Unit 5: Heat Conduction and Calorimetry
Grade 11 Physics - Advanced Workbook

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Contents

Unit 5: Heat Conduction and Calorimetry Workbook

5.1 The Concept of Heat Workbook

Multiple Choice Questions

1. Which of the following best defines heat in physics?

   (A) The degree of hotness or coldness of a body.
   (B) The total kinetic energy of molecules in a substance.
   (C) Energy in transit due to a temperature difference.
   (D) A property possessed by an object.

   Answer: (C) Explanation: Heat is specifically defined as energy transferred from a hotter object to a colder object due to their temperature difference. Temperature (A) is a measure of average kinetic energy. Internal energy (related to B) is the total energy within a substance. Heat is not a property possessed by an object (D) but rather energy in transfer.

2. Internal energy of a substance is the sum of:

   (A) Only the kinetic energy of its molecules.
   (B) Only the potential energy of its molecules.
   (C) Kinetic and potential energies of its molecules.
   (D) Heat and work done on the substance.

   Answer: (C) Explanation: Internal energy encompasses all forms of energy within the substance at the molecular level, including kinetic energy (translational, rotational, vibrational) and potential energy (due to intermolecular forces). Heat and work (D) are ways to change internal energy, not components of it.

3. Thermodynamic work is defined as:

   (A) The heat supplied to a system.
   (B) The quantity of energy transferred from one system to another, not due to temperature difference.
   (C) The change in internal energy of a system.
   (D) The random motion of molecules.

   Answer: (B) Explanation: Thermodynamic work is energy transfer that is not heat (i.e., not due to temperature difference). This often involves a force acting over a distance, like a piston moving.

Short Answer Questions

1. Explain the difference between heat and temperature.

2. Describe a scenario where work is done on a system, leading to an increase in its internal energy without heat transfer.

Workout Problems

1. A gas in a cylinder does 200 J of work by expanding against a piston. Simultaneously, 50 J of heat is lost to the surroundings. What is the change in the internal energy of the gas? **Solution:**
   Given: Work done by the gas, $W = +200\,\text{J}$ (positive as work is done *by* the system). Heat lost by the gas, $Q = -50\,\text{J}$ (negative as heat is lost *by* the system).
   Find: Change in internal energy, ΔU.
   Formula: First Law of Thermodynamics: $\Delta U = Q - W$.
   Calculation:
   $$\Delta U = (-50\,\text{J}) - (+200\,\text{J})$$
   $$\Delta U = -50\,\text{J} - 200\,\text{J}$$
   $$\Delta U = -250\,\text{J}$$
   Answer: The change in internal energy of the gas is $-250\,\text{J}$ (it decreases).

5.2 Heat transfer mechanisms Workbook

Multiple Choice Questions

1. The transfer of heat through direct contact between particles of a substance is called:
   (A) Conduction
   (B) Convection
   (C) Radiation
   (D) Advection

   Answer: (A) Explanation: Conduction is the mode of heat transfer where thermal energy is passed from one particle to an adjacent particle through collisions, primarily in solids.

2. Which of the following is the primary mode of heat transfer in fluids (liquids and gases) involving bulk movement of the fluid?
   (A) Conduction
   (B) Convection
   (C) Radiation
   (D) Insulation

   Answer: (B) Explanation: Convection involves the movement of the heated fluid itself, carrying thermal energy from one place to another. Hotter, less dense fluid rises, and cooler, denser fluid sinks, creating convection currents.

3. Heat from the Sun reaches the Earth primarily through:
   (A) Conduction
   (B) Convection
   (C) Radiation

(D) Evaporation

Answer: (C) Explanation: Radiation is the transfer of heat through electromagnetic waves, which can travel through the vacuum of space. This is how the Sun's energy reaches Earth.

Short Answer Questions

1. Why are metals generally good conductors of heat, while materials like wood or plastic are poor conductors (insulators)?
2. Explain how a sea breeze and a land breeze are formed, relating them to convection.
3. Why does wearing dark-colored clothes make you feel warmer on a sunny day compared to light-colored clothes?

5.3 Heat Capacity and Specific Heat Capacity Workbook

Multiple Choice Questions

1. The amount of heat required to raise the temperature of an entire object by 1 °C (or 1 K) is known as:

   (A) Specific heat capacity
   (B) Latent heat
   (C) Heat capacity
   (D) Thermal conductivity

   Answer: (C) Explanation: Heat capacity (C) is a property of an object and depends on its mass and the material it's made of. It's defined as $C = Q/\Delta T$.

2. The specific heat capacity of a substance is defined as the amount of heat required to:

   (A) Raise the temperature of the entire substance by 1 °C.
   (B) Change the phase of 1 kg of the substance.
   (C) Raise the temperature of 1 kg of the substance by 1 °C.
   (D) Melt 1 kg of the substance without a temperature change.

   Answer: (C) Explanation: Specific heat capacity (c) is an intrinsic property of a material, defined as $c = Q/(m\Delta T)$.

3. If substance A has a higher specific heat capacity than substance B, and equal masses of both are supplied with the same amount of heat, then:

   (A) Substance A will have a greater temperature rise.
   (B) Substance B will have a greater temperature rise.
   (C) Both substances will have the same temperature rise.
   (D) The temperature rise depends on their initial temperatures.

   Answer: (B) Explanation: Since $Q = mc\Delta T$, for the same Q and m, if c is higher, ΔT must be smaller. Thus, substance B (with lower c) will experience a greater temperature rise.

Short Answer Questions

1. Explain why water is often used as a coolant in car engines and industrial processes. Refer to its specific heat capacity.

2. Two objects, X and Y, have the same mass. Object X has a heat capacity of $200\,\mathrm{J\,K^{-1}}$ and object Y has a heat capacity of $400\,\mathrm{J\,K^{-1}}$. Which object is made of a material with a higher specific heat capacity? Explain.

Workout Problems

1. How much heat energy is required to raise the temperature of 0.5 kg of water from 20 °C to 80 °C? (Specific heat capacity of water = $4186\,\mathrm{J\,kg^{-1}\,^\circ C^{-1}}$) **Solution:**
   Given: Mass, $m = 0.5\,\mathrm{kg}$. Initial temperature, $T_i = 20\,^\circ\mathrm{C}$. Final temperature, $T_f = 80\,^\circ\mathrm{C}$. Specific heat capacity of water, $c = 4186\,\mathrm{J\,kg^{-1}\,^\circ C^{-1}}$.
   Find: Heat energy, Q.
   Formula: $Q = mc\Delta T = mc(T_f - T_i)$.
   Calculation:

$$\Delta T = 80\,^\circ\mathrm{C} - 20\,^\circ\mathrm{C} = 60\,^\circ\mathrm{C}$$

$$Q = (0.5\,\mathrm{kg}) \times (4186\,\mathrm{J\,kg^{-1}\,^\circ C^{-1}}) \times (60\,^\circ\mathrm{C})$$

$$Q = 125\,580\,\mathrm{J}$$

   Answer: The heat energy required is 125 580 J or 125.58 kJ.

2. A 200 g block of an unknown metal at 100 °C is placed in 100 g of water at 20 °C. The final equilibrium temperature is 25 °C. If the specific heat capacity of water is $4.2\,\mathrm{J\,g^{-1}\,^\circ C^{-1}}$, what is the specific heat capacity of the metal? (Assume no heat loss to surroundings). **Solution:**
   Given: Mass of metal, $m_m = 200\,\mathrm{g}$. Initial temp of metal, $T_{im} = 100\,^\circ\mathrm{C}$. Mass of water, $m_w = 100\,\mathrm{g}$. Initial temp of water, $T_{iw} = 20\,^\circ\mathrm{C}$. Final equilibrium temperature, $T_f = 25\,^\circ\mathrm{C}$. Specific heat of water, $c_w = 4.2\,\mathrm{J\,g^{-1}\,^\circ C^{-1}}$.
   Find: Specific heat capacity of metal, c_m.
   Formula: Heat lost by metal = Heat gained by water.

$$m_m c_m (T_{im} - T_f) = m_w c_w (T_f - T_{iw})$$

   Calculation:

$$(200\,\mathrm{g}) \times c_m \times (100\,^\circ\mathrm{C} - 25\,^\circ\mathrm{C}) = (100\,\mathrm{g}) \times (4.2\,\mathrm{J\,g^{-1}\,^\circ C^{-1}}) \times (25\,^\circ\mathrm{C} - 20\,^\circ\mathrm{C})$$

$$200\,\mathrm{g} \times c_m \times 75\,^\circ\mathrm{C} = 100\,\mathrm{g} \times 4.2\,\mathrm{J\,g^{-1}\,^\circ C^{-1}} \times 5\,^\circ\mathrm{C}$$

$$15\,000\,\mathrm{g\,^\circ C} \times c_m = 2100\,\mathrm{J}$$

$$c_m = \frac{2100\,\mathrm{J}}{15\,000\,\mathrm{g\,^\circ C}}$$

$$c_m = 0.14\,\mathrm{J\,g^{-1}\,^\circ C^{-1}}$$

   Answer: The specific heat capacity of the metal is $0.14\,\mathrm{J\,g^{-1}\,^\circ C^{-1}}$.

5.4 Thermal expansion Workbook

Multiple Choice Questions

1. Thermal expansion refers to the tendency of matter to:

   (A) Change its chemical composition with temperature.

   (B) Change its volume (or length/area) in response to a temperature change.

   (C) Become a better conductor of heat at higher temperatures.

   (D) Absorb heat without a change in temperature.

   Answer: (B) Explanation: Thermal expansion is the physical change in size (length, area, or volume) of a material when its temperature changes.

2. The coefficient of linear expansion (α) depends on:

   (A) The initial length of the material only.

   (B) The change in temperature only.

   (C) The nature of the material.

   (D) Both the initial length and the change in temperature.

   Answer: (C) Explanation: The coefficient of linear expansion is an intrinsic property of the material itself, indicating how much it expands per unit length per degree Celsius (or Kelvin) temperature rise.

3. If a metal ring is heated, its inner diameter will:

   (A) Increase

   (B) Decrease

   (C) Remain the same

   (D) Depend on the thickness of the ring

   Answer: (A) Explanation: When a material with a hole in it expands, the hole also expands as if it were made of the same material. This is because all linear dimensions of the material increase.

Short Answer Questions

1. Why are gaps left between sections of railway tracks or concrete slabs in pavements?

2. Explain the principle behind a bimetallic strip and give one application.

3. Describe the anomalous expansion of water and its significance for aquatic life in cold climates.

Workout Problems

1. A steel rod is 2.0 m long at 20 °C. If the coefficient of linear expansion for steel is $1.2 \times 10^{-5}\,°C^{-1}$, what is its length at 120 °C? **Solution:**
   Given: Initial length, $L_0 = 2.0\,\text{m}$. Initial temperature, $T_0 = 20\,°C$. Final temperature, $T_f = 120\,°C$. Coefficient of linear expansion, $\alpha = 1.2 \times 10^{-5}\,°C^{-1}$.
   Find: Final length, L_f.
   Formula: $\Delta L = \alpha L_0 \Delta T$ and $L_f = L_0 + \Delta L = L_0(1 + \alpha \Delta T)$.
   Calculation:
   $$\Delta T = T_f - T_0 = 120\,°C - 20\,°C = 100\,°C$$
   $$\Delta L = (1.2 \times 10^{-5}\,°C^{-1}) \times (2.0\,\text{m}) \times (100\,°C)$$
   $$\Delta L = 0.0024\,\text{m}$$
   $$L_f = L_0 + \Delta L = 2.0\,\text{m} + 0.0024\,\text{m} = 2.0024\,\text{m}$$
   Answer: The final length of the steel rod is 2.0024 m.

2. A brass plate has an area of $0.5\,\text{m}^2$ at 10 °C. If the coefficient of linear expansion for brass is $1.9 \times 10^{-5}\,°C^{-1}$, what is its area at 90 °C? (Assume coefficient of area expansion $\beta \approx 2\alpha$). **Solution:**
   Given: Initial area, $A_0 = 0.5\,\text{m}^2$. Initial temperature, $T_0 = 10\,°C$. Final temperature, $T_f = 90\,°C$. Coefficient of linear expansion, $\alpha = 1.9 \times 10^{-5}\,°C^{-1}$.
   Find: Final area, A_f.
   Formula: $\beta \approx 2\alpha$. $\Delta A = \beta A_0 \Delta T$ and $A_f = A_0 + \Delta A = A_0(1 + \beta \Delta T)$.
   Calculation:
   $$\beta = 2 \times 1.9 \times 10^{-5}\,°C^{-1} = 3.8 \times 10^{-5}\,°C^{-1}$$
   $$\Delta T = T_f - T_0 = 90\,°C - 10\,°C = 80\,°C$$
   $$\Delta A = (3.8 \times 10^{-5}\,°C^{-1}) \times (0.5\,\text{m}^2) \times (80\,°C)$$
   $$\Delta A = 0.001\,52\,\text{m}^2$$
   $$A_f = A_0 + \Delta A = 0.5\,\text{m}^2 + 0.001\,52\,\text{m}^2 = 0.501\,52\,\text{m}^2$$
   Answer: The final area of the brass plate is $0.501\,52\,\text{m}^2$.

5.5 Change of phase Workbook

Multiple Choice Questions

1. The energy absorbed or released during a phase change at constant temperature is called:
   (A) Specific heat
   (B) Latent heat
   (C) Heat capacity
   (D) Thermal energy

   Answer: (B) Explanation: Latent heat is the energy associated with a phase transition (e.g., melting, boiling) that occurs without a change in temperature.

2. The process of a solid changing directly into a gas without passing through the liquid phase is called:
   (A) Condensation
   (B) Evaporation
   (C) Sublimation
   (D) Fusion

   Answer: (C) Explanation: Sublimation is the direct transition from solid to gas (e.g., dry ice).

3. At the triple point on a phase diagram:
   (A) Only the solid phase can exist.
   (B) Only the liquid phase can exist.
   (C) Only the gas phase can exist.
   (D) Solid, liquid, and gas phases can coexist in equilibrium.

   Answer: (D) Explanation: The triple point is a unique combination of temperature and pressure where all three phases (solid, liquid, gas) of a substance can exist in thermodynamic equilibrium.

Short Answer Questions

1. Explain why sweating cools the body, referring to latent heat.
2. What is the difference between latent heat of fusion and latent heat of vaporization?
3. Sketch a typical heating curve for water, starting from ice below $0\,^\circ\mathrm{C}$ to steam above $100\,^\circ\mathrm{C}$. Label all phase changes and segments where temperature increases.

Workout Problems

1. How much heat is required to melt 0.2 kg of ice at $0\,^\circ\mathrm{C}$? (Latent heat of fusion for ice $= 3.34 \times 10^5\,\mathrm{J\,kg^{-1}}$) **Solution:**
   Given: Mass of ice, $m = 0.2\,\mathrm{kg}$. Latent heat of fusion, $L_f = 3.34 \times 10^5\,\mathrm{J\,kg^{-1}}$.
   Find: Heat required, Q.
   Formula: $Q = mL_f$.
   Calculation:
   $$Q = (0.2\,\mathrm{kg}) \times (3.34 \times 10^5\,\mathrm{J\,kg^{-1}})$$
   $$Q = 66\,800\,\mathrm{J}$$
   Answer: The heat required to melt the ice is 66 800 J.

2. How much heat is released when 50 g of steam at $100\,^\circ\mathrm{C}$ condenses to water at $100\,^\circ\mathrm{C}$? (Latent heat of vaporization for water $= 2.26 \times 10^6\,\mathrm{J\,kg^{-1}}$) **Solution:**
   Given: Mass of steam, $m = 50\,\mathrm{g} = 0.05\,\mathrm{kg}$. Latent heat of vaporization, $L_v = 2.26 \times 10^6\,\mathrm{J\,kg^{-1}}$.
   Find: Heat released, Q.

Formula: $Q = mL_v$.
Calculation:

$$Q = (0.05\,\text{kg}) \times (2.26 \times 10^6\,\text{J}\,\text{kg}^{-1})$$
$$Q = 113\,000\,\text{J}$$

Answer: The heat released during condensation is 113 000 J.

5.6 Calorimetry Workbook

Multiple Choice Questions

1. Calorimetry is primarily concerned with the measurement of:

   (A) Temperature changes
   (B) Heat exchanged
   (C) Specific heat capacity only
   (D) Latent heat only

   Answer: (B) Explanation: Calorimetry is the science of measuring heat changes in chemical or physical processes.

2. The principle of mixtures states that in an isolated system:

   (A) Heat gained by the cold body equals heat lost by the hot body.
   (B) The final temperature is always the average of the initial temperatures.
   (C) All substances reach 0 °C.
   (D) Heat is always converted into work.

   Answer: (A) Explanation: This is the fundamental principle of calorimetry for an isolated system where no heat is exchanged with the surroundings: Heat lost = Heat gained.

3. When using an electrical heater to determine the specific heat capacity of a liquid, the energy supplied by the heater is usually calculated as:

   (A) $E = mc\Delta T$
   (B) $E = mL$
   (C) $E = P \times t$ (Power × time)
   (D) $E = V \times I$ (Voltage × Current)

   Answer: (C) Explanation: The electrical energy supplied by a heater is the product of its power (P) and the time (t) for which it operates. $E = P \times t$. $E = VIt$ is also correct if P is substituted by VI.

Short Answer Questions

1. Why is a calorimeter usually made of a good conductor (like copper or aluminum) and often has a stirrer?

2. What are some potential sources of error when performing a calorimetry experiment using the method of mixtures?

Workout Problems

1. 100 g of water at 80 °C is mixed with 200 g of water at 10 °C in a calorimeter. What is the final equilibrium temperature of the mixture? (Assume no heat loss and neglect the heat capacity of the calorimeter. Specific heat of water = $4.2\,\text{J g}^{-1}\,°\text{C}^{-1}$). **Solution:**
Given: Hot water: $m_h = 100\,\text{g}$, $T_h = 80\,°\text{C}$. Cold water: $m_c = 200\,\text{g}$, $T_c = 10\,°\text{C}$. Specific heat of water, $c_w = 4.2\,\text{J g}^{-1}\,°\text{C}^{-1}$.
Find: Final equilibrium temperature, T_f.
Formula: Heat lost by hot water = Heat gained by cold water.

$$m_h c_w (T_h - T_f) = m_c c_w (T_f - T_c)$$

Since c_w is the same for both, it cancels out:

$$m_h (T_h - T_f) = m_c (T_f - T_c)$$

Calculation:

$$100\,\text{g}(80\,°\text{C} - T_f) = 200\,\text{g}(T_f - 10\,°\text{C})$$

Divide by 100 g:

$$1(80\,°\text{C} - T_f) = 2(T_f - 10\,°\text{C})$$
$$80\,°\text{C} - T_f = 2T_f - 20\,°\text{C}$$
$$80\,°\text{C} + 20\,°\text{C} = 2T_f + T_f$$
$$100\,°\text{C} = 3T_f$$
$$T_f = \frac{100\,°\text{C}}{3} \approx 33.33\,°\text{C}$$

Answer: The final equilibrium temperature of the mixture is approximately 33.33 °C.

2. An electrical heater rated at 500 W is used to heat 1 kg of a liquid for 2 minutes. The temperature of the liquid rises from 20 °C to 50 °C. Calculate the specific heat capacity of the liquid, assuming no heat loss. **Solution:**
Given: Power of heater, $P = 500\,\text{W}$. Mass of liquid, $m = 1\,\text{kg}$. Time, $t = 2\,\text{minutes} = 2 \times 60 = 120\,\text{seconds}$. Initial temperature, $T_i = 20\,°\text{C}$. Final temperature, $T_f = 50\,°\text{C}$.
Find: Specific heat capacity of liquid, c.
Formula: Heat supplied by heater, $Q_{supplied} = P \times t$. Heat absorbed by liquid, $Q_{absorbed} = mc\Delta T$. Assuming no heat loss, $Q_{supplied} = Q_{absorbed}$.

$$P \times t = mc\Delta T$$

Calculation:

$$\Delta T = T_f - T_i = 50\,°\text{C} - 20\,°\text{C} = 30\,°\text{C}$$
$$(500\,\text{W}) \times (120\,\text{s}) = (1\,\text{kg}) \times c \times (30\,°\text{C})$$
$$60\,000\,\text{J} = (1\,\text{kg}) \times c \times (30\,°\text{C})$$
$$c = \frac{60\,000\,\text{J}}{1\,\text{kg} \times 30\,°\text{C}}$$
$$c = \frac{60\,000\,\text{J}}{30\,\text{kg}\,°\text{C}}$$
$$c = 2000\,\text{J kg}^{-1}\,°\text{C}^{-1}$$

Answer: The specific heat capacity of the liquid is $2000\,\text{J kg}^{-1}\,°\text{C}^{-1}$.