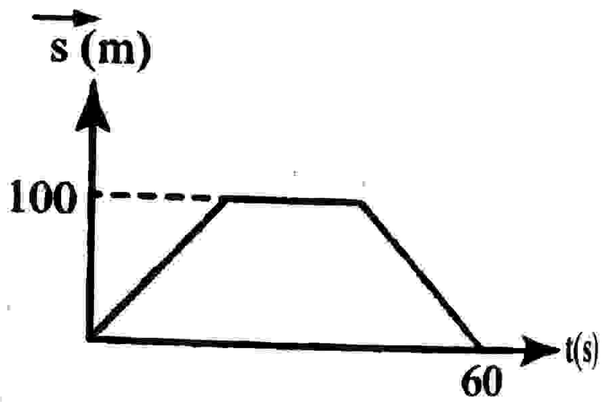
70. Can the distance time graph goes down? What about the displacement time graph? Explain

Explanation

Never! Distance - time graph can not have negative slope, but displacement - time graph can have, such a slope. For example, if you walk 100m due east and return to your initial position in 60 seconds, along the same route, your distance - time and displacement - time graph looks the following



Distance - Time Graph



Displacement - Time Graph

Illustrative Examples

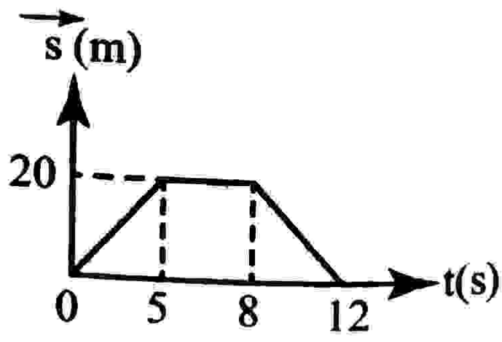
71. If a car experienced a displacement - time graph as follows

A. State the nature of its motion

B. Calculate its total distance

C. Calculate its velocities

D. What is its displacement



Solution

A. From 0 to 5 sec, the car is moving at constant speed, from 5 to 8 sec it is at rest. From 8 to 12 sec, it is slowing down.

B. Distance moved = Total area

$$S_T = \frac{1}{2}(5)(20) + (3)(20) + \frac{1}{2}(5)(20)$$
$$= 160m$$

C. $v_1 = \frac{\Delta s_1}{\Delta t_1} = \frac{20 - 0}{5} = 4m/s,$

$v_2 = \frac{\Delta s_2}{\Delta t_2} = 0$

$v_3 = \frac{\Delta s_3}{\Delta t_3} = \frac{0 - 20}{4} = -5 m/s$

D. Displacement $= \Delta S_1 + \Delta S_2 + \Delta S_3 = (20 - 0) + (20 - 20) + (0 - 20)$

$\Delta S = 0$, zero. The car returned to its starting point.

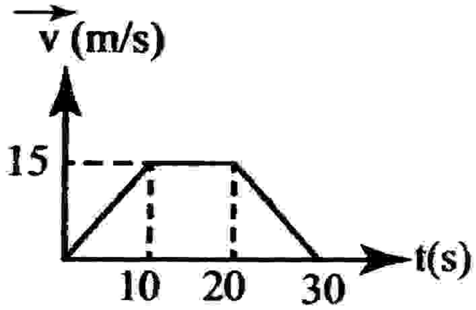
72. If the velocity - time graph of a body is plotted as follows;

A. Describe the nature of its motion

B. Calculate acceleration of the body

C. Find distance covered by the body

D. What is the displacement of the body



Solution

A. From 0 to 10 sec, the body is speeding up, accelerating at $1.5m/s^2$. From 10 sec to 20 sec, the body is moving at a constant velocity of 15m/s, zero acceleration. From 20 sec to 30 sec, the body is slowing down, decelerating at $1.5m/s^2$, until it comes to rest.

B. $a_1 = \frac{\Delta V_1}{\Delta t_1} = \frac{15 - 0}{10 - 0} = 1.5 m/s^2$

$a_2 = \frac{\Delta V_2}{\Delta t_2} = \frac{15 - 15}{20 - 10} = 0$, zero

$a_3 = \frac{\Delta V_3}{\Delta t_3} = \frac{0 - 15}{30 - 20} \; -1.5 m/s^2$

C. $S_T = S_1 + S_2 + S_3 = \frac{1}{2}(10)(15) + (15)(10) + \frac{1}{2}(10)(15)$

$= 300m$

D. $\Delta S = (Vav_1)(\Delta t_1) + (Vav_2)(\Delta t_2) + (Vav_3)(\Delta t_3)$

$\Delta S = \left(\frac{0+15}{2}\right)10 + \left(\frac{15+15}{2}\right)10 + \left(\frac{15+0}{2}\right)10$

$= 300m$

73. If a body has the following journey history, answer the following questions.

128	72	32	8	0	$\vec{s}$(m)
8	6	4	2	0	t (s)

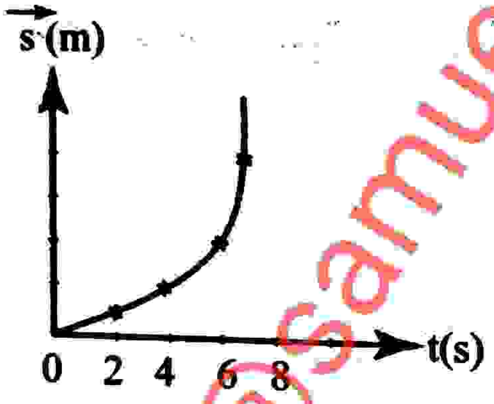
A. Plot the displacement - time graph

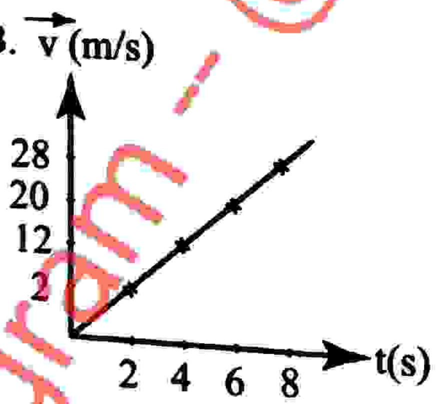
B. Plot the velocity - time graph

C. Plot the acceleration - time graph

D. Is the body in uniform motion or a uniform acceleration

Solution

A.


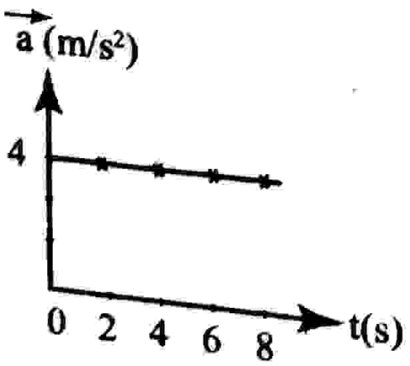
B.


$$V_1=\frac{\Delta s_1}{\Delta t_1}=\frac{8-0}{2-0}=4m/s$$

$$V_2=\frac{\Delta s_2}{\Delta t_2}=\frac{32-8}{4-2}=12m/s$$

$$V_3=\frac{\Delta s_3}{\Delta t_3}=\frac{72-32}{6-4}=20m/s$$

$$V_4=\frac{\Delta s_4}{\Delta t_4}=\frac{128-72}{8-6}=28m/s$$

C.


$$a_1=\frac{\Delta v_1}{\Delta t_1}=\frac{12-4}{4-2}=4\,m/s^2$$

$$a_2=\frac{\Delta v_2}{\Delta t_2}=\frac{20-12}{6-4}=4\,m/s^2$$

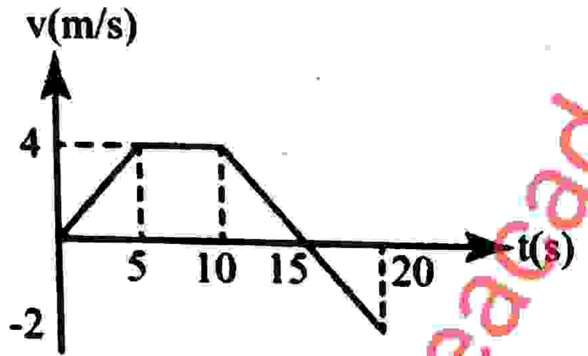
$$a_3=\frac{\Delta v_3}{\Delta t_3}=\frac{28-20}{8-6}=4\,m/s^2$$

D. The body is moving at constant acceleration of $4m/s^2$ starting from rest.

74. The velocity - time graph of a truck is given as follows. Calculate:

A. Distance moved

B. Displacement of the truck



Solution

A. Distance travelled = Total area under the curve

$$S_T = \frac{1}{2}(5)(4) + \frac{1}{2}(5)(2) + \frac{1}{2}(5)(2)$$
$$= 45m$$

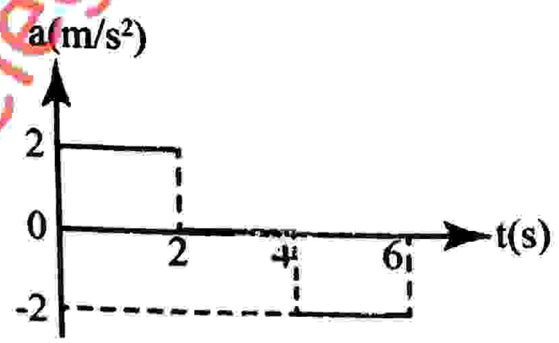
B. Displacent = $\Delta S_1 + \Delta S_2 + \Delta S_3 + \Delta S_4$

$$\Delta S = (Vav_1)\Delta t_1 + (Vav_2)\Delta t_2 + (Vav_3)\Delta t_3 + (Vav_4)\Delta t_4$$

$$\Delta S = \left(\frac{4+0}{2}\right)5 + \left(\frac{4+4}{2}\right)5 + \left(\frac{0+4}{2}\right)5 + \left(\frac{0+(-2)}{2}\right)5$$

$$\Delta S = 35m$$

75. If the acceleration - time graph for a car starting from rest looks the following



A. Calculate its velocity at each interval

B. Draw the velocity - time graph.

Solution

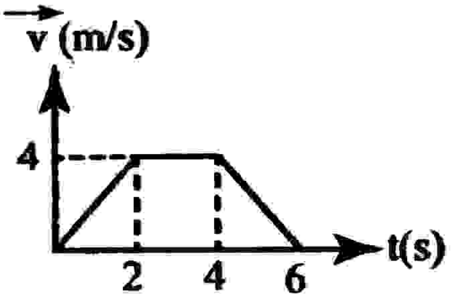
A. From 0 to 2 Sec, $\Delta V_1 = a\,\Delta t_1 = (2)(2) = 4m/s$

From 2 to 4 Sec, $\Delta V_2 = a\,\Delta t_2 = 0$, zero

From 4 to 6 sec, $\Delta V_3 = a\,\Delta t_3 = -4m/s$

That is at t=2 sec, V=t=4Sec, at 4se, V=4m/s, at t=6sec V=0, zero

B.



3.5 Relative Velocity in One Dimension

The motion of a body is relative. It depends on the frame of reference from which it is observed.

Relative Velocity: Is the rate at which a body changes its position with respect to another reference point.

For example, when you are moving in a car, for an observer standing by the road, you are moving at the speed of the car, but, for an observer who sit next to you in the car, you are not moving at all. Therefore, a body that seems to move with respect to one reference frame may not be moving at all as seen from another frame of reference.

The relative velocity between two bodies is obtained by taking the difference of their velocities. That is, if body A is moving at velocity V_A and body B at veloccity V_B with respect to say the ground, their relative velocities are

$V_{AB} = V_A - V_B$, velocity of body A with respect to body B

$V_{BA} = V_B - V_A$, velocity of body B with respect to body A

☑ When calculating the relative velocity of a body, we need to consider direction of motion of the bodies, and when two bodies are moving perpendicularly, then, their relative velocity is obtained using pythagora's theorem.

Illustrative Examples

76. Two car A and B are moving at velocities of V_A 30m/s and V_B = 40m/s. What will be their relative velocity if they are moving

A. In the same direction

B. In opposite direction

C. At right angle to each other

Solution

A. $V_{AB} = V_A - V_B = 30 - 40 = -10m/s = 10m/s$, left The minus sign indicates that, for an observer in car B, car A seems to move back ward.

$V_{AB} = V_B - V_A = 40 - 30 = 10$ m/s, right

B. $V_{AB} = V_{BA} = V_A - (-V_B) = V_A + V_B = 30 + 40 = 70$ m/s

C. $V_{AB} = V_{BA} = V_{AB}$

$= V_{BA} = \sqrt{V_A^2 + V_B^2} = \sqrt{(30)^2 + (40)^2} = 50m/s$

77. The position of a car that accelerates uniformly starting form rest is given below.

t (s)	0	1	2	3
s (m)	0	2	8	X

What is the distance covered by the car in t = 3 seconds?

Solution

$$S = ut + \frac{1}{2}at^2,\ u = 0,\ \text{at } t = 2\,\text{sec},\ (S) = 8m$$

$$8 = 0 + \frac{1}{2}(a)(2)^2 \Rightarrow a = 4\,m/s^2$$

Hence, at $t = 3$sec, $S = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(4)(3)^2 = 18m$

78. If the position of a body with time looks the following

x (m)	5	15	25	35	45	55
t (s)	0	5	10	15	20	25

relat x and t

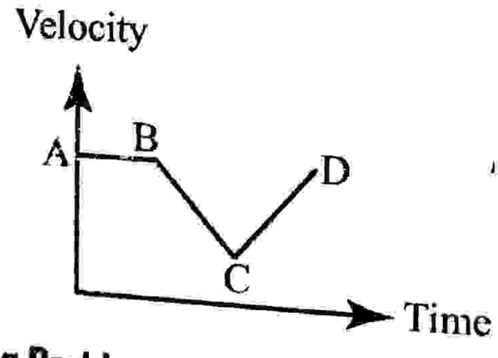
Solution

$x = 2t + 5$

End of unit Questions and problems

I. Give Short Answer to The Following Questions

1. When do we say body a is in motion?
2. What is distance covered by a body?
3. What is displacement of a body?
4. Explain the difference between speed and velocity?
5. Explain the difference between average speed and average velocity
6. What is instantaneous velocity of a body?
7. What is acceleration?
8. What do we mean by uniform motion?
9. Is there any difference between uniform motion and uniformly accelerated motion? Explain
10. What is Free Fall? Explain
11. If a velocity - time graph became horizontal, what will happen to the acceleration of the body.
12. Explain what relative velocity mean
13. What dose the area of velocity - time graph represent?
14. When will acceleration a body became negative.
15. Based on the given velocity - time graph, explain the nature of motion of the body.



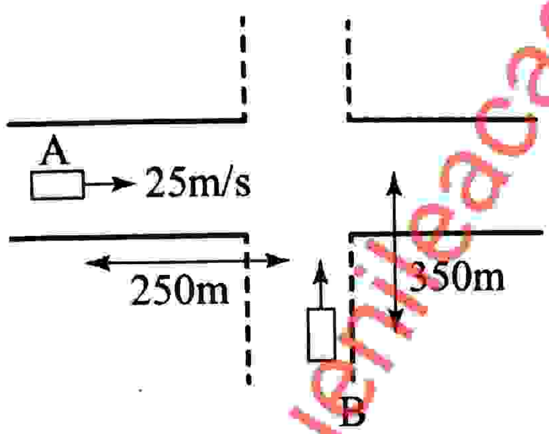
Solve the Following Problems

16. If you are running at 6m/s and decelerate at $2m/s^2$,
    A. How long will it take you to stop?
    B. How far will you go?
17. A uniformly moving train covered a 24 km in 10 minutes. How far will

it travel in 1hr and 30 minutes?

18. Two soccer players are approaching each other, each with a speed of 8m/s when they are 48m apart. How much time passes before they collide?

19. Two cars heading to a cross road with uniform velocities. If they collide at the center of the road, what must be the speed of car B?



20. The distance of a body is expressed by the relation; $S = 2t^2 + t + 10$. What is its average speed during the first 10 seconds of its motion ?

21. A body with an initial speed of 1 m/s accelerates uniformly at $2m/s^2$. What distance does it cover in the third second?

22. An autho mobile driver moving at 20m/s spotted a track 50m ahead that is moving at 10m/s. How long will it take him to overtake the truck?

23. A car speeds up from 5m/s to 25m/s in 10sec. What is its acceleration?

24. A body initially at rest accelerates uniformly at $2m/s^2$. How long will it take him to cover 400m

25. A body accelerates at 3m/s while its velocity changes from 20m/s to 40m/s. What is the distance covered by the body?

26. A car starts from rest and accelerates uniformly at $2m/s^2$ in a straight li...

   A. What is its speed after 5 seconds

   B. How far will it travel in 10 seconds

   C. How long will it take the car to cover 400m

27. A body kicks a ball upwards with an initial speed of 10m/s. What is the ball's

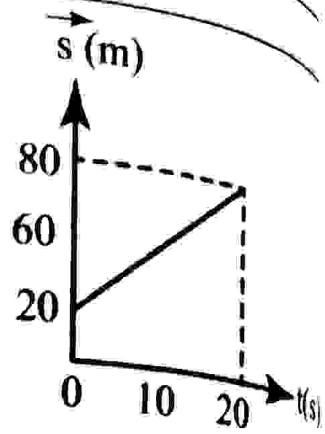
   A. Maximum height

   B. Time of flight

28. What is the relative velocity of a car moving at 40m/s due east with

respect to itself

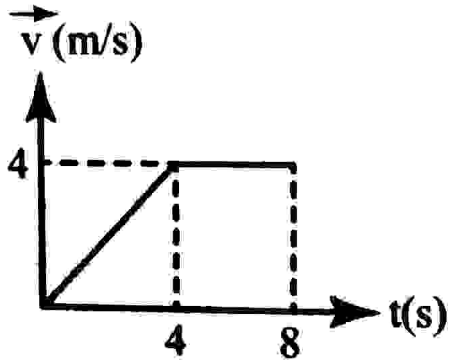
29. From the displacement - time graph shown, find the velocity of the body



30. From the velocity - time graph. Find

A. Acceleration of the body

B. Total distance travelled



II. Explanation to the Questions

1. When it changes position with time
2. Distance is the total path length travelled by a body
3. Displacement is the change in position of a body in a certain direction
4. Speed is distance per unit time, while velocity is displacement per unit time.
5. Average speed is total distance divided by total time taken while average velocity is displacement per unit time.
6. Instantaneous velocity is the velocity of the body at a specific instant of time or position
7. Acceleration is the rate of change of velocity
8. Uniform motion is motion of a body at constant speed
9. Yes. In uniform motion acceleration is zero.
10. Free Fall is a body that is dropped or thrown in to the air in any direction so that the only force acting on it is gravity
11. Velocity is constant and acceleration is zero
12. Relative velocity is the velocity of a body with respect to different frame of references.
13. Displacement
14. When the body slows down

15. From A to B, moved atonstant speed, B to C, it slows down and from C to D it speeds up.

II. Solution for the problems

16. A. $t = \frac{v - u}{a} = \frac{0 - 6}{-2} = 3sec$

B. $S = ut - \frac{1}{2}at^2 = (6)(3) - \frac{1}{2}(2)(3)^2 = 9m$

17. $V = \frac{S_1}{t_1} = \frac{24}{0.166} = 144.5km/h$

$V = \frac{S_2}{t_2} \Rightarrow S_2 = (V_2)(t_2) = (144.5)(1.5) = 216km$

18. Since they are approaching, their relative velocity is

$V = \frac{s}{t} \Rightarrow t = \frac{s}{v} = \frac{48}{16} = 3sec$

19. $V_A = \frac{S_A}{t_A} \Rightarrow t_A = \frac{S_A}{V_A} = \frac{250}{25} = 10sec$

$V_B = \frac{S_B}{t_B} = \frac{350}{10} = 35m/s$

20. $V_{av} = \frac{S_T}{t_T} = \frac{2t^2 + t + 10}{10} = \frac{2(10)^2 + 10 + 10}{10} = 22 m/s$

21. $S_n^{th} = u + \frac{a}{2}(2t - 1) = 1 + \frac{2}{2}(2(3) - 1) = 6m$

22. $S_a = S_t + 50 \Rightarrow V_a t = V_t t + 50$

$(20 - 10)t = 50 \Rightarrow t = 5sec$

23. $a = \frac{v - u}{t} = \frac{25 - 5}{10} = 2 m/s$

24. $S = ut + \frac{1}{2}at^2 \Rightarrow t^2 = \frac{2(S)}{a} = \frac{2(400)}{2} \Rightarrow t = 20sec$

25. $V^2 = u^2 + 2as \Rightarrow S = \frac{V^2 - u^2}{2a} = \frac{(40)^2 - (20)^2}{2(3)} = 200m$

26. A. $V = u + at = (5)2 = 10m/s$

B. $S = ut + \frac{1}{2}at^2 = \frac{1}{2}(2)(10)^2 = 100m$

C. $S = ut + \frac{1}{2}at^2 \Rightarrow t = \sqrt{\frac{2(S)}{a}} = \sqrt{\frac{2(400)}{2}}$

$t = 20$ Seconds

27. A. $V^2 = u^2 - 2gh_{max}$, $V = 0$

$h_{max} = \frac{V_2}{2g} = \frac{(10)^2}{2(10)} = 5m$

B. $h = ut - \frac{1}{2}gt^2$, $h = 0$

$t = \frac{2u}{g} = \frac{2(10)}{10} = 2sec$

28. $V_A = V_A - V_A = 40 - 40 = 0$, zero

29. $V = \text{slope} = \frac{\text{Rise}}{\text{Run}} = \frac{\Delta H}{\Delta x} = \frac{\Delta S}{\Delta t} = \frac{80 - 20}{20 - 0} = 2\,m/s$

30. A. $a_1 = \frac{\Delta V_1}{\Delta t_1} = \frac{4 - 0}{4} = 1\,m/s^2$, $a_2 = \frac{\Delta V_2}{\Delta t_2} = \frac{4 - 4}{4} = 0$, zero

B. $S_T = \frac{1}{2}(4)(4) + (4)(4) = 24m$

UNIT -4

4. Force, Work, Energy and Power

4. Force, Work, Energy and Power

Dear learner, how are you? This unit provides you the most common terms we use in our every day life. So now you will not only be able to define the concepts, force, work, energy and power, but also explain the variations and relations among them. Have a nice time.

4.1 What is Force

In our everyday life, we use the terms force, energy and power interchangeable as if they mean the same thing In physics however, they, are distinct terms with different meanings as we define them in the coming sessions.

Force: Is a pull or a push interaction between bodies

Force is a vector quantity and its SI unit is the newton (N), and the instrument used to measure force is called **newton meter**, which can be **digital** or analogue.

What are types of Forces

The interaction between bodies may involve physical contact or may be at distant. Therefore, a force can be contact or non - contact.

Contact force: Is a force for which the interacting bodies are in touch with each other.

Examples include, a body kicking a ball, a man pushing a cart, a girl carrying a bag.

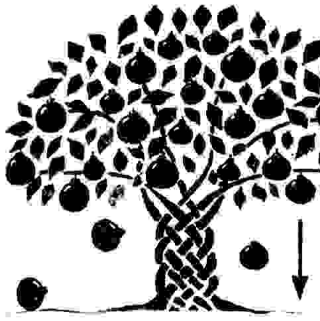

kicking ball


pushing a cart


carrying a bag

Non - Contact Force: Is a force that can act at a distance with out the need of physical contact between the interacting bodies.

Examples include, gravity, magnetic force and electro static force



Gravity

magnetic force

electro static force

Effects of Force

When a force acts on a body, it may deform or change the state of motion of the body.

Therefore, a force may cause a body to:

- Change its size and shape
- Start motion
- Stop motion
- Change its direction of motion

Conceptual Example

1. Can a force always cause motion? Explain

Explanation

No! it is a net force that causes motion

2. What is needed to make an object change its motion?

Explanation

A force is needed to change motion speeding up, slowing down, turning, and speeding all are motion changes that need a force.

4.2 Newton's Laws of Motion

The three laws of motion formulated by Isaac newton are stated as follows:

Newton's First Law → The law of Inertia

This law is valid for a body that do not experience net external force.

Newton's 1st law states that;

"A body at rest remains at rest and a body in motion continues its motion at constant speed in a straight line as long as no net force acts it"

Did You Know?

Inertia is natural tendency of a body to remain in its existing state of motion and that is why we call the first law, the law of inertia and, the bigger the mass of a body, the larger its inertia.

Conceptual Example

3. How is inertia of a body related to the mass of the body? Explain?

Explanation

Because, mass is the measure of amount of matter contained in a body. Hence lighter bodies such as small plastic balls have few particles and can easily be stopped or moved. But, heavier bodies such as a big rock have much particles and can not be easily stopped or moved.

4. What will happen to your body if the car you are in suddenly
   - A) Starts motion
   - B) Stops motion
   - C) Change its direction of motion

Explanation

A) Your body will lean backward since it wants to remain at rest

B) Your body will be thrown forward since you body wants to keep moving at the car's speed

C) Your body will be thrown side ways since it want to move at constant speed in a straight line

Newton's Second Law → The law of Acceleration

When no net force acts on a body, the body remains at rest or move at constant velocity. But, when a net force acts on it, the body accelerates and this is explained by the second law of newton

Newton's 2nd Law States that;

"The acceleration (a) produced on a body is directly proportional to the applied net force (F) and inversely proportional to the mass (m) of the body".

Mathematically, Newton's 2nd law is expressed as

$$\vec{F} = m\vec{a}$$

Therefore, 1N = 1kg m/s^2

- One newton is the force that when acts on a body of mass 1kg produces an acceleration of 1m/s^2

Conceptual Example

5. What is needed to give an object a greater acceleration?

Answer: A larger force cause a larger acceleration.

6. What will happen to the acceleration of a body.

A) Keeping the mass constant, the net force acting is doubled

B) Keeping the net force constant, the mass is doubled

Explanation

A) From, $F = ma \Rightarrow a = \frac{F}{m}$

$$a_1 = \frac{F_1}{m_1}$$

$$a_2 = \frac{F_2}{m_2} = \frac{2F_1}{m_1} = 2a, \text{ it is doubled.}$$

B) Again, from $a = \frac{F}{m}$

$$a_1 = \frac{F_1}{m_1}$$

$$a_2 = \frac{F_2}{m_2} = \frac{F_1}{2m_1} = \frac{1}{2}a_1, \text{ it is halved}$$

7. Is there any difference between mass and weight of a body ? Explain

Explanation

Yes there is Mass is the measure of the amount of matter contained by a body and it is a scalar quantity that is constant every where. But, weight is the gravitational force acting on a body towards the canter of the earth and it is a vector quantity that varies from place to place.

Illustrative Examples

8. What a net force will cause a 10kg body to increase its velocity from 8m/s to 20 m/s in 3 seconds.

Solution

$$F = ma = m\left(\frac{v - u}{t}\right) = 10\left(\frac{20 - 8}{3}\right) = 40N$$

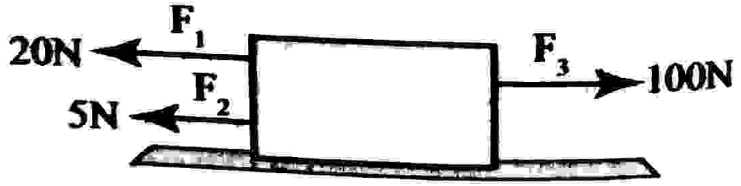
9. A force of 100N acts on a 25kg body that is initially at rest. At what time will the body attain a velocity of 20m/s?

Solution

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{100}{25} = 4\,{}^{m}\!/\!{}_{s^2}$$

$$a = \frac{v - u}{t} \Rightarrow t = \frac{v - u}{a} = \frac{20 - 0}{4} = 5\,seconds$$

10. If a block of mass 25kg resting on a smooth horizontal surface is subjected to the external forces shown. What acceleration will it experience?



Solution

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{F_3 - (F_1 + F_2)}{m} = \frac{100 - (20 + 5)}{25} = 3\,{}^{m}\!/\!{}_{s^2}$$

11. The engine of a car produces an acceleration of $6 m/s^2$ in the car. If this

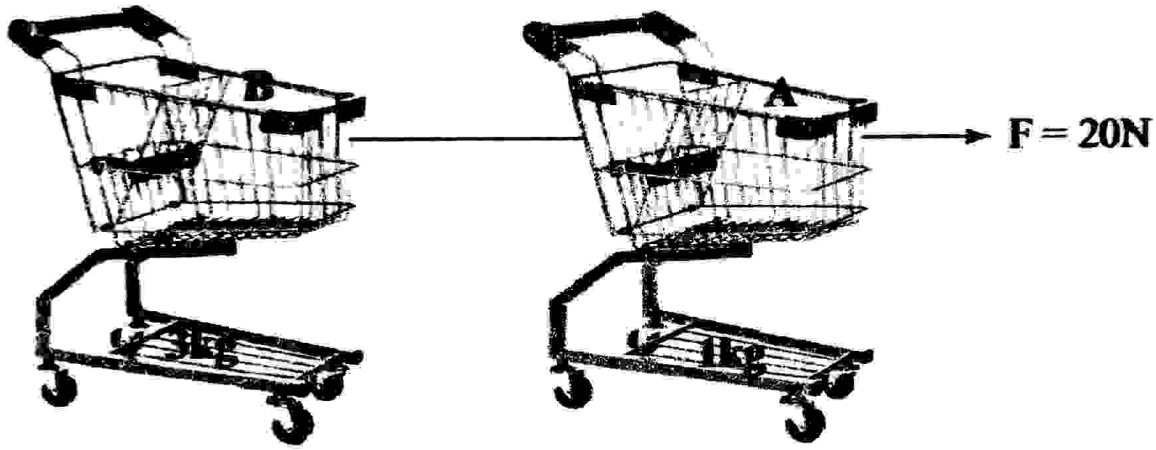
car pulls another car of the same mass, what would be its acceleration?

Solution

$$F_1 = F_2 \Rightarrow m_1a_1 = m_2a_2$$

$$a_2 = \frac{m_1 a_1}{m_2} = \frac{m_1 a_1}{2m_1} = \frac{a_1}{2} = \frac{6}{2} = 3 \, m/s^2$$

12. Two carts are pulled by a child on a smooth surface. What is the force exerted on the string by cart B?



Solution

For cart A : $F - T = m_A a$ .... (1)

For cart B: $T = m_B a$ .... (2)

From the equations; $a = \frac{F}{m_A + m_B} = \frac{20}{3+1} = 5 \, m/s^2$

$$\Rightarrow T = m_B a = (3)(5) = 15N$$

13. Which Combination of fundamental quantities can be used to express force?

A) Acceleration and mass

B) Mass, time and velocity

C) Acceleration, Length and time

D) Time, length, mass

Hint: From, $F = ma \Rightarrow 1N = 1kg \, m/s^2 = \frac{ML}{T^2}$

Answer: D

14. Two children are fighting over a toy. One pulls on it with a force of 75N East, the other pulls with a force of 65N west. What is the net force on the toy?

A) 140N East B) 140N West C) 10N East D) 10N West

Hint: $F = F_{East} - F_{west} = 75 - 65 = 10N$ East

Answer: C

15. "You cannot push a table without it pushes back on you" which of the physics laws describes this statement.

A) Newton's first law
B) Newton's second law
C) Newton's third law
D) kepler's third law

Hint: This is the law of action and reaction

Answer: C

16. What happens to a body on which a constant net force acts?

A) It velocity increases constantly
B) Its acceleration increases constantly
C) It moves with constant velocity
D) Its acceleration becomes opposite to the force

Hint: A constant net force give the body a constant acceleration and which in turn cause the velocity of the body to increase at a constant rate

Answer: A

Newton's Third law →The law of Action and Reaction

The existence of force in pairs is explained by the third law of newton as follows

Newton's 3rd law states that;

"For every action, there is an equal and opposite reaction"

That is, if body 1 exerts an action force on body 2, then body2 exerts an equal but opposite reaction force on body 1

Mathematically, this can be expressed as;

$$F_{12} = -F_{21}$$

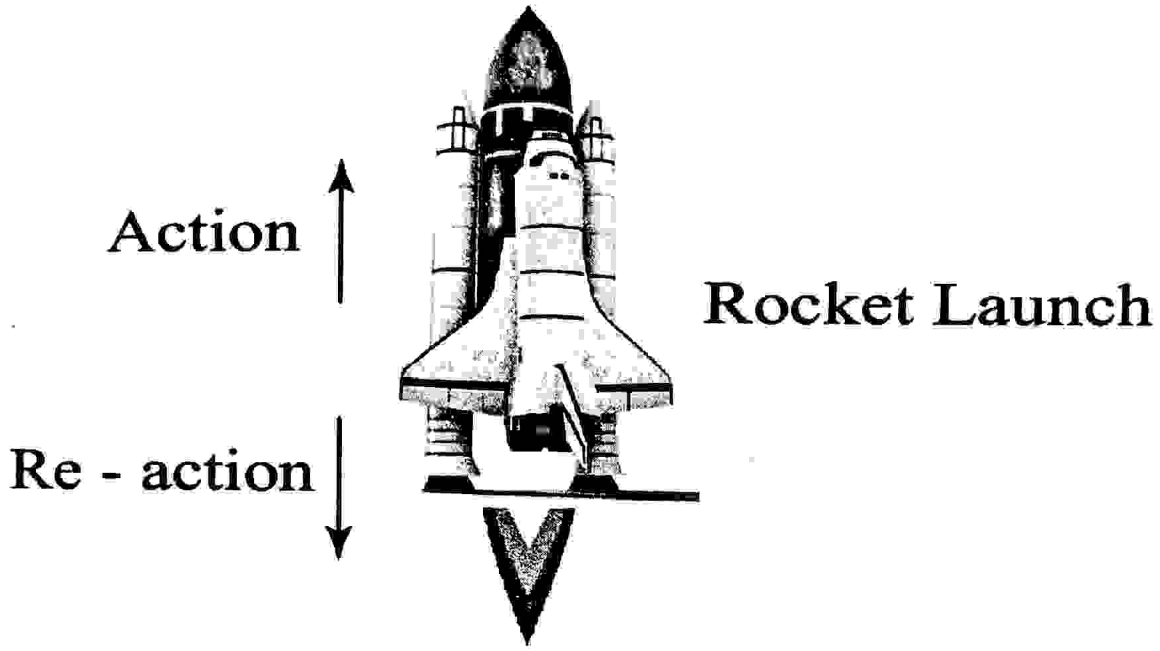
Where: F_{12} = Force exerted by body 1 on body 2
F_{21} = Force exerted by body 2 on body 1

(-) = The force act in opposite direction

- The action and reaction forces act on two different bodies.

As an example, consider the following situations;

In a rocket. launch, the fuel is burnt and the resulting hot gases are forced out of the rocket and the reaction force drives the rocket forward



Conceptual Example

17. A boy kicks a ball with a force of 400N due east. What is the magnitude and direction of the reaction force of the ball.

Explanation

If the action force is the force of the boy on the ball, them the reaction force became the force of the ball on the boy. Therefore, the reaction force magnitude is 400N and its direction is due west.

4.3 What is Friction Force?

When one surface tries to slide over another surface, there is resistance to motion by the other surface, this resistance to motion is called *friction force*

Friction: Is a force that opposes then relative motion of surfaces that are in contact.

The force of friction depends on:

- The nature of the surfaces in contact. That is the roughness or smoothness of the surfaces, which is expressed using the coefficient of friction, μ (mu)

- The normal force (F_N), which is the pressing or supporting force perpendicular to the surfaces in contact.

Mathematically, friction force is calculated using

$$f = \mu F_N$$

Where: f = friction force

μ = coefficient of friction

F_N = Normal Force

Types of Friction

Depending on the relative movement between the surfaces in contact, friction is of two types - static and kinetic.

Static Friction: Is a friction that arises between two surfaces in contact when one surface tries to slide over the other but not yet moving.

Mathematically, it is obtained by;

$$f_s = \mu_s F_N$$

Where: The subscript (s) stands for static

- The maximum static friction that arises on the verge of motion is called **static friction.**

Kinetic Friction: Is a friction force between two surface that are in relative motion with each other.

Mathematically, it is obtained by;

$$f_k = \mu_k F_N$$

Where: The subscript (k) stands for kinetic.

- Static friction is usually greater than kinetic friction.

That is, $f_s > f_k$

$\mu_s F_s > \mu_k F_N$

$\Rightarrow \mu_s > \mu_k$

- Coefficient of static friction is greater than the coefficient of kinetic friction.

Conceptual Examples

18. Why do vehicles, easily get stuck in a mud? Explain

Explanation

Because, the friction force between the tires and the ground surface is reduce.

19. Is there any advantage we get from friction force? Explain

Explanation

Yes. Friction helps us to walk, to write and it also help cars to move and to stop.

20. Friction causes shoes, cloths, car tires and parts of machinery to wear out and it retards motion, produces noise and causes wastage of energy. What should we do to reduce such negative effects of friction?

Explanation

We need to lubricate, smoothen and polish surfaces and use rolling instead of sliding motion.

Illustrative Examples

21. A 5kg block is at rest on a horizontal table. If the static and kinetic coefficient of friction between the surfaces in contact are $\mu_s = 0.75$ and $\mu_k = 0.45$. What force is needed to

A) Stare the block move

B) Keep the

C) $f_s = \mu F_s = (0.75)(mg) = (0.75)(10)(5)$
$= 37.5N$

D) $f_k = \mu_k F_N = (0.45)(mg) = (0.45)(10)(5)$
$= 22.5N$

22. A block slides down a 37^0 incline plane with a constant velocity. What is the coefficient of friction between the surfaces?

Solution

$$F - f\,ma = 0 \Rightarrow mag\sin\theta - \mu mg\cos\theta = 0$$

$$\mu = \sin\theta/\cos\theta = 0.6/0.8 = 0.75$$

4.4 What is work?

In every day language, work is any activity that requires physical or mental effort to be accomplished. In physics however, work is a technical term and is defined as follows:

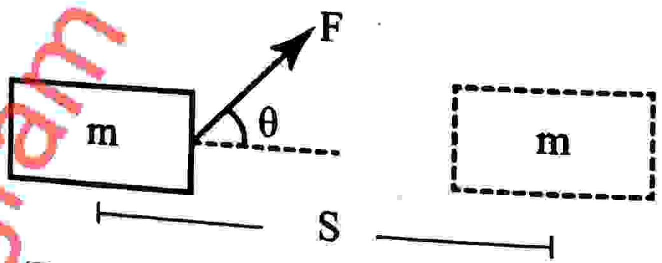
Work: Is a transfer of energy from one body to the other and obtained by to the product of a force and a displacement.

Work is a scalar quantity and its SI unit is the Joule (J)

In physics, work to be done, the conditions are:

- Force must be exerted
- The body must be displaced, and
- The orientation between the force and the displacement must be considered.

Mathematically, the work done on a body can be computed as follows:
If a body of mass **m** is moved a distance **S** by the application of external force F that makes an angle θ with the displacement, as shown.



Then, work = (Force) (Displacement in the force direction)

$$W = FS\cos\theta$$

$$1J = 1Nm$$

- One joule of work is done when 1Newton of force moves a body a displacement of 1meter in the direction.

Conceptual Examples

23. What will be the nature of the work done when the angle between the force and the displacement is

A) $\theta < 90^0$

B) $\theta = 90^0$

C) $\theta > 90^0$

Explanation

We know, $W = Fs \cos \theta$

A) $\theta < 90^0$, $\cos\theta$ is positive $\Rightarrow W = +$ ve, positive

B) $\theta = 90^0$, $\cos\theta$ is zero $\Rightarrow W = 0$, zero

C) $\theta > 90^0$, $\cos\theta$ is negative $\Rightarrow W = -$ ve, negative

24. What is the work done by gravitational force on a satellite orbiting the earth, Explain

Explanation

In this case, the force and displacement are perpendicular and hence, the work done is zero.

25. Suppose you lifted a load from the ground and carried it then you walked for some distance on a horizontal level road at constant velocity. Is there any work you did on the load?

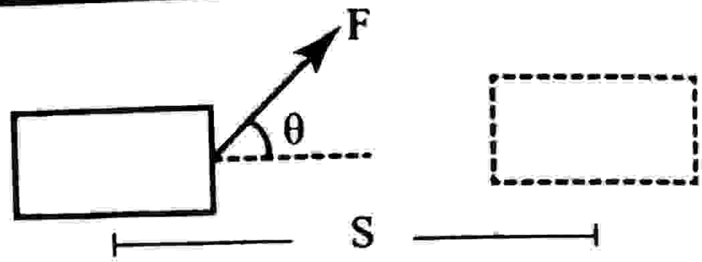
Explanation

Yes. You did some work when you were lifting the load up.

Illustrative Examples

26. A man pulled a box by a force of 200N with a rope that makes an angle of 60^0 from the horizontal. What is the work done by the man if he displaced the box 100m along the horizontal?

Solution



$W = Fs\cos\theta$

$= (200)(100)(\cos 60^0) = (20{,}000)\left(\frac{1}{2}\right)$

$= 10{,}000J$

27. When a force of 150N acts on a body that is at rest, its velocity became 10 m/s in 5 seconds. What is the work done by the force?

Solution

$$W = Fs\cos\theta = F\left(\frac{v+u}{2}\right)t = 150\left(\frac{10+0}{2}\right)5 = 3750J$$

Note: $\theta = 0^0$, $Coso^0 = 1$

and, $S = \left(\frac{u+v}{2}\right)t$

28. A block is dragged a distance of 10m by a rope under a constant force of 120N. If a 720J of work is done by the force, what angle does the rope make with the ground?

Solution

$$W = Fs\cos\theta \Rightarrow Cos\theta = \frac{W}{Fs} = \frac{720}{(120)(10)} = 0.6$$

$\theta = Cos^{-1}(0.6) = 53^0$

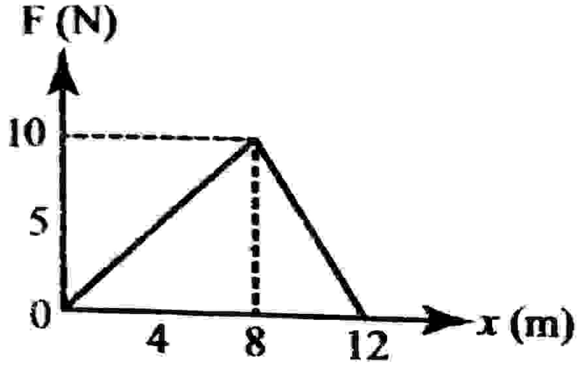
29. What is the work done by a crane that lifted 1000 boxes each with 25 kg to a height of 10m

Solution

$$W = Fs\cos - \theta = mgh = 1000(25)(10)(10)$$

= 2500000J

30. A force varies with the displace as shown below. What is the work done by this force as the body is displaced from $x = 0$ to $x = 12$m



Solution

Work done = Area under the $\vec{F}$ - x graph

$$\frac{1}{2}bh$$

$$W = \frac{1}{2}(10)(12) = 60J$$

31. How much work is done by a 65kg runner on himself to accelerate from rest to 10m/s?

Solution

We know, $W = Fs\cos\theta$, if $\theta = 0^0$, $\cos 0^0 = 1$

$W = FS = (ma)S$, but $v^2 = u^2 + 2as$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2, u = 0$$

$$W = \frac{1}{2}mv^2 = \frac{1}{2}(65)(10)^2$$

$= 3250J$

4.5 What is Mechanical Energy?

A body that has energy can do work, and a work done on a body can be stored as an energy by the body.

Energy: Is the capacity or ability to do work.

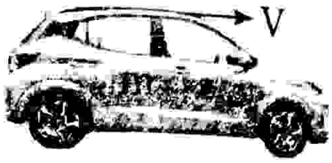
Energy is scalar quantity and its SI unit is the joule (J)

- Regardless of its difference forms, energy is always either kinetic or potential.

Kinetic Energy: Is the energy possessed by a body because of its motion

Kinetic energy of a body depends on the mass (m) and the speed (v) of the body, and mathematically, it is obtained by;

$$\text{Kinetic Energy} = \frac{1}{2}(\text{mass})(\text{speed})^2$$



Conceptual Examples

32. Can the kinetic energy of a body ever be negative ? Explain

Explanation

No! Since kinetic energy of a body is expressed as a product of its mass and its speed squared, both non-negatives, it can never be negative.

33. What will happen to the kinetic energy of a body if for

A) Fixed speed, mass is doubled

B) Fixed speed, mass is halved

C) Fixed mass, speed is doubled

D) Fixed mass, speed is halved

Explanation

A) $KE_1 = \frac{1}{2}m_1V^2$

$$KE_2 = \frac{1}{2}(2m_1)v^2 = 2\left(\frac{1}{2}m_1v^2\right)$$

$KE_2 = 2KE_1$, doubled

B) $KE_1 = \frac{1}{2}m_1V^2$

$$KE_2 = \frac{1}{2}\left(\frac{m_1}{2}\right)v^2 = \frac{1}{2}\left(\frac{1}{2}m_1v^2\right)$$

$$KE_2 = \frac{1}{2}KE_1, \text{halved}$$

C) $KE_1 = \frac{1}{2}m_1V^2$

$$KE_2 = \frac{1}{2}m\,(2v_1)^2 = 4\left(\frac{1}{2}m_1v^2\right)$$

$$KE_2 = 4KE_1, \text{Became four-times}$$

D) $KE_1 = \frac{1}{2}KE_1$

$$KE_2 = \frac{1}{2}m\left(\frac{1}{2}v_1\right)^2 = \frac{1}{4}\left(\frac{1}{2}m_1v^2\right)$$

$$KE_2 = \frac{1}{4}KE_1, \text{Became one-fourth}$$

Work - Energy Theorem

Since work done is energy transfer, this theorem says, if external force acts on a body, it will cause its kinetic energy to change.

Work - Energy Theorem States that; "The work done on a body is equal to the change in its kinetic energy".

This theorem can be expressed mathematically as follows:

We know, $W = Fs\cos\theta = Fs$, maximum

$$W = (ma)\,S$$

And, from, $v^2 = u^2 + 2as \Rightarrow as = \frac{v^2 - u^2}{2}$

$$W = m\left[\frac{v^2 - u^2}{2}\right]$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$KE_f - KE_i$$

$$\boxed{W = \Delta K_E}$$

Illustrative Examples

34. A car of mass 400kg is traveling at a speed of 20m/s. What is the kinetic energy of the car?

Solution

$$K_E = \frac{1}{2}mv^2 = \frac{1}{2}(400)(20)^2$$
$$= 80{,}000J$$

35. An object of mass 100kg revolves around the earth with a kinetic energy of 2.45×10^{10}J. What is the speed of the object?

Solution

$$K_E = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2k_E}{m}}$$

$$V = \sqrt{\frac{2(2.45\times10^{10})}{1000}} = 7\times10^3\, m/s$$

36. What is the work done by a force in accelerating a 10kg body from rest to a speed of 15m/s ?

Solution

$$W = \Delta K_E = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$W = \frac{1}{2}(10)(15)^2 - \frac{1}{2}(10)(0)$$

$$W = 1125J$$

37. A 100J of work accelerates a car from rest to 5m/s. How much work is

needed to accelerate the car from 5m/s to 15m/s

Solution

$$W_1 = \Delta KE_1 = \frac{1}{2}mv_1^2 - \frac{1}{2}mu_1^2$$

$$m = \frac{2W}{V_1^2} = \frac{2(100)}{(5)^2} = 8kg$$

$$W_2 = \Delta KE_2\ W = \frac{1}{2}m\left[v_2^2 - v_1^2\right]$$

$$W = \frac{1}{2}(8)\left[(15)^2 - (5)^2\right]$$

$$= 800J$$

38. If a 4kg body initially at rest travels a distance of 5m in 2seconds under the action of a constant force, what work is done on the body during this time?

Solution

$$W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$u = 0,\ s = \left(\frac{v-u}{2}\right)t \Rightarrow v = \frac{2(s)}{t} = \frac{2(5)}{2} = 5m/s$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m\left[v^2 - u^2\right]$$

$$W = \frac{1}{2}(4)\left[(5)^2 - (0)^2\right]$$

$$W = 50J$$

39. What Average force is needed to stop a 100g bullet travelling at 300m/s as 300m/s as it penetrates in to wood a distance of 10 cm ?

Solution

$$W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2,\ V = 0$$

$$fs = -\frac{1}{2}mu^2 \Rightarrow F = \frac{-mu^2}{2s}$$

$$F = \frac{-(0.1)(300)^2}{2(0.1)} = -45000N$$

The negative sign indicates the force is resistive force

40. The driver of a 2000kg car traveling at 20m/s applies the brakes of the car. If the brakes provide a frictional force of 4000N. What would be the stopping distance of the car?

Solution

$$W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2, V = 0$$

$$-fs = -\frac{1}{2}mu^2 \Rightarrow s = \frac{mu^2}{2f}$$

$$S = \frac{(2000)(400)}{(2)(4000)} = 100m$$

Potential Energy: Is the energy possessed by a body because of its position or configuration

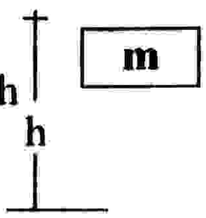
Potential energy is of two types Gravitational and Elastic.

Gravitational Potential Energy: Is the energy stored by a body because of its position from some reference surface.

It depends on the height (h) and mass (m) of the body and is give by

Gravitational potential Energy = (Mass)(height)(Acceleration due to gravity)

GPE = mgh

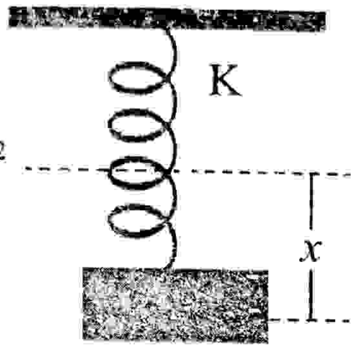


The heavier the mass and the higher the body is from the ground, the greater its gravitational potential energy.

Elastic Potential Energy: Is the energy stored by a body because of its configuration. That is, compression or extension of the body.

It depends on the force constant (K) and deformation (x) of the material and is given by;

Elastic potential = $\frac{1}{2}$ (force constant) (Deformation)



- The larger the force constant and the greater the deformation the bigger the elastic potential energy stored.

Conceptual Example

41. If a ball is raised to the same height, once on the moon and the other time on the earth, in which case the ball will have greater gravitational potential energy?

Explanation

We know, GPE = mgh, since m and h are same, and since g is greater on the earth than it is on the moon, the ball has larger GPE on the earth.

42. If the deformation of a material is doubled, by what factor will its elastic potential energy change?

Explanation

$EP_{E_1} = \frac{1}{2}Kx_1^2$ and $EP_{E_2} = \frac{1}{2}kx_2^2$

But, $x_2 = 2x_1$ Hence

$$EpE_2 = \frac{1}{2}k(2x_1)^2 = 4\left(\frac{1}{2}Kx_1\right)^2$$

$$Ep_{E2} = 4Ep_{E1}$$

Illustrative Examples

43. A weight lifter raises a 200kg rock to a height of 2m. What is the increase in the potential energy of the rock?

Solution

GPE = mgh = (200) (10) (2)

= 4000J

44. A spring of force constant 500N/m is compressed so that 0.625J of energy is stored in it. What is the deformation of the spring?

Solution

$$EP_E = \frac{1}{2}k\times 2 \Rightarrow x = \sqrt{\frac{1}{2}kx^2}$$

$$= \sqrt{\frac{2(0.625)}{500}} = 0.05\text{m}$$

$$= 5\text{cm}$$

45. When a force of 120N is applied on a spring, it causes a stretch of 4cm. What potential energy is stored when it is compressed by 5cm?

Solution

$$EP_E = \frac{1}{2}kx^2\text{, but } F = kx \Rightarrow k = \frac{F}{x} = \frac{120}{0.04} = 3000\frac{\text{N}}{\text{m}}$$

$$\Rightarrow EPE = \frac{1}{2}(3000)(0.05)^2 = 3.75\text{J}$$

- In the absence of dissipative force energy is conserved. And this is expressed by the conservation law.

Law of Conservation of Energy states that; "energy cannot be created or destroyed but it transfered from one form to the other"

That is for a closed system, the change in mechanical energy of body is zero.

$$\Delta ME = 0$$

$$\Rightarrow ME\text{ initial} = ME\text{ final}$$

$$KE_i + PE_i = KE_f + PE_f$$

Where : M_E = Mechanical Energy

P_E = Potential Energy

K_E = kinetic Energy

4.6 Mechanical Power

How fast work is done or energy is transformed is expressed using the concept of power.

Power: Is the rate at which work is done or energy is transferred from one form one from to the other.

Power is a scalar quantity and its SI unit is the watt (W)

Mathematically, power is obtained by

$$\text{Power} = \frac{\text{Work done}}{\text{Time Taken}} = \frac{\text{Energy Transferred}}{\text{Time Taken}}$$

$$\boxed{P = \frac{W}{t}}$$

$$\text{Hence, } 1W = \frac{1J}{s}$$

- One watt is the power developed when 1 Joule of work is done in 1 second

Conceptual Examples

46. Mr A and Mr. B are give the same work. If Mr A finished it in 2 hours and Mr. B in 3hours, who is more powerful? Explain

Explanation

Mr A is more powerful, since he finished the work in a shorter time.

47. Force one does 5J of work in 10s. Force two does 3J of work in 5s. Which force produces greater power?

Explanation

$$P_1 = \frac{w_1}{t_1} = \frac{5}{10} = 0.5W$$

$$P_2 = \frac{W_2}{t_2} = \frac{3}{5} = 0.6W$$

Force two produced more power.

Illustrative Examples

48. A kettle uses 180,000J of electrical energy in 3 minutes. What is the power of the kettle?

Solution

$$P = \frac{w}{t} = \frac{180{,}000}{3(60)}$$

$$P = 100w$$

49. A man lifts 50kg box to a height of 20m in 30 seconds. What is the power he developed?

Solution

$$P = \frac{mgh}{t} = \frac{(50)(10)(20)}{30}$$

$$P = 333W$$

50. A 1000kg car accelerates uniformly formly from 10m/s to 30m/s in 2 seconds. Calculate

A) The work dine on the car

B) The power developed

Solution

A) $W = \Delta K_E = \frac{1}{2}m\left[V^2 - u^2\right]$

$$W = \frac{1}{2}(1000)\left[30^2 - 10^2\right] = 400{,}000J$$

B) $P = \frac{W}{t} = \frac{400,000}{2}$

$P = 200,000W = 200KW$

51. Show that the power developed by a body can be computed by;
$P = Fv\cos\theta$

Where : F = net force magnitude

V = speed of the body

Solution

We know, $P = \frac{w}{t} = \frac{Fs\cos\vartheta}{t} = (F\cos\theta)\frac{s}{t}$

$P = Fv\cos\vartheta$

52. A body is able to walk at a speed of 1.5 m/s pushing a bag along the horizontal with a force of 100N. What is the power he developed?

Solution

$P = Fv\cos\theta$

$P = (100)(1.5)\cos(0^0) = 150W$

53. A ball is kicked up in to the air. The work done by gravity and air resistance is respectively?

A) Positive, positive

B) Positive, negative

C) Negative, negative

D) Negative, Positive

Hint: The force are opposite to the direction of motion.

Answer: C

54. Which of the following is equivalent to 1J?

A) Kg m/s

B) Kg m/s²

C) Kg m²/s²

D) Kg m²/s

Hint: $1J = 1Nm = 1kg\ m/s^2 . m = kg\ m^2/s^2$

Answer: C

55. A spring of force constant 160N/m lies on a friction less table. If 2 kg block moving at 12 m/s strikes it, what will be the block speed when the spring is compressed by 1m?

A) 4m/s B) 8m/s C) 6m/s D) 10m/s

Hint: $\frac{1}{2}mu^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$

$$\frac{1}{2}(12)(12)^2 = \frac{1}{2}(12)v^2 + \frac{1}{2}(160)(1)^2$$

$$v = 8\,m/s$$

Answer: B

56. How much work is done on a 0.5kg object to change its speed from 4m/s to 12 m/s

A) 4J B) 8J C) 16J D) 32J

Hint: $W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}(0.5)(12)^2 - \frac{1}{2}(0.5)(4)^2$

$W = 32J$

Answer: D

57. A force does a negative work when

A) The force is perpendicular to the displacement

B) The force is opposite to the displacement

C) Both, force and displacement are positive

D) Both, force and displacement are negative

Hint: $W = Fs\cos\theta$, = Negative when $\theta = 180^0$

Answer: B

58. What is the average power generated by a 60kg man as he moved up stair 200m at an average speed of 15cm/s ?

A) 9000W B) 900W C) 90W D) 9W

Hint: $P = \frac{W}{t} = Fv = mgv$

$P = (60)(10)(0.15)$

$= 90w$

Answer: C

59. The maximum work is done when the force and the displacement are

A) Parallel to each other B) Perpendicular to each other

C) At 45^0 to each other   D) At 30^0 to each other

Hint: $W = Fs \cos\theta$

Answer: A

60. A 20kg body is displaced a height of 10m. The work done against gravity and the work done by gravity are respectively.

A) 2000J, 2000J   C) -2000J, 2000J

B) 2000J, -2000J   D) -2000J, -2000J

Hint: W = mgh = (20) (10) (10) = 2000J

Answer: B

61. If both the mass and the speed of a body are doubled, by what factor will the kinetic energy change?

A) 4   B) 2   C) 8   D) 6

Hint: $KE_1 = \frac{1}{2} m_1 v_1^2$

$$KE_2 = \frac{1}{2} m_2 v_2^2 = \frac{1}{2} (2m_1)(2v_1)^2$$

$$KE_2 = 8 (KE_1)$$

Answer: C

62. A 1kg block is released from rest along a rough inclined plane of 1m height. If the speed of the block at the bottom of plane is 4m/s, what is the work done by friction?

A) 10J   B) 8J   C) 2J   D) 4J

Hint: Work done by friction $= mgh - \frac{1}{2} mv^2$

$$W_f = (1)(10)(1) - \frac{1}{2}(1)(4)2 = 2J$$

Answer: C

63. A 60kg man juimps down from a 0.8m hight table. What will be his speed when he hits the ground?

A) 2m/s   B) 4m/s   C) 6m/s   D) 8m/s

Hint: $\frac{1}{2} mv^2 = mgh \Rightarrow v = \sqrt{2gh} = \sqrt{2(10)(0.8)} = 4 \, m/s$

Answer: B

End of unit Questions problems

I. Give short answers to the following questions.

1. What is force?
2. List the types of forces
3. Explain the effects of force
4. State the laws of motion
5. Explain the difference between mass and weight
6. What are the requirements for work to be done?
7. What is energy?
8. What is the difference between kinetic energy and potential energy?
9. What is power?
10. The unit of work is kg m^2/s^2. True or False ?
11. What is friction force?

II. Solve the following problems

12. What is the acceleration of a 10kg block when a force of 50N acts on it?
13. What force will let a 25kg object to accelerate at $4m/s^2$?
14. What is the weight of a 250kg object on the moon where the acceleration due to gravity is $1.6m/s^2$?
15. A box is displaced 6m by a 10N force along the horizontal. What is the work done?
16. A loader lifts a 500kg stone at a height of 8m in 2seconds. What is the power developed by the loader?
17. What is the kinetic energy of a 200g bullet fired at a speed of 300m/s?
18. Calculate
    A) The potential energy of a 10kg stone at a height of 10m
    B) The position of the 10kg stone if it possesses a potential energy of 400J

19. A crane is capable of doing 1.5×10^5J of work in 10 seconds. What is the power of the crane?

20. What is the driving force of a sport car of 400KW engine power so as to let it move at 40m/s

21. A 65kg bicyclist rides his 10kg cycle at 12m/s.

A) How much work must be done to stop the bicycle?

B) How far it travel if it takes 4seconds to stop it?

C) What is the magnitude of the stopping force?

22. A spring of 200N/m force constant is used to launch a 10g ball. If the spring is compressed by 5cm, calculate;

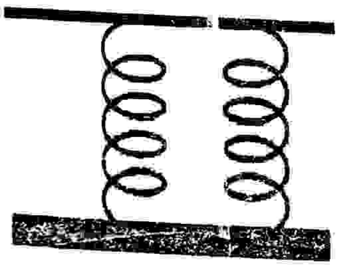
A) The energy stored in the spring

B) The velocity of the ball

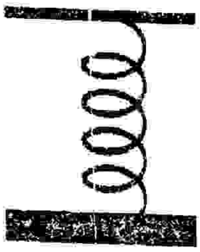
C) The height reached by the ball

23. If two springs with force constants K_1 and K_2 are connected in;

A) Parallel



B) Series



How much work is needed in each case, to stretch the system a distance x?

I. **Short Answers and Explanations**

1. Force is a push or a pull interaction between bodies.
2. Force can be contact or non-contact
3. Force may cause deformation and change in the state of motion of a body
4. The laws of motion are formulated by newton and are the following.

Newton's 1st law, the law of inertia

Newton's 2nd law, the law of acceleration

Newton's 3rd law, the law of action & reaction

5. Mass is the measure of amount of matter contained by a body and it is constant everywhere. Weight is the gravitational pull on a body and it varies from place to place. Weight and mass are related by, W = mg

6. In physics, work to be done; the necessary conditions are;
   - Force must be exerted on the object
   - The object must be displaced in the force direction
   - The angle between the force and the displacement must be considered.

7. Energy is the capacity or the ability to do work.

8. Kinetic energy is the energy of motion while, potential energy is the energy of position.

9. Power is the rate at which work is done or energy is transffered.

10. Work is defined as the product of force and displacement in the force direction.

$$W = Fscons\theta$$

$$1J = 1Nm = 1kg\,(m/s^2)m = 1kg\,m^2/s^2.$$ True

11. Frictional force is a force that opposes the motion of one surface over the other.

II. Solution to the end of unit problems.

12. $F = ma \Rightarrow a = \frac{F}{m} = \frac{50}{10} = 5\,m/s^2$

13. $F = ma = (25)(4) = 100N$

14. $W = mg = (250)(1.6) = 400N$

15. $W = Fs\cos\theta = (10)(6)\cos(0^0) = 60J$

16. $P = \frac{mgh}{t} = \frac{(500)(10)(8)}{2} = 20{,}000W = 20KW$

17. $K_E = \frac{1}{2}mv^2 = \frac{1}{2}(0.2)(300)^2 = 9000J$

18. A) $PE = mgh = (10)(10)(10) = 1000J$

B) $P_E = mgh \Rightarrow h = \frac{PE}{mg} = \frac{400}{(10)(10)} = 4m$

19. $P = \frac{W}{t} = \frac{1.5 \times 10^5}{10} = 1.5 \times 10^4 W$

20. $P = FV \Rightarrow F = \frac{P}{V} = \frac{400{,}000}{40} = 10{,}000N$

21. A) $W = \Delta KE = \frac{1}{2}m\left[v^2 - u^2\right], m = 65 + 10 = 75kg$

$W = \frac{1}{2}(75)\left[0^2 - 12^2\right] = 5400J$

B) $S = \left(\frac{v+u}{2}\right)t = \left(\frac{0+12}{2}\right)4 = 24m$

C) $fs = W \Rightarrow f = \frac{W}{S} = \frac{5400}{24} = 225N$

22. A) $EP_E = \frac{1}{2}Kx^2 = \frac{1}{2}(200)(0.05)^2 = 0.25J$

B) $K_E = EP_E \Rightarrow \frac{1}{2}mv^2 = 0.25$

$V = 7 m/s$

C) $GPE = kE \Rightarrow mgh = 0.25$

$h = 2.5m$

23. A) $W = EPE = \frac{1}{2}KX^2$

For parallel springs, $K = K_1 + K_2$

$\Rightarrow W = \frac{1}{2}(K_1 + K_2)x^2$

B) $W = EPE = \frac{1}{2}Kx^2$

For series springs, $K = \frac{K_1 K_2}{K_1 + K_2}$

$\Rightarrow W = \frac{1}{2}\left(\frac{K_1 K_2}{K_1 + K_2}\right)x^2$

UNIT 5

5. Simple Machines

5. What are Simple Machines?

Dear learner,how do you do ? In this unit,you are going to define simple machines, mention types of simple machines, describe the propose of simple machines and get to know terms such as effort, load mechanical advantage, velocity,ratio, work input, work output, efficiency and so much more things. Enjoy !

5.1 Purpose of simple Machines

In our every day life , we use simple machines . but ,you may ask , what are these machines any way ?

Simple machine :- Is a device that helps us to do work more easily.

A **simple machine** is machine that takes one force and changes its direction,distance, or strength. The force you apply to a machine is called the **effort**. These machines help us to get a jop done easily, by multiplying force, multiplying speed or distance and by Changing the direction of a force.

No matter what the type of simple machine may be,it will,serve as one of the following purposes.

Force multiplier:- Enables us to move a big load using a small force.

Speed or Distance multiplier:- Enables us to move a load greater distance in a short time.

Direction changer:- Enables us to move a load in opposite direction to the applied force.

Now,let's be families with the terms we may face frequently in this unit.

Effort (E):- Is the input force that is exerted on the simple machine .

Load (L):- Is the out put force that is exerted by the simple machine on the object.

Work Input (Win):- Is the work done one the machine by the effort.

Work output (Wout):- Is the work done by the machine on the object.

5.2 Mechanical Advantage, velocity Ratio and Efficiency of simple Machines

Here,under, we are going to be clear about the concepts mechanical advantage, velocity ratio and efficiency of simple machines

Mechanical advantage:- Is the ratio of Load to Effort.

$$\text{Mechanical Advantage} = \frac{\text{load}}{\text{Effort}}$$

$$\boxed{MA = \frac{L}{E}}$$

➥ It is a unit less quantity.

Mechanical Advantage is of two types ; Actual and Ideal

Actual Mechanical Advantage:-Is the ratio of load to effort taking into account energy lose .

$$\boxed{AMA = \frac{L}{E}}$$, There is friction

Ideal Mechanical Advantage :- Is the ratio of load to effort assuming no energy loss due to friction

$$\boxed{IMA = \frac{L}{E}}$$, No friction

Velocity Ratio :- Is the ratio of distance moved by effort to the distance moved by the load .

$$\text{Velocity Ratio} = \frac{\text{Distance Moved by Effort}}{\text{Distance Moved by load}}$$

$$\boxed{V.R = \frac{S_E}{S_L}}$$

➥ It is a unit less quantity.

Efficiency:- Is the ratio of work out put to work input

$$\text{Efficiency} = \frac{\text{Work out put}}{\text{Work in put}}$$

$$\eta = \frac{W\,out}{W\,in})100\%$$

Since, Work out put = (load) (Distance of load)Wort (L) (SL) Work input = (Effort (Distance of Effort) Win = (E) (SE) Then we have ;

$$\eta = \left(\frac{W_{Out}}{W_{in}}\right)100\%$$

$$\left[\eta = \frac{(L)(S_L)}{(E)(S_E)}\right] = 100\%$$

$$\eta = \left(\frac{MA}{VR}\right)100\%$$

Conceptual Examples

1. Can a simple machine multiply Energe ? Explain

   Explanation:- No. That will violet conservation of energy

2. Can a simple machine multiply force and speed at a time ? Explain

   Explanation:-No. Energy can not be created or destroyed.

Illustrative examples

3. If a force of 100N is applied on a simple machine to lift a load of 50 kg to a height of 1m assuming the distance moved by the applied force to be 8m .calculate the;

   A) Effort
   B) Load
   C) Mechanical advantage
   D) Velocity ratio
   E) Work input
   F) Work out put
   G) Efficiency of the machine

Solution:

A) Effort = Applied force = 100 N

B) Load = Weight = Mg = (50)(10) = 500

C) $MA = \frac{L}{E} = \frac{500}{100} = 5$

D) $VR = \frac{S_E}{S_L} = \frac{8}{1} = 8$

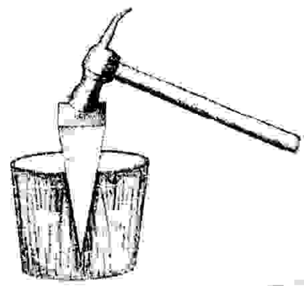
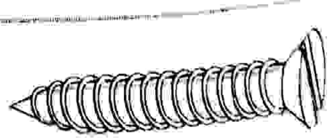
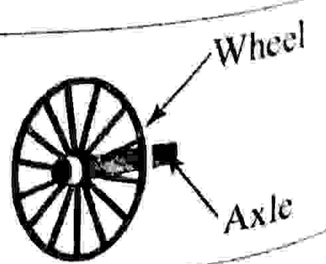
E) $W_{in} = (E)(S_E) = (100)(8) = 800J$

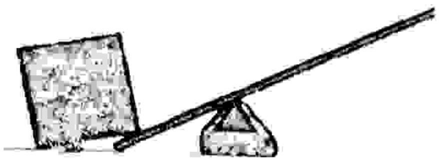
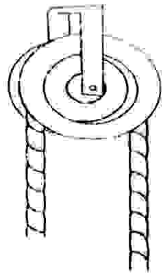
F) $W_{Out} = (L)(S_L) = (500)(1) = 500J$

G) $\eta = \left(\frac{Wout}{Win}\right)100\% = \left(\frac{500}{800}\right)100\% = 62.5\%$

5.3 Types of Simple Machines

There are six simple machines. They are the lever, inclined plane, wedge, screw, wheel and axle, and pulley.

Simple Machine	Picture
Inclined plane	
Wedge	
Screw	
Wheel and Axle	

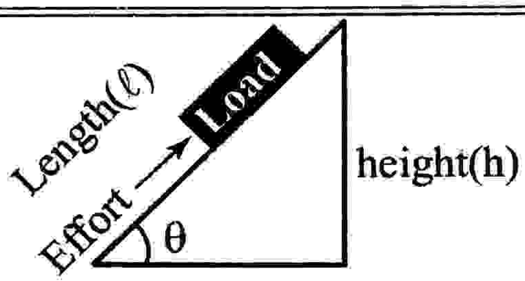
Lever	
Pulley	

Now,let us study the Mechanical advantage, velocity ratio and efficient y of each Simple Machines .

Inclined plane:- Is a Sloping Surface that is used to lift a body to some height.

$$MA = \frac{load}{effort} = \frac{L}{E}$$

$$VR = \frac{Length}{height} = \frac{L}{h}$$



Inclined plane is also called a ramp and is a force multiplier machine .

Illustrative Example

4. If an effort of 80N is needed to push a 240N box up a ramp of 40m length and 8m height. Calculate ;
   A) MA
   B) VR
   C) η of the ramp

Solution:

A) $MA = \frac{L}{E} = \frac{240}{80} = 3$

B) $VR = \frac{L}{h} = \frac{40}{8} = 5$

C) $\eta = \left(\frac{MA}{VR}\right)100\% = \left(\frac{3}{5}\right)100\% = 60\%$

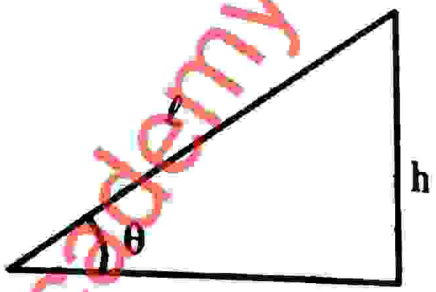
5. What is the velocity ratio of an inclined place of 30 inclination from the horizontal ?

Solution :

$$VR = \frac{L}{h}$$

$$\sin\theta = \frac{h}{L}$$

$$VR = \frac{1}{\sin\theta} = \frac{1}{0.5} = 2$$



6. If the efficiency of an inclined plane is obtains to be . 0.8, then What is the mechanical advantage assuming the velocity ratio is 4

Solution :

$$\eta = \frac{MA}{VR} \Rightarrow MA(\eta) = (VR) = (0.8)4 = 3.2$$

7. What is the input energy in to a ramp of 50 % efficiency if the out put energy is 450 J

Solution:

$$\eta = \left(\frac{W_{out}}{W_{in}}\right)100\%$$

$$50\% = \left(\frac{450}{W_{in}}\right)100\%$$

$$0.5 = \frac{450}{Win} \Rightarrow W_{in} = \frac{450}{0.5}$$

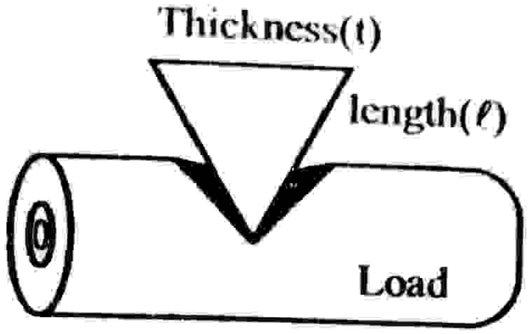
$$W_{in} = 900J$$

Wedge:- Is a piece of metal or wood thicker at one edge, thinner at the other used to split a body

$MA = \frac{L}{E}$

$VR = \frac{\text{Length}}{\text{Thickness}} = \frac{L}{t}$

$\eta = \frac{MA}{VR} = \frac{Lt}{EL}$



Illustrative Examples

8. An effort of 200N is applied on to a Wedge of 4cm thick and 12cm long to split a log of 500N into parts . calculate

   A) MA

   B) VR

   C) η of the wedge

Solution

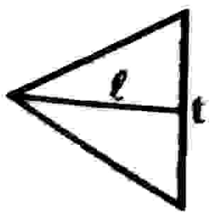
A) $MA = \frac{L}{E} = \frac{500}{200} = 2.5$

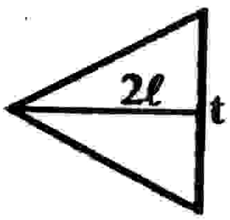
B) $VR = \frac{L}{t} = \frac{12}{4} = 3$

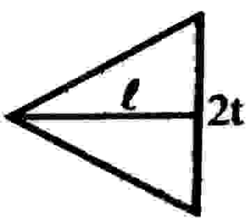
C) $\eta = \frac{MA}{VR} = \frac{2.5}{3} = 0.83$

$\eta = 83\%$

9. Which Wedge has the greater V.R

A) 

B) 

C) 

Solution

A) $VR_1 = \frac{L}{t}$

B) $VR_2 = \frac{2L}{t} = 2\left(\frac{L}{t}\right) = 2VR_1$

C) $VR_3 = \frac{L}{2t} = \frac{1}{2}\left(\frac{L}{t}\right) = \frac{1}{2}VR_1$

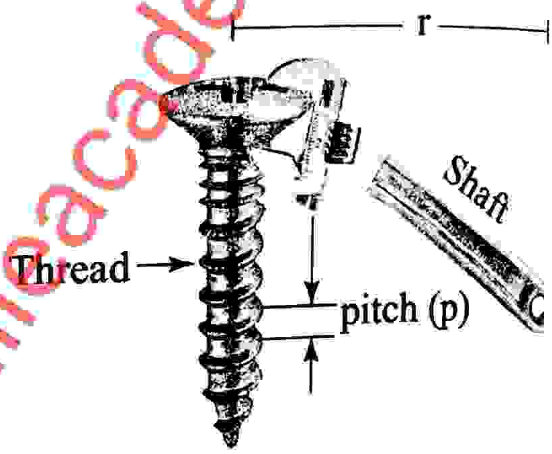
Therefore, Wedge B has greater Volatility Ratio

Screw :-Is a cylinder with helical threads around it and used to fix objects together.

$$VR = \frac{\text{circumfrence of shaft}}{\text{Pitch}}$$

$$VR = \frac{2\pi r}{P}$$

$$VR = \frac{\pi d}{P}$$



Where : r = radius of shaft

d = diameter of shaft

p = Pitch

Illustrative Example

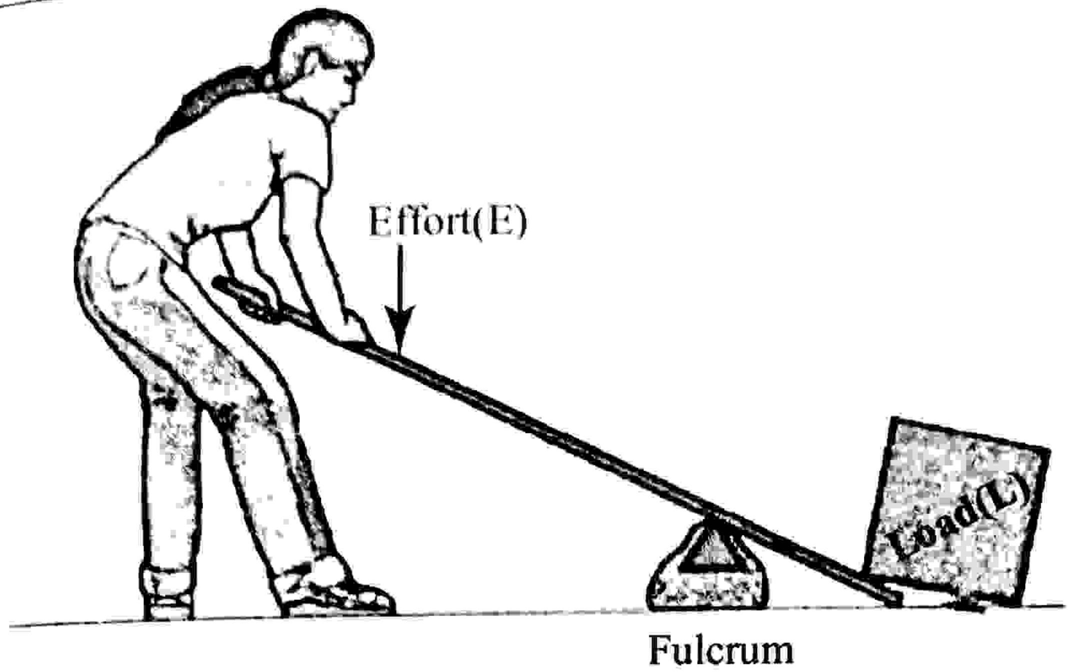
10. What is the velocity ratio of a Screw of Pitch 10mm if a shaft of 15.9cm radius makes one cycle .

Solution

$$VR = \frac{2\pi r}{p} = \frac{(2)(3.14)(15.9)}{0.1} = 1000$$

Lever:- Is a rigid bar of metal or wood free to turn about a pivot point celled fulcrum and is used to raise an object.

A **lever** is a bar that rotates around a pivot - point called **fulcrum.** Levers can multiply **an effort** or multiply distance and speed.



Effort Arm:- Is the part of the lever that extends from the fulcrum to the effort . load arm , is then the part of the lever that extends from the fulcrum to the load.

Classes of a Lever

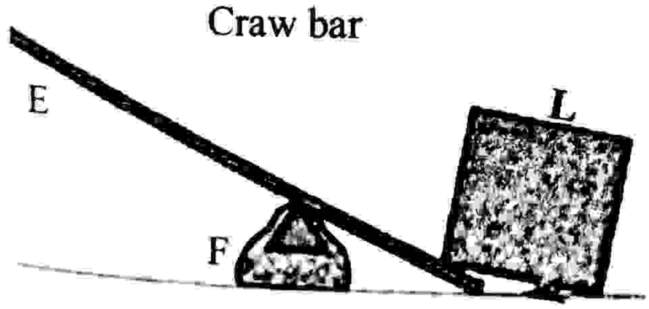
Depending on the relative positions of a fulcrum, a load and an effort , there are three classes of a lever. Those are 1st class, 2nd class, and 3rd class lever.

Now,let us investigate each class of lever one by one.

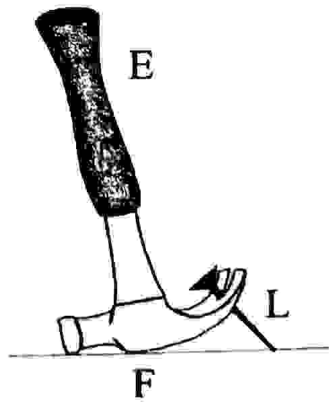
First - Class Lever:-The fulcrum is between the load and the effort .

Examples of the 1st class lever includes

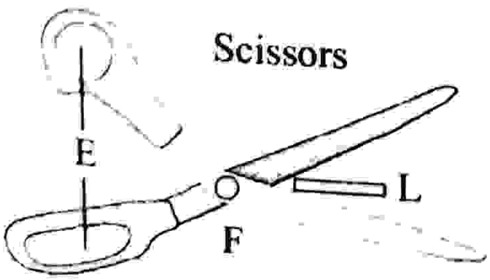
Craw bar



Claw hammer



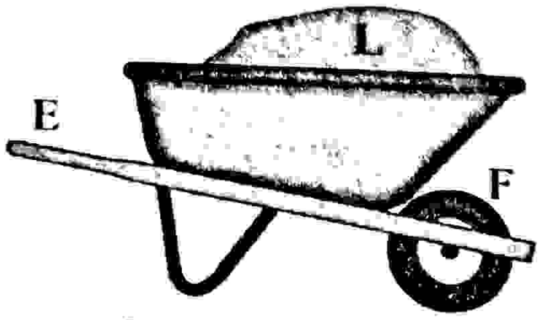
Scissors

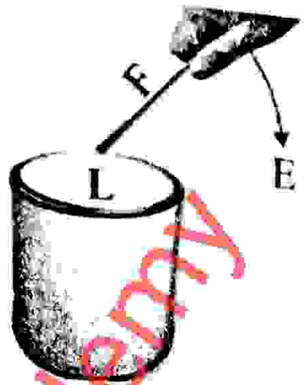


Second - class Lever:- The load is between the effort and the fulcrum

Examples of the 2nd class lever include

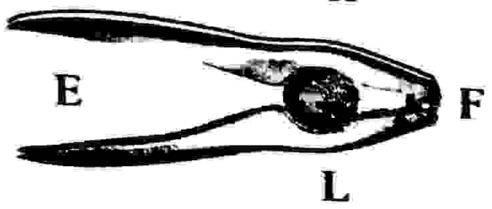
Wheel barrow





Bottle opener

Nut Cracker

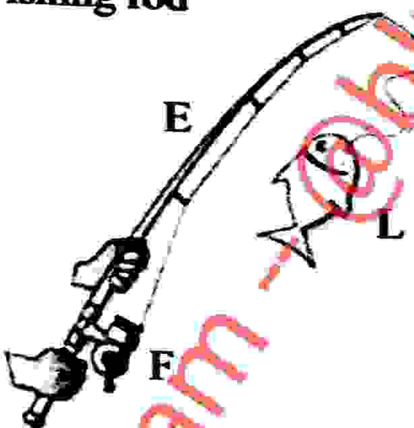


VR is always greater than one

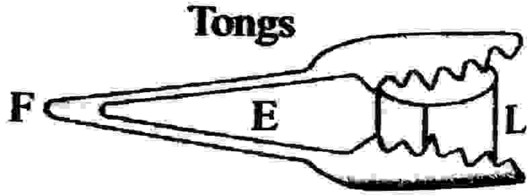
Third - class Lever:- The effort is between the load and fulcrum

Examples of the 3rd class lever include;

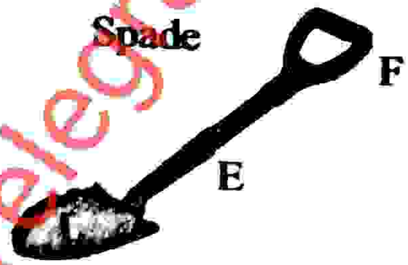
Fishing rod



Tongs



Spade



Illustrative Example

11. In a nut cracker, a nut is located 2cm from the fulcrum and an input force of 20N is applied at the handles 10cm from the fulcrum. What force is applied on the nut ?

Solution

Assuming no friction ; MA = VR

$$\frac{L}{E} = \frac{s_E}{s_L} \Rightarrow L = \left(\frac{s_E}{s_L}\right)$$

$$E = \left(\tfrac{10}{2}\right)20 = 100N$$

12. What is the velocity ratio of a claw hammer if a force is applied 30cm from the nail and the fulcrum is 2cm from the nail?

Solution

$$VR = \frac{S_E}{S_L} = \frac{28}{2}$$

$$VR = 14$$

13. An iron bar 3m long is used to lift a 60kg block. If the fulcrum is 80cm from the block, find

A) IMA

B) Effort, E

Solution

A) $IMA = VR = \frac{S_E}{S_L} = \frac{2.2}{0.8}$

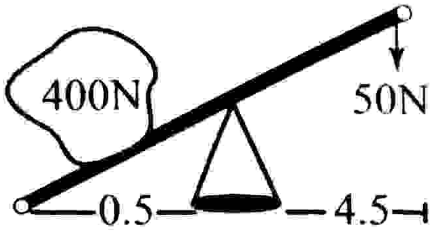
$= 2.75$

B) IMA=VR

$$\frac{L}{E} = \frac{S_E}{S_L} \Rightarrow E = L\left(\frac{S_L}{S_E}\right) = 600\left(\frac{0.8}{2.2}\right)$$

$$E = 218N$$

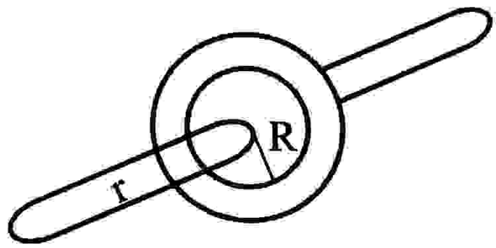
14. For the following lever system, find the VR



Solution

$$VR = \frac{S_E}{S_L} = \frac{4.5}{0.5} = 9$$

Wheel and Axle:-Is a wheel secured to a rod .called an axle and is used to multiply force or speed



$$VR = \frac{\text{Circumfrence of Wheel}}{\text{Circumfrence of Axle}} = \frac{2\pi R}{2\pi r}$$

$$VR = \frac{R}{r} \qquad VR \text{ can} > 1, < 1 \text{ or} = 1$$

Illustrative Example

15. Using a wheel and axle, a 400N load is lifted by a 50N force applied at the rim of the wheel. of the radii of the wheel and axle are 85cm and 6cm respectively, determine

A) MA

B) VR

C) η of the wheel and axle

Solution

A) $MA = \frac{L}{E} = \frac{400}{50} = 8$

B) $VR = \frac{R}{r} = \frac{85}{6} = 14.2$

C) $\eta = \frac{MA}{VR} = \frac{8}{14.2} = 0.56 = 56\%$

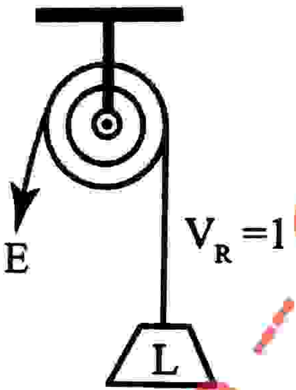
Pulley:-Is a wheel with a grooved surface over which a rope or a chain passes

The VR value of a pulley is equal to the number of strings or ropes supporting the load .

VR of a pulley can be greater than one > 1, less that one < 1 or equal to one $= 1$

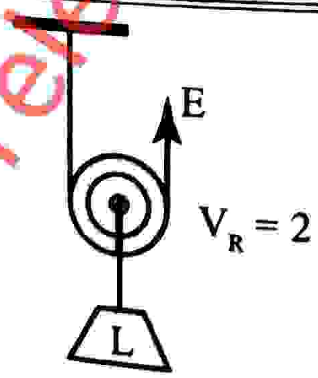
A pulley system is divided in to three as fixed , movable and compound.

Fixed pulley:- Is a pulley with a fixed axle and a rope wrapped sped over the top.



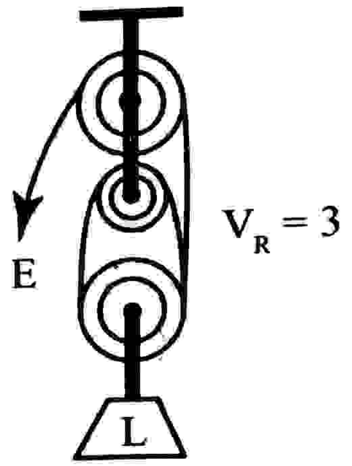
A Fixed pulley has a velocity ratio of one VR = 1 and is used to change direction of the applied force.

Movable Pulley :- Is a pulley with an axle that is free to move up and down with the load



A Movable Pulley has a velocity ratio of two VR = 2 and is used to multiply force .

Compound pulley:- Is a combination of fixed and movable pulley. It is also called a block and tackle.

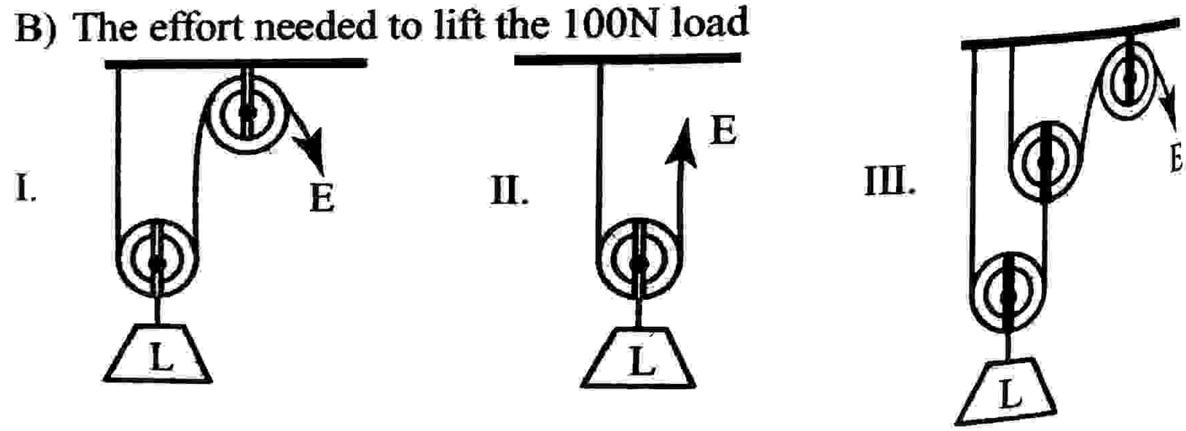


Illustrative Examples

16. For each of the pulley Systems, determine ;

A) VR

B) The effort needed to lift the 100N load



Solution

I. A) VR = 2

B) $2E = 100 \Rightarrow E = 50N$

II. A) VR = 2

B) $2E = 100 \Rightarrow E = 50N$

III. A) VR = 4

B) $4E = 100 \Rightarrow E = 25N$

17. Which kind of pulley makes your effort force larger?

A) Fixed pulley

B) Movable pulley
C) Compound pulley
D) Fixed pulley and movable pulley

Answer: B

18. Which simple machine can Not be used to increase force?

A) Lever
B) Wheel and axle
C) Fixed pulley
D) Movable pulley

Answer: C

19. In a simple machine effort of 120N acts through 3m to raise a load of 480N to a height of 0.6m. The efficiency of the machine is:

A) 70% B) 80% C) 90% D) 100%

Solution

$$\eta = \frac{MA}{VR} = \left(\frac{480/120}{3/0.6}\right)100\% = \left(\frac{4}{5}\right)100\% = 80\%$$

Answer: B

20. A 100N force is applied to a load to a height of 10m using a machine of efficiency 60%. If the effort moved distance of 50m what is the magnitude of the load?

A) 100N B) 200N C) 300N D) 400N

Solution

$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta\ (VR)$$

$$\frac{L}{E} = (0.6)\left(\frac{50}{100}\right)$$

$$L = (100)\ (0.6)\ (5)$$

$$L = 300N$$

Answer: C

21. A machine with a velocity ration of 12 needed 1600J of work to raise a load of 1200N to a height of 1m. What is the efficiency of the machine?

A) 50% B) 60% C) 70% D) 75%

Solution

$$\eta = \left(\frac{\text{Wout Put}}{\text{Win Put}}\right)100\%, \text{ Woutput} = \text{LSL} = (1200)(1) = 1200\text{J}$$

$$\eta = \left(\frac{1200}{1600}\right)100\%$$

$$\eta = 75\%$$

Answer: D

22. A simple machine has an efficiency of 0.75 and velocity ratio of 12. What is the mechanical advantage of the machine?

A) 9 B) 12 C) 6 D) 3

Solution

$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta(VR)$$

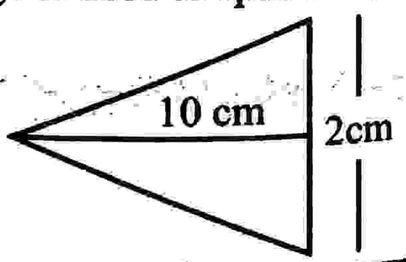
$$MA = (0.75)(12)$$

$$MA = 9$$

Answer: A

23. A 10cm long and 2cm wide metal wedge is used to split a wood. What is the velocity ration of the wedge?

A) 3
B) 5
C) 6
D) 9



Solution

$$VR = \frac{\ell}{t} = \frac{10}{2}$$

$$VR = 5$$

Answer: B

24. A screw shaft has a diameter of 4 cm and its adjacent threads are 0.314cm apart. What is the velocity ration of the screw?

A) 10 B) 20 C) 30 D) 40

Solution

$$VR = \frac{2\pi r}{p} = \frac{2(3,14)(2)}{0.314}$$

$$VR = 40$$

Answer: D

25. Which one of the following is true about simple machines?

A) Velocity ration is usually less than mechanical advantage

B) Mechanical advantage is always less than one

C) For speed multiplier machine, VR < 1

D) For a force multiplier machine, MA < 1

Hint: VR < 1 or MA < 1, speed multiplier machine

VR > or MA > 1, force multiplier machine

VR = 1 or MA = 1, direction changer machine

Answer: C

26. A 50N force is needed to raise a 20 kg object a height of 3m. If the length of the plane is 15m, What is its efficiency?

A) 75% B) 80% C) 85% D) 90%

Hint: $\eta = \frac{MA}{VR} = \frac{L/E}{SE/SL} = \frac{200/50}{15/3} = 0.8$

$\eta = 80\%$

Answer: B

27. If an inclined plane of 4m length and 1m height has an efficiency of 50%, what is its mechanical advantage?

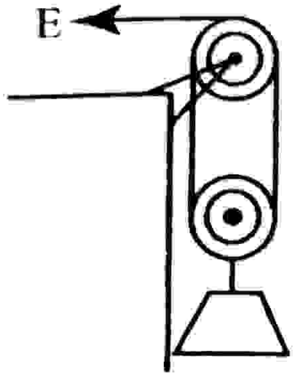
A) 3 B) 2 C) 5 D) 6

Solution

$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta(VR) = (0.5)(4) = 2$$

Answer: B

28. What is the purpose of the pulley system shown below

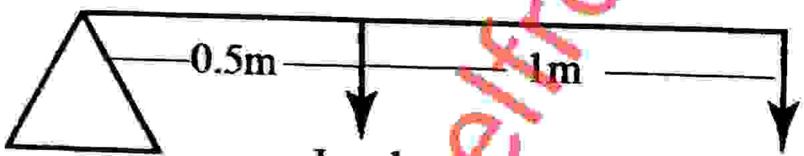


A) Speed multiplier
B) Force multiplier
C) Direction change
D) Has no purpose

Hint: VR = 2

Answer: B

29. What is the velocity ration of the lever shown below



A) 2
B) 0.5
C) 3
D) 5

Hint: $VR = \frac{SE}{SL} = \frac{1.5}{0.5}$

$VR = 3$

Answer: C

30. A 7 cm thick and 15 cm long wedge is used to pierce an object of 2m long and 20 cm diameter. What is the velocity ratio of the wedge?

A) 1
B) 10
C) 0.47
D) 2.14

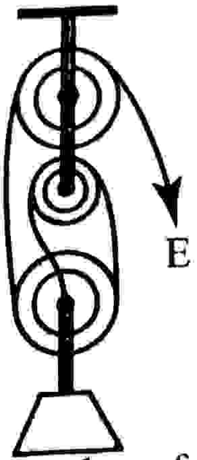
Hint: $VR = \frac{\ell}{t} = \frac{15}{7}$

$VR = 2.14$

Answer: D

31. What is the velocity ratio of the pulley system shown

A) 4
B) 3
C) 5
D) 6



Hint: Velocity ration = number of ropes supporting the block

Answer: B

End of unit Questions and problems

i. Give short Answers for the Following Questions

1. What is a Simple Machine?
2. What are the purposes of Simple Machines
3. List the Six types of Simple Machines
4. Define the following terms
   a) Effort
   b) Load
   c) Mechanical advantage
   d) Velocity Ratio
   e) Work input
   f) Work output
   g) Efficiency of simple machines
5. What is the difference between Ideal Mechanical Advantage and Actual Mechanical Advantage
6. Describe the three classes of a lever
7. Explain the three types of pulley
8. How can we determine velocity ratio of a pulley system
9. Give examples for the force multiplier ; speed . multiplier and direction changer simple machine.
10. How can we determine the purpose of a simple machine based on its mechanical advantage or velocity ratio value ? Explain

ii. Solve the Following Problems

11. A 6000N block is pushed up a ramp by a force of 300N - Assuming no emerge lose ; calculate

    A) MA

    B) VR

    C) Length of the ramp if its height is 10m

12. A 12cm long and a 3cm wide metal wedge is pushed into a wood . If there is no friction , calculate

    A) VR

    B) The load if the effort is 20N

13. If a lever raised a block 4m when the effort is moved 2m , what is the purpose of the lever ?

14. An effort of 30N moved a load of 150N , using a pulley . by how much does the machine multiply the effort ?

15. A Simple machine used an effort of 50N , through a distance of 8m to lift a load of 100N through a distance of 4m. What is the efficiency of the machine ?

16. A wheel and axle of radii 30cm and 5cm respectively is used to lift a bracket of water of 40 N out of a well . What is the

    A) VR

    B) Effort needed

    C) Efficiency of the machine

17. A movable pulley is used to move a 140N load . If there is a 5N friction force,

    A) Can this load be lifted with a 75N applied force

    B) Would a fixed pulley does the hop instead?

18. The efficiency of an inclined plane is 50% .If the plane has a length of 4m and a height of 1m, What is its Mechanical Advantage?

19. On a 1.5m lever, a load is placed 0.5m away from the fulcrum, How large is the VR , if the lever is

    A) 1st Class

B) 2nd class

20. A Simple machine has an efficiency of 0.75 and a VR of 12. Determine the MA and the load that can be moved by an effort of 100N

21. A 40 percent efficient machine performs 200J of useful work . What input work was introduced ?

22. A 60 % efficient machine lifts a 10kg mass at a speed of 3m/s . What is the required input power ?

23. What must be the thickness of a wedge of 20cm long if it is desired that the input force be one - tenth of the out put force ?

24. The handle of a Screw jack is 50cm long . If the screw has five threads per centimeter, What is the ideal mechanical advantage of the Screw.

I. Short answers and explanations

1. It is a machine that helps us to do work easier
2. They help us to multiply force or to multiply Speed or to change direction
3. Inclined plane, wedge, screw, lever,wheel and axle and pulley
4. a) Is the force applied on the machine

   b) Is the force the machine exerted on the object .

   c) MA is the ratio of load to effort

   d) VR is the ratio of distance moved by the effort to the distance moved by the load

   e) Is the work done by the effort Win =(E) (SE)

   f) Is the work done by the machine . Wout = (L) (SL)

   g) Is the ratio of work output to work input

$$\eta = \frac{W_{out}}{W_{in}} = \frac{MA}{VR}$$

5. AMA is the ratio of load to effort in the presence of friction but IMA is the ratio of load to effort in the absence of friction
6. 1st class, fulcrum is between load and effort

2nd class,load is between effort and load

3rd class, effort is between load and fulcrum

7. Fixed, movable and compound pulley
8. VR of, a pulley is equal to the number of strings supporting the load
9. Force multiplier :- Inclined plane, lever, compound pulley

   Speed multiplier :- lever, wheel, and axle

   Direction changer:- pulley, wheel and axle
10. If MA or VR >1, force multiplier

    MA or VR <1, speed multiplier

    MA or VR = 1,direction changer

II. Solution to the End of Unit Problems

11.

A) $MA = \frac{6000}{300} = 20$

B) $VR = MA = 20$

C) $VR = MA \Rightarrow \frac{L}{h} = \frac{L}{E} \Rightarrow L = \left(\frac{L}{E}\right)h = \left(\frac{6000}{300}\right)(10) = 200m$

12. A) $VR = \frac{L}{t} = \frac{12}{3} = 4$

B) $MA = VR \Rightarrow \frac{L}{E} 4 L = E(4) = (20)(4) 80N$

13. $MA = \frac{S_E}{S_L} = \frac{2}{4} = 0.5$, speed multiplier

14. $MA = \frac{L}{E} = \frac{150}{30} = 5$, it multiplied the effort five times.

15. $\eta = \frac{MA}{VR} = \frac{(L)(S_L)}{(E)(S_E)} = \frac{(100)(4)}{(50)(8)} = 1 = 100\%$

16. A) $VR = \frac{R}{r} = \frac{30}{5} = 6$

B) $MA = VR \Rightarrow \frac{L}{E} = \frac{R}{r} \Rightarrow E = L\left(\frac{r}{R}\right) = 40\left(\frac{5}{30}\right) = 6.7N$

C) $\eta = \frac{MA}{VR} = 1 = 100\%$

17. A) $MA = \frac{L}{E} = \frac{145}{75} = 2,150 > 145$ yes!

B $MA = \frac{L}{E} = \frac{145}{75} = 1,75 < 145$ No!

18. $\eta = \frac{MA}{VR} \Rightarrow 0.5 = \frac{MA}{4}$, Hence, $MA = 2$.

19. A) $VR = \frac{S_E}{S_L} = \frac{1}{0.5} = 2$

B) $VR = \frac{S_E}{S_L} = \frac{1.5}{0.5} = 3$

20.

$\eta = \frac{MA}{VR} \Rightarrow MA = \eta(VR) = 0.75(12) = 8.5$

Since $MA = \frac{L}{E} \Rightarrow L = MA(E) = 8.5(100) = 850N$

21.

$\eta = \frac{W_{Out}}{W_{in}} \Rightarrow 0.4 = \frac{200}{W_{in}}$, $Win = 500J$

22. $\eta = \frac{W_{Out}}{W_{in}} = \frac{P_{Out}}{P_{in}}$, $P_{Out} = mgv = (10)(3)(10) = 300w$

$\Rightarrow P_{in} = \frac{P_{Out}}{\eta} = \frac{300}{0.6} = 500$ Watt

23.

$IMA = VR \Rightarrow \frac{L}{t} = \frac{L}{E} \Rightarrow t = L\left(\frac{E}{L}\right) = 20\left(\frac{1}{10}\right) = 2cm$

24.

$IMA = VR = \frac{2\pi R}{P} = \frac{2(3.14)(50)}{0.2} = 1570$

UNIT 6

6. Mechanical Oscillation and Sound Wave

6. Mechanical Oscillation and Sound Wave

Hello reader, we are very excited to meet you in this interesting unit where you will get to know term such as oscillation, wave and disturbance, be familiar with terms such as frequency, period and wavelength, explain types of waves, describe common properties of waves, find out period and frequency of oscillation of simple pendulum and spring-mass system, define sound waves, and understand the production and application of echo. For sure, you will love it. Enjoy!

6.1 Oscillations and Waves

Waves and oscillations are phenomena's generated by natural or artificial processes.

Now, let us define them one by one.

Wave: Is a continues disturbance that moves from place to place carrying energy.

A wave may be mechanical or electromagnetic, and a transverse or a longitudinal, all of which we will discuss in the coming session.

Oscillation: Is a periodic or repeated here and there, up and down or to and fro motion of a body.

Motion of simple pendulum and the motion of spring-mass system are best examples of oscillatory motion.

The terms that are used to describe wave motion and oscillation are the following;

- Equilibrium position: Is the rest or undisturbed position of a particle or a field.
- Amplitude, A: Is the maximum displacement of a particle from equilibrium position.
- Its unit is meter(m)

- Period, T: Is the time taken to cover one cycle.

$$\text{Period} = \frac{\text{Time taken}}{\text{Number of cycles}}$$

Its unit is second(s)

- Frequency, F: is the number of cycles made per second

$$\text{Frequency} = \frac{\text{Number of cycles}}{\text{Time taken}}$$

Its unit is hertz (Hz)

Frequency is the reciprocal of period

$$f = \frac{1}{T}$$

$\Rightarrow$ 1Hz = S^{-1}, read as per second

- Wavelength, λ(lambda) : Is the distance between identical points or complete cycles.

  Its unit is meter (m)

- Wave speed, V : Is the distance moved by a particle per second.

$$\text{Wave speed} = \frac{\text{Wave length}}{\text{Time taken}}$$

$$V = \frac{\pi}{T}; f = \frac{1}{T}$$

$$\boxed{V = \lambda f}$$

Its unit is meter per second, (m/s)

Illustrative Examples

1. A body 40 oscillations in 20 seconds. What is its

   A) Period of oscillation

   B) Frequency of oscillation

Solution:

A) $\text{period} = \frac{\text{Time taken}}{\text{Oscillation made}}$

$$T = \frac{20}{40} = 0.5\text{sec}$$

B) $\text{Friquency} = \frac{\text{Oscillation made}}{\text{Time taken}} = \frac{40}{20} = 2\text{Hz}$

2. If the frequency of oscillation of a body is found to be 5Hz.

A) What does it mean when we say 5Hz

B) What is the period of oscillation of the body

Solution:

A) 5Hz means, the body moved 5 complete cycle in just one second.

B) $T = \frac{1}{f} = \frac{1}{5} = 0.2\,\text{sec}$

3. An oscillating body takes 10 seconds to move a 50cm complete cycle. What is the speed of the oscillating body?

Solution:

$$V = \lambda f = \frac{\lambda}{T}$$

$$V = \frac{0.5}{10} = 0.05\text{m/s}$$

Match the items in "A" Column with those in column "B"

A	B
4. frequency	A. distance moved in one cycle
5. period	B. cycles moved in one second
6. amplitude	C. time taken to move one cycle
7. equilibrium	D. maximum displacement

8.wave speed
9.wavelength

E. zero displacement
F. distance per unit time
G. speed per unit time

Answers

4. B
5. C
6. D
7. E
8. F
9. A

6.2 Simple Pendulum and Spring-Mass System

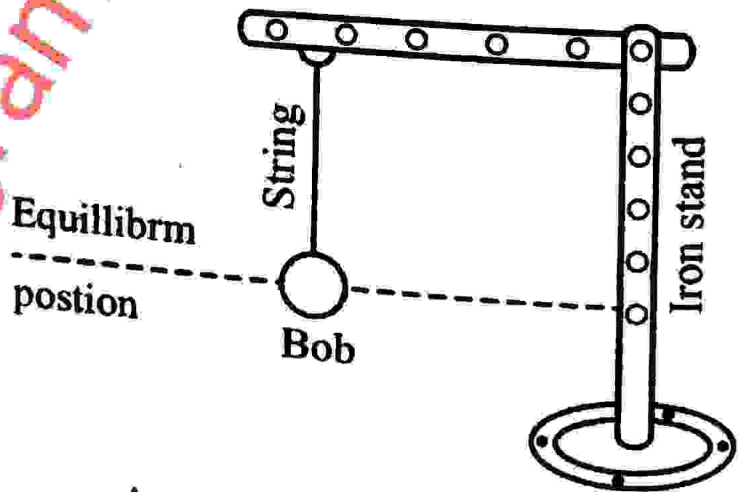
The most common examples of periodic motion are simple pendulum and spring-mass system.

Periodic motion: Is a motion that repeats itself over and over again.

Now, let us make use of simple relations to find the period and frequency of this oscillators.

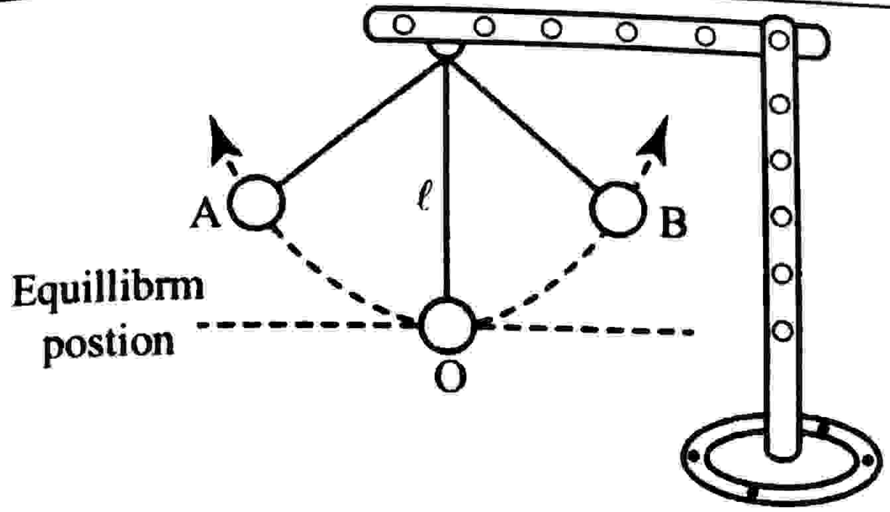
Simple Pendulum

It consists of a point mass called **bob** suspended by a massless string fixed at a frictionless stand as shown below:



A typical simple pendulum

If the bob is displaced and then released, from some height, it oscillate here and there as shown below:



When the bob is taken from point 0 to point A and then released, it moves from A to 0 then to point B, and from the transformation of energy the bob will move back to 0 and A and the cycle repeats.

And, the time it takes the bob to come back to point A that is to cover one cycle is obtained by:

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

Where : T = period of simple - pendulum

ℓ = length of the string

g = acceleration due to gravity

And, frequency of oscillation of the simple-pendulum is obtained by:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\ell}}$$

This relation is derived from the fact that , frequency and period of oscillation are reciprocal to each other.

That is, $f = \frac{1}{T}$

Conceptual Example

10. Will there be any difference in the period of oscillation of a simple pendulum on the moon and on the earth?

Explanation:

We know, $T = 2\pi\sqrt{\frac{l}{g}}$

And, the acceleration due to gravity on the moon is one-sixth that on the earth.

$$T_{earth} = 2\pi\sqrt{l/g}$$

$$T_{moon} = 2\pi\sqrt{\frac{l}{g_{moon}}} = 2\pi\sqrt{\frac{l}{\frac{1}{6}g}}$$

$$T_{moon} = 2\pi\sqrt{\frac{6l}{g}} = \sqrt{6}\left(2\pi\sqrt{\frac{l}{g}}\right)$$

$$T_{moon} = \sqrt{6}T_{earth}$$

On the moon, the period of oscillation of the pendulum increases

11. What will happen to the period of oscillation of a simple pendulum, if the bod mass is doubled?

Explanation:

Since, $T = 2\pi\sqrt{\frac{l}{g}}$

Period of oscillation of a simple pendulum does not depend on the mass of the bob. It will remain the same.

12. What will happen to the frequency of a simple pendulum if the string length is..

A) doubled

B) halved

Explanation:

A) $T^1 = 2\pi\sqrt{\frac{2l}{g}} = \sqrt{2}\left(2\pi\sqrt{\frac{l}{g}}\right)$

$T^1 = \sqrt{2}\,T$, increases

B) $T' = 2\pi\sqrt{\frac{\frac{1}{2}l}{g}} = \frac{1}{\sqrt{2}}\left(2\pi\sqrt{\frac{l}{g}}\right) = \frac{1}{\sqrt{2}}T$, decrease

$$T' = \frac{1}{\sqrt{2}}T, \text{ decreases}$$

Illustrative Examples

13. What is the period of oscillation of a simple pendulum of length 90cm on the surface of the earth?

Solution:

$$T = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{0.9}{10}}$$

$$T = \frac{6\pi}{10} = 1.9\,\text{second}$$

14. If the period of oscillation of a simple pendulum is $\sqrt{\frac{2}{3}}$ second on the earth surface, what will be the period of oscillation of this pendulum on the moon where $g_{moon} = \frac{1}{6}g$

Solution

$$T = 2\pi\sqrt{\frac{l}{g}} = \sqrt{\frac{2}{3}}$$

$$T_{moon} = 2\pi\sqrt{\frac{l}{g_{moon}}} = 2\pi\sqrt{\frac{l}{\frac{1}{6}g}}$$

$$T_{moon} = 2\pi\sqrt{\frac{6l}{g}} = \sqrt{6}\left(2\pi\sqrt{\frac{l}{g}}\right)$$

$$T_{moon} = (\sqrt{6})\left(\sqrt{\frac{2}{3}}\right) = \sqrt{\frac{12}{3}} = \sqrt{4}$$

$$T_{moon} = 2\,\text{sec}$$

15. A simple pendulum of length 900cm is found to have a period of second. What is the acceleration due to gravity of the place where oscillation is made?

Solution:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$\frac{T}{2\pi} = \sqrt{\frac{l}{g}}$$

$$\frac{T^2}{4\pi^2} = \frac{l}{g}$$

$$g = \frac{4\pi^2 l}{T^2} = \frac{(4\pi^2)(9)}{\pi^2}$$

$$g = 36\,m/s^2$$

16. What is the frequency of a simple pendulum of length 40cm on the earth surface?

Solution:

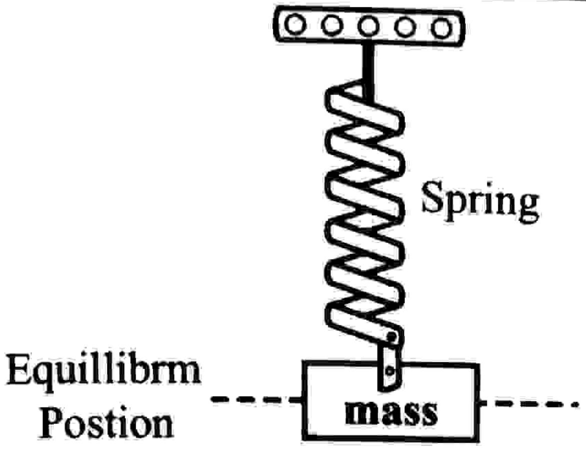
$$f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{10}{0.4}} = \frac{1}{2\pi}\sqrt{\frac{100}{4}}$$

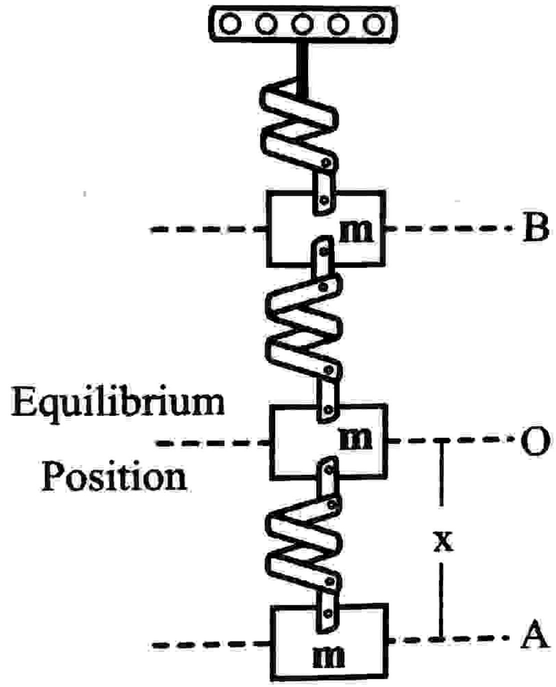
$$f = \frac{5}{2\pi}\,Hz$$

Spring - mass System

It consists of a mass attached to one of the free end of a spring as shown below:



If we stretch or compress the system and then release, it will oscillate up and down.



For example, if we stretch the system down to point A and then release, it will move from A to 0 then to B and back to point A. And, the cycle repeats.

The time taken by the system to complete, one cycle that is to come back to point A is obtained by:

$$T = 2\pi = \sqrt{\frac{m}{k}}$$

Where: T = period of oscillation of the spring-mass system

m = mass of the block

k = spring constant or force constant of the spring

Moreover, frequency of oscillation of the spring-mass system is obtained by:

$$T = 2\pi\sqrt{\frac{m}{k}}, \text{ and}$$

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}}$$

The above relation is obtained from the fact,that, frequency and period of oscillation are reciprocal to each other That is, $f = \frac{1}{T}$

Conceptual Example

17. What will happen to the period of a spring-mass system if the mass attached to the spring, keeping others constant is:

A) double

B) halved

Explanation:

A) $T = 2\pi\sqrt{\frac{m}{k}}$

$T' = 2\pi\sqrt{\frac{2m}{k}} = \sqrt{2}\left(2\pi\sqrt{\frac{m}{k}}\right)$

$T' = \sqrt{2}T$, increases

B) $T = 2\pi\sqrt{\frac{m}{k}}$

$T' = 2\pi\sqrt{\frac{\frac{1}{2}m}{k}} = \frac{1}{\sqrt{2}}\left(2\pi\sqrt{\frac{m}{k}}\right)$

$T' = \frac{1}{\sqrt{2}}T$

18. What will happen to the period of a spring-mass system if the spring length, keeping others constant is:

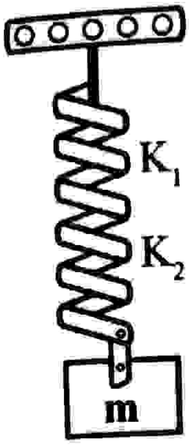
A) doubled, connected in series

B) halved, connected in parallel

Explanation:

A) $T = 2\pi = \sqrt{\frac{m}{k'}}$

When spring length increases, its spring constant decreases by the same amount.



$x = x_1 + x_2$

$\frac{F}{K} = \frac{F}{k_1} + \frac{F}{k_2}, k_1 = k_2$

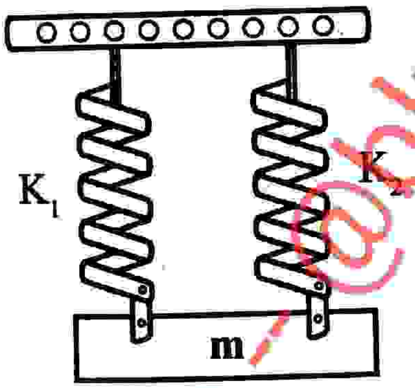
$\frac{1}{k'} = \frac{1}{k_1} + \frac{1}{k_2} = \frac{2}{k}$

$k' = \frac{k}{2}$

$$T' = 2\pi\sqrt{\frac{m}{k_1}} = 2\pi\sqrt{\frac{m}{k/2}}$$

$$T' = \sqrt{2}T, \text{ increases}$$

When spring length decreases, its spring constant increases by the same amount.



$F = F_1 + F_2$

$k'x = k_1 x k_2 x, k_1 = k_2$

$k' = 2k$

$$T' = 2\pi\sqrt{\frac{m}{k'}} = 2\pi\sqrt{\frac{m}{2k}}$$

$$T' = \frac{1}{\sqrt{2}}\left(2\pi\sqrt{\frac{m}{k}}\right)$$

$$T' = \frac{1}{\sqrt{2}}T, \text{ decrease}$$

Illustrative Example

19. What is the force constant of a spring with a period of oscillation of $\frac{\pi}{10}$ second when 4kg mass is suspended on it?

Solution:

$$T = 2\pi\sqrt{\frac{m}{k'}}$$

$$\frac{T^2}{4\pi^2} = \frac{m}{k}$$

$$k = \frac{4\pi^2 m}{T^2} = \frac{4\pi^2(4)}{\frac{\pi^2}{100}}$$

$$= 1600\,N/m$$

20. What is the period of a spring-mass system when a mass of 0.9kg is attached to a spring of force constant 10N/m?

Solution:

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{0.9}{10}}$$

$$T = 0.6\pi \text{ second}$$

21. What will happen to the frequency of a spring-mass system of initial frequency πHz, if the force constant is doubled and the mass is halved?

Solution:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$f' = \frac{1}{2\pi}\sqrt{\frac{k'}{m'}}, k' = 2k \text{ and } m' = \frac{1}{2}m$$

$$f' = \frac{1}{2\pi}\sqrt{\frac{2k}{\frac{1}{2}m}} = \frac{1}{2\pi}\sqrt{\frac{4k}{m}}$$

$$f' = 2f = 2(\pi)$$

$$f' = 2\pi Hz$$

22. What will happen to the period of oscillation of a spring-mass system if the mass is double and the force constant is halved?

Solution:

$$T_1 = 2\pi\sqrt{\frac{m_1}{k_1}}$$

$$T_2 = 2\pi\sqrt{\frac{m_2}{k_2}}, m_2 = 2m_1 \text{ and } k_2 = \frac{1}{2}k_1$$

$$T_2 = 2\pi\sqrt{\frac{2m_1}{\frac{1}{2}k_1}} = 2\pi\sqrt{\frac{4m_1}{k_1}} = 2\left(2\pi\sqrt{\frac{m_1}{k_1}}\right)$$

$$= 2T_1, \text{doubled}$$

6.3 What are the Types of Waves?

Wave is a continues disturbance that travels from place to place carrying energy, with out transporting particles of the medium

I. Mechanical and Electromagnetic Waves

Depending on whether the wave requires material medium for its production and propagation, or not, we classify waves as mechanical and electromagnetic.

Mechanical Wave: Is a wave that requires material medium for its production and propagation.

For example, sound wave, string wave, water wave . . . etc. are mechanical waves.

Electromagnetic Wave: Is a wave produced by the interaction of electric and magnetic fields and can propagate in vacuum.

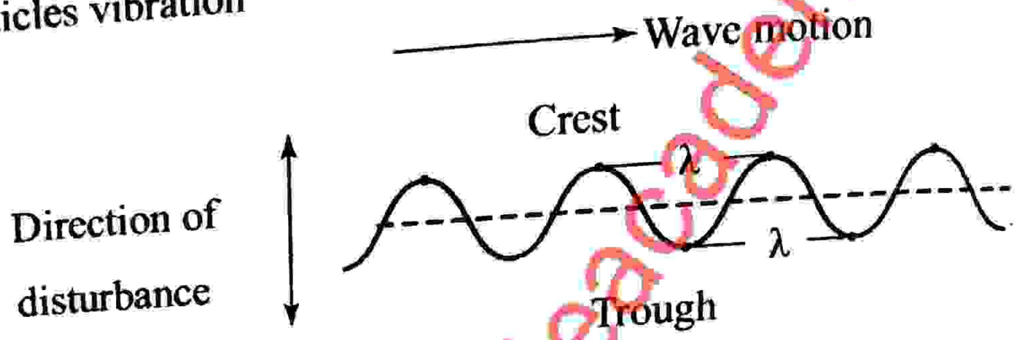
For example, x-ray, light ray, gamma ray....etc. are electromagnetic waves.

II. Transverse and Longitudinal Waves

And depending on the direction of wave motion and the direction of disturbance, we classify waves as transverse and longitudinal.

Transverse Wave: Is a wave for which the direction of the wave motion is perpendicular to the direction of disturbance made on the medium

In such a wave, the direction of wave motion is at right angel to the direction of particles vibration



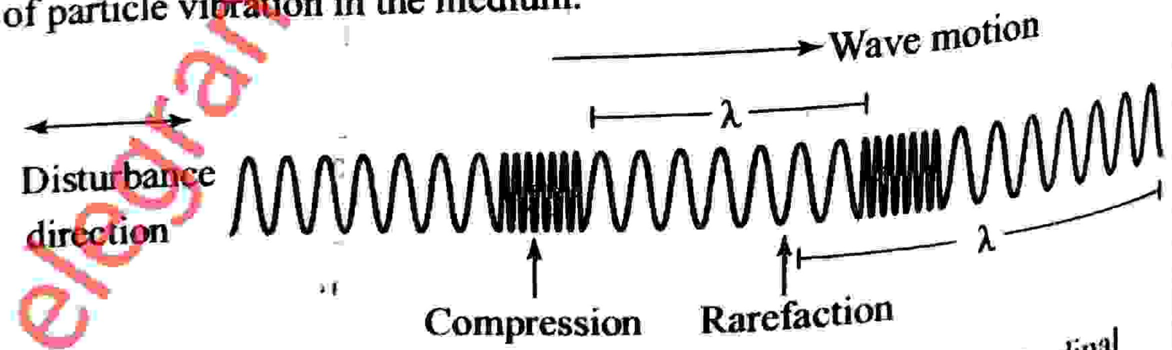
String wave and all the electromagnetic wave are transverse waves.

- **Crest:** Is the highest point above the equilibrium position.
- **Trough:** Is the lowest point below the equilibrium position.

And, the distance between two adjacent crests or adjacent troughs is equal to one wavelength.

Longitudinal Wave: Is a wave for which the direction of wave motion is parallel to the direction of disturbance.

For such a wave, the direction of the wave motion is the same to direction of particle vibration in the medium.



Sound wave and waves on a silky spring are examples of longitudinal wave.

- **Compression:** Is region of high pressure where particles of the medium come closer together.
- **Rarefaction:** Is region of low pressure where particles of the medium become far apart.

And, the distance between two adjacent compressions or adjacent rarefactions is equal to one wavelength.

Match the Item in Column 'A' with those in Column 'B'

A	B
23. Mechanical wave	A) High pressure region
24. Electromagnetic wave	B) Low pressure region
25. Transverse wave	C) Need medium
26. Longitudinal wave	D) Can travel in vacuum
27. Crest	E) Highest point
28. Trough	F) Lowest point
29. Compression	G) Disturbance and propagation at 90°
30. Rarefaction	H) . Disturbance and propagation at 0° or 180°
	I) Wave equation

Answers

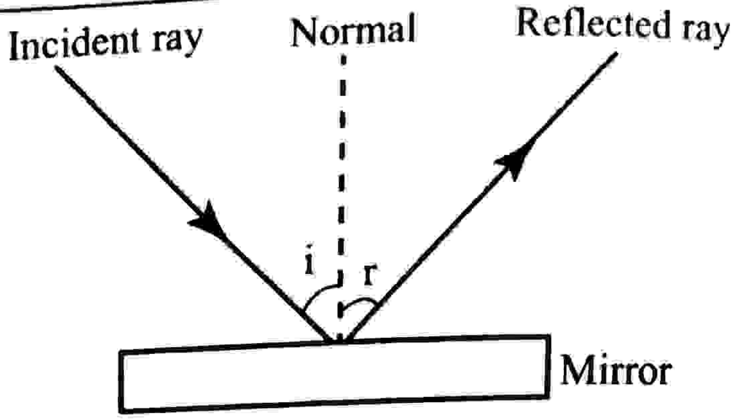
23.C	25.G	27.E	29.A
24.D	26.H	28.F	30.B

6.4 What are the Properties of Waves?

All waves exhibit common characteristic. These characteristics are reflection, refraction, diffraction and interference.

Reflection: Is bouncing back of a wave from a hard and smooth surface.

For example, if a light ray encounters a mirror, it will reflect back as shown below in to its initial medium.



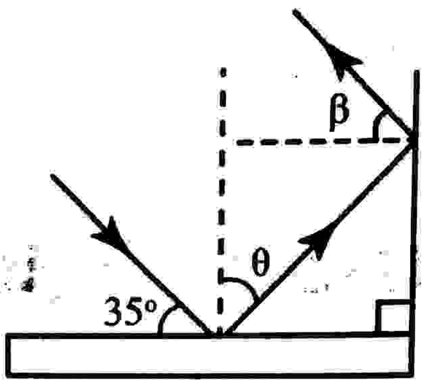
According to the law of reflection, the angle of incidence is equal to the angle of reflection.

That is, $i = \hat{r}$

Illustrative Example

31. For the following case, where a light ray performed reflections on two perpendicular mirrors.

Find the value of θ and β



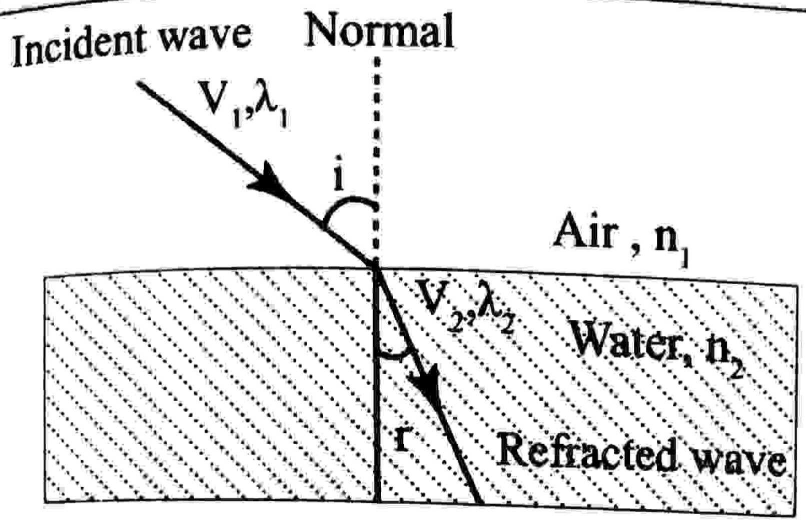
Solution:

Using the fact that complimentary angles add up to 90°, interior angles sum of a triangle is 180° and angle of incidence is equal to the angle of reflection we have,

$\theta = 55°$ and $\beta = 35°$

Refraction: Is the bending of a wave due to a change in its speed as it moves from one medium to the other.

For example, if light ray moves from air into water, its speed decreases and it bend towards the normal



According to Snell's law, we have the following relation.

$$\frac{\sin i}{\sin r}=\frac{n_2}{n_1}=\frac{v_1}{v_2}=\frac{\lambda_1}{\lambda_2}$$

Where: n = refractive index

V = speed of the wave

λ = wavelength of wave

1 = medium one

2 = medium two

Illustrative Examples

32. If a light wave of wavelength 600nm entered from air into glass of refractive index 1.5 at an incidence angle of 53°, find the

A) speed of light in glass

B) angle of refraction

C) wavelength of light in glass

Solution:

A) $\frac{n_2}{n_1}=\frac{v_1}{v_2}$

$$\frac{1.5}{1}=\frac{3\times10^8}{v_2}$$

$v_2 = 2\times10^8 \, m/s$

B) $\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$

$\frac{\sin(53°)}{\sin r} = \frac{1.5}{1} \Rightarrow \frac{0.8}{\sin r} = 1.5$

$\sin r = \frac{0.8}{1.5} \Rightarrow r = \sin^{-1}(0.53)$

$r = 32.20$

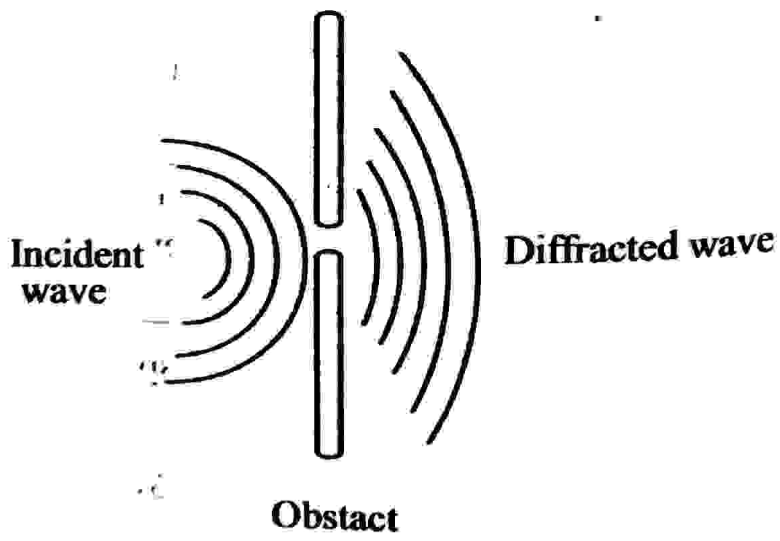
C) $\frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2}$

$\frac{1.5}{1} = \frac{600}{\lambda_2}$

$\lambda_2 = 400nm$

Diffraction: Is the spreading out of a wave though narrow opening or around sharp corners.

For example, if a wave faced an obstacle on its way as shown below, it will diffract.



Interference: Is the mixing up of two waves of the same kind

The magnitude of the resultant wave obtained after the mixing of the waves is obtained by the super-position principle.

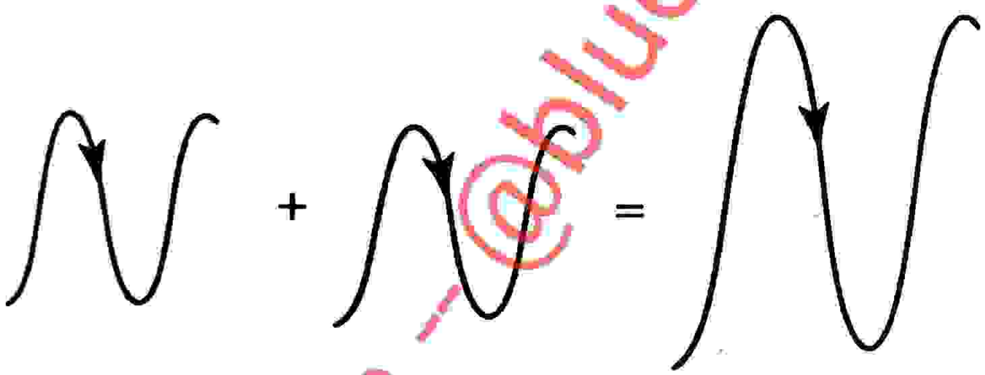
Superposition: States that, the magnitude of the resultant amplitude of the mixing waves at a point is equal to the vector sum of the amplitude of the mixing waves.

Superposition or interference of waves is of two types; constructive or destructive

Constructive Interference: Occurs when two waves that are in phase moving in the same direction with the same frequency and wavelength mix-up

Two waves are said to be in phase if there corresponding points reach maximum or minimum value at the same time.

As an example, when two waves interfere constructively, they form a bigger wave as shown below:



- The amplitude of the resultant wave is larger than the amplitude of the individual mixing waves.

Destructive Interference: Occurs when two wave that are out of phase moving in the same direction with the same frequency and wavelength mix-up.

Two waves are said to be out of phase if there corresponding points reach opposite displacements at the same time.

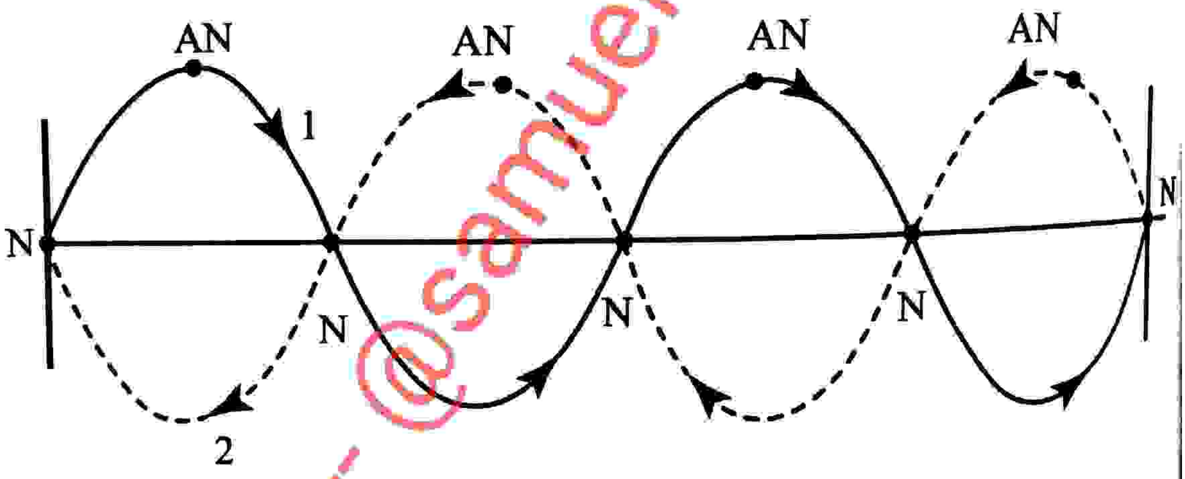
As an example, when two waves interfere destructively, they form a smaller wave as shown below

The amplitude of the resultant wave is smaller than the amplitude of the individual mixing waves.

Standing Wave

Is also called *stationary* wave and is created when two waves of the same type travelling in opposite directions mix up.

For example, plucking a guitar string produces standing wave.



This standing wave is formed when wave -1,travelling to the right mix up with wave -2,moving to the left.

Node, N: Is a point of zero displacement, and occurs due to destructive interfrence.

Anti-node, AN: Is a point of maximum displacement and occurs due to constructive interfrence.

What is more, the distance between successive nodes or adjacent anti-nodes is equal to half a wavelength, $\lambda/2$. And,that between a node and an anti-node is quarter of a wavelength, $\lambda/4$ okay.

Illustrative Example

Match the items in column 'A' with those in column 'B'

A	B
33. Reflection	A) In phase mixing
34. Refraction	B) Out of phase mixing
35. Diffraction	C) Point of maximum displacement
36. Interfrence	D) Point of zero displacement
37. Constructive	E) Bouncing back
38. Destructive	F) Mixing-up
39. Node	G) Spreading out
40. Anti-Node	H) Bending through medium
	I) Travelling Wave

Answers

33.E	35.G	37.A	39.C
34.H	36.F	38.B	40.D

6.5 What is Sound Wave?

Sound is a mechanical as well as a longitudinal wave produced by a body that is in a state of vibration.

- Sound to be produced and detected, there must be source, and medium for transmission

Speed of Sound

The speed sound depends on the state of mater of the substance through which it is moving. Therefore; the speed of sound in gases is different from its value through liquids and solids.

Speed of Sound in Air

The speed of sound in air increases as temperature, increases and it is obtained by;

$$v = 331 + 0.6T$$

$$v = 331\sqrt{1 + \frac{T}{273}}$$

Where: 331m/s is the speed of sound in air at 0°c , and T is temperature in °c.

Speed of Sound in Liquid

The speed of sound in liquid has no significant variation as temperature changes.

$$v = \sqrt{\frac{B}{\rho}}$$

Where: B, is bulk modulus and is a measure of compressibility of the liquid .

ρ, is density of the liquid.

Speed of Sound in Solid

The speed of sound in solids does not significantly vary with a change in temperature.

$$v = \sqrt{\frac{Y}{\rho}}$$

Where: Y,is Young's modulus and is a measure of stiffness of the solid ρ, is density of the solid

Remember: The speed of sound is greatest in solids than it is in liquids and gases. And, it is greater in liquids than it is in gases. OK!

Illustrative Example

41. What is the speed of sound in air at 14°c ?

Solution

$$v = 331 + 0.6T$$

$v = 331 + 0.6(14)$

$v = 340 m/s$

or

$$v = 331\sqrt{1+\frac{T}{273}}$$

$$v = 331\sqrt{1+\frac{14}{273}}$$

$v = 340 m/s$, Same

42. What is the speed of sound in water of bulk modules 2×10^9pa and density $1000 kg/m^3$?

Solution:

$$v = \sqrt{\frac{B}{\rho}}$$

$$v = \sqrt{\frac{2\times10^9}{1000}}$$

$= 1400 m/s$

43. What is the speed of sound in steel of young's modulus 2×10^9pa and density $7900 kg/m^3$?

Solution

$$v = \sqrt{\frac{Y}{\rho}}$$

$$v = \sqrt{\frac{196\times10^9}{7900}}$$

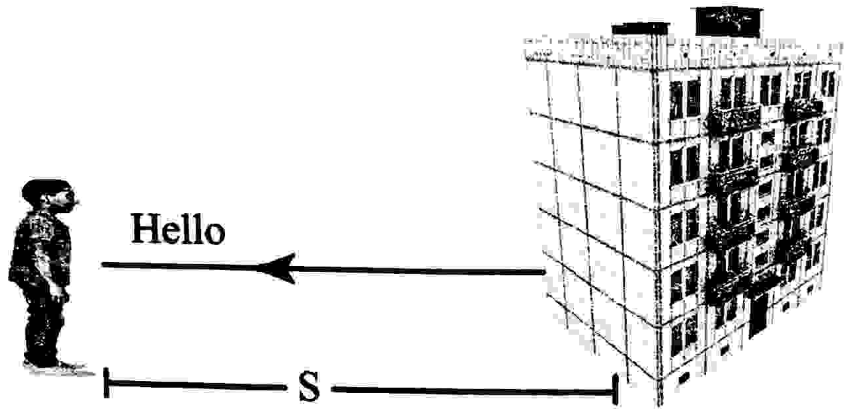
$= 4980 m/s$

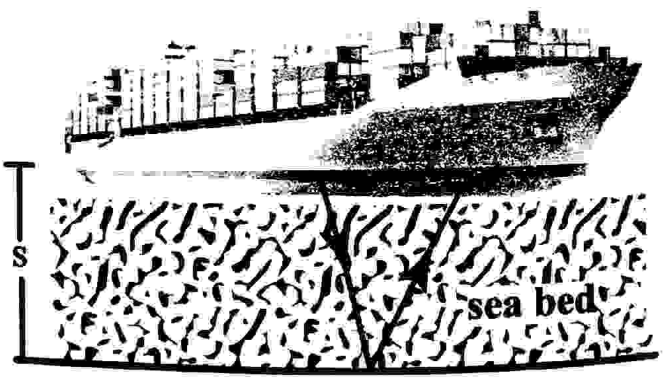
Production of Echo

The reflection of sound from hard surface such as a rock, a cliff, a buildi etc., is called an *echo*.

If you shout in front of a tall building or a mountain, you will hear the orig sound and the reflected sound,that is the echo as two separate sou

Echo, is used to determine the depth of an ocean and the distance building or a cliff from a sound source merely by talking the time take the sound wave to came back to the sound source after reflection.





In both cases, $2s = vt$

$$s = \frac{vt}{2}$$

Where: v = speed of sound in the given medium

t = total time taken of by sound to move from obstacle back to source

s = distance between the sound source and the obstacle

Illustrative Example

44. At a moment when the speed of sound in air is 340m/s, a boy shouts "Hello" in front of a cliff and hears the echo after 5 seconds. How far is the cliff from the boy?

Solution:

$$s=\frac{vt}{2}=\frac{(340)(5)}{2}$$

$$s=850m$$

45. What is the speed of sound in sea water if a ship 1500m above the sea bed detected an echo after 2 seconds?

Solution:

$$s=\frac{vt}{2}\Rightarrow v=\frac{25}{t}=\frac{2(1500)}{2}$$

$$=1500m/s$$

Characteristics of Sound Wave

Some of the characteristics of sound wave are pitch,loudness and timber

Pitch: Is the lowness or highness of sound and it depends on the frequency of the sound wave.

In higher pitch sound, the particles of the medium vibrate more often past their rest position each second.

Example; girls have hight pitch than boys.

Loudness: Is the magnitude or intensity of sound and it depends on the amplitude of the sound wave.

In louder sound, the particles of the medium move further away from their rest position.

Example, roar of lion is louder than mew of a cat.

Remember; sound level, that is loudness is measured in decibel (dB) and sound is said to be polluted or painful when above 120dB.

Timber: Is the quality of sound and it depends on the tone produced by the sound source.

Timber or quality of sound, doesn't mean a bad or good sound. It refers to the difference in sound note produced by different sound sources.

Examples, violin has a different timber as compared to guitar.

Match the items in column A with those in column B

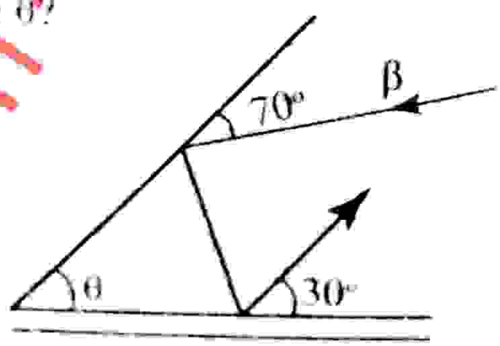
A	B
46. Echo	A) Reflection of sound
47. Pitch	B) Amplitude of sound
48. Timber	C) Frequency of sound
49. Loudness	D) Quality of sound
	E) Refraction of sound

Answers

46.A 47.C 48.D 49.B

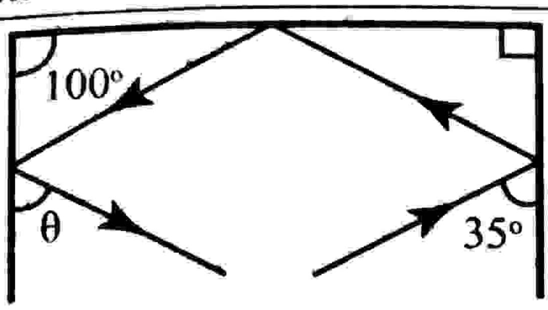
Illustrative Examples

50. If a ray of light is reflected by two mirrors as shown below, what is the value of angle θ?



Hint: using law of reflection and interior angle sum of a triangle: θ = 80

51. A ray of light is reflected by three mirrors as shown what is the value of angel θ?



Hint: Use law of reflection and interior angle sum, $\theta = 25^0$

52. By what factor must the length of a simple pendulum be changed in order to double its period of oscillation?

A) 2 B) 1/2 C) 4 D) 1/4

Solution:

$$T_1 = 2\pi\sqrt{\frac{l_1}{g}}$$

$$T_2 = 2\pi\sqrt{\frac{l_2}{g}},\ T_2 = 2T_1$$

$$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} \Rightarrow \frac{2T_1}{T_1} = \sqrt{\frac{l_1}{l_2}}$$

$$2 = \sqrt{\frac{l_2}{l_1}}$$

$$4 = \frac{l_2}{l_1} = l_2 \Rightarrow 4l_1$$

Answer: C

53. The period of a mass-spring system is 5 second. If the spring is cut into four equal parts and the mass is suspended on one of the parts, the period will be?

A) 5 sec B) 2.5 sec C) 1.2sec D) 10sec

Solution:

$$T_1 = 2\pi\sqrt{\frac{m}{k_1}}$$

$$T_2 = 2\pi\sqrt{\frac{m}{k_2}},\ k_2 = 4k_1$$

$$\frac{T_2}{T_1} = \sqrt{\frac{k_1}{k_2}} \Rightarrow \frac{T_2}{5} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

$$T_2 = \frac{5}{2} = 2.5\text{sec}$$

Answer: B

54. If the period of oscillation of mass M on a spring is 1sec, the period of 4M will be

A) 2sec B) 0.5sec C) 4sec D) 0.25sec

$$T_1 = 2\pi\sqrt{\frac{m_1}{k}}$$

$$T_2 = 2\pi\sqrt{\frac{m_2}{k}},\ m_2 = 4m_1$$

$$\frac{T_2}{T_1} = \sqrt{\frac{m_2}{m_1}} = \sqrt{\frac{4}{1}}$$

$$T_2 = 2\text{sec}$$

Answer: A

55. What will be the period of oscillation of a pendulum on a planet whose mass and diameter are twice that of the earth ? Assume its period is 1sec on earth.

A) $\frac{1}{\sqrt{2}}$ sec B) $\sqrt{2}$ sec C) 2 sec D) $\frac{1}{2}$ sec

Solution:

$$T = 2\pi\sqrt{\frac{l}{g}} \quad , \quad g = \frac{GM}{R^2}$$

$$g_{planet} = \frac{GM_{planet}}{R_{planet}}, M_{planet} = 2M, R_{planet} = 2R$$

$$g_{planet} = \frac{GM_{planet}}{R_{planet}}, \frac{1}{2}\left(\frac{GM}{R^2}\right) = \frac{1}{2}g$$

$$T_{planet} = 2\pi\sqrt{\frac{l}{g_{planet}}} = 2\pi\sqrt{\frac{l}{\frac{1}{2}g}} = \sqrt{2}\left(2\pi\frac{\ell}{g}\right)$$

$$T_{planet} = \sqrt{2}T = \left(\sqrt{2}\right)(1)$$

$$= \sqrt{2}\sec$$

Answer: B

56. Which wave phenomena is demonstrated with the diagram shown below?

A. Reflection B. Refraction C. Diffraction D. Interfrence

Hint: The spreading out of a wave through a narrow gap is known as diffraction.

Answer: C

57. The pitch of a sound depends on?

A) Frequency B) Amplitude

C) Wavelength D) Speed

Hint: Pitch of sound depends on frequency, the larger the frequency, the higher the pitch.

Answer: A

58. The loudness of a sound depends on ?

A) Frequency C) Wavelength

B) Amplitude D) Speed

Hint: The loudness of a sound depends on amplitude of the sound wave. The bigger the amplitude, the louder the sound.

Answer: B

59. As the speed of a wave decrease, its wavelength also will decrease. Then, the frequency of the wave will

A) Decrease C) Remain constant

B) Increase D) Increase and then decrease

Hint: $\nu = \frac{v}{\lambda}$ Frequency of wave remains constant

Answer: C

60. Which of the following term tells us the maximum displacement of a particle from its rest position.

A) Frequency C) Wavelength

B) Period D) Amplitude

Hint: Maximum displacement of a particle from its equilibrium position is called amplitude.

Answer: D

61. The spreading out of a wave through a narrow gap or around sharp edge is known as?

A) Reflection C) Diffraction

B) Refraction D) Interfrence

Answer: D

62. The change in direction of a wave as it move from one medium to the

other is known as?

A) Reflection

B) Refraction

C) Diffraction

D) Interfrence

Answer: B

3. An elephant is calling her mate that is 476m away with a frequency of 5Hz. How many cycles of sound wave are there between the two animals .Assuming the speed of sound in air is 340m/s.

A) 5 B) 6 C) 7 D) 8

Solution:

$$\lambda = \frac{v}{f} = \frac{340}{5} = 68m$$

$$\text{Number of cycles} = \frac{s}{\lambda} = \frac{476}{68} = 7$$

Answer: C

4. All electromagnetic waves travel with the same speed in

A) Air B) Water C) Metal D) Vacuum

Hint: Electromagnetic waves travel at a speed of $3x10^8$m/s in vacuum.

Answer: D

5. Infra-sound refers to a sound wave of frequency

A) Lower than 20Hz

B) Greater than 20,000Hz

C) Equal to 20Hz

D) Equal to 20,000Hz

Answer: A

56. Ultrasound refers to a sound wave of frequency

A) Lower than 20Hz

B) Greater than 20,000Hz

C) Equal to 20Hz

D) Equal to 20,000Hz

Answer: B

67. The audible ranges of frequency for the normal human ear is?

A) Between 20Hz and 200Hz B) Between 20Hz and 2000Hz

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C) Between 20Hz and 20,000Hz D) Between 20Hz and 200,000Hz

Answer: C

68. What causes an echo?

A) Refraction
B) Diffraction
C) Reflection
D) Interfrence

Hint: Reflection of sound from hard surface such as wall,mountain, building,,,etc...is called an echo.

Answer: C

69. Sound moves fastest in

A)Gas B)Liquid C)Solid D)Critical fluid

Answer: C

70. Unlike sound wave , light wave can travel through

A) Air B) Water C) Vacuum D) Metal

Hint: Sound wave is mechanical wave, while,light wave is electromagnetic.

Answer: C

71. What happens to a duck floating on sea water as a pulse of water passes past her?

A) It moves back and forth
B) It moves, forward
C) It remains at rest
D) It moves up and down

Hint: Since the water wave is transverse, the duck oscillates up and down

Answer: D

72. As a wave moves through a medium, the particles of the medium will

A) Move with the wave
B) Move in opposite direction
C) Oscillate about their rest position
D) Move out of the medium

Hint: Wave can not transport particle of a medium.

Answer: C

3. Which wave characteristic change during refraction

A) Frequency and wave length

B) Speed and frequency

C) Speed and wavelength

D) Speed,frequency and wavelength

Hint: During refraction, frequency of the wave remains constant..

Answer: C

4. When the frequency of a wave is halved, its period will be?

A) Halved B) Doubled C) Quartered D) Unchanged

Hint:

$$T_1 = \frac{1}{f_1}, T_2 = \frac{1}{f_2}$$

$$f_2 = \frac{f_1}{2}$$

$$T_2 = \frac{1}{\left(\frac{f_1}{2}\right)} = 2\left(\frac{1}{f_1}\right) = 2T_1$$

Answer: B

5. If the speed of an electromagnetic wave is C and its wavelength is λ in Vacuum, and if it is moving at 0.5c in a Liquid, what will be its wavelength in the liquid?

A) λ B) 0.75 λ C) 0.5 λ D) 0.95 λ

Hint:

$$v = \lambda f \Rightarrow \lambda = \frac{v}{f}$$

$$\lambda = \frac{c}{f}$$

$$\lambda' = \frac{v'}{f} = \frac{0.5c}{f}$$
$$= 0.5\lambda$$

Answer: C

76. The turning back of a waves in to its initial medium is?

A) Reflection
B) Refraction
C) Diffraction
D) Interfrence

Hint: The bouncing of a wave into the original medium from a smooth, polished and hard surface is called reflection.

Answer: A

77. The mixing up of two waves of the same type is known as?

A) Reflection
B) Refraction
C) Diffraction
D) Interfrence

Hint: The overlap between two waves of the same type is known as Interfrence

Answer: D

78. The most infiuncial factor for interfrence pattern to be constructive or destructive is?

A) Phase B) Speed C) Frequency D) Wavelength

Hint: Being in phase or out of phase determines the interfrence type

Answer: A

79. Which of the following is not true about mechanical waves.

A) They need medium
B) They transport energy
C) They travel through vacuum
D) They can be longitudinal or transverse

Hint: Mechanical waves can not pass through vacuum.

Answer: C

80. When a transverse wave move toward east, its particle will vibrate

towards:

A) East

B) West

C) North and South

D) East and West

Hint: In a transverse wave, direction of wave motion and particles disturbance is perpendicular.

Answer: C

When a longitudinal wave move toward east, its particles will vibrate towards:

A) East

B) West

C) North and South

D) East and West

Hint: In a longitudinal wave, direction of wave motion and direction of particles disturbance is parallel or anti-parallel.

Answer: D

What type of wave represents the back and forth, sway of crops as a wind blows across a field of grains?

A) Helical

B) Transverse

C) Longitudinal

D) Spherical

Hint: The crops sway back and forth in the wind direction:

Answer: C

83. Which of the following is a unique property of electromagnetic waves?

A) They travel through vacuum

B) They are transverse waves

C) They travel through medium

D) Their speed is always $3x10^8$m/s

Hint: Electromagnetic waves have a speed of $3x10^8$m/s in vacuum.

Answer: A

84. Constructive interference occurs when two waves move in

A) Opposite direction, in phase

B) Same direction, out of phase

C) Opposite direction, out of phase

D) Same direction, in phase

Hint: For constructive interference, the mixing waves should be coherent

Answer: D

85. When sound travels from air to water, it

A) Continuous with the same speed

B) Travels faster

C) Stops suddenly

D) Travels slower

Hint: Speed of increases as the medium density increases

Answer: B

86. Frequency of a wave is the

A) Distance between identical points

B) Distance moved in one second

C) Time taken to move one cycle

D) Number of cycles moved per second

Hint: $frequency = \frac{\text{cycle}}{\text{Time}}$

Answer: D

87. How many times a minute will a boat bob up and down on ocean wave that has a wavelength of 30m and 5m/s speed?

A) 10 B) 6 C) 12 D) 36

Hint: $f = \frac{v}{\lambda} = 5/30 = \frac{1}{6}$ Hz

in one minute, the frequncy is $\left(\frac{1}{6}\right)(60) = 10$

Answer: A

88. The distance between two adjacent crests in a pond is 0.4m. If six crests pass a point every second without considering the reference crest, what is the speed of the wave?

A) 1.2 m/s B) 2.4m/s C) 4.8m/s D) 6.4m/s

Hint: $v = \lambda f = (0.4)(6) = 2.4m/s$

Answer: B

89. All of the following are applications of microwaves Except?

A) Sonar
B) TV signal
C) Cell phone
D) FM radio

Hint: Sonar uses sound wave

Answer: A

90. Which physical quantities decrease as sound travels from water to air?

A) Speed and frequency
B) Wavelength and speed
C) Frequency and wavelength
D) Frequency and period

Hint: Speed of sound decreases as it moves from water to air

Answer: B

91. The property of sound wave is related to loudness is?

A)Wavelength B) Pitch C) Intensity D) Speed

Hint: A louder sound has bigger amplitude and intensity.

Answer: C

92. What is the period of a wave of frequency 4000 Hz?

A) 0.25sec
B) 0.0025sec
C) 0.00025sec
D) 2.5 sec

Hint: $T = \frac{1}{f} = \frac{1}{4000} = 0.00025 sec$

Answer: C

93. A radio station has a frequency of 1500 kHz. What is the wave[illegible]?

A) 200m B) 20m C) 100m D) 50m

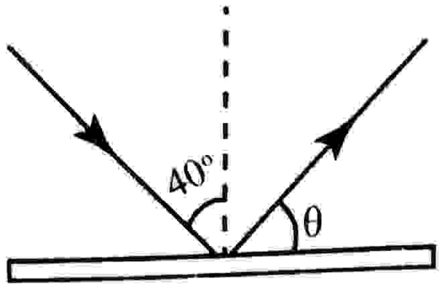
Hint: $T = \frac{1}{f} = \frac{1}{4000} = 0.00025 sec$

Answer: A

94. The value of θ is ?

A) 50^0 B) 40^0 C) 30^0 D) 90^0

Hint: Use the law of refection, $\theta = 50^0$

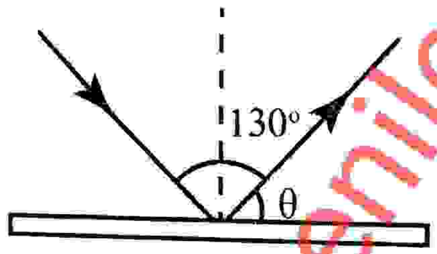


Answer: A

95. The value of θ

A) 65^0 B) 25^0 C) 75^0 D) 30^0

Hint: use the law of refection, $\theta = 25^0$



Answer: B

96. A ship is sailing on a sea 600m above the seabed. How long will it take a pulse of sound to echo back to the ship assuming the speed of sound in sea water is 1500m/s

A) 0.8 second

B) 8 seconds

C) 0.4 seconds

D) 4 seconds

Hint: $t = \frac{2s}{v} = \frac{2(600)}{1500} = 0.8$ second

Answer: A

End of Unit Questions and Problems

I. End of Unit Questions

1. What is oscillation?
2. What is wave?
3. What is Mechanical wave?
4. What is Electromagnetic wave?
5. What is Transverse wave?
6. What is Longitudinal wave?
7. What is Standing wave?

8. What are the properties of all waves?
9. What is Sound wave?
10. What is an Echo?
11. What is Pitch of sound?
12. What is timber of sound?

II. End of Unit Problems

13. What is frequency of an electromagnetic wave of wavelength 10 nm?
14. A simple pendulum of string length 30cm is oscillating at place where the acceleration due to gravity is $1.2m/s^2$. What is the pendulum
    a) Period of oscillation
    b) Frequency of oscillation
15. A mass of 2kg is oscillating at the end of a spring of stiffness 800N/m.
    a) Period of oscillation
    b) Frequency of oscillation
16. What is the speed of sound in a steel rod if it takes only 0.0008second to travel 4m through it?
17. What is the speed of sound in air at 30°c?
18. A boy standing in front of cliff claps his hands and hears the echo after 2seconds. How far is the cliff from the boy?(V=340m/s)
19. How long will it take the sonar to detect a pulse of sound sent by a ship that is 500m above the seabed if the speed of sound in sea water is 1500m/s?
20. What is the period of a wave with a frequency of 2Hz?
21. Two identical waves of amplitude 4cm meet. What will be the extreme amplitude of the resultant wave at a point where the interfrence is
    a) Constructive
    b) Destructive
22. What is the speed of sound in a liquid whose density is $10,000kg/m^3$ and whose bulk modulus is $4x10^{10}$pa?

Short Answer to the End of Unit Questions

1. Oscillation is a periodic here and there, up and down or to and fro repeated motion of a body about its mean position?

2. Wave is a continues disturbance of particles or fields that propagates from point to point carrying energy.
3. Mechanical wave is a wave that requires material medium for its production and propagation.

   Example, Sound wave.
4. Electromagnetic wave is a wave that can travel through medium and vacuum. **Example,** Light wave.
5. Transverse wave is a wave in which the direction of wave motion is at right angle to the direction of particles vibration.

   Example, String wave
6. Longitudinal wave is a wave in which the direction of disturbance is parallel to the direction of wave motion

   Example, Sound wave
7. Standing wave is a wave formed when two waves of the same type moving in opposite directions mix-up.
8. Reflection, refraction diffraction and interfrence are common properties of all waves.
9. Sound wave is a mechanical longitudinal wave created from a vibrating body.
10. Echo is the reflection of sound from a hard surface.
11. Pitch is the lowness or highness of sound and depend on its frequency
12. Timber is the quality of sound notes depending on its source

Solution to End of Unit Problem

13. $v = \lambda f$

$$f = \frac{v}{\lambda} = \frac{3\times10^{8}}{10\times10^{-9}} = 3\times10^{16}\,\text{Hz}$$

14. A. $T = 2\pi\sqrt{\frac{l}{g}}$

$$T = 2\pi\sqrt{\frac{0.3}{1.2}} = 3.14\text{second}$$

B. $f=\frac{1}{T}=\frac{1}{3.14}$

$f=0.318Hz$

15. A. $T=2\pi\sqrt{\frac{m}{k}}=2\pi$

$T=\sqrt{\frac{2}{800}}=0.314sec$

B. $f=\frac{1}{T}=\frac{1}{0.314}$

$f=3.18Hz$

16. $v=\frac{s}{t}=\frac{4}{0.0008}$

$v=5000\,m/s$

17. $v=331+0.6T$

$v=331+0.6T$

$=349m/s$

18. $s=\frac{vt}{2}$

$s=\frac{(340)(2)}{2}=340m$

19. $s=\frac{vt}{2}\Rightarrow t=\frac{25}{v}$

$t=\frac{2(500)}{1500}=0.67second$

20.
$$T=\frac{1}{f}$$

$$T=\frac{1}{2}=0.5\text{second}$$

A. $a=a_1+a_2$

21. $a=4+4=8m$

B. $a=a_1-a_2$

$a=4-4=0m$

22. $v=\sqrt{\frac{B}{\rho}}=\sqrt{\frac{4\times10^{10}}{1^{4}0}}$

$=2\times10^{3}\ m/a$

UNIT 7

7. Temperature and Thermometry

7.1 Temperature and Our Life

7.2 Temperature Scales

7.3 Types of Thermometers

7.4 Thermal Expansion of Materials

7 . Temperature and Thermometry

Hello there! We are very glad to meet you in this fascinating unit where you will be able to; define temperature, explain types of temperature scales, list types of thermometers and solve problems related to temperature scales conversion and linear expansion of materials. You will love and enjoy it!

7 . 1 Temperature and Our Life

Usually, temperature is described as the measure of the degree of hotness and coldness of a body.

However, this description is not reliable since it depends on individuals sensitivity to hot and cold. Therefore, the formal definition of temperature is the following

Temperature: Is the measure of average kinetic energy of particles of a body.

✓ A body is said to have high temperature if its particles average kinetic energy is large and low temperature if its particles have small kinetic energy.

Temperature is a scalar quantity and its SI Unit is the Kelvin(k). Other units of temperature are degree Celsius (°c) and degree Fahrenheit (°F)

In nature, temperature has wide ranges. From very high sun's outer surface temperature of about 5500°c to the very low liquid nitrogen temperature of -196°c. What is more,on the earth surface, it varies from about 30°c on the equatorial zone to about -40°c on the polar zone.

✓ On the average, the normal human body temperature to be about 37°c the surrounding environment needs to be about 28°c.

Conceptual Examples

1. What is room temperature? Explain.

Explanation:

Room temperature is a temperature in the range of 18°c to 22°c with which human are comfortable.

2. What is extreme temperature? Explain.

Explanation:

Extreme temperature is a temperature which is too high or too low from the room temperature.

3. What is Greenhouse effect? Explain

Explanation:

Greenhouse effect is the warming of the earth when atmospheric gases such as carbon dioxide, methane, nitrous oxide, water vapor and fluorinated gases trap heat from the sun.

4. What is global warming? Explain.

Explanation:

Global warming is the increase in the temperature of the world as a whole .

5. What is the cause of global warming ? Explain.

Explanation:

Global warming is caused mainly by the burning of fossil fuels, natural gas, cola,..etc. by humans in an attempt to generate energy.

6. What are the effects of extreme temperature? Explain.

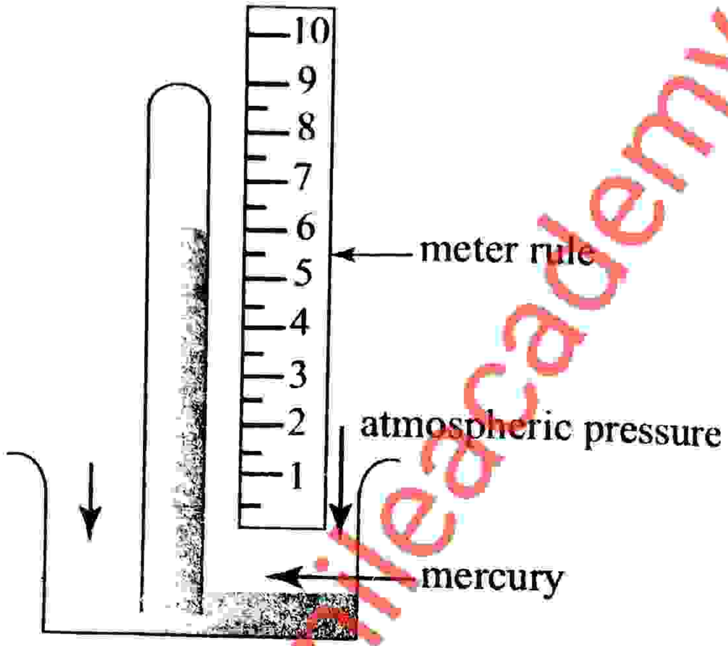
Explanation:

Too low temperature causes snow and ice and death to plants and animals. Too high temperature causes draught, desert, famine and death to animals and plants and rivers, lakes and other water resource will dry.

- ✓ Higher temperature causes heat waves and leads to heat cramps and heat stroke and death.

The device that is used to measure temperature of a body is called *Thermometer.*

A typical thermometer is a cylindrical tube with a small bulb at its base, and filled with mercury or alcohol to a certain height. Parts of a mercury thermometer are shown blow.



A typical mercury Thermometer

Conceptual Example

7. How do the Mercury and Alcohol thermometer work? Explain.

Explanation:

They do work by expansion and contraction that is rising or falling through the tube when the temperature changes.

8. Mercury thermometer may not be used at temperature below -40°c. Why?

Explanation:

This is because, mercury freezes and changes to solid at this temperature.

7.2 Temperature Scales

The most common temperature scales are three Those are centigrade or Celsius, Fahrenheit and Kelvin scales. And, in designing typical thermometers, two point are marked on it. The lower fixed point and the upper fixed point.

✓ The lower fixed point, LFP is the freezing, ice or melting point of water and upper fixed point, UFP is the steam or boiling point of water.

Now, let us go through the three temperature scales one by one.

The Celsius Scale

This scale, the Celsius is also called the *Centigrade scale* and was developed by Anders Celsius. He assigned 0°c to the ice point of water and 100°c to the boiling point of water.

✓ This scale has 100 equal divisions.

The Fahrenheit Scale

It was developed by Daniel Fahrenheit. He assigned 32° F to the ice point of water and 212° F to the boiling point of water.

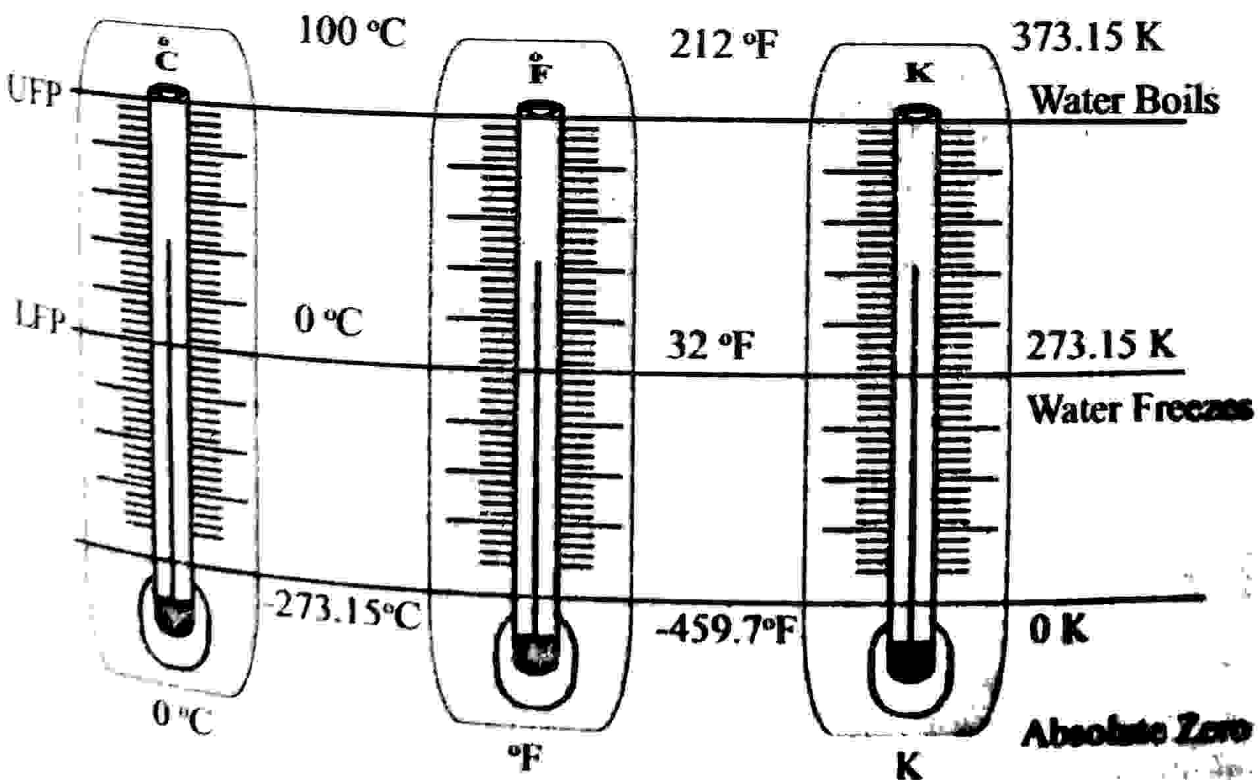
✓ This scale has 180 equal divisions.

The Kelvin Scale

It was developed by Lord Kelvin. He assigned 273.15k to the ice point of water and 373.15k to the boiling point of water.

✓ This scale has 100 equal divisions.

The three scales with their lower and upper fixed points are shown using the mercury thermometer as follows,



Absolute Zero: Is the temperature at which particles stop movement and the body will not have thermal energy.

$$\text{Absolute Zero } 0k = -273.15^{0}c$$

Conversion Between Temperature Scales

To convert temperature scale x to temperature scale y or vice-versa, use the following relation

$$x \rightleftarrows y$$

$$\frac{T_x - T_{x(ice)}}{T_{x(boiling)} - T_{x(ice)}} = \frac{T_y - T_{y(ice)}}{T_{y(boiling)} - T_{y(ice)}}$$

Or

$$\frac{T_x - T_{x(LFP)}}{T_{x(UFP)} - T_{x(LFP)}} = \frac{T_y - T_{y(LFP)}}{T_{y(UFP)} - T_{y(LFP)}}$$

Using the above relations, We can have the following specific cases

A) To convert Celsius scale to Fahrenheit scale or vice-versa

$$°C \rightleftarrows °F$$

$$\frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32}$$

$$\frac{T_C}{100} = \frac{T_F - 32}{180}$$

B) To convert Celsius scale to Kelvin scale or vice-versa

$$°C \rightleftarrows K$$

$$\frac{T_C - 0}{100 - 0} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_c}{100} = \frac{T_K - 273.15}{180}$$

C) To convert Fahrenheit scale to kelvin scale or vice-versa

$^{0}F \rightleftarrows K$

$$\frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

Illustrative Examples

9. Convert 50°F in to

a) .°C

b) .K

Solution:

a) $$\frac{T_F - 32}{212 - 32} = \frac{T_C - 0}{100 - 0}$$

$$\frac{T_F - 32}{180} = \frac{T_C}{100}$$

$$\frac{50 - 32}{180} = \frac{T_C}{100}$$

$$TC = 20^0C$$

b) $$\frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

$$\frac{50 - 32}{180} = \frac{T_K - 273.15}{100}$$

$$T_K = 283.15K$$

10. Convert 20°c into

a) .°C

b) K

Solution:

a) $\frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32}$

$\frac{T_C}{100} = \frac{T_F - 32}{180}$

$\frac{20}{180} = \frac{T_F - 32}{180} = 68^0 F$

$T_F = 68^0 F$

b) $\frac{T_C - 0}{100 - 0} = \frac{T_K - 273.15}{373.15 - 273.15}$

$\frac{T_C}{100} = \frac{T_K - 273.15}{100}$

$\frac{20}{180} = \frac{T_K - 273.15}{100} = 293.15K$

$T_K = 293.15K$

11. Convert 573.15k into

a) .°C

b) .°F

Solution:

a) $\frac{T_K - 273.15}{373.15 - 273.15} = \frac{T_C - 0}{100 - 0}$

$\frac{T_K - 273.15}{100} = \frac{T_C}{100}$

$\frac{573.15 - 273.15}{100} = \frac{T_C}{100}$

$T_C = 200^0\ c$

b) $\frac{T_K - 273.15}{373.15 - 273.15} = \frac{T_F - 32}{212 - 32}$

$\frac{573.15 - 273.15}{100} = \frac{T_F - 32}{180}$

$\frac{573.15 - 273.15}{100} = \frac{T_F - 32}{180} = 392^0 F$

$T_F = 392^0$ F

12. An unknown thermometer x has a boiling point of 312° and an ice point of 112°. If a body temperature is found to be 28°c, what will be this value with temperature scale x ?

Solution:

$$\frac{T_C - 0}{100 - 0} = \frac{T_x - 112}{312 - 112}$$

$$\frac{T_C}{100} = \frac{T_x - 112}{200} = 168^0$$

$$T_X = 168^0$$

13. At what temperature will they read the same

a) .°C and °F

b) .°C and

c) .°F and

Solution:

a) $\frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32}$

let $T_C = T_F = T$

$\frac{T}{100} = \frac{T - 32}{180} = -40^0$

$T_C = T_F$ at -40^0

b) $\frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$

let $T_F = T_K = T$

$T = 574.6^{o}$

c) $\frac{T_C - 0}{100 - 0} = \frac{T_K - 273.15}{373.15 - 273.15}$

let $T_C = T_K = T$

$\frac{T}{100} = \frac{T - 273.15}{100}$

They never read the same

14. A sample of gas cools from -120°c to -180°c. What is the change in temperature in

a) Kelvin scale

b) Fahrenheit scale

Solution:

a) $\frac{T_{C1} - 0}{100 - 0} = \frac{T_{K1} - 273.15}{373.15 - 273.15}$

$\frac{-120 - 0}{100} = \frac{T_{K1} - 273.15}{100}$

$T_{K1} = 153.15K$

$\frac{T_{C2} - 0}{100 - 0} = \frac{T_{K2} - 273.15}{373.15 - 273.15}$

$\frac{-180}{100} = \frac{T_{K2} - 273.15}{100}$

$T_{K2} = 93.15K$

$\Delta T_K = T_{K2} - T_{K1} = 93.15 - 153.15 = -60K$

b) $\frac{T_{C1}-0}{100-0}=\frac{T_{F1}-32}{212-32}$

$\frac{-120}{100}=\frac{T_{F1}-32}{180}=-184^{o}F$

$T_{F1}=184^{0}F$

$\frac{T_{C2}-0}{100-0}=\frac{T_{F2}-32}{212-32}$

$\frac{-180}{100}=\frac{T_{F2}-32}{180}=-292^{o}F$

$T_{F2}=292^{0}\ F$

$\Delta T_K=T_{F2}-T_{F1}=-292-(-184)=-108^{o}F$

15. If the change in temperature is found to be 25°c, what will be this value in

a) K

b) .°F

Solution:

a) $\frac{T_{C1}-0}{100-0}=\frac{T_{K1}-273.15}{373.15-273.15}$

$\frac{T_{C1}}{100}=\frac{T_{K1}-273.15}{100}$

$T_{C1}=T_{K1}-273.15$

$\frac{T_{C2}-0}{100-0}=\frac{T_{K2}-273.15}{373.15-273.15}$

$T_{C2}=T_{K2}-273.15$

$\Delta T_C=T_{C2}-T_{C1}=25^{o}C$

$\Delta T_K=T_{K2}-T_{K1}=25K$

b) $$\frac{T_{C1}-0}{100-0}=\frac{T_{F1}-32}{212-32}$$

$$\frac{T_{C1}}{100}=\frac{T_{F1}-32}{180}$$

$$T_{C1}=\frac{5}{9}(T_{F1}-32)$$

$$T_{C2}=\frac{5}{9}(T_{F2}-32)$$

$$\Delta T_C = T_{C2}-T_{C1}=\frac{5}{9}[(T_{F2}-32)-(T_{F1}-32)]$$

$$25=\frac{5}{9}\Delta T_F$$

$$\Delta T_F = 45^0F$$

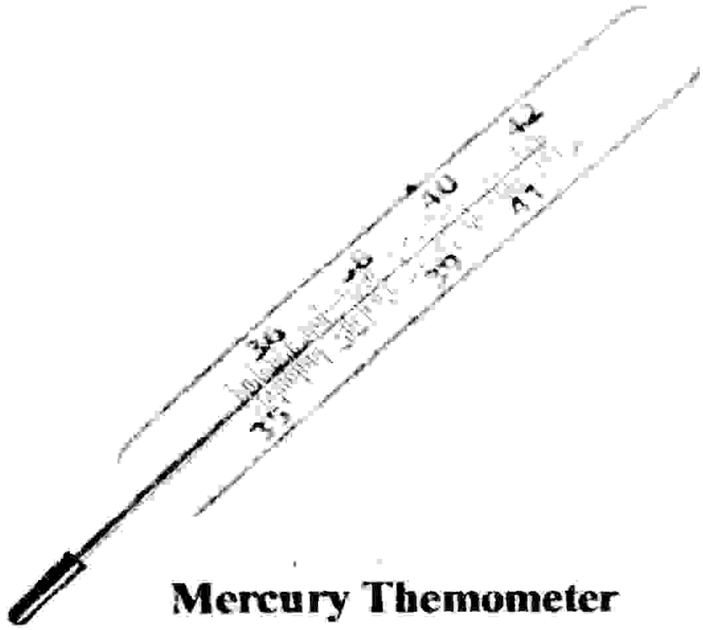
✓ The change in temperature in the Celsius scale is the same as the change in temperature of the Kelvin scale.

7.3 What are the Types of Thermometers?

For their operation, most thermometers make use of a change in physical property with a change in temperature. For example, the thermometric property of mercury thermometer is the length of mercury column and that of a constant volume gas thermometer is the pressure of the gas. Now, let us be familiar with some of the thermometer types.

Mercury Thermometer

Is a tube filled with mercury and a standard temperature scale is marked on it. With a change in temperature, the mercury expands and contacts, so that the temperature of a body can be read from the scale.

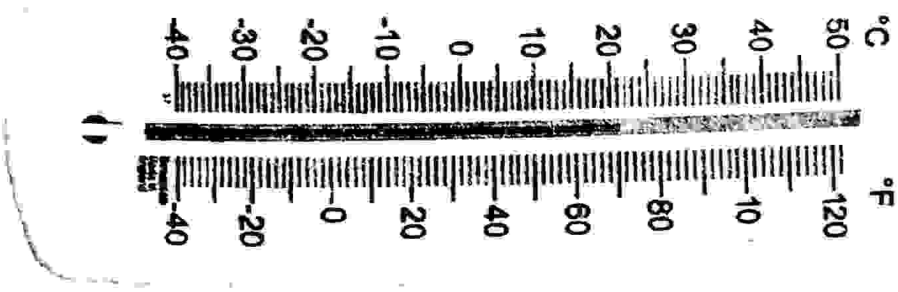


Mercury Themometer

✓ It is used to measure temperature between -30°c and 300°c.

Alcohol Thermometer

Makes use of the expansion and contraction of alcohol such as ethanol in response to a change in temperature.

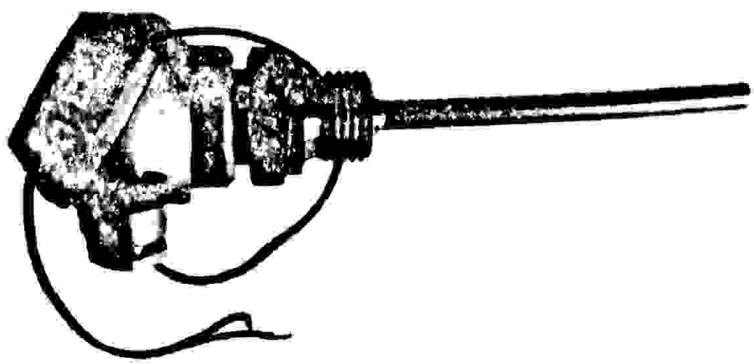


Alcohol Thermomete

✓ It is used to measure temperature between -115°c and 78.15°c

Resistance Thermometer

It uses the change in resistance of materials such as platinum to measure temperature of a body.

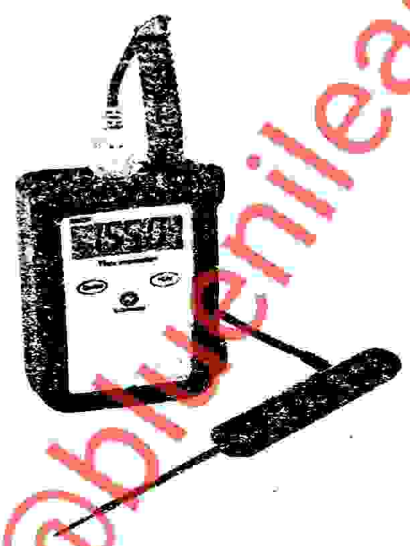


✓ It is used to measure temperature between -270°c and 700°c

Thermocouple Thermometer

It consists of thin wires of different metals usually copper and, a copper-nickel alloy welded together to form two junctions.

One of the junction, called the "*hot*" junction is placed in contact with the body whose temperature is to be measured while the other junction, called the "*reference*" junction is kept at a known temperature, usually an ice-water mixture at 0°c.



✓ It is used in scientific laboratories to measuring temperature as high as 2300°c and as low as -270°c

Thermistor Thermometer

It uses the change in resistance of metallic oxide when temperature changes. It is of two types: negative temperature coefficient, with low resistance at high temperature and positive temperature coefficient, with high resistance at high temperature.

It has precision with in a temperature range of 50°c.

Radiation Thermometer

It uses electromagnetic radiation of a body whose temperature is to be measured

✓ It is used in hospitals and in glass and electrical industries to check the temperature of components of a motor or machine.

Illustrative Examples

Match the items in column 'A' with those in column 'B'

Column A	Column B
16. Mercury Thermometer	a) Andres Celsius
17. Alcohol Thermometer	b) Daniel Fahrenheit
18. Resistance Thermometer	c) Lord Kelvin
19. Thermocouple Thermometer	d) -30°C to 300°C
20. °C	e) -115°C to 78.15°C
21. °F	f) -270°C to 700°C
22. K	g) -270°C to 2300°C
	h) -295°C to 10,00°C

Answers

16.d 17.e 18.f 19g 20.a 21.b 22.c

7.4 Thermal Expansion of Materials

Most materials expand when heated and contract when cooled.

Conceptual Examples

23. Why do materials expand or contract when the temperature changes? Explain.

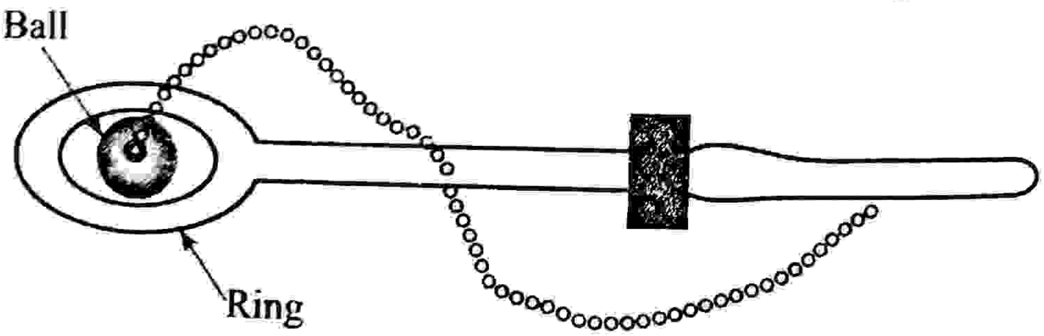
Explanation:

Because, when heated, the particles of the body gain more energy and move further apart from each other and when cooled, the particles lose energy and come closer together, in this manner, expansion and contraction of materials take place.

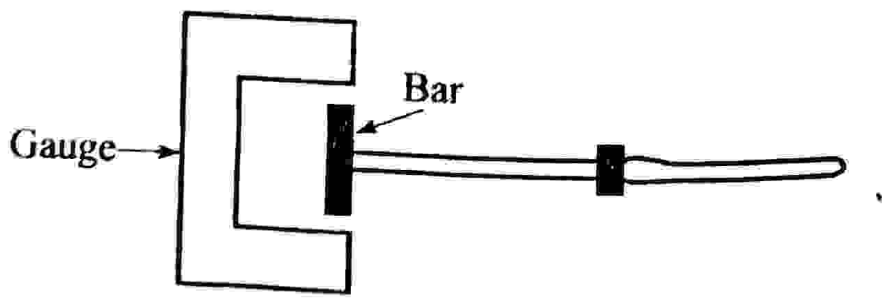
Thermal Expansion: Is the increase in size of a body when heated.

When a body is heated, its particles move further apart and its size increases.

The ball and ring experiment is a good demonstration of expansion of a material. The cold metal ball easily pass through the ring. After heating, the ball expands and it is no longer able to pass through the ring.



In the same manner, the metal bar will just fit into the gap in the gauge when both the bar and the gauge are cold



In general, when a material is heated, its expansion can be one dimensional -linear, two dimensional - area or three dimensional-volume. In this level however, we will only describe linear expansion.

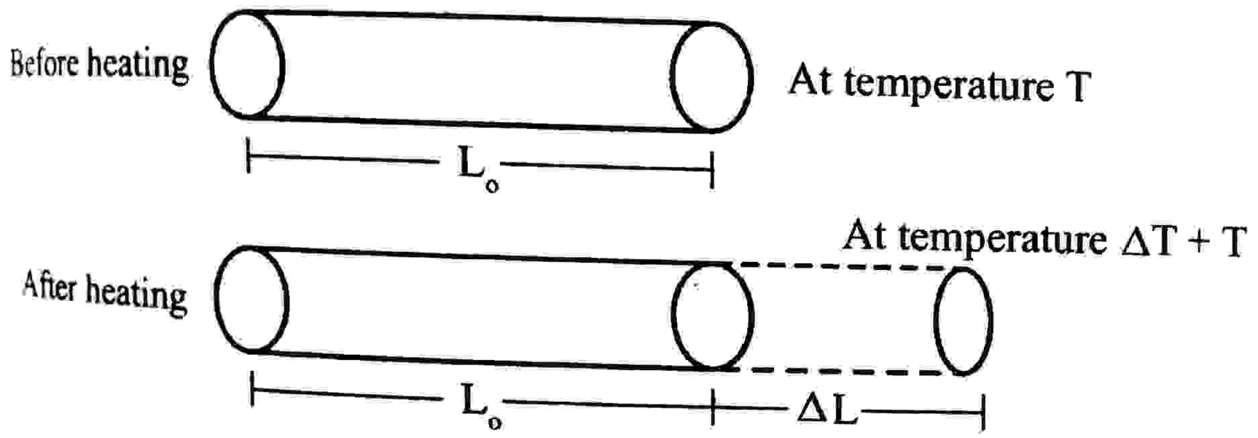
Linear Expansion of Materials

When a metal rod is heated , it expands and increase in length. This type of expansion. is called *linear expansion.*

Linear Expansion: Is the increase in length of a rod due to heating.

The expansion, that is the increment or the change in length, ΔL of a rod of initial length L_0 at a temperature of T is found to be directly proportional to the original length and the change in temperature, ΔT.

That is, if we have;



Then, it is observed experimentally that:

$\Delta L \sim L_0$, and $\Delta L \sim \Delta T$

Hence, $\Delta L \sim L_0 \Delta T$

$$\boxed{\Delta L = \alpha L_0 \Delta T}$$

Where: α(alpha) is called coefficient of linear expansion and its unit is per Kelvin(K^{-1}) or per Celsius($^oC^{-1}$)

The total length of the rod after heating is obtained by,

$$L = L_0 + \Delta L$$
$$= L_0 + \alpha L_0 \Delta T$$
$$L = L_0[1 + \alpha\Delta T]$$

✓ Different materials expand or contract at different rates and hence they have different coefficients of thermal expansion.

The coefficient of linear expansion of some solids is given below.

Material	Coefficient of Linear expansion($^{o}C^{-1}$)
Aluminium	2.6×10^{-5}
Brass	1.9×10
Concrete	1.2×10^{-5}
Copper	1.7×10^{-5}
Common	8.3×10^{-5}
Glass	3.3×10^{-5}
Pyrex Glass	1.4×10^{-5}
Gold	1.2×10^{-5}
Iron or Steel	2.9×10^{-5}
Lead	1.3×10^{-5}
Nickel	0.5×10^{-5}
Quartz	1.9×10^{-5}
Silver	

Conceptual Examples

24. The coefficient of linear expansion of steel is found to be $1.2 \times 10^{-5}\,^{o}C^{-1}$. What does this mean?

Explanation:

It means that, a 1m steel rod will expand or increase by 1.2×10^{-5}m for every $1^{o}C$ rise in temperature.

Illustrative Examples

25. A Gold rod of length 0.5m at a temperature of $30^{o}C$ is heated to a temperature of $50^{o}C$. What will be the change in length after the process

Solution:

$$\Delta L = \alpha L_0 \Delta T = \left(1.4\times10^{-5}\right)(0.5)(50-30)$$

$$\Delta L = 1.4\times10^{-4}\,m$$

26. A steel rod has a length of 200cm at a temperature of $20^{o}C$. What will

be the total length of the rod at 120°C?

Solution:

$$L = L_o[1+\alpha\Delta T]$$

$$= 2[1+(1.2\times10^{-5})(120-20)]$$

$$L = 2.00\ 24m$$

27. What change in temperature is needed so as to let a 1.5 long silver rod to increase by 10cm?

Solution:

$$\Delta L = \alpha L_o \Delta T \Rightarrow \Delta T = \frac{\Delta L}{\Delta L_o} = \frac{0.1}{(1.9\times10^{-5})(1.5)} = \frac{10000}{285}$$

$$\Delta T = 35^0C$$

28. At what temperature will the increase in length of a 2m brass rod at 0°C become 5.7mm

Solution:

$$\Delta L = \alpha L_o \Delta T \Rightarrow \Delta T = \frac{\Delta L}{\alpha L_o} = \frac{5.7\times10^{-3}}{(1.9\times10^{-5})(2)} = 150$$

$$\Delta T = 150^0C$$

$$\Delta T = T_2 - T_1 = 150$$

$$T_2 - 0 = 150$$

$$T_2 = 150°C$$

Coefficient of linear expansion is α(alpha), coefficient of volume expansion is β(beta), β = 2α and the coefficient of volume expansion is γ(gamma), γ = 3α. So we have:

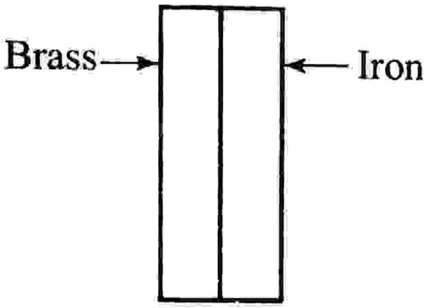
- ✓ Linear Expansion, $\Delta L = \alpha L_0 \Delta T$
- ✓ Area Expansion, $\Delta A = \beta A_0 \Delta T$
- ✓ Volume Expansion, $\Delta V = \gamma V_0 \Delta T$

The Bimetallic Strip

A bimetallic strip is a strip made of two metals welded together.

Bimetallic Strip: Is a strip made of two different metals bonded together along their length.

For example, if iron and brass are bonded together, since coefficient of linear expansion of iron $1.2 \times 10^{-5}\,^{\circ}C^{-1}$ is less than that of brass, $1.9 \times 10^{-5}\,^{\circ}C^{-1}$, when the strip is heated, the brass expands more than the iron and the strip bends.



A bimetallic Strip

Illustrative Example

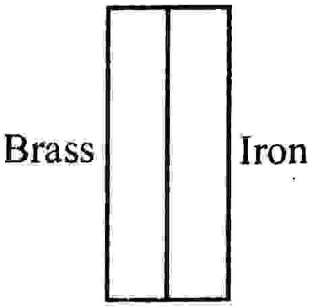
29. What will happen to a brass-iron bimetallic strip when it is

a) Heated

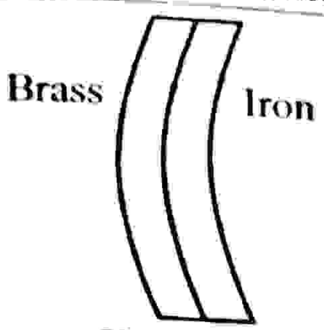
b) Cooled

Explanation:

The strip is linear at a room temperature

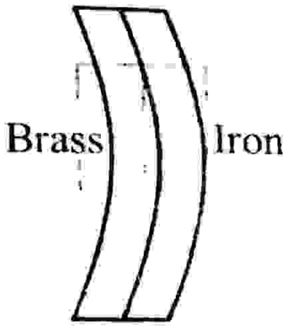


a) When heated, the brass expands more than the iron since it has greater coefficient of thermal expansion and the strip bends towards the iron.



Heated Strip

b) When cooled, the strip bends towards the brass as shown



Cooled Strip

Additional Examples

30. A change in temperature of 25°C is equivalent to

A) 45°F B) 72°F C) 32°F D) 25°F

Solution:

$$\Delta T_F = \frac{9}{5}\Delta T_C = \frac{9}{5}(25) = 45^{\circ}F$$

Answer: A

31. The normal temperature of a human body is x degrees above absolute zero. What is the value of x?

A) 100 B) 200 C) 310 D) 340

Solution:

$T_C = 37^{\circ}C$, and $T_K = T_C + 273$

$T_K = 37 + 273$

$T_K = 310K$

Answer: C

32. The upper and lower fixed points of a faulty thermometer are 5°C and

105°C. If this thermometer reads 25°C, What is the actual temperature?

A) 15°C B) 30°C C) 20°C D) 35°C

Solution:

$$\frac{25-5}{105-5}=\frac{x-0}{100-0}\Rightarrow x=20^{0}C$$

Answer: C

33. At what temperature is the Fahrenheit scale reading equal to twice the Celsius scale reading?

A) 160°C B) 320°C C) 175°C D) 273°C

Solution:

$$\frac{T_F-32}{180}=\frac{T_C}{100}, \text{Now } T_F=2T_C$$

$$\frac{2T_C-32}{180}=\frac{T_C}{100}$$

$$T_C=160^{0}C$$

Answer: A

34. Which of the following temperatures is highest?

A) 100 B) -13°F C) -20°C D) -28°C

Solution:

-13°F=25°c, and 100k = -173°C

Answer: C

35. Two thermometer, one Celsius and the other of Fahrenheit scale are kept in a bath. If the Fahrenheit reads twice that of Celsius, what is temperature of the bath?

A) 80°C B) 80°F C) 32°C D) 12°C

Solution:

$$\frac{T_F-32}{180}=\frac{T_C}{100}, \text{Now } T_F=3T_C\Rightarrow T_C=\frac{T_F}{3}$$

$$\frac{T_F-32}{180}=\frac{T_F}{300}$$

$$T_F=80^{0}F$$

Answer: B

In a hypothetical scale x, the ice point is 40° and the steam point is 120°. For another scale Y, the ice point and the steam point are -30° and 130° respectively. If x reads 50°, then Y would read?

A) -5 B) -10° C) -80° D) 12

Solution:

$$\frac{50-40}{120-40}=\frac{y-(-30)}{130-(-30)} \Rightarrow y=-10^0$$

Answer: B

When a Celsius thermometer reads 90°C, a Fahrenheit scale will read?

A) 124°F B) 164°F C) 120°F D) 194°F

Solution:

$$\frac{T_F-32}{180}=\frac{90-0}{100-0} \Rightarrow 194^\circ F$$

Answer: D

What is the ratio of the coefficient of linear expansion to the coefficient of volume expansion?

A) 1:2 B) 1:4 C) 1:3 D) 1:2

Solution:

$$\frac{\alpha}{\gamma}=\frac{\alpha}{3\alpha}=\frac{1}{3}=1:3$$

Answer: C

... iron and zinc are riveted together to form a bimetallic ... when heated. The iron is on the inside of the bend ...

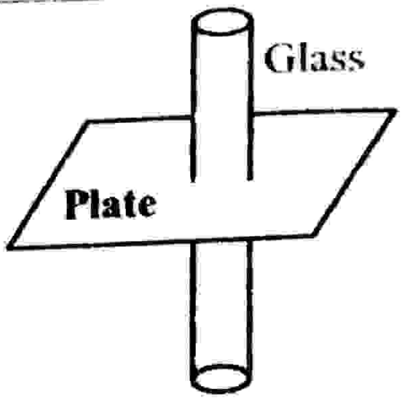
... heat ... Lower coefficient of expansion

... specific heat D) Higher coefficient of exp...

... $\times 10^{-6}$/°C and ...

Answ...

... rod, α = 0.9 × 10^{-5}/°C is fitted into a hole of the same ... plate, α=1.7 × 10^{-5}/°C. What will happen when the sy... is ...



A) The plate will drop

B) The glass will crack

C) The plate will fold

D) There will be no change

Hint: Since $\alpha_{Cooper} > \alpha_{Glass}$ it expands more. **Answer: A**

41. A steel beam is 25m long in winter at 0^oC. How much will the length change in summer at 30^oC? ($\alpha_{Steel} = 1.2 \times 10^{-5}/^oC$)

A) 6mm B) 9mm C) 25mm D) 5mm

Solution:

$$\Delta L = \alpha L_0 \Delta T = (1.2 \times 10^{-5})(25)(30-0)$$

$$\Delta L = 0.009m = 9mm$$

Answer: B

End of Unit Questions and Problems

I. Give Short Answer to the Following Questions.

1. What is Temperature?
2. What is the SI unit of temperature?
3. The instrument used to measure temperature is known as____
4. What is Greenhouse effect?
5. What is Global warming?
6. What the most common temperature scale?
7. [illegible] types of thermometers
8. What is the room temperature in Celsius
9. What is the average normal human body temperature in

   A) Celsius

   B) Fahrenheit

C) Kelvin Scale

10. What are the lower and upper fixed points represent in a thermometer scale.

11. What are the lower and upper fixed points of water in

A) Celsius

B) Fahrenheit

C) Kelvin Scale

12. What is the lowest possible temperature in nature?

13. What is thermal expansion?

14. What is the coefficient of linear expansion of materials?

15. Absolute zero is equivalent to _____ degree Celsius.

II. Solve the Following Problems

16. If the surrounding temperature is $82^{O}F$, What is its value in

A) Celsius

B) Kelvin

17. At what temperature will the Fahrenheit and Celsius scales read the same?

18. What is the temperature in Celsius if it is zero in Fahrenheit scale?

19. If the temperature of an object is 310k, what is this temperature in

A) Celsius

B) Fahrenheit

20. The ice and the steam pints of a thermometer are found to be 25^{o} and 125^{o} respectively. What will this thermometer read if a body temperature is $62^{o}C$?

21. What is the increase in length of a 2m copper rod that is heated from $20^{o}C$ to $140^{o}C$?

22. What empty space is needed to protect a 3m long concerte from $25^{O}C$ to $38^{o}C$?

23. Which one is largest? $1^{O}C$ or $1^{O}F$ or 1K justify your answer.

I. Short Answers and Explanations

1. Temperature is the measure of average Kinetic energy of particle of a body
2. Kelvin
3. Thermometer
4. It is the warming of the earth by the green house gases that have trapped sun's thermal energy.
5. It is the increases in temperature over all the world.
6. Celsius, Fahrenheit and Kelvin
7. Mercury, Alcohol, Resistance, Thermocouple, Thermistor, Radiant Thermometers
8. It is in the range 18°C and 22°C
9. A) 37°C

   B) 99°C

   C) 310°C
10. Lower fixed point represents the freezing, melting or ice point of water while the upper fixed point represents the boiling or steam point of water.
11.

Scale	LFP	UFP
°C	0	100
°F	32	212
K	273.15	373.15

12. It is the absolute zero. Zero Kelvin, Ok!
13. It is the increases in size of body up on heating.
14. It is the increases in length of a 1m rod of a given substance when its temperature increase by 1k.
15. Ok = -273.15°C

11. Solution to the End of Unit Problems

16. A) $\frac{T_C}{100} = \frac{82-32}{180} \Rightarrow \frac{T_C}{5} = \frac{50}{9} = 55.5^oC$

B) $\frac{T_K - 273.15}{100} = \frac{82-32}{180} \Rightarrow \frac{T_K - 273.15}{5} = \frac{50}{9}$

$T_K = 328.65K$

17. $\frac{T_C}{100} = \frac{T_F - 32}{180}$, let $T_C = T_F = T$

$\frac{T}{5} = \frac{T-32}{9} \Rightarrow T = -40^oC$

18. $\frac{T_C}{100} = \frac{T_F - 32}{180}$

$\frac{T_C}{5} = \frac{0-32}{9} \Rightarrow T_C = -15.5^oC$

19. A) $\frac{T_C}{100} = \frac{310-273}{100} \Rightarrow T_C = 37^oC$

B) $\frac{T_F - 32}{180} = \frac{310-273}{100} \Rightarrow T_F = 99^oF$

20. $\frac{62}{100} = \frac{T_x - 25}{100} \Rightarrow T_x = 87^o$

21. $\Delta L = \alpha L_o \Delta T = (1.7 \times 10^{-5})(2)(140 - 20) = 4.08 \times 10^{-3}m = 4.08mm$

22. $\Delta L = \alpha L_o \Delta T = (1.2 \times 10^{-5})(3)(38 - 25) = 0.00047m = 0.47mm$

23. $1^oF = -17.2^oC$ and $1k = -272.15^oC$, Therefore: 1^oC is the largest