MODEL TEXTBOOK OF PHYSICS

Based on National Curriculum of Pakistan 2022-23

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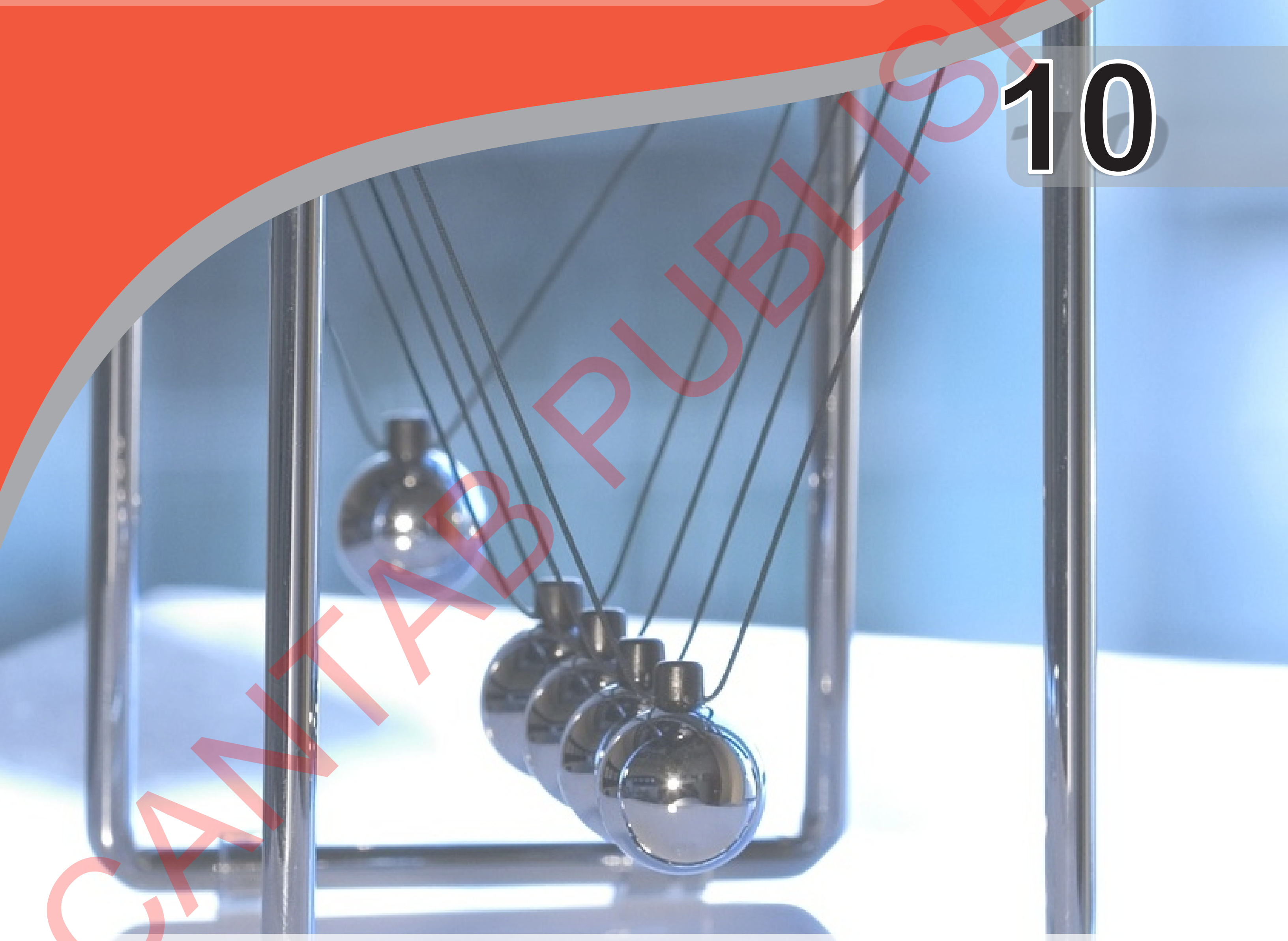

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A Textbook of Physics
for Grade 9

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First Edition - First Impression

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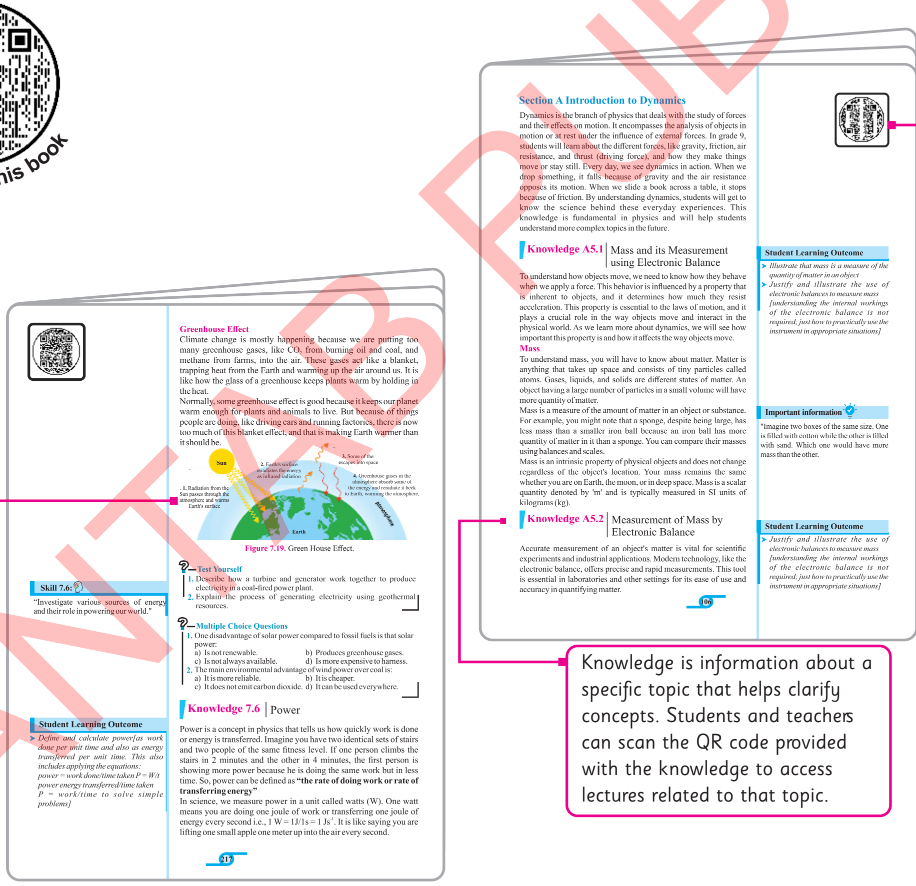
Preface

This Grade 9th Physics textbook, crafted in accordance with the National Curriculum Council's guidelines, is a comprehensive educational tool. This book offers a concise introduction to the core concepts of physics, starting with the nature of the subject and its significance in understanding the universe. From there, we delve into the essentials of measurement, the intricacies of scalar and vector quantities, the dynamics of motion and forces, the principles of torque and stability, the fundamentals of work, energy, and power, the behavior of deforming solids, the concepts of pressure and temperature, and finally, the fascinating world of magnetism. Our textbook is designed to make your learning experience engaging and effective. Within each chapter, you'll find multiple-choice questions and "Test Yourself" exercises to reinforce your understanding. Clear and informative diagrams facilitate a conceptual approach to learning. Additionally, video lectures are provided for each section, accessible via QR codes, to offer a visual and interactive learning experience. Skill sheets are included to enhance your skills further and provide targeted practice on critical topics. Embark on your journey through the world of physics with this book, which is designed not only to provide a solid foundation but also to ignite a lifelong interest in the subject. Understanding physics is not just about passing a test; it's about gaining a deeper understanding of the world around us and developing critical thinking skills that will benefit you in many areas of life. We hope you enjoy learning with us!

How to use this book



The purpose of a skill is to apply knowledge. Students and teachers can scan the provided QR code to access a worksheet that enhances their understanding.

Knowledge is information about a specific topic that helps clarify concepts. Students and teachers can scan the QR code provided with the knowledge to access lectures related to that topic.

Knowledge is information about a specific topic that helps clarify concepts. Students and teachers can scan the QR code provided with the SLO Tab to access lectures related to that topic.

SLO Based Model Video Lecture

Salient Features

Comprehensive Learning
Engage students with videos, simulations, and practical worksheets.

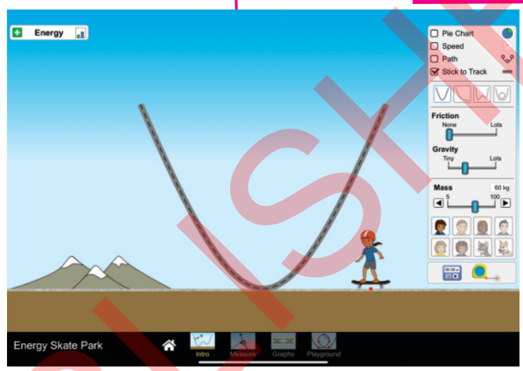
Structured Lesson Plan
Well-organized with clear objectives, PPTs, and a self-assessment questions.

Engaging Multimedia
Visual appeal through PPTs and interactive simulations.

Assessment & Tracking
Diverse question from daily life and progress monitoring.

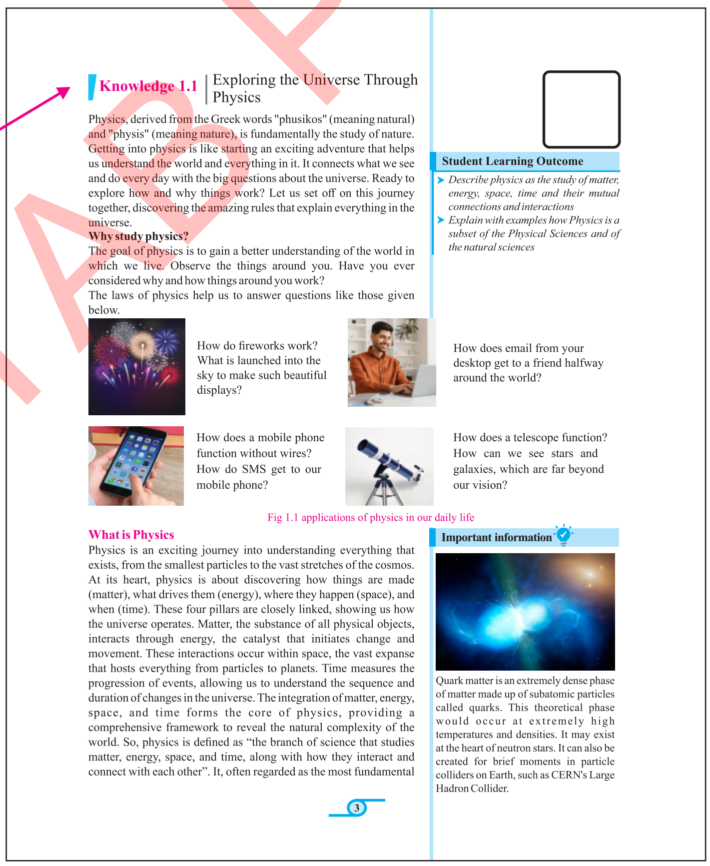
Adaptable & Accessible
Scalable and accessible, suitable for all learners.

Simulation



SLO No: P: 09 - B -66
SLO statement: Use all formulas for kinetic and gravitational potential energy to solve the problem involving simple energy conversions.

KNOWLEDGE



Knowledge 1.1 | Exploring the Universe Through Physics

Physics, derived from the Greek words "phusikos" (meaning natural) and "physis" (meaning nature), is fundamentally the study of nature. Getting into physics is like starting an exciting adventure that helps us understand the world and everything in it. It connects what we see and do every day with the big questions about the universe. Ready to explore how and why things work? Let us set off on this journey together, discovering the amazing rules that explain everything in the universe.

Why study physics?
The goal of physics is to gain a better understanding of the world in which we live. Observe the things around you. Have you ever considered why and how things around you work?
The laws of physics help us to answer questions like those given below.

How do fireworks work? What is launched into the sky to make such beautiful displays?

How does email from your desktop get to a friend halfway around the world?

How does a mobile phone function without wires? How do SMS get to our mobile phone?

How does a telescope function? How can we see stars and galaxies, which are far beyond our vision?

Fig 1.1 applications of physics in our daily life

What is Physics
Physics is an exciting journey into understanding everything that exists, from the smallest particles to the vast stretches of the cosmos. At its heart, physics is about discovering things are made (matter), what drives them (energy), where they happen (space), and when (time). These four pillars are closely linked, showing us how the universe operates. Matter, the substance of all physical objects, interacts through energy, the catalyst that initiates change and movement. These interactions occur within space, the vast expanse that hosts everything from particles to planets. Time measures the progression of events, allowing us to understand the sequence and duration of changes in the universe. The integration of matter, energy, space, and time forms the core of physics, providing a comprehensive framework to reveal the natural complexity of the world. So, physics is defined as "the branch of science that studies matter, energy, space, and time, along with how they interact and connect with each other". It, often regarded as the most fundamental

Student Learning Outcome
- *Describe physics as the study of matter, energy, space, time and their mutual connections and interactions*
- *Explain with examples how Physics is a subset of the Physical Sciences and of the natural sciences*

Important information

Quark matter is an extremely dense phase of matter made up of subatomic particles called quarks. This theoretical phase would occur at extremely high temperatures and densities. It may exist at the heart of neutron stars. It can also be created for brief moments in particle colliders on Earth, such as CERN's Large Hadron Collider.

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Skills Sheet

CONTENTS

CHAPTER 1

Heat and Thermodynamics

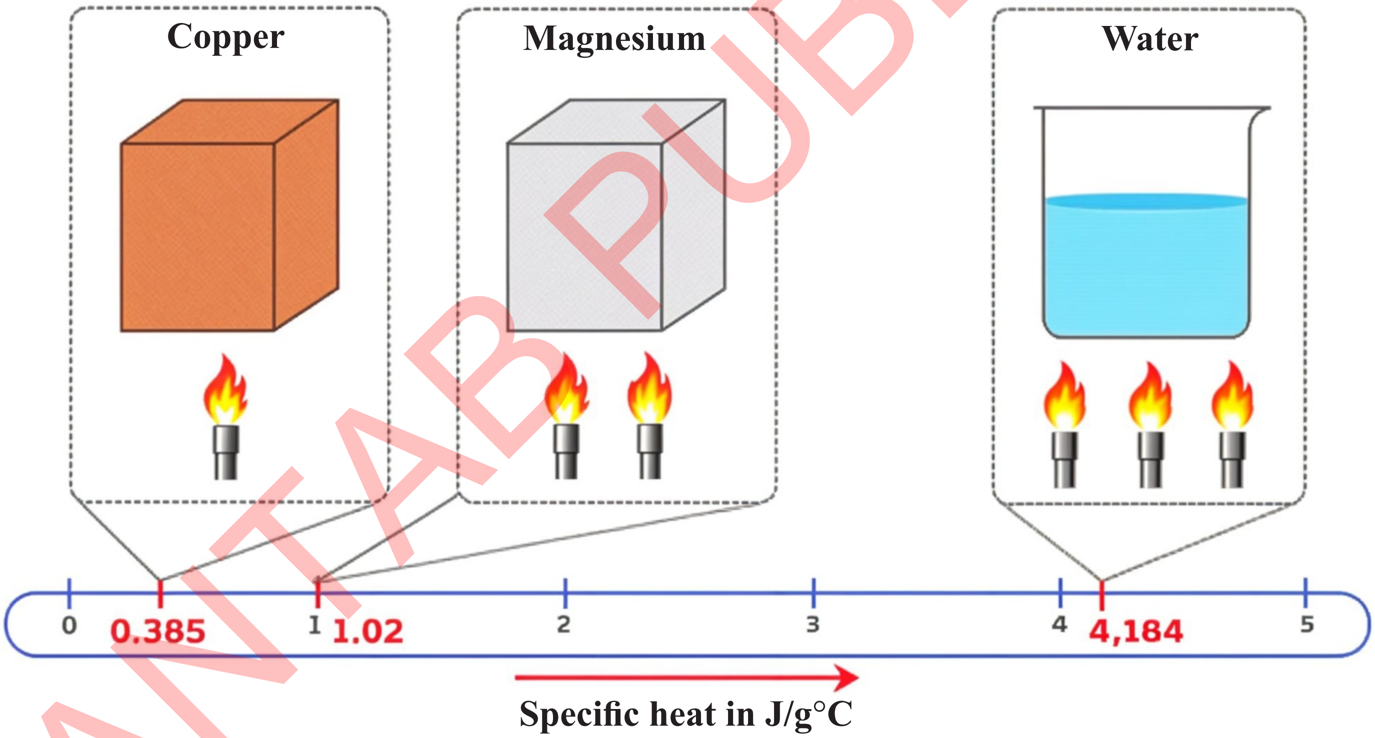
Section A
Specific Heat Capacity

A1.1 Knowledge

Specific Heat Measurement and Real-Life Effects

Student Learning Outcomes

[SLO: P-10-C-01]: *Define and calculate specific heat*
[SLO: P-10-C-02]: *Suggest experiments to measure the specific heat capacity [of a solid and of a liquid]*
[SLO: P-10-C-03]: *Analyse everyday effects due to the large specific heat of water.*



Introduction

Understanding thermal physics begins with three key concepts: temperature, heat, and internal energy. Temperature tells us how hot or cold something is and depends on the average kinetic energy of its particles. Higher temperatures mean faster-moving particles. Heat is the energy transfer between objects due to a temperature difference and continues until they reach the same temperature. Internal energy is the total energy within a substance, including both kinetic energy from moving particles and potential energy from particle interactions.

In this chapter, you will explore specific heat capacity, which is the amount of heat required to change the temperature of a substance. You will learn how to calculate specific heat and design experiments to measure it in solids and liquids. Additionally, we will analyze how water's high specific heat affects everyday life, such as climate regulation, cooking, and body temperature stability.

A1.1 Knowledge

Specific Heat Measurement and Real-Life Effects

Have you ever noticed how some foods remain hot longer than others? For example, if you remove a piece of toast from the toaster and pour hot soup into a bowl simultaneously, you will observe that a few minutes later, the soup remains pleasantly warm, while the toast has cooled off significantly. Similarly, if you let a slice of hot roast beef and a scoop of mashed potatoes sit for a short while after cooking, both initially at the same temperature, you will find that the meat cools off more rapidly than the potatoes. This difference in how quickly substances lose energy can be explained by the concept of specific heat capacity which is defined as "the amount of energy required to raise the temperature of 1 kg of a substance through 1K".

In physics, the word 'specific' means that unit mass is being considered.

To understand this better, let us take a deeper look. When you heat a material, the energy is distributed among various types of molecular motion, including vibration, rotation, and sometimes even changes in potential energy within the material. Water, for example, requires 4186 J of energy to raise the temperature of 1 kg of water by 1K. In comparison, iron requires only 462 J to achieve the same temperature change. This means water has a much higher specific heat capacity (4186 J/kg K) than iron (462 J/kg K).

To quantify the specific heat capacity for a mass m absorbing heat energy ΔQ, which results in a change in temperature ΔT, we use the formula:

$$c = \frac{\Delta Q}{m\Delta T}$$

where c is the specific heat capacity of the material, and ΔQ is the heat absorbed, resulting in a temperature change ΔT for a mass m. In words, this can be expressed as:

The unit of specific heat capacity is joules per kilogram per kelvin

$$(\mathrm{J/kg^{-1}\,K^{-1}}) \text{ or } \mathrm{Jkg^{-1}\,^{\circ}C^{-1}}$$

Rearranging equation (1.1), the heat energy required to change the temperature by $\quad \Delta Q = mc\Delta T$

Specific heat capacity can be considered as thermal inertia. Just as inertia in mechanics refers to the resistance of an object to a change in its state of motion, thermal inertia signifies the resistance of a substance to a change in its temperature.

Figure 1.1 indicates the specific heat capacities of common materials, showing water with the highest capacity and copper with the lowest, measured in joules per kilogram per degree Celsius (J/kg·°C).

Do You Know?

It is important to understand that a **calorie (cal)** is a unit of energy, defined as the amount of heat needed to raise the temperature of 1 gram of water by 1°C. In contrast, a **Calorie (Cal)**, with a capital C, is actually a kilocalorie (kcal), which is 1000 calories. This larger unit is used to measure the energy content in foods, representing the amount of energy required to raise the temperature of 1 kilogram of water by 1°C.

Do You Know?

Do You Know the Difference Between Heat Capacity and Specific Heat Capacity

Heat capacity is the amount of heat energy required to raise the temperature of an entire object by 1°C and depends on the mass of the substance (formula: $C = \frac{\Delta Q}{m\Delta T}$ unit: (J/°C or J/K).

Specific heat capacity is the amount of heat energy needed to raise the temperature of 1 kilogram of a substance by 1°C , depending on the nature of the material and is independent of the mass (formula: $C = \frac{\Delta Q}{m\Delta T}$,unit: J/kg°C or J/kg K).

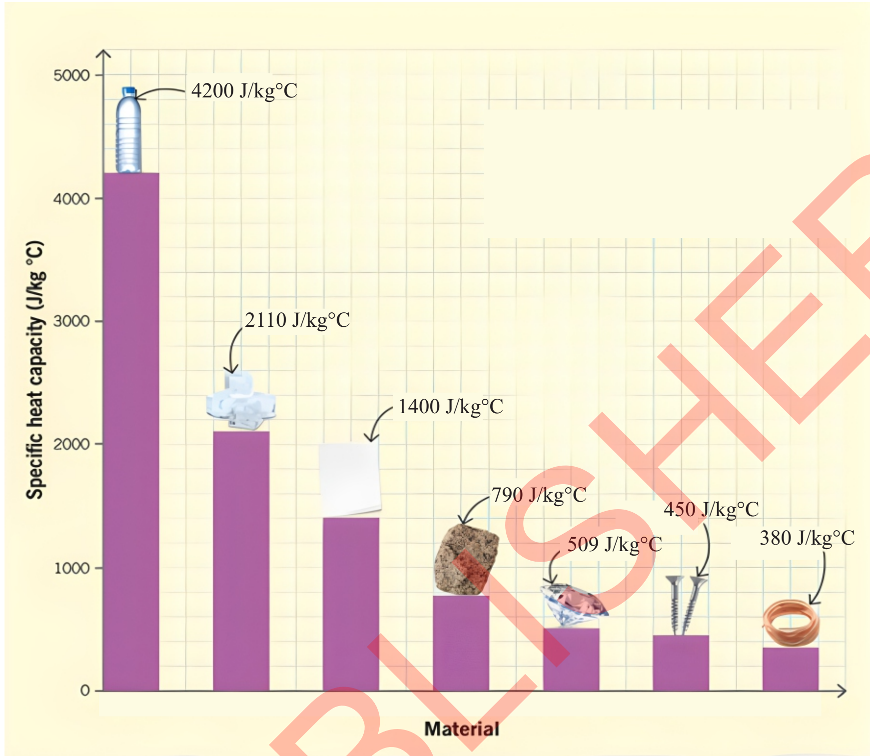


Figure 1.1: Graph illustrating the specific heat capacity of various common materials.

1.1 EXAMPLE

A cup holds 300 g of tea. The water used to brew the tea was initially at 7 °C, and it needs to be heated to its boiling point 100 °C. Given°that the specific heat capacity of water is 4200 J/kg·°C, calculate the amount of energy required to heat the tea to boiling.

Solution m): 0.3 kg
Mass of water (T_{initial}): 7°C
Initial temperature(T_{final}): 100°C
Final temperature (c): 4200 J/kg^{-1}°C^{-1}
Specific heat capacity of water
Energy required (ΔE)

Calculation: $\Delta T = T_{\text{final}} - T_{\text{initial}} = 100°\text{C} - 7°\text{C} = 93°\text{C}$

$$\Delta E = mc\Delta T$$

$$\Delta E = 0.3 \text{ kg} \times 4200 \text{ J/kg}^{-1}\text{°C}^{-1} \times 93 \text{ °C}$$

$$\Delta E = 0.3 \times 4200 \times 93$$

$$\Delta E = 117{,}180 \text{ J}$$

Therefore, the energy needed to bring the water to boiling point is 117,180 joules.

Measurement of Specific Heat Capacity

To measure the specific heat capacity of liquids and solids, we use an electric immersion heater to transfer a known amount of energy to the substance and record the resulting temperature change. This method is applicable for both water (liquid) and aluminium (solid).

Measuring the Specific Heat Capacity of Water:

In the experiment to measure the specific heat capacity of water, we use the setup shown in Fig.1.2. It includes a 12V electric immersion heater, an aluminium pan, a thermometer, and 1 kg of water. The heater, with a power rating of 40W, transfers 40 joules of energy per second.

Begin by ensuring safety precautions, such as wearing eye protection and carefully handling hot equipment. Weigh 1 kg of water and pour it into the aluminium pan. Record the initial temperature of the water using the thermometer. Insert the immersion heater into the water and turn on the 12 V power supply. Stir the water continuously to ensure even heating throughout the process. After 5 minutes (300 seconds), turn off the heater but continue stirring the water to ensure an even distribution of temperature. Record the highest temperature reached by the water.

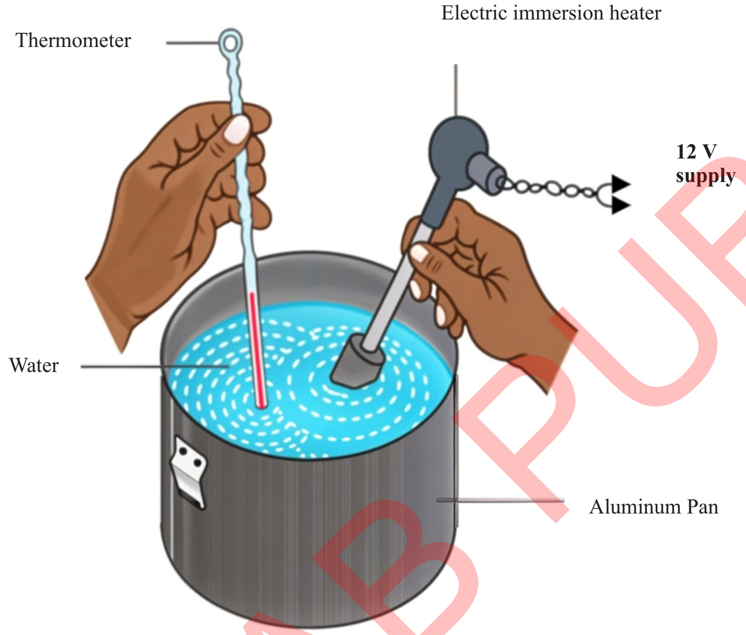


Figure 1.2: Depicts an experimental setup to measure the specific heat capacity of water using an immersion heater and a thermometer.

The energy transferred to the water (Q) is calculated using the power of the heater and the duration it was on:

$$\Delta Q = \text{Power of heater} \times \text{Time heater on}$$

Given that the heater's power is 40 W and it was on for 300 s:

$$\Delta Q = 40\,\text{J}\,\text{s}^{-1} \times 300\ \text{s} = 12000\ \text{J}$$

Next, calculate the specific heat capacity of water (c) using the formula:

$$c = \frac{\Delta Q}{m\Delta T}$$

where ΔE is the change in energy (12000 J), m is the mass of the water (1kg), and ΔT is the rise in temperature. Assuming the initial temperature of the water was 20 ℃ and the final temperature after heating was 23 ℃, the temperature rise (ΔT) is: $\Delta T = 23\ ℃ - 20\ ℃ = 3\ ℃$

$$c = \frac{12000\ \text{J}}{1\ \text{kg} \times 3\ ℃} = 4000\ \text{J}\,\text{kg}^{-1}\,℃^{-1}$$

Points to ponder

- When equal masses of a solid and a liquid are heated to achieve the same temperature increase, the liquid requires more heat energy than the solid.
- An object with a lower specific heat capacity will heat up faster to a given temperature because it requires less heat to raise its temperature by 1°C.
- An object with a lower specific heat capacity cools down more quickly because it stores less heat, while a substance with a higher specific heat capacity takes longer to cool down.

Measuring the Specific Heat Capacity of Aluminium:

The setup for measuring the specific heat capacity of aluminium involves an aluminium cylinder weighing 1 kg with two drilled holes, an electric immersion heater, and a thermometer. Insert the immersion heater into the central hole of the aluminium cylinder and the thermometer into the other hole to measure the temperature as shown in Fig. 1.3.

Record the initial temperature of the aluminium cylinder. Connect the heater to the 12 V power supply and switch it on. Heat the aluminium cylinder for 5 minutes (300 seconds), ensuring consistent heating. After 5 minutes, turn off the heater and continue monitoring the temperature. Record the highest temperature reached.

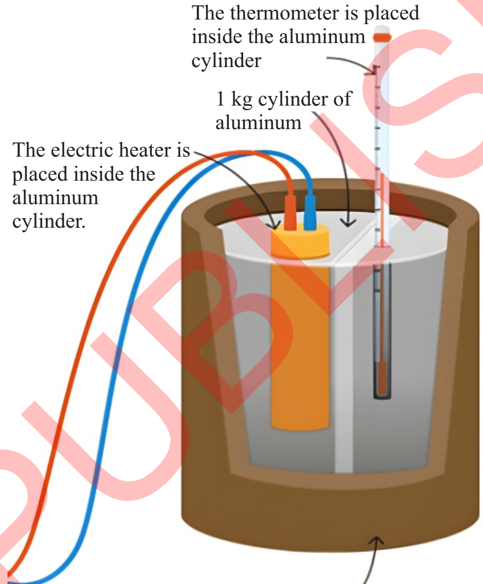


Figure 1.3: Experimental setup for measuring specific heat capacity of aluminium

The energy transferred to the aluminium cylinder ΔQ is calculated using the same formula as for water:

$$\Delta Q = 40\,\mathrm{J\,s^{-1}} \times 300\ \mathrm{s} = 12000\ \mathrm{J}$$

Next, calculate the specific heat capacity of aluminium (c) using the same formula:

$$c = \frac{\Delta Q}{m\Delta T}$$

Assuming the initial temperature of the aluminium was 20 ℃ and the final temperature after heating was 33.5 ℃, the temperature rise ΔT is:

$$\Delta T = 33\,℃ - 20\,℃ = 13\,℃$$

$$c = \frac{12000\ \mathrm{J}}{1\ \mathrm{kg} \times 13\,℃} = 923\ \mathrm{J\,kg^{-1}\,℃^{-1}}$$

The calculated specific heat capacities of water and aluminium deviate from the actual values (4200 J $\mathrm{kg^{-1}}$· $℃^{-1}$ and 900 J $\mathrm{kg^{-1}}$· $℃^{-1}$, respectively) due to experimental errors like heat loss and measurement inaccuracies, leading to overestimates. Accuracy can be improved by insulating the metal block, leaving holes for the wires and thermometer. This technique can also be used for different masses or types of metal.

Daily Life Effects of Large Specific Heat of Water

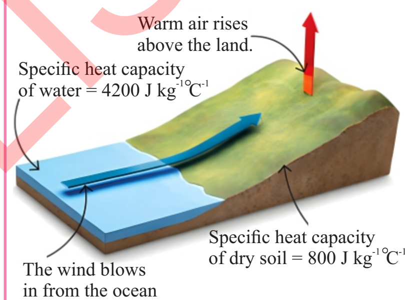
1.The specific heat capacity of water is 4200 J $kg^{-1}\cdot K^{-1}$, while that of dry soil is about 810 J $kg^{-1}\cdot K^{-1}$. This difference means soil heats up and cools down five times faster than water for the same amount of heat. Consequently, land experiences more rapid temperature fluctuations than the sea. Islands, surrounded by water, have smaller temperature changes from summer to winter compared to large land masses like Central Asia. Therefore, locations near the sea exhibit smaller seasonal temperature variations than inland regions.

2.Water's high specific heat capacity, along with its low cost and availability, makes it ideal for cooling engines and central heating systems. In automobile cooling systems, water absorbs the substantial heat generated by the engine as it circulates. This heat is then dissipated through the radiator, preventing the engine from overheating.

3.The high specific heat capacity of water is also important for warm-blooded animals, including humans, due to its impact on physiological processes. This property allows water to absorb and store significant heat with minimal temperature change, ensuring a stable internal environment. In warm-blooded animals, blood, which is high in water content, helps regulate body temperature. When the body produces excess heat, the water in the blood absorbs it, preventing rapid temperature increases. This thermal regulation, facilitated by water's high specific heat capacity, allows warm-blooded animals to remain active and functional across diverse environments, ensuring their survival and well-being.

Important Information

If you live near the coast, you have likely observed that the wind frequently blows in from the ocean on sunny days. This occurs because land has a lower specific heat capacity than water. When the Sun shines, the land heats up faster than the ocean since it requires less energy to increase its temperature. As the land warms, it heats the air above it, causing the warmer air to rise in a convection current, which then draws in cooler air from the ocean.



Multiple Choice Question

1. What happens to the temperature of water when it absorbs heat but does not undergo a phase change?
   a) Decreases b) Remains constant
   c) Increases based on specific heat
   d) Increases at a fixed rate
2. Why is it important to stir the liquid in a calorimeter while measuring its specific heat capacity?
   a) To prevent heat loss to the surroundings
   b) To ensure uniform temperature throughout the liquid
   c) To increase the heat transfer rate
   d) To reduce the heat capacity of the calorimeter
3. How does the high specific heat capacity of water influence the climate of coastal regions?
   a) It causes extreme temperature changes
   b) It stabilizes temperature, keeping coastal climates moderate
   c) It absorbs heat from the land and cools it rapidly
   d) It causes rapid evaporation and temperature fluctuations

Skill:1.1

Objective:

- Define specific heat and calculate the specific heat capacity of solids and liquids, while also suggesting and describing experiments to measure it, including the required apparatus and procedures.
- Analyze and explain the real-life effects of water's large specific heat capacity in regulating temperature in the environment and living organisms.

Test Yourself

Short answer-based questions

1 How does the high specific heat capacity of water affect weather patterns and temperature regulation on Earth?
2 Why is the concept of specific heat important when designing materials for thermal insulation?
3 Why does the sand on a beach heat up faster during the day compared to the water in the sea?

Key Points

- Temperature measures the average kinetic energy of particles in a substance.
- Heat is the energy transferred from a hotter object to a cooler one, measured in joules (J) or calories (cal).
- Internal Energy is the total energy of a substance, including kinetic and potential energy of particles.
- Specific heat is the amount of heat required to raise the temperature of 1 kg of a substance by 1°C.
- Water has a high specific heat capacity (4200 J/kg °C), meaning it takes more energy to heat compared to substances like iron (462 J/kg ·°C).
- The energy required to heat a substance is calculated by the formula $Q = mc\Delta T$, where c is the specific heat capacity, m is mass, and ΔT is the temperature change.
- Thermal Inertia refers to a substance's resistance to changes in temperature, which is related to its specific heat.
- Specific heat can be measured using an immersion heater to transfer a known amount of energy to a substance and calculate the temperature change.
- Water's high specific heat helps moderate temperatures in coastal regions and stabilize internal body temperatures in warm-blooded animals.
- Water's ability to absorb and store heat with minimal temperature change is essential in cooling systems and climate regulation.

Exercise

After completing the chapter students practice SLO based exercise to prepare for examination. Each SLO include three types of question: Multiple choice question (MCQs), Short response question (SRQs), Extended response question (ERQs) and detailed exercise solution available in QR code.

Define and calculate specific heat. (Knowledge + Understanding)

Multiple-Choice Questions

1. What is the specific heat capacity of water?

a) 500 J/kg · °C b) 4186 J/kg · °C c) 1000 J/kg · °C d) 2000 J/kg · °C

2. Which of the following materials has the lowest specific heat capacity?

a) Iron b) Water c) Copper d) Wool

Short Response Questions

1. Why water has a higher specific heat capacity than metals like iron and copper?

2. Calculate the specific heat of a substance if 500 J of heat is required to raise the temperature of 2 kg of the substance by 10 °C.

3. How specific heat relates to the ability of materials to store heat. Provide an example.

Extended Response Questions

1. A 500 g sample of water at 20°C is heated using a 200 W heater for 10 minutes. Calculate the final temperature of the water if the specific heat capacity of water is 4200 J/kg °C. **[77.14 °C]**

2. A metal block weighs 1 kg and absorbs 1000 J of heat, raising its temperature by 5°C. What is the specific heat capacity of the metal? **[200 J/kg °C]**

3. If 0.5 kg of water at 10 °C is heated by 500 J, what will be the temperature change? Use the specific heat capacity of water as 4200 J/kg °C. **[0.24 °C]**

Suggest experiments to measure the specific heat capacity [of a solid and of a liquid] (Application)

Multiple-Choice Questions

1. Which apparatus is essential for measuring the specific heat capacity of a liquid?

a) Calorimeter b) Thermometer c) Barometer d) Calliper

2. Why is water used in a calorimeter when measuring a solid's specific heat capacity?

a) Low specific heat, heats quickly b) High specific heat, resists temperature change

c) Increases solid's temperature d) Reflects heat for easier measurement

Short Response Questions

1. What would happen to marine life if water's specific heat capacity were significantly lower?
2. How might alternative cooling fluids, like oils or specialized coolants, differ from water in terms of specific heat capacity and cooling efficiency?
3. Can you think of a scenario where thermal insulation might not be beneficial in maintaining temperature?
4. What precautions should be taken to minimize heat loss when measuring the specific heat capacity of a liquid?

Extended Response Questions

1. Design an experiment to determine the specific heat capacity of a liquid (e.g., water). Include the apparatus, procedure, calculations, and potential sources of error with ways to minimize them.
2. Design an experiment to determine the specific heat capacity of a solid (e.g., aluminium). Include the apparatus, procedure, calculation method, and potential sources of error with ways to minimize them.

Analyse everyday effects due to the large specific heat of water. (Application)

Multiple-Choice Questions

1. What happens when a substance with a low specific heat capacity absorbs heat?
a) It cools down
b) It remains at the same temperature
c) It heats up faster
d) It freezes

2. How does the specific heat of water benefit the climate of coastal regions?
a) It causes rapid temperature changes
b) It helps to stabilize the temperature, keeping coastal climates moderate
c) It absorbs heat and heats the surroundings rapidly
d) It causes evaporation to increase drastically

3. How does water's high specific heat benefit living organisms?
a) It helps stabilize internal body temperature
b) It decreases the rate of evaporation
c) It increases the rate of temperature fluctuations
d) It increases energy loss in the body

4. Why is the concept of specific heat important in designing thermal insulators?
a) It helps materials maintain their shape
b) It helps determine how fast a material heats up
c) It controls how much heat energy can be transferred
d) It determines the weight of materials

5. Why does sand heat up faster than water?
a) Sand has a higher specific heat capacity than water
b) Sand has a lower specific heat capacity than water
c) Sand absorbs less heat than water
d) Water heats up faster than sand

Short Response Questions

1. Why do coastal regions experience more moderate temperatures compared to inland regions?
2. Analyze the impact of water's high specific heat on the stability of internal body temperature in humans.
3. What would happen to marine life if water's specific heat capacity were significantly lower?

Extended Response Questions

1. Analyze the impact of water's high specific heat capacity on Earth's climate, including its role in moderating seasonal temperature changes.

CHAPTER 1

B1.1 Knowledge

Changes in State Between Solids, Liquids, and Gases

Student Learning Outcomes

[SLO: P-10-C-04]: *Use the terms for the changes in state between solids, liquids, and gases [including deposition and sublimation]*

B1.2 Knowledge

Evaporation

Student Learning Outcomes

[SLO: P-10-C-22]: *Describe evaporation in terms of particles [in terms of the escape of more energetic particles from the surface of a liquid]*

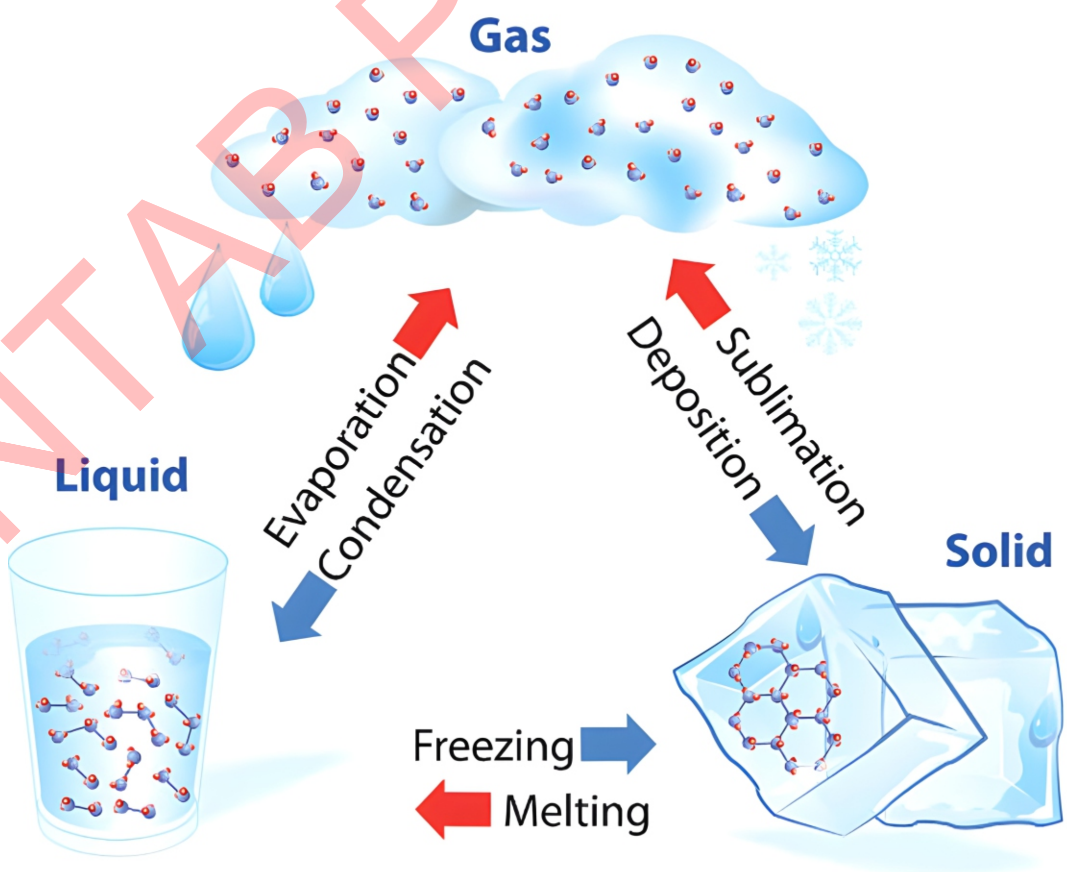
[SLO: P-10-C-24]: *Explain how evaporation causes cooling*

[SLO: P-10-C-25]: *Describe the use of cooling caused by evaporation in the refrigeration process without using harmful CFCs.*

[SLO: P-10-C-23]: *Analyze how temperature, humidity, surface area, and air movement over a surface affect evaporation*

Section B

Phase Transition and Latent heat



B1.3 **Knowledge**

Transfer of Energy Without Change of Temperature

Student Learning Outcomes

[SLO:P-10-C-07]: *Analyze melting, solidification, boiling, and condensation in terms of energy transfer without a change in temperature*

[SLO:P-10-C-26]: *Explain latent heat [as the energy required to change the state of a substance and explain it in terms of particle behavior and the forces between particles]*

[SLO:P-10-C-27]: *Justify experiments to determine latent heat of fusion and latent heat of vaporization of ice and water [including illustrating the analysis of data by sketching temperature-time graph on heating ice]*

B1.4 **Knowledge**

Melting and Boiling

Student Learning Outcomes

[SLO:P-10-C-08]: *State the melting and boiling temperatures for water at standard atmospheric pressure*

[SLO:P-10-C-12]: *Differentiate between boiling and evaporation*

Introduction

This chapter covers phase changes and energy transfer, fundamental concepts in thermal physics. Matter transitions between solid, liquid, and gas through melting, freezing, boiling, condensation, sublimation, and deposition, driven by energy transfer without a temperature change. You will explore latent heat, the energy required for phase transitions, and analyze it using temperature-time graphs. The chapter also examines evaporation, its cooling effect, and applications in refrigeration without harmful CFCs. Additionally, you will study factors affecting evaporation, such as temperature, humidity, surface area, and air movement, highlighting the role of thermal energy in everyday life. Finally, you will differentiate between boiling and evaporation and state the melting (0°C) and boiling (100°C) points of water at standard atmospheric pressure.

B1.1 Knowledge

Changes in State Between Solids, Liquids, and Gases

Matter exists in four common phases: solid, liquid, gas, and plasma. Ice is the solid phase of water (H_2O). When you add energy, the solid molecules move more freely and become liquid water. Adding more energy changes the liquid into gas. If you keep adding energy, the gas molecules break into ions and electrons, creating plasma. The phase of matter depends on its temperature and pressure. Changing phases usually needs an energy transfer.

Understanding these changes requires familiarity with terms like melting, freezing, vaporization, boiling, condensation, sublimation, and deposition. These terms describe the transitions between solid, liquid, and gas states and explain how energy is absorbed or released during these changes without altering the temperature.

Melting, or **fusion**, is when a solid turns into a liquid by absorbing heat. The temperature at which this happens is the melting point. For example, ice melts into water at 0°C.

Freezing, or **solidification**, is the opposite process where a liquid turns into a solid by losing heat. For example, water freezes into ice at 0°C.

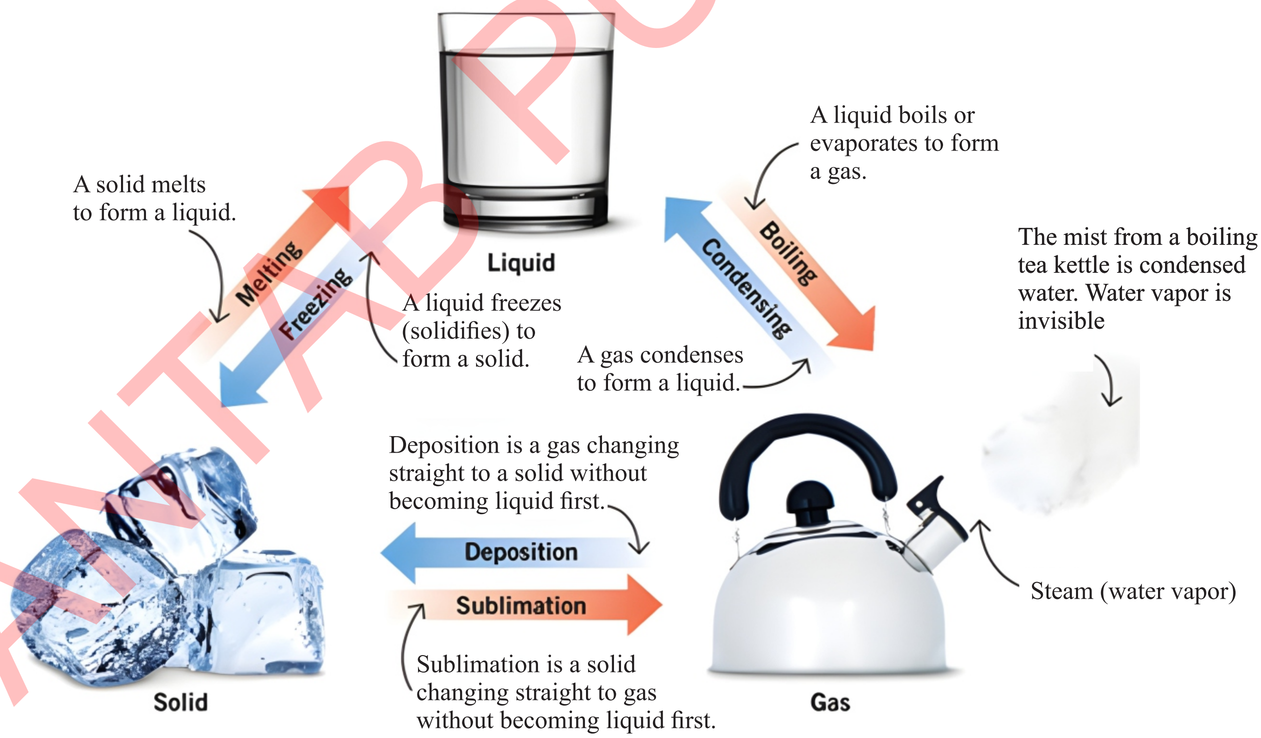


Figure 1.1: Illustration of changes of state of water between solid(ice), water(liquid) and gas (steam: water vapor)

Vaporization is when a liquid changes into a gas. This can happen at any temperature as molecules on the surface gain enough energy to become gas.

Boiling is a specific type of vaporization that happens throughout the liquid when it reaches at certain temperature called its boiling point. For example, water boils at 100°C to become steam.

Condensation is the reverse process, where a gas turns into a liquid by losing heat. For example, steam turns back into water when cooled.

Sublimation is when a solid changes directly into a gas without becoming a liquid first. A common example is dry ice (solid carbon dioxide) turning into carbon dioxide gas. Deposition is the reverse process, where a gas changes directly into a solid without becoming a liquid. Frost forming from water vapor is an example of deposition.

Experimentally, these processes occur without a temperature change, as the absorbed or released heat changes the potential energy, not the kinetic energy, of the particles as shown in Fig.1.1.

B1.2 Knowledge

Evaporation

When water is left in an open pan, it gradually disappears because it turns into water vapor through a process called evaporation. Evaporation is the process by which a liquid changes into a gas, and it happens at the surface of the liquid without needing the entire liquid to boil. This can occur at temperatures below the boiling point.

To understand evaporation, imagine that liquids are made up of tiny particles called molecules. These molecules are always in motion, moving and bumping into one another. In a liquid, molecules are loosely connected but still close enough to hold together. They have enough energy to move around but not enough to completely break free from the liquid.

The energy of these molecules is not the same for all. Some molecules move faster and have more kinetic energy, while others move slower and have less. This difference in energy levels is the key to evaporation.

At the surface of a liquid, the molecules are exposed to the air and have fewer neighboring molecules pulling them back into the liquid. When molecules collide with each other, some gain extra energy. If a surface molecule gains enough energy, it can overcome the attractive forces of the liquid and escape into the air as a gas. This is how evaporation occurs. Only the fastest moving, most energetic molecules, with the highest kinetic energy, can break free and transition into the gaseous phase.

Evaporation is Cooling Process

In the evaporation process, the energy needed for the molecules to escape comes from the remaining molecules in the liquid. This process can be compared to "billiard-ball physics," where molecules that gain energy leave the liquid, while those that lose energy remain behind as indicated

Important Information

Steam is an invisible gas. What we often call steam is actually a white cloud made up of many tiny drops of liquid water floating in the air.

Steam coming out of a boiling kettle is invisible. As it cools, it condenses into clouds of tiny liquid droplets.

The clouds we see in the sky are made up of water droplets or tiny ice crystals.

On a cold day, when humans or animals breathe out, the water vapor in their breath condenses into liquid droplets, forming visible mist.

Skill:1.1

Objective:

- Identify and describe the processes of phase changes between solids, liquids, and gases, including melting, freezing, evaporation, condensation, sublimation, and deposition.

in Fig. 1.2. This causes the average kinetic energy of the remaining molecules in the liquid to decrease, making evaporation a cooling process. Interestingly, the fast-moving molecules that escape are slowed down as they move away from the surface due to their attraction to it. Therefore, while water cools during evaporation, the air above does not experience a corresponding increase in temperature.

This process helps explain everyday phenomena, like why puddles dry up or why sweat cools our body

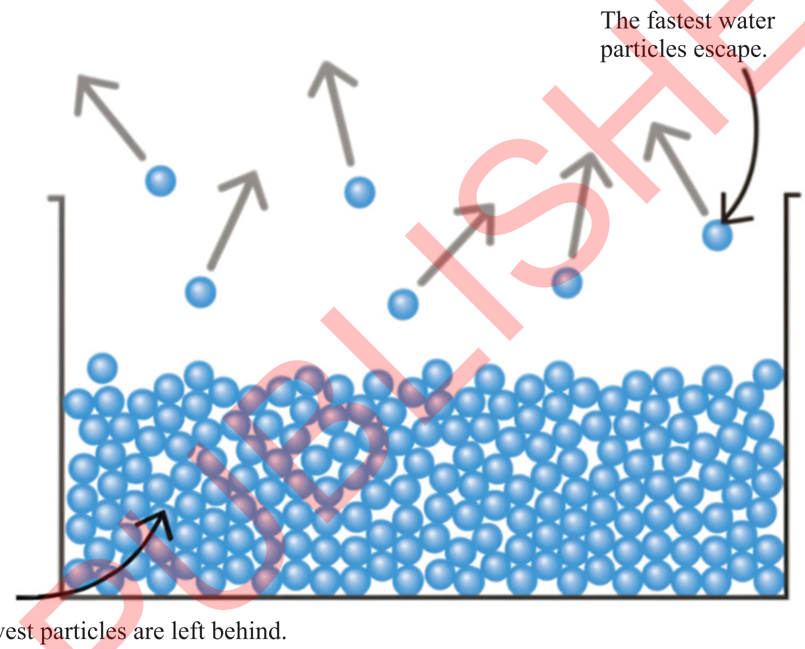


Figure 1.2: Depicts the evaporation process: Fastest water molecules escape from the liquid surface, leaving behind slower particles and causing a decrease in temperature.

Why Does Water in a Bottle Wrapped in Fabric Remain Cool?

When a metal bottle is wrapped in wet fabric as indicated in Fig. 1.3, it remains cool due to the process of evaporation. The faster moving water molecules on the surface of the wet fabric escape into the air, causing a decrease in the temperature of the fabric. This cooler, damp fabric transfers its coolness to the metal bottle through conduction. As a result, the bottle cools down and lowers the temperature of the water inside.

Figure 1.3: The wet cloth around the metal bottle aids in cooling the water.

How Does Sweating Cool Our Bodies?

When our bodies overheat, sweat glands produce perspiration as a natural cooling mechanism. As the sweat evaporates from the surface of our skin, it absorbs heat from our body, cooling us down and helping to maintain a stable body temperature.

However, not all animals have sweat glands. Many animals with few or no sweat glands rely on other methods to cool themselves, such as panting or seeking shade, to regulate their body temperature as depicted in Fig. 1.4. These adaptations help them survive in different environments.

a) b)

Figure 1.4: (a)The dog cools down by panting because his sweat glands are only located between his toes. Panting helps him regulate his body temperature by allowing moisture to evaporate from his tongue and mouth. (b) Pigs, lacking sweat glands, cool themselves by wallowing in the mud, which helps to lower their body temperature.

Do You Know?

When water changes from a liquid to a gaseous state, it becomes water vapor, an invisible gas that mixes with the air.

The Use of Cooling Caused by Evaporation in the Refrigeration Process

Refrigeration is an essential process for preserving food, storing medicines, and maintaining controlled temperatures in various industries. The principle behind refrigeration is the cooling effect caused by evaporation, a process where a refrigerant absorbs heat and lowers the surrounding temperature.

To understand how this works, imagine a liquid called a refrigerant. Inside the refrigerator, the refrigerant flows through the evaporator coil shown in Fig. 1.5, where it starts as a cold liquid. When it comes into contact with the warmer air or surfaces inside the refrigerator, it absorbs heat from them. This absorbed heat gives the refrigerant enough energy to change its state from a liquid to a gas-this is called evaporation. As the refrigerant takes heat away during this process, the interior of the refrigerator becomes cooler.

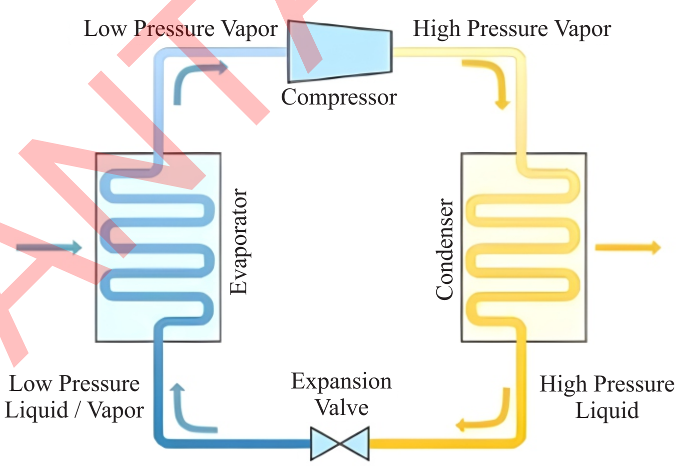


Figure 1.5: Depicts the refrigeration cycle, highlighting cooling through evaporation in the evaporator.

The refrigerant, now in gas form, moves to a compressor. The compressor increases its pressure and temperature, preparing it to release the absorbed heat efficiently in the condenser. The hot, high-pressure refrigerant gas then flows to the condenser coil, located outside the refrigerator. In the condenser, the gas releases the absorbed heat into the surrounding air and condenses back into a liquid. This liquid refrigerant is then sent back to the evaporator coil to repeat the cycle.

Modern refrigeration systems avoid harmful chlorofluorocarbons (CFCs), which were once used as refrigerants but are now known to damage the ozone layer and contribute to global warming. Instead, safer refrigerants like hydrofluorocarbons (HFCs) or hydrocarbons are used. These substances effectively absorb heat without causing harm to the environment.

Important Information

Nearly 90% of the moisture in Earth's atmosphere originates from the evaporation of oceans, lakes, and rivers, while the remaining portion comes from plant transpiration.

Factors Effecting the Evaporation

The rate of evaporation increases at **higher temperatures** due to a larger proportion of molecules possessing enough kinetic energy to break free from the liquid and transition into vapor. While water can still evaporate at lower temperatures, the process occurs at a much slower pace. For example, a puddle of water may gradually dry up on a cool day, although the evaporation is less pronounced than it would be under warmer conditions.

Evaporation is significantly influenced by factors such as humidity, surface area, and air movement over the liquid's surface. **Humidity** refers to the amount of water vapor already present in the air. When humidity levels are high, the air is saturated with water vapor, making it more difficult for additional water molecules to evaporate. On the other hand, when humidity is low, the air has a greater capacity to hold more water vapor, facilitating a higher rate of evaporation.

Surface area is another significant factor. A larger surface area allows more molecules to be exposed to the air, increasing the chances of evaporation. For example, a shallow pan of water will evaporate faster than the same volume of water in a tall, narrow container because the surface area exposed to air is greater.

Air movement or wind over the surface of the liquid can also enhance evaporation by removing the water vapor that accumulates above the liquid, which would otherwise slow down the evaporation process. By continuously replacing the saturated air with drier air, wind effectively increases the rate at which the liquid can evaporate.

Multiple Choice Question

1 How does evaporation occur in terms of particle movement?
a) Low-energy particles escape
b) Only central particles escape
c) High-energy particles escape, leaving lower-energy ones
d) All particles escape at once

2 Which factor will increase the rate of evaporation of a liquid?
a) Higher humidity in the surrounding air

b) Increased surface area of the liquid
c) Decreased air movement over the surface
d) Lower temperature of the liquid

Skill:1.2

Objective:

- Explain evaporation through particle energy and examine how temperature, humidity, surface area, and air movement affect it, while relating its cooling effect to applications like refrigeration without harmful CFCs.

Test Yourself

Short answer-based questions

1 How the energy of particles changes during evaporation and how this leads to cooling.
2 Describe the role of temperature and surface area in increasing the rate of evaporation.
3 How evaporation-based cooling is used in the refrigeration process to avoid harmful CFCs.

B1.3 Knowledge

Transfer of Energy Without Change of Temperature

Energy transfer plays a critical role in changing the state of matter. In this section, we will explore how energy is absorbed or released during phase changes like melting, boiling, and condensation, without causing a change in temperature, and understand the concept of latent heat through experiments and analysis.

Energy Transfer and Particle Behavior During Melting, Solidification, Boiling, and Condensation

Matter undergoes phase changes when energy is transferred in or out as indicated in Fig. 1.6, and the behavior of particles changes accordingly. These changes occur at specific temperatures and pressures and involve either the absorption or release of heat. Let us explore how energy transfer and particle behavior are involved in the processes of melting, solidification, boiling, and condensation.

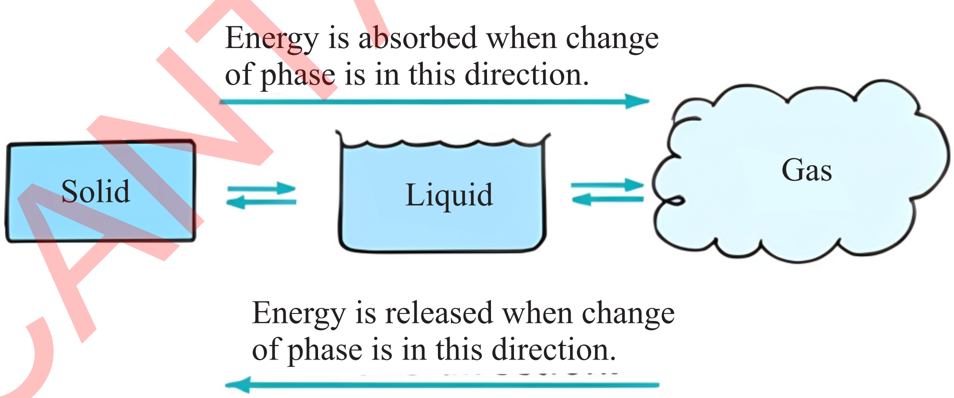


Figure 1.6: Energy transfer to change phase of matter

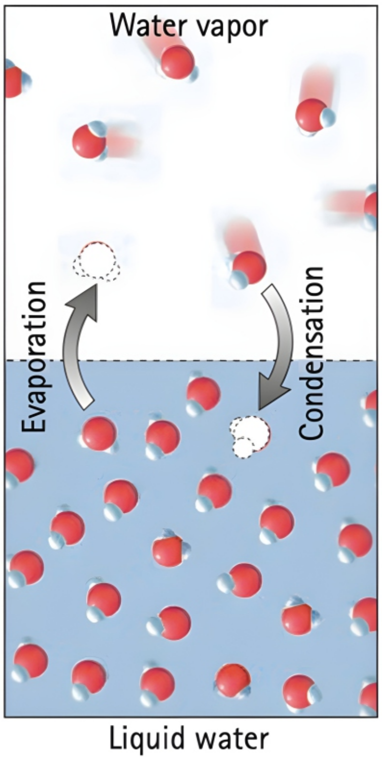


Figure 1.7: Depicts the molecular process of evaporation and condensation at the boundary between liquid water and water vapor.

Do You Know?

The latent heat of vaporization is greater than the latent heat of fusion because more energy is needed for liquid molecules to transition into a gas. This is due to the additional energy required to work against the external atmospheric pressure during the phase change.

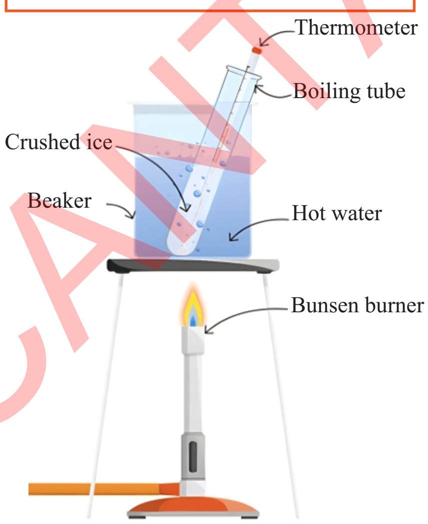


Figure 1.8: Experimental setup for determining the latent heats.

Melting occurs when a solid absorbs energy, causing its particles to gain enough energy to overcome the intermolecular forces holding them in fixed positions. As this energy is absorbed, the temperature of the solid remains constant because the energy input is used to increase the potential energy of the particles rather than their average kinetic energy, which would otherwise cause a temperature rise. As the particles continue to vibrate in place, they gradually acquire enough energy to break free from their fixed positions. Once they have enough energy to move past each other, the solid transitions into a liquid, with the input thermal energy being converted to potential energy without changing the temperature. The energy required to convert a given mass of solid into liquid without changing temperature is called the latent heat of fusion.

In the reverse process of **solidification**, the liquid releases the same amount of energy, causing the particles to slow down, lose some of their freedom of movement, and re-establish the fixed positions characteristic of a solid, with the potential energy being transferred from the particles to thermal energy in the surroundings, maintaining the temperature.

Boiling is the process by which a liquid absorbs energy and transforms into a gas. The energy required for this transition, known as the latent heat of vaporization. This energy allows the particles to overcome the attractive forces that maintain the liquid state and to push back the surrounding atmosphere during the expansion that occurs when the liquid vaporizes. As in the case of melting, the temperature also remains constant throughout the boiling process because the energy is used to increase the potential energy of the particles rather than their kinetic energy. Therefore, the latent heat of vaporization is large enough to both overcome the intermolecular forces and enable the expansion of vapors into the atmosphere.

Condensation occurs when a gas releases energy and transitions into a liquid. This released energy reduces the particles' potential energy, allowing them to form intermolecular bonds. The temperature remains constant during this process, as the energy released equals the latent heat absorbed during boiling. The atmosphere's work on the vapor and the decrease in potential energy contribute to thermal energy in the surroundings.

The process of evaporation and condensation are represented in the Fig. 1.7.

In summary, **latent heat** is the amount of energy required to change the state of matter from solid to liquid or liquid to gas (or in reverse) without changing its temperature. During phase changes, this energy alters the potential energy of particles by breaking or forming intermolecular bonds, which explains why temperature does not change during these transition.

Justifying Experiments to Determine Latent Heat of Fusion and Latent Heat of Vaporization

To understand the concepts of latent heat of fusion and vaporization, consider an experiment using an immersion heater as shown in Fig. 1.8. A thermometer is placed in a boiling tube containing crushed ice at –10 °C, which is then submerged in a beaker of hot water. As the ice absorbs heat, its temperature rises until it reaches 0 °C. At this point, despite continued heat transfer, the temperature remains constant, as indicated by the thermometer, as the ice absorbs energy to melt completely into liquid water at 0 °C, which is the melting point. This energy is the latent heat of fusion, which is the energy required to change the ice into water without changing its temperature.

The results can be represented in a temperature-time graph as indicated in Fig. 1.9 which is important for understanding the energy transfer during phase changes:

- **OA Section:** The temperature rises from –10 °C to 0 °C, representing the warming of solid ice as energy increases the kinetic energy of the particles.
- **AB Section:** At 0 ℃, the graph becomes flat, showing that the temperature remains constant while energy is absorbed as latent heat of fusion. This energy is used to overcome the intermolecular forces holding the ice together.

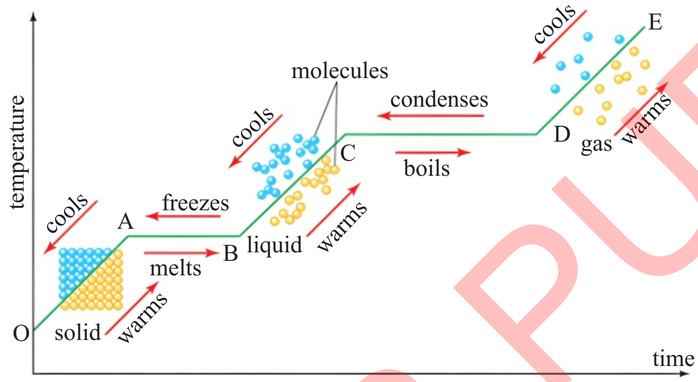


Figure 1.9: Particle behavior changes during phase transitions due to latent heat

Once the ice has fully melted, the temperature of the water rises again. As heat continues to be added, the temperature eventually reaches 100°C, called the boiling point, where the water begins to boil. At this stage, the temperature again remains constant, as indicated by the thermometer, even though energy is still being absorbed. This energy is used to vaporize the water into steam. This energy is known as the latent heat of vaporization for a given mass of water, which is the energy required to convert water into steam without changing its temperature.

The graph in Fig. 1.9 also represents the energy transfer during boiling:

- BC Section: The temperature rises from 0°C to 100°C, indicating the warming of liquid water as energy increases the kinetic energy of water molecules.
- CD Section: At 100°C, the graph flattens, showing that the temperature remains constant while energy is absorbed as latent heat of vaporization. This energy is used to break intermolecular forces and overcome atmospheric pressure, converting the liquid into steam.

When the process is reversed, the steam releases the same amount of energy (latent heat of vaporization) as it condenses back into liquid water without a temperature change. Similarly, when water freezes into ice, it releases the same amount of energy (latent heat of fusion) without changing temperature.

To calculate the latent heat for a given mass of a substance (without a temperature change), use the equation:

$$Q = m \times l$$

Here, is the specific latent heat, representing the energy required to change the phase of a substance from solid to liquid (specific latent heat of fusion) or liquid to vapor (specific latent heat of vaporization). Specific latent heat values for various substances are listed in Table 1.1.

For example, to melt an ice igloo with a mass of 750 kg:

$$Q = 750\ \text{kg} \times 335\ \text{J/g} \times 1000\ \text{g/kg} = 2.51 \times 10^8\ \text{J or } 251\text{MJ}$$

Table 1.1: Specific latent heats of fusion and Evaporation for various materials

Heat of Fusion and Vaporization of Common Substances		
Material	**Heat of Fusion H_f (J/kg)**	**Heat of Vaporization H_v (J/kg)**
Copper	2.05×10^5	5.07×10^6
Mercury	1.15×10^4	2.72×10^5
Gold	6.3×10^4	1.64×10^6
Methanol	1.09×10^5	8.78×10^5
Iron	2.66×10^5	6.29×10^6
Silver	1.04×10^5	2.36×10^6
Lead	2.04×10^4	8.64×10^5
Water (ice)	3.34×10^5	2.26×10^6

Do You Know?

The high latent heat of vaporization of water plays a key role in the **Mpemba effect**, where hot water can freeze faster than warm water. This occurs due to the **evaporation effect**: when hot water spreads over a large surface, rapid evaporation occurs. Each gram of evaporating water absorbs **540 calories** from the remaining water, significantly cooling it. This energy loss through evaporation far exceeds the **1 calorie per degree Celsius** lost through thermal conduction, leading to rapid cooling and potentially causing hot water to freeze faster. The same principle is used in **flooding a skating rink**, where hot water melts rough spots on the ice. As it evaporates, it removes a large amount of heat, helping the water freeze quickly and smooth the rink more efficiently than warm water would.

Multiple Choice Question

1. Which of the following best describes latent heat?
   a) Energy to raise temperature
   b) Energy for state change without temperature change
   c) Energy to break chemical bonds
   d) Energy released during cooling
2. What happens to the particles of a substance during melting?
   a) They lose energy and move closer together.
   b) They gain energy and overcome some of the forces holding them together.

c) They remain stationary while bonds between them strengthen.
d) They gain energy and completely break apart into free-moving particles.

3. Why does the temperature remain constant during boiling?
   a) Heat increases liquid pressure
   b) Heat breaks intermolecular forces and change the state, not to increase kinetic energy.
   c) Heat is released by liquid.
   d) Heat moves solid particles faster

Test Yourself

Short answer-based questions

1 Define latent heat and explain it in terms of particle behavior and intermolecular forces.
2 How can you justify the design of an experiment to determine the latent heat of fusion of ice?
3 Why does a substance require energy to change its state even when its temperature does not increase?
4 How does the process of sublimation differ from melting in terms of energy transfer and particle behavior?
5 Why the temperature-time graph for heating ice remains flat during melting and boiling but rises when the substance is not changing state.

B1.4 Knowledge

Melting and Boiling

Grasping the properties of water and its behavior at different temperatures is essential for understanding how substances change state under various conditions. This section focuses on key concepts related to the thermal characteristics of water, specifically its melting and boiling points, and clarifies the differences between boiling and evaporation.

Melting Point

The melting point of ice, or the temperature at which it transitions from a solid to a liquid, is a critical physical property. For water, this occurs at 0°C under standard atmospheric pressure. At this temperature, ice absorbs heat energy without an increase in temperature, allowing its molecules to overcome the rigid structure of the solid phase and move more freely into the liquid phase. This absorption of energy without a temperature change is known as latent heat. The curve from A to B in the graph of Fig. 1.10 represents the absorption of 335 J of heat required to melt 1 gram of ice at 0°C.

The melting point of solids generally increases with pressure due to the particles being packed more tightly in an ordered structure. However, ice behaves uniquely; under high pressure, the melting point decreases, meaning it will melt at a temperature below 0°C. This is because the solid form of water (ice) has a lower density than its liquid form. High pressure

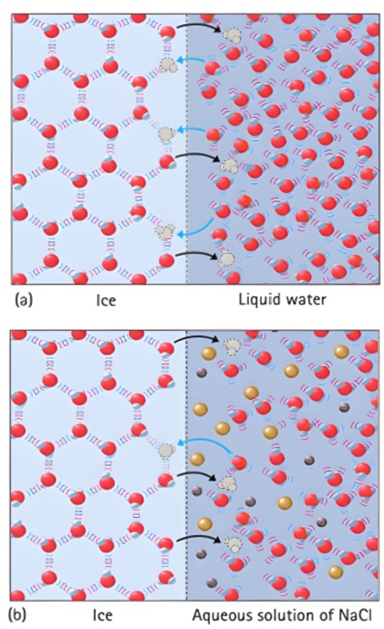
Skill:1.4

Objective:

- Analyze phase changes through energy transfer, explain latent heat via particle behavior, and justify experiments using temperature-time graphs.

Important Information

Adding impurities, such as salt or sugar, to water lowers its freezing point because these foreign particles disrupt the hydrogen bonding between water molecules. They interfere with the formation of the crystalline lattice needed for ice, requiring water molecules to move more slowly (at a lower temperature) to form ice. As a result, the freezing or melting process occurs at a reduced temperature.



destabilizes the open lattice structure of ice, making it easier to transition into the denser liquid phase. This explains how ice skates create a thin water layer for smooth gliding.

A pure substance has a definite melting or freezing point at any pressure. Adding impurities to a substance lowers this temperature. Therefore, the freezing or melting point can indicate the purity of a substance.

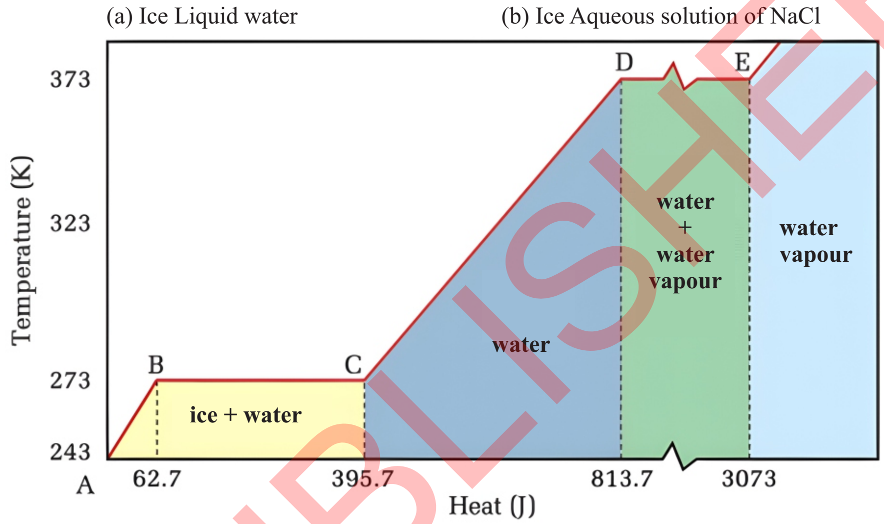
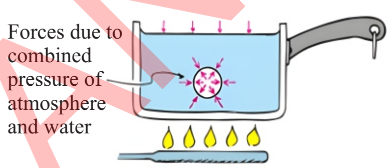


Figure 1.10: Graph showing the energy involved in heating and phase changes of 1 gram of H_2O. The flat sections on this heating curve correspond to phase changes.

Important Information

The process of boiling is influenced by the interaction of vapor pressure, atmospheric pressure, and external conditions. As shown in figure, the vapor pressure inside a steam bubble is generated by the movement of water vapor molecules. This vapor pressure must overcome the combined pressure of the surrounding atmosphere and the water for the bubble to expand and escape. If vapor pressure is insufficient, the bubble collapses, preventing boiling.



Boiling Point

Boiling occurs when evaporation happens beneath the surface of a liquid, forming vapor bubbles that rise and escape. This phase change occurs at certain temperature called boiling point, where the vapor pressure equals the external pressure. For water at atmospheric pressure, the boiling point is 100°C, as shown in Fig. 1.10, during which 2260 J of energy per gram is absorbed to convert water into vapor without a temperature change, a process known as the latent heat of evaporation. Boiling is influenced by pressure; higher external pressure raises the boiling point, while lower pressure, such as at high altitudes, lowers it.

Adding impurities to a liquid like water also increases the boiling point. This is because the impurities disrupt the formation of vapor bubbles within the liquid, requiring more heat energy to be added for the liquid to reach its boiling point.

Difference Between Boiling and Evaporation

Boiling and evaporation are both processes by which a liquid turns into a gas, but they differ in several key ways. Boiling occurs when a liquid is heated to its boiling point, causing rapid vaporization throughout the entire liquid, with bubbles forming and rising to the surface. It happens at a specific temperature, known as the boiling point, and only under certain conditions when the vapor pressure equals the external pressure. On the other hand, evaporation is a slower, surface-level process where individual molecules gain enough energy to escape into the air, occurring at any temperature below the boiling point. Unlike boiling, evaporation does not require the liquid to reach a specific temperature and happens gradually as surface molecules gain energy from their surroundings. While both processes involve a change of state from liquid to gas, boiling is a vigorous, rapid process throughout the liquid, while evaporation is a gentle, gradual process occurring only at the surface.

Boiling and Evaporation

Evaporation occurs from the surface of a liquid at any temperature. For example, puddles dry up even though the water temperature never reaches the boiling point. Boiling, on the other hand, happens when water turns to gas so rapidly that bubbles form deep within the liquid. These bubbles are filled with water vapor, not air.

Multiple Choice Question

1. Why does water boil at 100°C at standard atmospheric pressure but at a lower temperature at high altitudes?
   a) Atmospheric pressure is lower at high altitudes, reducing the boiling point.
   b) Atmospheric pressure is higher at high altitudes, raising the boiling point.
   c) The temperature at high altitudes is too cold for boiling.
   d) The heat energy is less effective at high altitudes.
2. How does evaporation differ from boiling?
   a) Evaporation occurs throughout the liquid, while boiling occurs only at the surface.
   b) Evaporation happens at any temperature, while boiling happens at a specific temperature.
   c) Boiling requires no energy, while evaporation does.
   d) Boiling occurs only in solids, while evaporation occurs in liquids.

Test Yourself

Short answer-based questions

1. State the melting and boiling temperatures of water at standard atmospheric pressure.
2. Explain how evaporation and boiling differ in terms of process and conditions

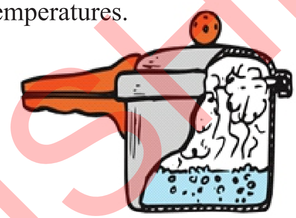
Skill:1.5

Objective:

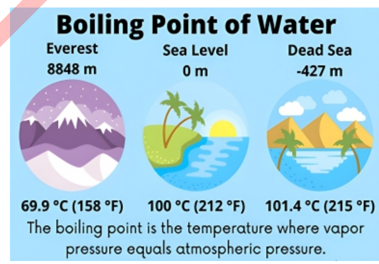
- Identify the melting and boiling points of water at standard atmospheric pressure and distinguish between boiling and evaporation based on their processes and conditions.

Do You Know?

A pressure cooker demonstrates the effect of increased pressure on boiling. The tight lid traps water vapor above the liquid, increasing the pressure inside. This elevated pressure raises the boiling point of water, allowing it to boil at a temperature higher than 100°C. This principle is used in cooking to reduce cooking time by maintaining higher temperatures.



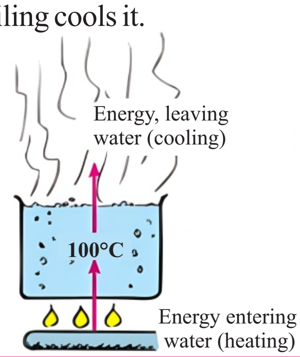
Do You Know?



Important Information

Boiling is a cooling process because, during boiling, a liquid's temperature remains constant as heat energy is used to convert the liquid into vapor. This prevents the temperature from rising, effectively cooling the liquid as it boils. In a pressure cooker, boiling is inhibited, allowing the temperature to increase beyond the normal boiling point.

Heating warms the water, and boiling cools it.



Key Points

- Melting: The process where a solid turns into a liquid by absorbing heat (latent heat of fusion).
- Freezing: The reverse of melting, where a liquid turns into a solid by losing heat.
- Vaporization: The change of a liquid into a gas (latent heat of vaporization), happening throughout the liquid at its boiling point.
- Boiling: A specific type of vaporization where bubbles form inside the liquid and rise to the surface when the liquid reaches its boiling point.
- Condensation: The process where a gas turns into a liquid by releasing heat.
- Sublimation: When a solid changes directly into a gas without becoming a liquid first.
- Deposition: When a gas changes directly into a solid without becoming a liquid.
- Evaporation is the process where molecules at the surface of a liquid escape into the air. It occurs at temperatures below the boiling point and is a cooling process.
- Evaporation is affected by temperature, humidity, surface area, and air movement.
- Evaporation leads to cooling because the most energetic molecules leave the liquid, causing the average kinetic energy (temperature) of the remaining liquid to decrease.
- Sweating and cooling by evaporation in refrigeration systems rely on this principle.
- Latent Heat of Fusion: The energy required to change 1 kg of a substance from solid to liquid at its melting point without changing temperature.
- Latent Heat of Vaporization: The energy required to change 1 kg of a substance from liquid to gas at its boiling point without changing temperature.

Exercise

After completing the chapter students practice SLO based exercise to prepare for examination. Each SLO include three types of question: Multiple choice question (MCQs), Short response question (SRQs), Extended response question (ERQs) and detailed exercise solution available in QR code.

Use the terms for the changes in state between solids, liquids, and gases [including deposition and sublimation]. (Application)

Multiple-Choice Questions

1. How does the process of sublimation differ from deposition?

a) Sublimation: gas → solid, Deposition: solid → gas

b) Sublimation: solid → gas, Deposition: gas → solid

c) Both sublimation and deposition involve gas turning into a liquid

d) Sublimation and deposition are both types of boiling

2. Which of the following processes occurs when a gas changes directly into a solid?

a) Sublimation b) Evaporation c) Deposition d) Freezing

Short Response Questions

1. Why sublimation occurs without passing through the liquid phase, using examples like dry ice.

2. What is deposition, and where can it be observed in nature?

Extended Response Questions

Explain sublimation in terms of energy changes and particle behavior, and discuss its applications.

Explain how evaporation causes cooling. (Understanding)

Multiple-Choice Questions

Why is evaporation considered a cooling process?

a) It releases heat into the surrounding air

b) The molecules that escape leave behind lower energy particles

c) It increases the kinetic energy of the remaining liquid

d) The temperature increases as heat is absorbed

Short Response Questions

How the cooling effect from sweating helps to maintain body temperature in humans.

Extended Response Questions

Discuss how evaporation leads to cooling, explaining the process at a particle level.

Describe the use of cooling caused by evaporation in the refrigeration process without using harmful CFCs. (Application)

Multiple-Choice Questions

1. In modern refrigeration systems, which principle is used to cool the air inside the refrigerator without CFCs?

a) Conduction b) Evaporation of refrigerants c) Expansion of gases d) Compression of gases

2. Why is the use of CFCs being avoided in refrigeration systems?

a) CFCs cause increased energy consumption

b) CFCs are harmful to the ozone layer

c) CFCs are too expensive for commercial use

d) CFCs decrease the efficiency of the refrigeration process

Short Response Questions

1. Analyze the role of latent heat in refrigeration systems, explaining its use in modern refrigerators and the environmental impacts of CFC-free refrigerants.

2. Describe how modern refrigerants, other than CFCs, maintain cooling in refrigeration systems.

Extended Response Questions

Analyze the role of latent heat in refrigeration systems, explaining its use in modern refrigerators and the environmental impacts of CFC-free refrigerants.

Analyze how temperature, humidity, surface area, and air movement over a surface affect evaporation. (Application)

Multiple-Choice Questions

1. What effect does increasing air movement have on evaporation?

a) It slows down the rate of evaporation b) It speeds up the evaporation process

c) It has no effect on the rate of evaporation d) It decreases the temperature of the liquid

2. Which of the following factors would decrease the rate of evaporation?

a) High temperature b) High humidity

c) Increased surface area d) Increased air movement

Short Response Questions

1. How does increasing humidity affect the rate of evaporation? Describe with examples.

2. Evaluate the impact of increased air movement on the rate of evaporation, and how it influences the escape of particles from a liquid's surface.

Analyze melting, solidification, boiling, and condensation in terms of energy transfer without a change in temperature. (Application)

Multiple-Choice Questions

1. What happens when a substance reaches its boiling point?

a) It gains heat without changing state

b) It absorbs heat that increases its temperature.

c) It absorbs heat without a temperature change as it transitions to gas.

d) It cools down and freezes into a solid.

2. Which of the following occurs during the process of condensation?

a) A liquid turns into a gas b) A gas turns into a liquid

c) A solid turns into a liquid. d) A solid turns into a gas.

Short Response Questions

1. Compare and contrast the energy changes in evaporation and condensation.
2. Describe the process of condensation and how it releases energy during phase transition.
3. How does the presence of impurities in water affect its freezing point and boiling point?

Extended Response Questions

1. Analyze the energy transfer during melting and solidification, and explain why temperature remains constant during these phase changes. Provide examples.
2. Discuss energy transfer during boiling and condensation, and explain how these processes are used in everyday applications.

Explain latent heat [as the energy required to change the state of a substance and explain it in terms of particle behavior and the forces between particles]. (Understanding)

Multiple-Choice Questions

1. Which of the following correctly describes the latent heat of fusion?
a) The heat required to change a liquid into a gas at boiling point
b) The heat required to change a solid into a liquid at its melting point
c) The heat released when a liquid freezes into a solid
d) The heat required to raise the temperature of a liquid

2. What happens when a substance reaches its boiling point?
a) It gains heat without changing state
b) It absorbs heat that increases its temperature
c) It absorbs heat without a temperature change as it transitions to gas
d) It cools down and freezes into a solid

Short Response Questions

1. Discuss how the latent heat of fusion plays a role in ice melting and its effect on the surrounding environment.
2. How does latent heat affect the temperature of a substance during a phase change?

Extended Response Questions

Compare latent heat of fusion and latent heat of vaporization, and explain how they relate to energy required to change states.

Justify experiments to determine latent heat of fusion and latent heat of vaporization of ice and water [including illustrating the analysis of data by sketching temperature-time graph on heating ice]. (Application)

Multiple-Choice Questions

What is the main purpose of using a calorimeter in experiments to determine the latent heat of vaporization of water?
a) To measure the temperature of water during vaporization
b) To prevent heat loss to the environment
c) To measure the rate of boiling
d) To calculate the specific heat capacity of water

Short Response Questions

1. How the high latent heat of vaporization helps regulate temperature in natural systems, like oceans.
2. Why is the latent heat of vaporization higher than the latent heat of fusion?
3. Describe the significance of latent heat in practical applications like refrigeration and cooking.

Extended Response Questions

1. Calculate the energy required to melt 200 g of ice at 0 °C. **[67,000 J]**
2. How much energy is needed to convert 0.5 kg of water at 100 °C into steam? **[1,13 × 104 J]**
3. If 150 g of water absorbs 750 J of energy, what will be the temperature change of the water? **[1.19 °C]**
4. Design an experiment to determine the latent heat of fusion of ice, including apparatus, procedure, calculations, and error minimization.

State the melting and boiling temperatures for water at standard atmospheric pressure. (Knowledge)

Multiple-Choice Questions

1. What is the boiling point of water at standard atmospheric pressure?

a) 50 °C   b) 75 °C   c) 100 °C   d) 125 °C

2. At standard atmospheric pressure, water freezes at:

a) 0 °C   b) 10 °C   c) 25 °C   d) 100 °C

Short Response Questions

1. How does the presence of impurities in water affect its freezing point and boiling point?

2. State the boiling and melting points of water at standard atmospheric pressure and describe why these temperatures are important.

3. Why does water boil at 100°C and freeze at 0°C under standard atmospheric pressure? How this relates to the properties of water.

Differentiate between boiling and evaporation. (Understanding)

Multiple-Choice Questions

1. Which of the following occurs during boiling?

a) It happens only at the surface of a liquid
b) It occurs at a specific temperature for the liquid
c) It happens gradually throughout the liquid
d) It requires no heat

2. In which condition does evaporation take place?

a) Only at the boiling point
b) Only at the surface of the liquid
c) At all temperatures, from the surface of the liquid
d) At high altitudes

Short Response Questions

What are the differences between the concepts of boiling and evaporation in terms of energy and particle movement?

Extended Response Questions

Compare boiling and evaporation in terms of particle behavior, energy transfer, and conditions, and discuss their applications in natural and industrial systems.

CHAPTER 1

Section C

Thermal Expansion and Superconductivity

C1.1 Knowledge

Thermal Expansion

Student Learning Outcomes

[SLO: P-10-C-05]: *Explain thermal expansion in terms of kinetic theory [for solids, liquids, and gases. This includes stating the relative order of magnitudes of the expansion of solids, liquids, and gases]*

[SLO: P-10-C-06]: *Analyze the applications and consequences of thermal expansion in real life*

[SLO: P-10-C-09]: *Describe qualitatively the thermal expansion of solids [linear and volumetric expansion]*

[SLO: P-10-C-10]: *Explain the thermal expansion of liquids [real and apparent expansion]*

C1.2 Knowledge

Analyzing the Pressure of a Gas in Terms of Particle Behavior

Student Learning Outcomes

[SLO: P-10-C-11]: *Analyse the pressure and the changes in pressure of a gas in terms of particles [the forces exerted by particles colliding with surfaces, creating a force per unit area.]*

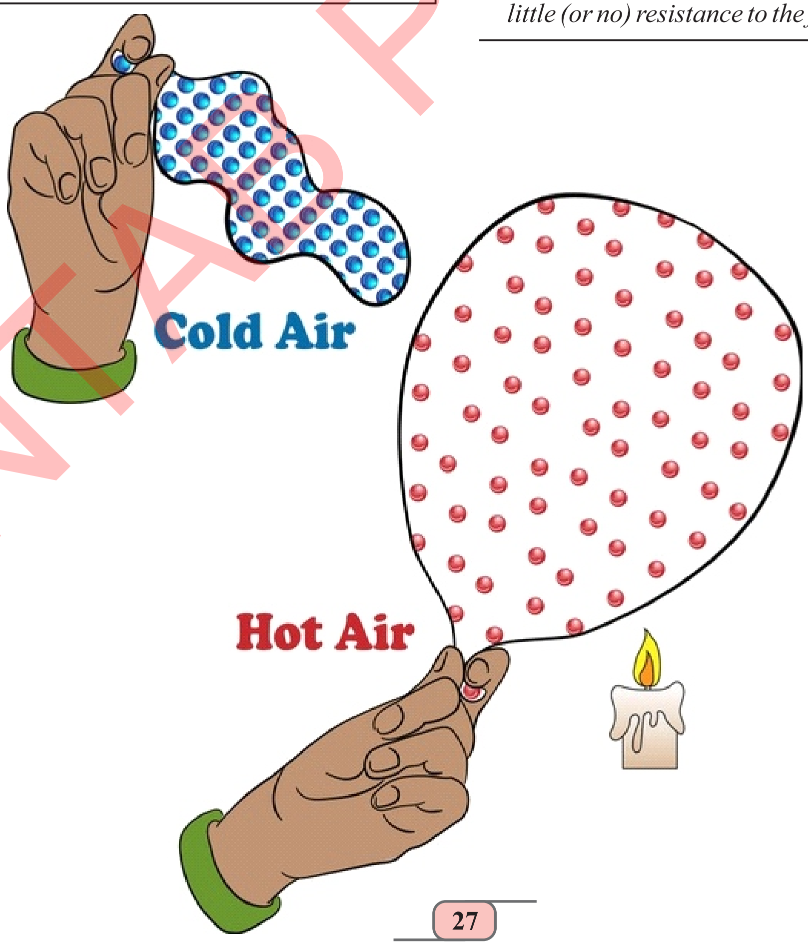
C1.3 Knowledge

Superconductivity

Student Learning Outcomes

[SLO: P-10 -C-28]: *State that certain materials, when cooled to near absolute zero, can exhibit superconductivity*

[SLO: P-10-C-29]: *Describe superconductivity [as when atoms are in this state, their kinetic energy is low, so there is little (or no) resistance to the flow of electrons.]*



Introduction

This chapter explores thermal expansion, gas behavior, and superconductivity, fundamental concepts in thermal physics. You will learn how solids, liquids, and gases expand due to increased particle motion, with gases expanding the most and solids the least. The chapter examines real-life applications and consequences of thermal expansion, including its effects on structures and devices. You will study the expansion of solids (linear and volumetric) and liquids (real and apparent) and analyze gas pressure based on particle collisions with surfaces. Finally, you will be introduced to superconductivity, a phenomenon where certain materials, when cooled near absolute zero, exhibit little to no electrical resistance due to minimal atomic motion, enabling highly efficient energy transfer.

C1.1 Knowledge

Thermal Expansion

Thermal expansion, the increase in the volume of a material when heated, plays an important role in various real-life applications and presents several challenges that must be managed carefully. After understanding the basics of thermal expansion for solids, liquids, and gases, it is essential to explore how this phenomenon is applied practically and the consequences it can have in everyday life. The different ways thermal expansion affects materials such as metals, liquids, and gases make it both a useful tool and a potential problem that needs to be controlled or utilized effectively. Thermal expansion demonstrated through boiling water as shown in Fig.1.1. The heat causes the liquid's molecules to move faster, increasing the volume of water vapor and creating visible bubbles.

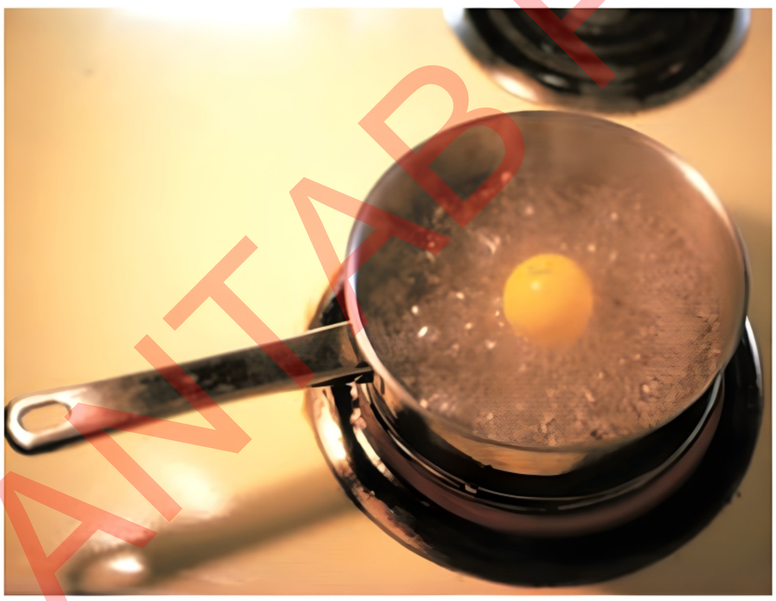


Figure 1.1: Boiling water showing thermal expansion.

Thermal Expansion and the Kinetic Theory for Solids, Liquids, and Gases

Thermal expansion occurs when the particles within a substance gain energy and move further apart as the temperature increases. According to the kinetic theory, particles in all states of matter solids, liquids, and gases

Important Information

Thermal Expansion:

Thermal expansion refers to the increase in the size of materials as they heat up. While it can be very useful in many applications, it can also cause problems if not properly managed.

Hot Air Balloons: Hot air balloons work by heating the air inside the balloon with a burner. The hot air expands, becoming less dense than the cooler air outside, which causes the balloon to rise.

Thermometers: Thermometers use the thermal expansion of liquids to measure temperature. As the liquid in the bulb heats up, it expands and moves up the thin glass tube, indicating the temperature.

Expansion Joints: Bridges are equipped with expansion joints to allow them to expand in hot weather and contract in cold weather. Without these joints, the forces from expansion and contraction could damage the structure. Engineers design these joints to accommodate size changes and maintain the integrity of the bridge.

are in constant motion, but the nature of this motion and the interactions between particles differ significantly across these states. In solids, particles are closely packed and can only vibrate in place due to strong forces of attraction between them. When a solid is heated, its particles vibrate more vigorously as shown in Fig.1.2, causing them to push slightly away from one another, leading to a small degree of expansion. The linear expansion of solids is typically minimal; for example, a 1-meter length of steel expands by just 0.012 mm for a 1°C rise in temperature. This small expansion is due to the restricted movement of particles, which remain closely bonded.

In liquids, the particles are further apart and less ordered than in solids, which allows for more movement. When heated, the kinetic energy of liquid particles increases, causing them to move more freely and expand. The expansion of liquids is generally about five times greater than that of solids for the same temperature increase. This greater expansion is due to weaker forces of attraction between the particles, which allows them to spread out more easily when thermal energy is added.

Gases, however, exhibit the most significant thermal expansion. Gas particles are very far apart, with minimal forces of attraction between them. When a gas is heated, its particles, which are already in rapid motion, move even faster and spread out significantly, causing the gas to expand. This expansion is typically about 20 times greater than that of liquids for a given temperature increase. The ease with which gas particles expand is due to the very weak interactions between them and their high kinetic energy.

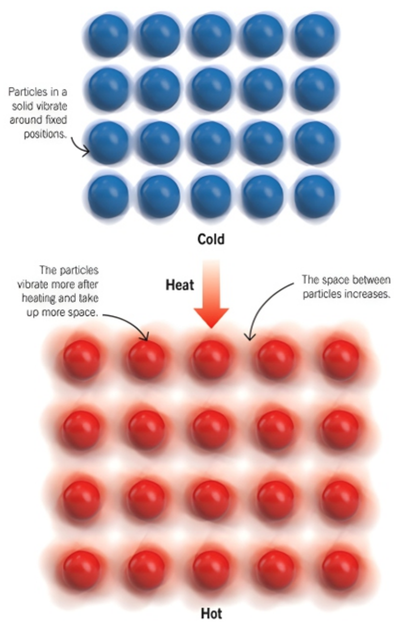


Figure 1.2: Particles of solid vibrate with large amplitude on heating and spaces between them increase.

Applications and Consequences of Thermal Expansion in Real Life

Thermal expansion, which refers to the increase in the volume of a material when heated, is a critical factor in various real-world applications. However, it also presents several challenges that require careful management. Once the fundamental principles of thermal expansion in solids, liquids, and gases are understood, it is important to consider its practical applications and the potential impact it can have on everyday life. The diverse effects of thermal expansion on materials, including metals, liquids, and gases, highlight its dual nature as both a valuable tool and a potential issue that must be effectively controlled or harnessed.

Practical Applications of Thermal Expansion

1. Fitting Components Together: One practical application of thermal expansion is seen in the fitting of mechanical components, such as axles and gear wheels as shown in Fig.1.3. In precision engineering, where tight fits are necessary, thermal expansion is used to assemble parts securely. For example, an axle can be cooled to extremely low temperatures, such as in liquid nitrogen at -196°C, causing it to contract. Once it contracts enough, a gear wheel can be slipped onto the axle. When the axle returns to room temperature, it expands, creating a very tight fit that ensures no slipping between the parts. This technique is used across many applications, from small-scale components in clocks to large-scale parts in vehicles like trains.

Figure 1.3: Shrink-fitting of axles into gear wheels using thermal expansion.

2. Everyday Uses in the Kitchen: Thermal expansion also has practical household uses. For example, removing a tight metal lid from a glass jar can be made easier by immersing the lid in hot water. The metal expands when heated as shown in Fig.1.4, loosening the lid from the glass, which expands much less. This simple trick leverages the differing expansion rates of materials to solve a common problem.

Figure 1.4: Thermal expansion of lid under hot water

3. Measurement of Temperature: Thermal expansion is fundamental to the functioning of thermometers. In both liquid and gas thermometers, the expansion of the substance (like mercury or alcohol) inside the thermometer provides a direct measure of temperature. As the liquid or gas heats up, it expands and rises within a calibrated tube, allowing us to read the temperature accurately as shown in Fig.1.5. This is because liquids and gases expand much more than solids for a given temperature rise, making their expansion easily visible and measurable.

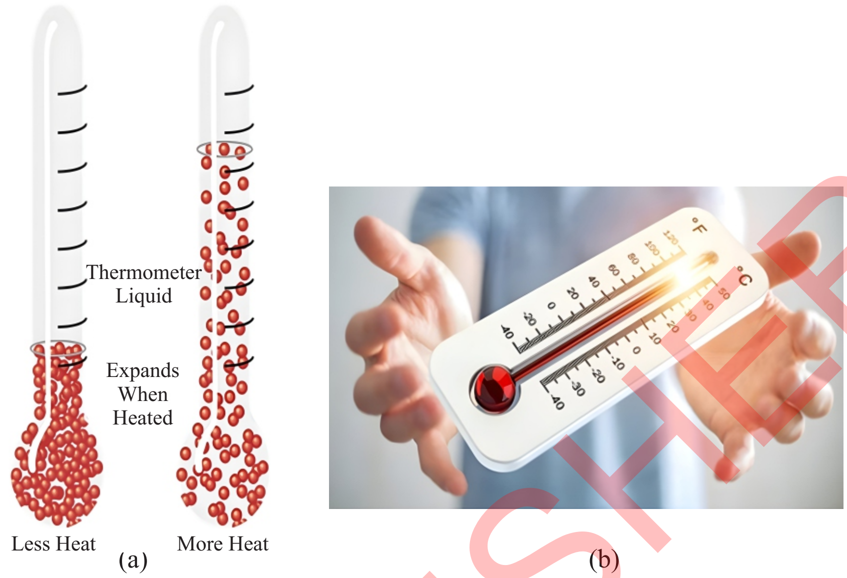


Figure 1.5: (a) Thermal expansion of liquid in thermometer (b) Mercury thermometer

4. Driving Mechanical Devices: In engines, such as those found in cars, thermal expansion is harnessed to perform mechanical work. An expanding gas, generated from the combustion of fuel, pushes the pistons within the engine as shown in Fig.1.6. The rapid expansion of gases due to the high temperatures created during combustion produces force, which is converted into mechanical energy to power the vehicle.

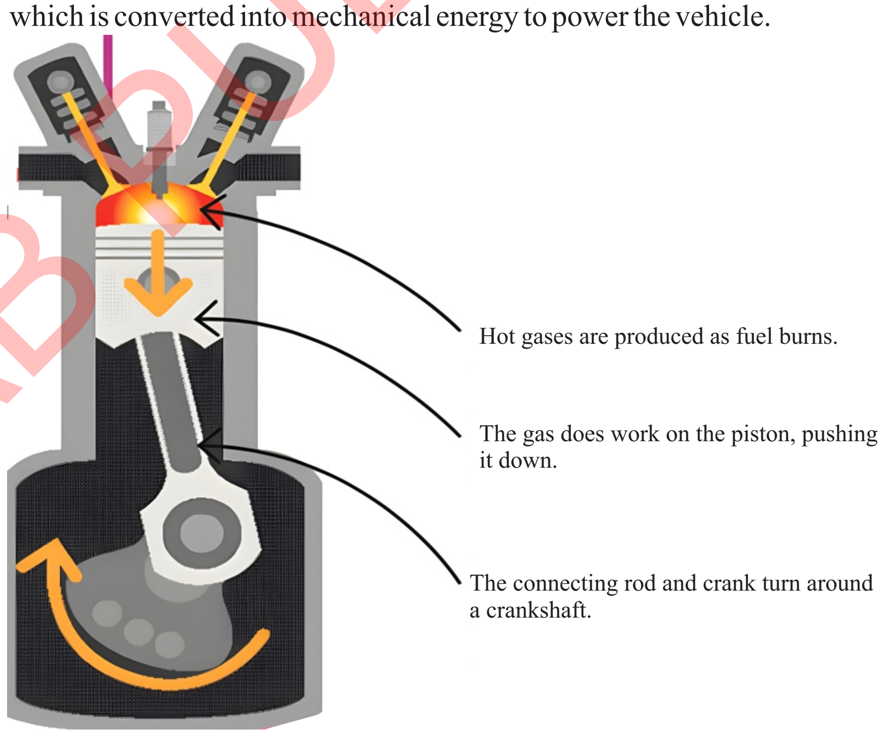


Figure 1.6: Expansion of hot gases pushes the piston, transferring energy to the crankshaft via the connecting rod.

5. Control Systems Using Bimetallic Strips:

Different substances expand at varying rates when subjected to temperature changes. When two strips of different metals as show in Fig.1.7, such as copper and iron, are joined together by welding or rivetting, their differing rates of expansion cause the composite strip to bend. This combined strip is known as a bimetallic strip. When heated, one side of the strip elongates more than the other, causing the strip to curve. Conversely, when cooled, the strip bends in the opposite direction because the metal that expanded more also contracts more. This bending motion can be used to operate a pointer, adjust a valve, or activate a switch. Bimetallic strips are commonly found in devices like fire alarm, , car indicators, thermostats in iron, electric toasters, and various other appliances. In a fire alarm, heat from a fire causes the bimetallic strip to bend and complete an electrical circuit, triggering the alarm bell as shown in Fig1.8 (a). Similarly, bimetallic strips are used in car indicators; an electric heating coil wound around the strip causes it to bend, intermittently completing the circuit and making the indicator lights flash.

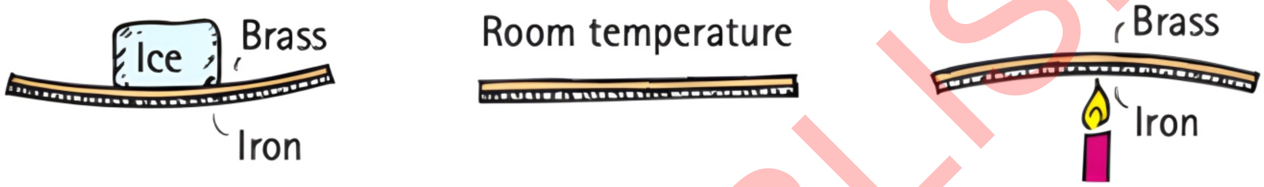


Figure 1.7: A bimetallic strip, showing how brass expands and contracts more than iron. This difference in expansion and contraction causes the strip to bend when heated or cooled.

In thermostats, which help maintain a constant temperature in appliances like irons or room heaters, the bimetallic strip bends when the desired temperature is reached, breaking the electrical circuit and turning off the heater. As the appliance cools slightly, the strip straightens and remakes the contact, turning the heater back on. This process results in a near-steady temperature. Adjusting the control knob changes how much the strip must bend to break the circuit, effectively setting a higher or lower temperature for the device as shown in Fig.1.8(b).

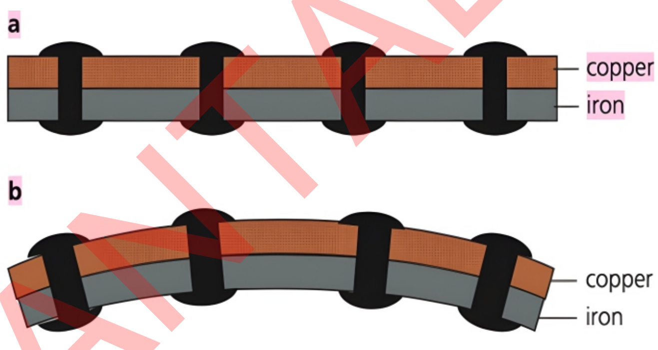


Figure 1.8 (a): Bimetallic strip bending due to different expansion rates of copper and iron.

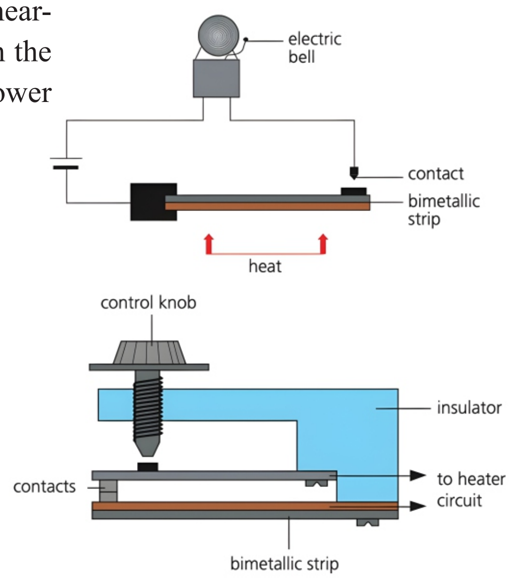


Figure 1.8 (b): Applications of bimetallic strips: (a) fire alarm, (b) thermostat in an iron.

Consequences of Thermal Expansion

1. Engineering Precautions: Thermal expansion must be carefully considered in the design of structures and mechanical systems to prevent damage. For example, railway tracks expand in hot weather. Traditionally, small gaps were left between rail sections to accommodate this expansion, creating the familiar 'clickety-clack' sound as trains passed. However, modern rails are welded into longer lengths and anchored by concrete sleepers that can withstand the forces generated by thermal expansion without buckling. At the ends, the rails are tapered and overlapped to allow some expansion and provide a smoother ride as shown in Fig.1.9.

Figure 1.9: Tapered rail overlap to accommodate thermal expansion.

2. **Structural Gaps and Expansion Joints:** Thermal expansion also affects buildings, bridges, and piping systems. Slight gaps are left between lengths of materials like aluminum in guttering to prevent warping or breakage during expansion in hot weather. In central heating systems, 'expansion joints' are used to accommodate the thermal expansion of hot water pipes as shown in Fig.1.10. These joints allow the copper pipes to expand safely when they carry hot water, preventing cracks or leaks in the system.

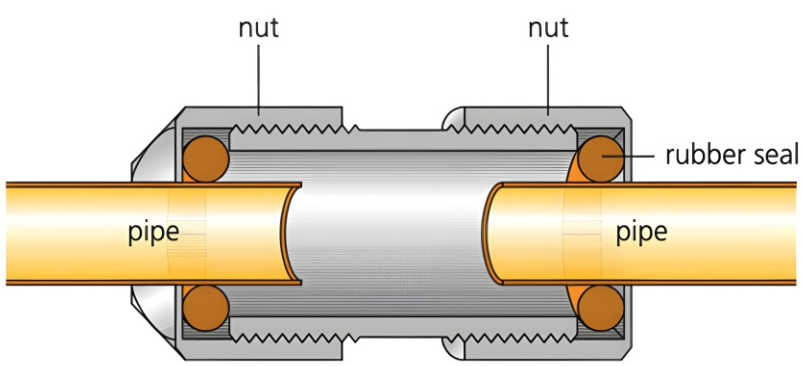


Figure 1.10: Expansion joint allowing pipes to expand.

3. **Potential Problems Due to Thermal Expansion:** While thermal expansion can be useful, it can also cause challenges. If materials are not allowed to expand or contract freely, large internal stresses can develop, leading to structural failure, warping, or damage. For example, in extreme temperature conditions, if expansion joints or gaps are not appropriately accounted for, bridges, buildings, and pipelines can suffer significant damage or deformation.

Linear and Volume thermal Expansion

Thermal expansion of solids is a fundamental concept that explains how materials alter in size or volume due to temperature changes. As we discussed, metal railway tracks lengthen during hot weather, which can lead to bending if the expansion is not managed properly. In a different application, hot air balloons showcase volumetric expansion: as the air inside is heated, it expands, increasing the balloon's volume and causing it to rise and float. These everyday examples highlight how both linear and volumetric expansions affect material behavior in practical situations.

Linear Expansion: When a solid object is heated, its atoms or molecules gain kinetic energy and vibrate more vigorously. This increased movement causes the material to expand along its length as shown in Fig.1.11. Linear expansion is most noticeable in elongated objects like metal rods or railway tracks. The amount of expansion is proportional to the original length of the object and the temperature change. This relationship can be expressed using the formula:

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T \text{------------------}(1.1)$$

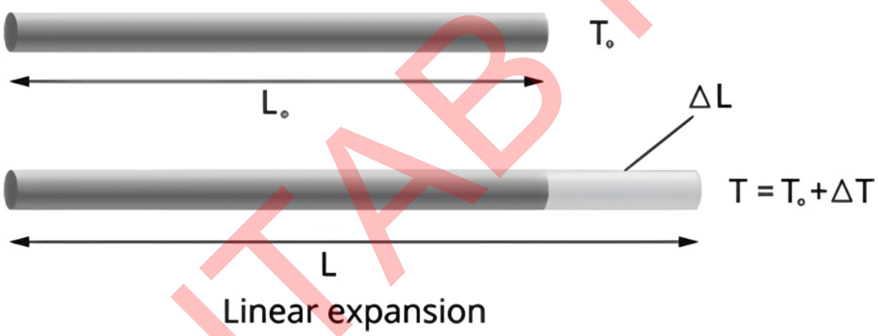


Figure 1.11: Thermal expansion of a rod, showing an increase in length with temperature change.

where ΔL is the change in length L_0, is the original length, α is the coefficient of linear expansion, and ΔT is the change in temperature. For example, a metal rod will lengthen when heated and shorten when cooled, which is essential for engineering applications to avoid structural failures due to temperature changes.

We can define the coefficient of linear thermal expansion a of a material as fractional increase of length per unit rise of temperature, the SI unit of a is k^{-1}.

$$\alpha = \frac{1}{L_0}\frac{\Delta L}{\Delta T}.$$

The increase in length $= \Delta L = L_T - L_O$

Where LT is the length at temperature T

So, the equation (1.1) can be expressed as

$L_T - L_O = \alpha L_O \Delta T$

$L_T = L_O + \alpha L_O \Delta T)$

$L_T = L_O (1 + \alpha \Delta T)$ …… (1.2)

1.4 EXAMPLE

The length of a metallic bar is 60 cm. The length becomes 60.127cm when the bar is heated from 8°C to 100°C. Calculate the coefficient of linear thermal expansion of the metal.

Solution:

Original length of bar, $L_O = 60$ cm

Length of bar after heating, $L_T = 60.127$ cm

Change in length, $A_L = L_T - L_O = 60.127\text{cm} - 60\text{cm} = 0.127$ cm Initial temperature, $T_O = 8\ °C\ _T$

Final temperature, T= 100°C

Change in temperature, $\Delta T = T - T_O = 100°C - 8°C = 92°C$ Coefficient of linear thermal expansion, α =?

The defining equation for α is: $\alpha = \frac{1}{L_o}\frac{\Delta L}{\Delta T}$, by putting the values:

$$\alpha = \frac{1}{60}\frac{0.127}{92} = 2.3 \times 10^{-5}\ °C^{-1} \text{ OR } 6.3 \times 10^{-3}\ K^{-1}$$

Volumetric Expansion: In addition to length, solids also expand in volume when heated. This volumetric expansion is observed in three-dimensional objects like cubes or spheres as shown in Fig.1.12. A striking example is a hot air balloon: as the air inside the balloon is heated, it expands, increasing the balloon's volume and causing it to rise. Similarly, traditional thermometers use the expansion of a liquid, such as mercury or alcohol, to measure temperature. As the liquid heats up, it expands and moves up the scale, providing an accurate temperature reading. This type of expansion can also be seen in everyday scenarios like freezing water pipes in winter. When water inside pipes freezes, it expands by about 9%, which can cause pipes to burst if not properly insulated. Volumetric expansion can be described by the formula:

$$\Delta V = V_O . \beta . \Delta T \text{ -----------(1.3)}$$

where ΔV is the change in volume, V_0 is the original volume, β is the coefficient of volumetric expansion and is known as the coefficient of cubical thermal expansion of the material, and ΔT is the temperature change. From this Eq. (1.3), we can define coefficient of volume thermal expansion of a substance as the fractional of change in volume per kelvin rise in temperature. The value of β depends upon the material and is different for different materials. The SI unit of coefficient of volume thermal expansion is K^{-1}. It is useful to write Eq. (1.3) in the form of increase in volume in the following manner:

$$V_T - V_O = \beta V_O \Delta T$$

$$V_T = V_O + \beta V_O \Delta T$$

$$V_T = V_O(1 + \beta \Delta T) \ldots\ldots\ldots (1.4)$$

Understanding thermal expansion is essential in various practical applications. For example, engineers need to consider how materials expand and contract in construction to keep structures safe. In manufacturing, materials are made to handle changes in temperature. Overall, both linear and volumetric expansion show how temperature changes can affect the properties of solid materials, influencing how they behave in everyday use and industrial work.

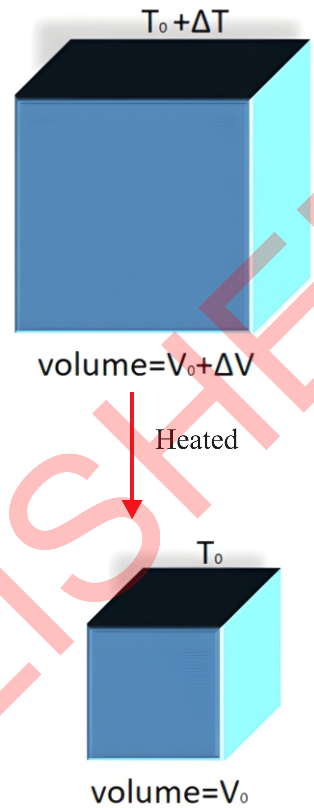


Figure 1.12: Volume expansion of a cube with temperature increase.

1.5 EXAMPLE

A 200 cm^3 piece of lead is at 10 °C. It is heated to the temperature of 40°C. Find the change in volume of the lead. Coefficient of volume thermal expansion $\beta = 0.87 \times 10^{-4}\,°C^{-1}$.

Solution: Original volume of piece of lead, $V_o = 200\ cm^3$

Initial temperature, $T_o = 10°C$

Final temperature, $T = 40\ °C$

Change in temperature, $\Delta T = T - T_o = \Delta T = 40°C - 10°C = 30°C$

Change in volume of the lead $\Delta V = ?$

The defining equation for the increase in volume is:

$\Delta V = \beta V_O \Delta T$, by putting the values:

$\Delta V = 0.87 x\, 10^{-4}\, C^{-1} \times 200\ cm^3 \times 30°C = 0.522\ cm^3$

Thermal Expansion of Liquids [Real and Apparent Expansion].

Thermal expansion in liquids presents a unique scenario compared to solids due to the inherent nature of liquids-they lack a definite shape and instead take the shape of their container. As a liquid is heated, it expands, but so does the container hold it. This dual expansion complicates our measurement of the liquid's true volume change with temperature. To address this, we define two types of thermal expansion for liquids: real expansion and apparent expansion.

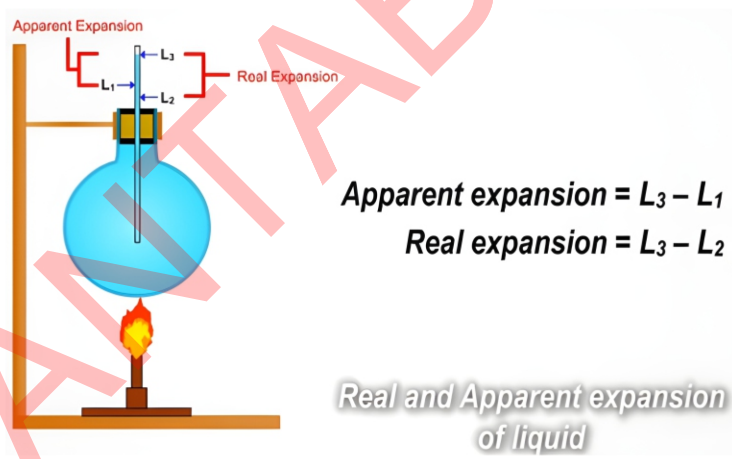


Figure 1.13: Real and apparent expansion of a liquid, showing the relationships $L_3 - L_1$ (apparent) and $L_3 - L_2$ (real).

Real expansion refers to the actual increase in the volume of a liquid resulting purely from a change in its temperature as shown in Fig.1.13, independent of any expansion of the container. If we could isolate the liquid from its container's influence, the real expansion would be the only measure of how much the liquid's molecules spread apart due to heating. In practical situations, however, this is not directly observable because the container also expands when heated, causing the liquid's expansion to appear different from its true extent.

This leads us to the concept of apparent expansion, which is the observed increase in the volume of a liquid when both the liquid and its container are heated. This apparent expansion is always less than the real expansion because it reflects the combined effect of both the liquid expanding and the container expanding. The container's expansion creates extra space, making the liquid's expansion appear smaller than it actually is.

The relationship between these two expansions can be captured mathematically. The real expansion of the liquid (ΔV_{real}) is the sum of the apparent expansion ($\Delta V_{apparent}$) and the expansion of the container ($\Delta V_{container}$). Thus, the formula can be expressed as:

$$\Delta V_{\text{real}} = \Delta V_{\text{apparent}} + \Delta V_{\text{container}}$$

For example, if a liquid seems to expand by 5 mL when heated in a container that itself expands by 2 mL, the real expansion of the liquid would actually be 7 mL, accounting for the expansion of both the liquid and the container.

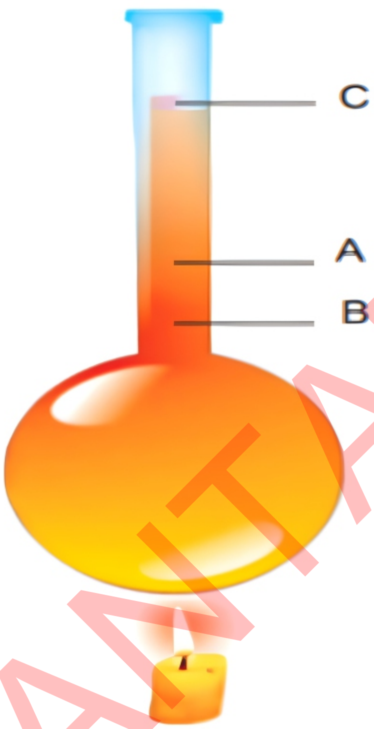


Figure 1.14: Real and Apparent expansion of Liquid.

Activity

Observing Real Volume Expansion of a Liquid

1 **Setup:** Take a long-necked flask and fill it with colored liquid up to mark A as shown in Fig.1.14. Begin heating the flask from the bottom.

2 **Observation:**

- The liquid level initially drops to point B and then rises to point C.
- This initial drop occurs because the flask expands before the liquid, causing the liquid level to fall.
- As the liquid heats up, it expands more than the flask, and the level rises to point C.

3 **Conclusion:**

- The rise from A to C represents the apparent expansion of the liquid.
- The real expansion of the liquid is greater, accounting for the flask's expansion as well.
- Mathematically: $\mathrm{BC} = \mathrm{AC} + \mathrm{AB}$.

4 **Definition:**

- The real rate of volume expansion β_r of a liquid is the true change in its volume per unit volume per 1°C (or 1 K) temperature increase.
- It is given by: $\beta_r = \beta_a + \beta_g$, where:
- β_r = Real expansion coefficient of the liquid
- β_a = Apparent expansion coefficient of the liquid
- β_g = Expansion coefficient of the container

Different liquids have unique coefficients of volume expansion.

C1.2 Knowledge

Analyzing the Pressure of a Gas in Terms of Particle Behavior

In gases, particles are much farther apart than in solids or liquids about ten times the distance. This spacing makes gases much less dense and easily compressible. The particles move rapidly (around 500 ms^{-1} for air molecules at 0°C) and occupy all the available space. The forces between particles only act during brief collisions with other particles or the surfaces of their container.

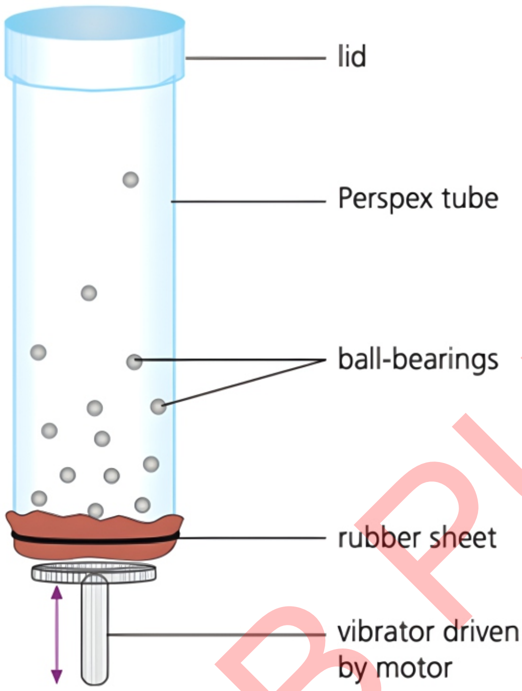


Figure 1.15: Model demonstrating particle behavior in a gas.

To visualize gas pressure, imagine a model where ball bearings represent gas particles as shown in Fig.1.15. When a vibrator shakes the tube, the bearings collide with the lid, tube, and each other, exerting force—this force per unit area is pressure. If the vibrator shakes faster, the bearings move faster, collide more frequently, and pressure increases, just as gas pressure rises with temperature. Adding more ball bearings simulates increasing the number of gas particles, similar to pumping more air into a tire, increasing pressure. A small polystyrene ball dropped into the tube moves erratically, demonstrating Brownian motion and supporting the kinetic particle model of matter.

Pressure in a gas results from these collisions of particles with the container walls. It is defined as the force exerted per unit area by these collisions.

Factors Affecting Gas Pressure:

1. Temperature: Increasing the temperature raises the kinetic energy of gas particles, making them move faster. This leads to more frequent and

Do You Know?

Unusual Expansion of Water

Water exhibits an unusual expansion behavior between 4°C and 0°C: it first contracts until it reaches its maximum density at 4°C. As it cools further to 0°C, water expands due to the formation of an open hexagonal structure by hydrogen bonds, requiring more space. Upon freezing at 0°C, this structure causes ice to occupy even more volume, making it less dense than liquid water, which is why ice floats.

Figure below shows a bottle of frozen milk demonstrating this expansion effect, where the water in the milk expands upon freezing, causing the bottle to crack.

Skill:1.1

Objective:

- Explain thermal expansion using kinetic theory for solids, liquids, and gases, compare their relative expansion, describe linear and volumetric expansion in solids, and analyze real and apparent expansion in liquids along with their applications and effects in real life.

forceful collisions with the container walls, increasing pressure. Lowering the temperature decreases particle speed, reducing pressure.

2. Volume: Reducing the volume of the container confines the gas particles to a smaller space, increasing the frequency of collisions and raising pressure. Expanding the volume gives particles more space, lowering the frequency of collisions and thus the pressure.

3. Number of Particles: Adding more particles to a fixed volume increases the number of collisions with the container walls, raising pressure. Removing particles has the opposite effect, decreasing pressure.

Multiple Choice Question

1. Which statement best describes thermal expansion in terms of kinetic theory?
   a) Particles slow down as temperature increases.
   b) Particles move faster and require more space as temperature increases.
   c) Particles move closer together as temperature increases.
   d) Particles remain stationary regardless of temperature changes.
2. Why do gases expand more than liquids and solids for the same temperature increase?
   a) Gases have weaker intermolecular forces.
   b) Gases are denser than solids and liquids.
   c) Gases contain fewer particles.
   d) Gases cannot transfer heat efficiently.
3. Which of the following is an application of thermal expansion?
   a) Gaps in railway tracks to prevent buckling due to heat expansion
   b) Expansion of water when it freezes
   c) Melting of ice at high temperatures
   d) Water boiling at high altitudes
4. What is apparent expansion in liquids?
   a) The expansion of a liquid relative to the container's expansion.
   b) The expansion of a liquid due to changes in pressure.
   c) The contraction of a liquid when cooled.
   d) The expansion of a liquid ignoring external factors.

Skill:1.2

Objective:

- Analyze gas pressure and its changes based on particle collisions exerting force per unit area on surfaces.

Test Yourself

Short answer-based questions

1 Explain why gases expand more than solids and liquids when heated, based on the kinetic theory.

2 Why are bridges and railway tracks designed with expansion gaps?

3 Differentiate between real and apparent expansion of liquids with examples.

4 Describe the difference between linear and volumetric expansion in solids.

C1.3 Knowledge

Superconductivity

As temperature of solids increases, the kinetic energy of particles also increases, causing more vibration and movement within the material. Conversely, when temperature decreases, the vibrational motion of particles slows down. This leads to the interesting question: can we stop particle vibrations entirely by lowering the temperature? The answer is yes-this has been observed in certain materials known as superconductors.

When cooled to extremely low temperatures near absolute zero or 0 K, some materials exhibit superconductivity as shown in Fig.1.16, a state where electrical resistance drops to zero. At these low temperatures, particle vibrations decrease significantly, and the material reaches a minimal energy state. This allows electric currents to flow without any energy loss. The temperature at which a material transitions into this superconducting state is known as the critical temperature (T_c). Different materials have different critical temperatures, for example:

- Mercury becomes superconducting at 4.2 K.
- Lead becomes superconducting at 7.2 K.
- High-temperature superconductors, like Yttrium Barium Copper Oxide (YBCO), can exhibit superconductivity at 92 K.

The discovery of superconductivity was made by Heike Kamerlingh Onnes in 1911 when he cooled mercury to 4.2 K and observed its electrical resistence dropped to zero. This breakthrough revolutionized our understanding of materials and their behavior at low temperatures.

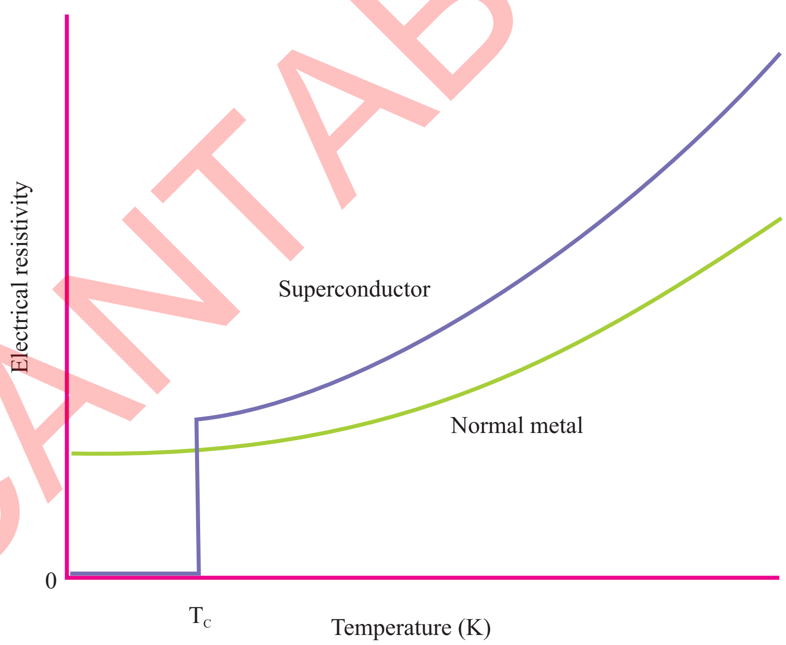


Figure 1.16: Variation of electrical resistivity with temperature for a superconductor and a normal metal.

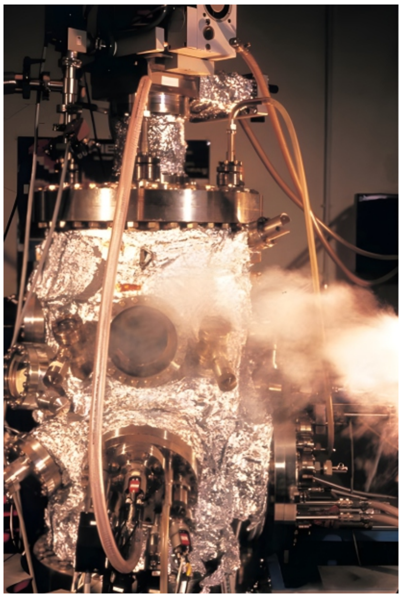


Figure 1.17: Equipment for fabricating superconducting films at high temperatures.

Do You Know?

Electron Behavior at Room Temperature:

At room temperature, the Drude model and classical free electron theory describe the behavior of electrons in a conductor. In these theories, electrons are treated like free particles that move through a "sea" of positive ions (the atomic lattice). The electrons are frequently scattered by vibrating atoms, leading to resistance and energy loss as heat. Unlike superconductors, in normal conductors, there is no mechanism to prevent these collisions, and resistance remains finite.

Skill:1.3

Objective:

- Explain superconductivity as a phenomenon where certain materials, when cooled near absolute zero, exhibit little or no electrical resistance due to low atomic kinetic energy.

Zero Resistance Through Low Kinetic Energy and Cooper Pairing

In the superconducting state, the kinetic energy of the atoms becomes extremely low, causing their vibrations to nearly stop. This creates a condition where **Cooper pairs** form—pairs of electrons bound together by a weak attractive force mediated by vibrations in the atomic lattice, called phonons. According to the BCS theory, these Cooper pairs move through the material in a coordinated manner, without scattering off atoms. In normal conductors, individual electrons scatter due to atomic vibrations, which creates electrical resistance. However, in superconductors, the formation of Cooper pairs allows electrons to flow smoothly without resistance, resulting in zero electrical resistance. This coordinated motion of Cooper pairs allows electric current to flow indefinitely without energy loss, which is the defining feature of superconductivity. Equipment used to fabricate films of composite materials that exhibit superconductivity, enabling zero electrical resistance through the formation of Cooper pairs as shown in Fig.1.17.

Multiple Choice Question

1. Which of the following materials exhibits superconductivity at the lowest temperature?
   a) Lead (7.2 K)
   b) Mercury (4.2 K)
   c) Yttrium Barium Copper Oxide (92 K)
   d) Iron (2 K)
2. What is the key characteristic of a material in the superconducting state?
   a) High electrical resistance
   b) The kinetic energy of atoms is high
   c) Electrical resistance drops to zero
   d) Electrons scatter off atoms
3. What forms when the kinetic energy of particles decreases to near absolute zero in superconductors?
   a) Cooper pairs of electrons
   b) Phonons that scatter electrons
   c) High energy vibrations
   d) Increased resistance

Test Yourself

Short answer-based questions

1. Why certain materials exhibit superconductivity when cooled to very low temperatures near absolute zero?
2. Describe how the behavior of electrons in superconductors differs from that in normal conductors.

Key Points

- Thermal expansion occurs when the temperature of a material increases, causing its particles to move apart.
- Solids have minimal expansion due to tightly packed particles, while liquids expand five times more and gases expand 20 times more than solids for the same temperature increase.
- Kinetic theory explains that as temperature increases, particles vibrate more, and in gases, this results in the particles moving even faster and spreading apart.
- Thermal expansion is used in precision engineering, such as in the fitting of mechanical components like axles and gears.
- In everyday life, thermal expansion helps loosen tight metal lids by heating them, as metals expand more than glass.
- It is used in thermometers, where liquids like mercury or alcohol expand with temperature to provide accurate readings.
- Thermal expansion in engines and bimetallic strips drives mechanical systems and controls devices like thermostats, fire
- alarms, and car indicators.
- Linear expansion refers to the change in length of a solid with temperature increase, represented by the formula $\Delta L = L \quad \alpha \; \Delta T$.
- Volumetric expansion is the change in volume of an object when heated, with the formula $\Delta V = V \quad \beta \; \Delta T$.
- Materials expand more in volume than in length for the same temperature change, with gases exhibiting the largest expansion, followed by liquids and solids.
- Liquids show real and apparent expansion. Real expansion is the true increase in the liquid's volume, while apparent expansion includes both the liquids and container's expansion, making the liquid's expansion seem smaller.
- Superconductivity occurs when certain materials are cooled to near absolute zero, causing electrical resistance to drop to zero.
- At low temperatures, particle vibrations slow down significantly, allowing electrons to flow without resistance in a state known as superconductivity.
- Materials such as mercury (4.2 K), lead (7.2 K), and YBCO (92 K) exhibit superconductivity at different temperatures.
- The BCS theory explains superconductivity through the formation of Cooper pairs, where electrons move in a coordinated manner, preventing scattering and eliminating electrical resistance.

Exercise

After completing the chapter students practice SLO based exercise to prepare for examination. Each SLO include three types of question: Multiple choice question (MCQs), Short response question (SRQs), Extended response question (ERQs) and detailed exercise solution available in QR code.

Explain thermal expansion in terms of kinetic theory. (Understanding)

Multiple-Choice Questions

1. Which of the following states of matter has the least thermal expansion upon heating?
   a) Solids b) Liquids c) Gases d) All states expand equally
2. What happens to the particles in a substance when it is heated and undergoes thermal expansion?
   a) The particles contract and move slower
   b) The particles move faster and spread apart
   c) The particles move slower and stay in place
   d) The particles do not change at all
3. What is the primary cause of thermal expansion in materials?
   a) The increase in the density of particles
   b) The decrease in the kinetic energy of particles
   c) The increase in the distance between particles due to the rise in temperature
   d) The increase in intermolecular forces between particles

Short Response Questions

1. How thermal expansion differs in solids, liquids, and gases according to the kinetic theory of matter.
2. Describe the behavior of materials when they are heated and how it affects their size and shape, both in solids and liquids.

Extended Response Questions

1. Explain thermal expansion in solids, liquids, and gases in terms of the kinetic theory of matter. How does the magnitude of expansion vary for these three states of matter?
2. Analyze the consequences of not accounting for thermal expansion when designing structures like bridges or railways.

Analyze the applications and consequences of thermal expansion in real life.

Multiple-Choice Questions

1. What is an example of thermal expansion in real life?
   a) A bridge shrinking in length during cold weather
   b) Metal railroads expanding and bending in hot weather
   c) Water freezing and expanding
   d) Air molecules becoming static when cooled
2. Why does a tightly fitting lid on a glass jar become easier to open when immersed in hot water?
   a) The glass expands more than the metal lid, loosening the fit
   b) The metal expands more than the glass lid, making it easier to twist off
   c) The expansion of the glass causes the metal to contract
   d) The temperature difference increases the friction between the lid and jar
3. How do thermal expansion and contraction affect the design of a railway track?
   a) Tracks are made shorter to prevent them from expanding during hot weather
   b) Gaps are left between sections to accommodate expansion in the summer
   c) Tracks are welded tightly to prevent any movement during heat
   d) Tracks are made of materials with low thermal expansion to avoid warping

Short Response Questions

1. How does the principle of thermal expansion apply to the functioning of a thermometer?
2. Why is it important to leave gaps between metal parts in mechanical systems during extreme temperature changes?

Extended Response Questions

1. Analyze the applications of thermal expansion in engineering and construction. How are expansion joints used to prevent damage in bridges and buildings?
2. Explain the design of a pressure cooker and how it utilizes the concept of thermal expansion.

Analyze the applications and consequences of thermal expansion in real life.

Multiple-Choice Questions

1. Which is an example of linear expansion in solids?
   a) Gas volume increase when heated
   b) Length of a metal rod expands
   c) Liquid column height increases
   d) Metal sheet area increases
2. How do bimetallic strips work?
   a) Both metals expand equally
   b) Metal with higher expansion bends more
   c) They maintain constant shape
   d) They expand and contract uniformly

Short Response Questions

1. Differentiate between linear and volumetric expansion in solids, providing examples of each.
2. How the expansion of a metal rod upon heating is an example of linear expansion.

Extended Response Questions

1. Explain the behavior of materials when they are heated and how this affects their size and shape, specifically in solids and liquids.
2. A metal rod of length 2 m expands by 0.004 m when heated from 25°C to 100°C. Find the coefficient of linear

expansion of the metal. **[2.67×10^{-5} °C^{-1}]**

3. A 300 cm^3 piece of lead is heated from 10°C to 40°C. Calculate the change in volume. The coefficient of volume thermal expansion of lead is 0.87×10^{-4}°C . **[0.522 cm^3]**
4. A 500 cm^3 volume of mercury is heated from 15°C to 35°C. The coefficient of volume thermal expansion for mercury is 1.8×10^{-4}°C^{-1}. What is the change in volume? **[1.8 cm^3]**

Explain the thermal expansion of liquids [real and apparent expansion].

Multiple-Choice Questions

1. When would apparent expansion of a liquid occur?
   a) Liquid heated in a non-expanding container
   b) Both container and liquid expand
   c) Liquid expands in an open container
   d) Liquid contracts without temperature change

Short Response Questions

1. Differentiate between real and apparent expansion in liquids, providing examples of each.
2. How does the expansion of a liquid in a thermometer demonstrate the concept of real expansion?

Extended Response Questions

1. Explain the concept of real and apparent expansion of liquids. How does this affect the measurement of liquid volume in thermometers or the functioning of devices that rely on the expansion of liquids?
2. Describe how the thermal expansion of liquids applies to thermometers and how real and apparent expansion play roles in the measurements.

Analyse the pressure and the changes in pressure of a gas in terms of particles. (Application)

Multiple-Choice Questions

1. What happens to gas particles as temperature increases?
   a) Move slower, gas contracts
   b) Move faster, gas volume increases
   c) Stay still, gas expands uniformly
   d) Lose energy, condensation occurs
2. What causes gas pressure according to the kinetic theory?
   a) The constant movement of gas molecules and their collisions with the container walls
   b) The attraction between gas molecules
   c) The temperature of the gas molecules
   d) The volume of the gas

Short Response Questions

1. Describe how the motion of gas particles leads to the generation of pressure on the walls of a container.
2. Why the pressure of a gas increases as its temperature increases, based on the kinetic theory.

Extended Response Questions

1. How does the pressure of a gas change with temperature and volume according to the kinetic theory? Analyze how this behavior explains phenomena like the increased pressure inside a car tire on a hot day.
2. Explain how the kinetic energy of gas particles changes with temperature and how it relates to pressure in a confined gas.

State that certain materials, when cooled to near absolute zero, can exhibit superconductivity. (Knowledge)

Multiple-Choice Questions

1. What happens when certain materials are cooled near absolute zero?
   a) They become superconductors
   b) They lose all their electrical properties
   c) They contract to a point where they can be compressed
   d) They remain unchanged

2. At what temperature range do materials typically exhibit superconductivity?

a) At high temperatures

b) At absolute zero or near absolute zero temperatures

c) At room temperature

d) At temperatures above 100°C

Short Response Questions

1. State the condition under which certain materials exhibit superconductivity.
2. Describe the concept of superconductivity and explain how it relates to the temperature of materials.

Describe superconductivity [as when atoms are in this state, their kinetic energy is low, so there is little (or no) resistance to the flow of electrons.] (Understanding)

Multiple-Choice Questions

1. Which of the following is a property of superconductors when cooled to near absolute zero?

a) They have high resistance to electric current

b) They allow current to flow without any resistance

c) They become magnetic

d) They lose all their electrons.

2. What is the main factor that causes superconductivity in materials?

a) The temperature rises to a critical level

b) The material gains a magnetic property

c) The atoms in the material have very low kinetic energy, allowing electrons to move freely.

d) The material becomes completely solid.

Short Response Questions

1. Why does superconductivity lead to zero resistance to the flow of electricity?
2. Describe how superconductivity can be useful in practical applications, such as in medical devices or power transmission.

Extended Response Questions

1. Describe the formation of Cooper pairs and explain how they result in superconductivity. How does this phenomenon affect the flow of electricity in superconductors?
2. Explain the conditions under which superconductivity occurs. Discuss how this phenomenon is utilized in technologies like MRI machines or particle accelerators.

CHAPTER 1

D1.1 **Knowledge**

Thermal Conduction in Solids

Student Learning Outcomes

[SLO: P-10-C-31]: Explain thermal conduction in all solids [in terms of atomic or molecular lattice vibrations and also in terms of the movement of free (delocalized) electrons in metallic conductors]

[SLO: P-10-C-30] Justify experiments to distinguish between good and bad thermal conductors.

D1.2 **Knowledge**

Thermal Energy Transfer by Radiation

Student Learning Outcomes

[SLO: P-10-C-32] Explain convection in liquids and gasses [in terms of density changes]. Justify experiments to illustrate convection.

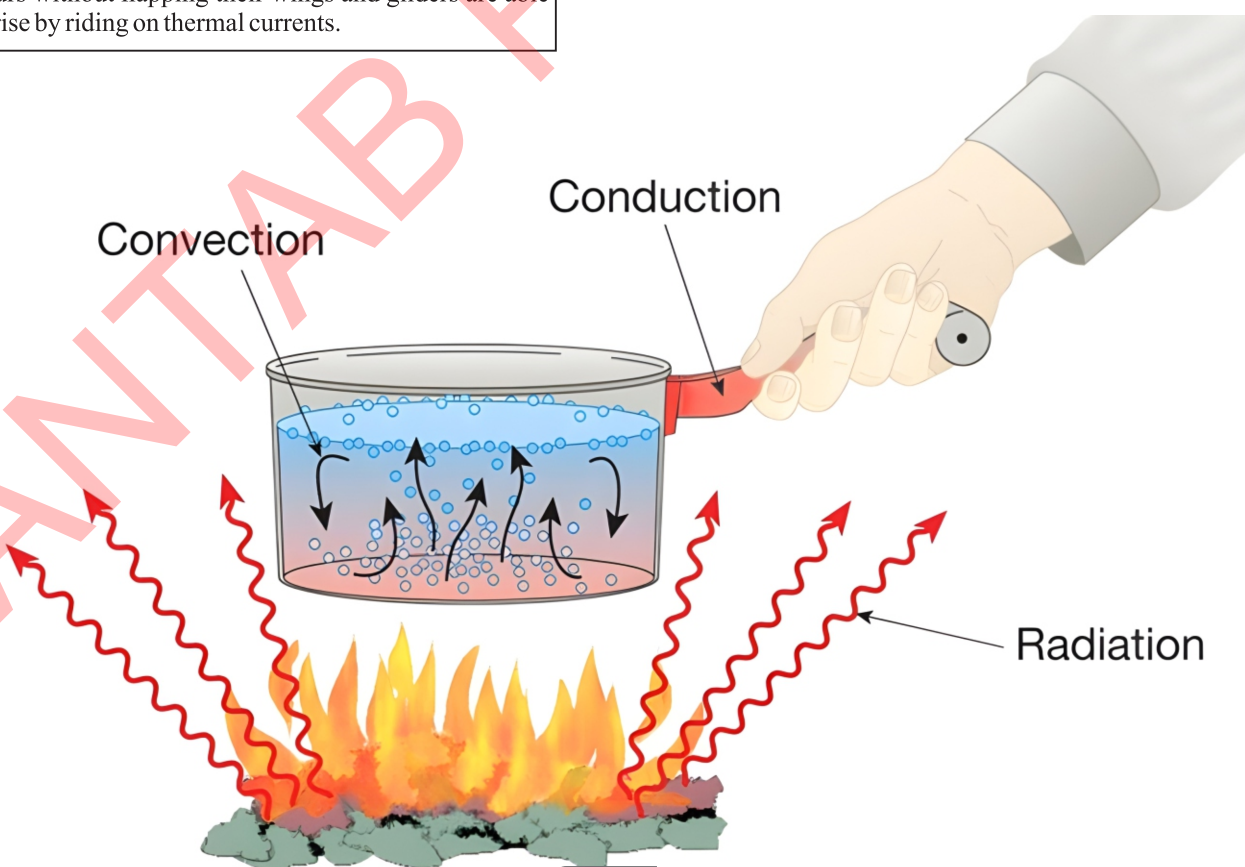
[SLO: P-10-C-34] Describe the role of land breezes and sea breezes in maintaining moderate coastal climates

[SLO: P-10-C-33] Explain convection in seawater to support marine life.

[SLO: P-10-C-35] Explain how birds are able to fly for hours without flapping their wings and gliders are able to rise by riding on thermal currents.

Section D

Modes of Heat Transfer and Its Applications



D1.3 Knowledge

Superconductivity

Student Learning Outcomes

[SLO: P-10-C-36] Describe the process of thermal energy transfer by radiation [and know that it does not require a medium]

[SLO: P-10-C-38] Justify qualitatively how the rate of emission of radiation depends on the surface temperature and surface area of an object

[SLO: P-10-C-37] Describe the effect of surface color and texture on the emission, absorption and reflection of infrared radiation

[SLO: P-10-C-39] Justify Experiments to distinguish between good and bad emitters and absorbers of infrared radiation

[SLO: P-10-C-40] Analyze the consequence of heat radiation in the greenhouse effect and its effect in global warming.

D1.4 Knowledge

Applications of Heat Transfer

Student Learning Outcomes

[SLO: P-10-C-41] Analyze everyday applications of conduction, convection and radiation **[Including:**

(a) heating objects such as kitchen pans
(b) heating a room by convection

(c) measuring temperature using an infrared thermometer

(d) using thermal insulation to maintain the temperature of a liquid and to reduce thermal energy transfer in buildings

(e) the mechanism of a household hot-water system**]**

Introduction

Heat transfer is essential in daily life, from cooking to climate control, and occurs through **conduction, convection, and radiation. Conduction** in solids transfers heat as vibrating particles pass energy to neighbors, with metals conducting efficiently due to free electrons. **Convection** in liquids and gases moves heat through rising warm fluid and sinking cool fluid, forming currents that warm rooms, regulate coastal climates, and sustain marine life. Birds and gliders use these currents to stay airborne. **Radiation** transfers heat through electromagnetic waves without a medium, as seen in the Sun's warmth. Dark surfaces absorb heat well, while shiny surfaces reflect it, influencing the **greenhouse effect** and global warming. These processes have practical applications, including heating pans, warming rooms, infrared thermometers, insulation, and household heating systems. Through experiments and real-world examples, this chapter explores the impact of heat transfer on technology, the environment, and daily life.

D1.1 Knowledge

Thermal Conduction in Solids

Thermal conduction is the process by which heat is transferred through a material from a region of higher temperature to a region of lower temperature, without the movement of material itself. In solids, conduction occurs in two main ways: lattice vibrations and free electron movement, particularly in metals. Understanding this process is key to explaining how heat travels through different materials, affecting everything from cooking to building design.

Thermal Conduction in Insulating Materials

Insulators, such as wood, plastic, Styrofoam, and wool, are poor conductors of heat because they lack free electrons, which play a key role in rapid heat transfer in metals. Instead, heat transfer in insulators occurs through lattice vibrations as shown in Fig.1.1, where atoms or molecules in a regular arrangement transfer energy to neighboring particles when heated. These vibrations are described as phonons, the quantized units of thermal energy in a lattice. However, phonons move less efficiently compared to free electrons, making the heat transfer in insulators slower and less effective. As a result, materials like wood, plastic, and glass rely on this slower phonon-based conduction, which makes them effective at retaining heat and preventing rapid energy loss.

For example, if you heat one end of a wooden spoon, it will take time for the heat to travel to the other end because the vibrations (phonons) move slowly through the tightly bound particles. This property makes materials like wood and plastic ideal for everyday objects, such as the handles of kitchen utensils or window frames, as they effectively slow down heat transfer and provide safety and comfort.

Conduction by lattice vibration

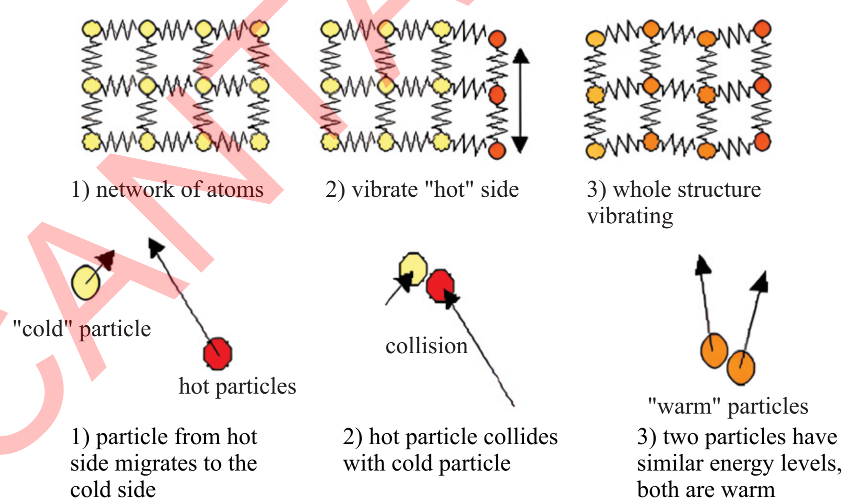


Figure 1.1: Heat conduction via lattice vibrations transferring energy through particle collisions.

Thermal conduction in metals

In metals, thermal conduction is rapid due to the presence of free electrons as shown in Fig.1.2, which can move freely within the material. When heated, these electrons gain energy and transfer heat by colliding with other electrons and atoms, allowing metals to conduct heat efficiently.

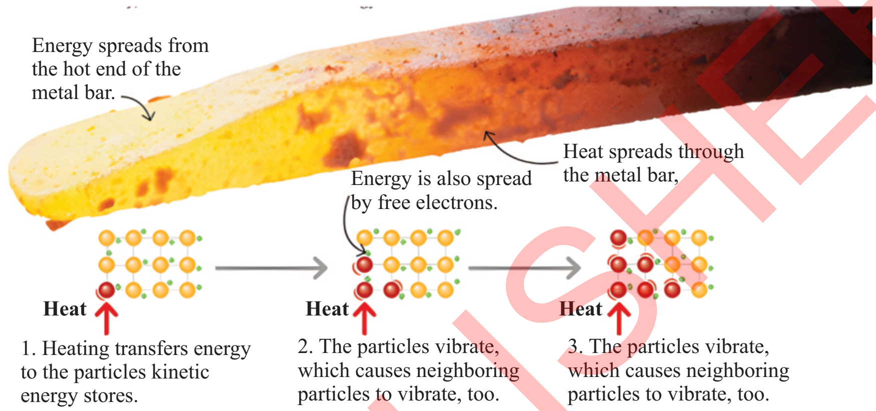


Figure 1.2: Heat conduction through a metal bar via particle vibrations and free electron movement.

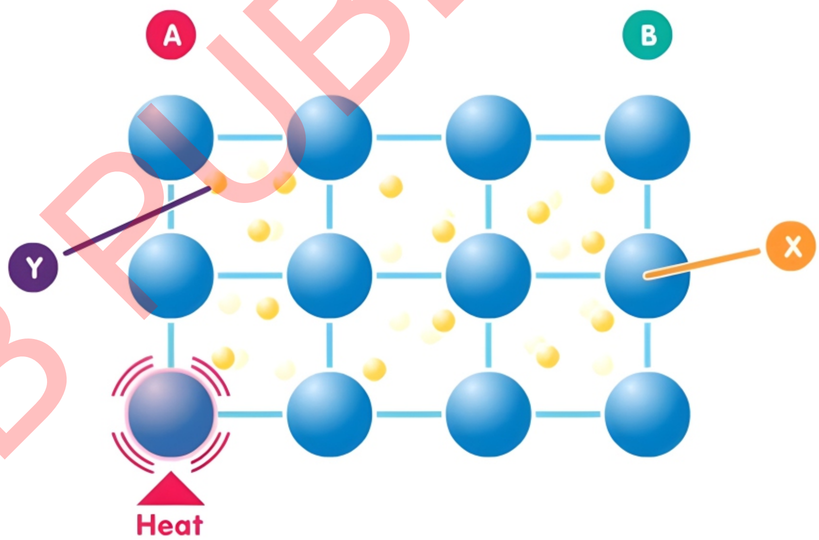


Figure 1.3: Heat transfer in a solid through particle vibrations and energy propagation.

For example, in a **metal spoon** placed in a hot drink, the free electrons in the metal rapidly carry heat from the hot end of the spoon to the cooler end, making the handle warm to the touch. The efficiency of this heat transfer depends on the metal's ability to allow free electrons to move; **copper** is one of the best conductors of heat, followed by **aluminum** and **iron**.

A classic experiment demonstrates this using metal rods made of different materials, as shown in Fig.1.4. A **copper rod** conducts heat quickly, causing a match attached to its far end with wax to fall off before matches on other materials like **aluminum**, **brass**, or **iron**. **Copper** is a better conductor because it has more free electrons to transfer the heat efficiently.

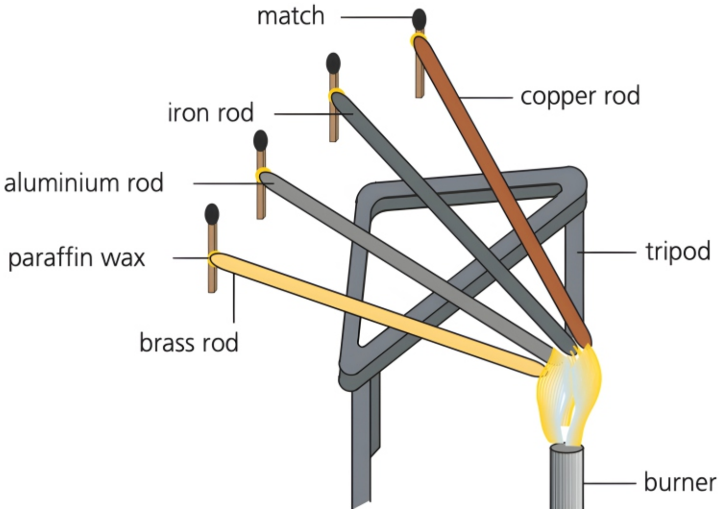


Figure 1.4: Comparing thermal conductivity of different metal

Conductors and Insulators

Dense and crystalline solids, such as metals, are excellent thermal conductors because their tightly packed particles in a lattice structure allow efficient energy transfer to neighboring particles. In contrast, air is a poor thermal conductor since its particles are widely spaced.

Materials that trap air, such as wool sweaters or foam coffee cups, act as thermal insulators by slowing down the transfer of heat. These materials are known as insulators. One of the most effective insulators is aerogel, a silicon-based material that consists of more than 99% air.

Justifying the Distinction Between Good and Bad Thermal Conductors

Good and bad thermal conductors can be distinguished through simple experiments that demonstrate differences in their ability to transfer heat. The following experiments provide clear evidence of this distinction:

Experiment 1: Heat Conduction in Brass and Wood

Wrap a piece of paper around a brass rod and a wooden rod as shown in Fig.1.5, then heat them under the same conditions. The paper on the wooden rod burns because wood, being a poor conductor, cannot transfer heat away quickly, causing heat to accumulate. In contrast, the paper on the brass rod remains intact because brass, a good conductor, efficiently dissipates heat. This demonstrates the higher heat transfer efficiency of good conductors like brass compared to poor conductors like wood.

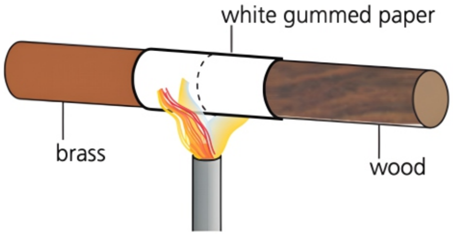


Figure 1.5: The paper over the brass remains unburned due to brass's superior heat conductivity.

THINK

When you touch a nail stuck in ice, does the cold flow from the nail to your hand, or does heat flow from your hand to the nail?

Figure 1.6: The tile floor feels colder than the wood floor due to tile's higher thermal conductivity, which conducts heat away faster.

Experiment 2: Sensation of Cold on Tile and Wood Floors

Place one foot on a tile floor and the other on a wooden floor as shown in Fig.1.6, ensuring both surfaces are at the same temperature. The tile feels colder because it rapidly transfers heat away from the foot due to its high thermal conductivity, while the wooden floor feels warmer as it restricts heat transfer. This illustrates the difference between good conductors (tile) and poor conductors (wood) based on their ability to transfer heat.

How Conductors and Insulators Feel

When you touch an object made of a good conductor like metal, it often feels colder than an object made of an insulator like wood, even if both are at the same temperature. This is because metals conduct heat away from your hand much faster than insulators. Since the metal quickly absorbs heat from your skin, it creates the sensation of coldness. On the other hand, insulators like wood transfer heat more slowly, so they feel warmer to the touch.

Practical Applications of Thermal Conductivity

Understanding thermal conduction is very important in designing tools, buildings, and everyday items. In **cold climates**, homes are insulated with materials like **fiber glass** and **rock wool** to slow the escape of heat as shown in Fig.1.7, making them more energy efficient. These materials trap air, which is a poor conductor of heat, reducing the rate of thermal conduction and keeping homes warm in winter and cool in summer.

In **cooking**, materials with different thermal properties are used to ensure both safety and efficiency. Pots and pans are made of metals like **aluminum** and **copper** to ensure rapid heating, while their handles are often made of plastic or wood to prevent burns.

Firewalkers rely on the low conductivity of materials like **wood** (in the form of hot coals) to walk over red-hot surfaces without burning their feet. The heat from the coals is not conducted quickly enough to cause burns, a demonstration of how materials with poor thermal conductivity can be used to control heat transfer in extreme situations.

Do You Know?

Liquids and gases are poor conductors of heat because their particles are spread farther apart and lack free electrons to transfer energy. For example, in an experiment where the top of a test tube filled with water is heated while ice is placed at the bottom, the water at the top can reach boiling point without melting the ice, demonstrating the slow heat transfer in liquids.

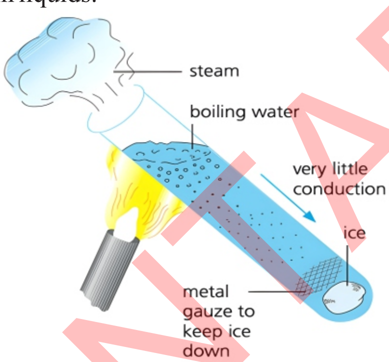


Figure 1.7: Snow patterns on a roof reveal areas of heat conduction and insulation.

Multiple Choice Question

1. How does thermal conduction occur in metals?
   a) Through free electron movement.
   b) Through atomic nuclei movement.
   c) By temperature increase only.
   d) By atom vibrations without electrons.
2. What differentiates good and bad thermal conductors?
   a) Number of free electrons.
   b) Material density.
   c) Atom size.
   d) Material color.
3. How does thermal conduction occur in non-metals?
   a) Through free electrons.
   b) Through lattice vibrations, with minimal electron involvement.
   c) Non-metals do not conduct heat.
   d) Equally through electrons and lattice vibrations.

Skill:1.1

Objective:

- Explain thermal conduction in solids through atomic or molecular lattice vibrations and free electron movement in metals, and justify experiments to compare good and poor thermal conductors.

Test Yourself

Short answer-based questions

1. Why metals are generally better thermal conductors than non-metals, considering their atomic structure and the role of free electrons.
2. Describe an experiment that could help distinguish between good and bad thermal conductors, and why the results of this experiment would be valid.

D1.2 Knowledge

Convection in Liquid and gases

Convection is a fundamental process for heat transfer in fluids, which includes both liquids and gases. Unlike conduction, where heat is transferred through the direct contact of particles, convection involves the movement of the fluid itself. This movement is driven by temperature-induced changes in density.

When a fluid is heated, its molecules gain energy and move more vigorously, causing the fluid to expand and become less dense. As a result, the warmer, less dense fluid rises. Cooler, denser fluid then sinks to replace the rising warm fluid, creating a circulating motion called a convection current as indicated in the Fig.1.8. It keeps the fluid stirred and helps distribute heat evenly throughout the fluid. Thus, the convection can be defined as the ***"Convection is the flow of thermal energy through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself."***

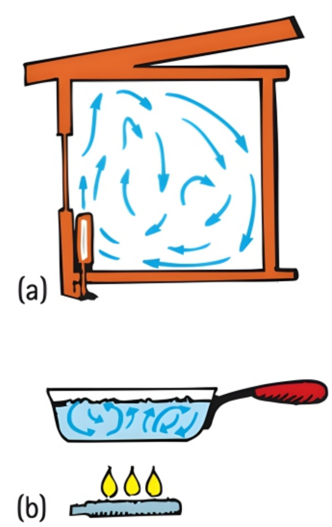


Figure 1.8: (a) Air convection currents. (b) Liquid convection currents.

Density Changes in Convection

Convection occurs due to changes in density when fluids like air or water are heated or cooled. Heating causes molecules to gain energy, move faster, and spread apart, reducing density. This makes the fluid lighter, so it rises. Cooling causes molecules to lose energy, move closer together, and become denser, making the fluid heavier and causing it to sink.

This cycle of rising and sinking fluid creates convection currents, which transfer heat efficiently. Warm, less dense fluid rises, carrying heat to cooler areas, while cooler, denser fluid sinks, maintaining a continuous circulation. This process ensures effective heat transfer in fluids, such as air or water.

Convection in Liquid

A simple way to observe convection in liquids is by heating water in a beaker as shown in Fig.1.9. As the water at the bottom heats up, it becomes less dense and rises, while the cooler, denser water from the top sinks, creating a circulation. Adding potassium permanganate can help visualize this movement, as the dye shows the warm water rising and the cool water sinking.

Convection currents are streams of warm fluid that move due to heating. When a fluid is heated, it expands, becomes less dense, and rises because cooler, heavier fluid moves underneath it, pushing it upward. This is why we say "hot water" or "hot air" rises. It is similar to how a cork in water floats up because it is lighter than the water. Lava lamps work using this same idea as shown in Fig.1.10.

Figure 1.9: Convection currents in water demonstrated using dye.

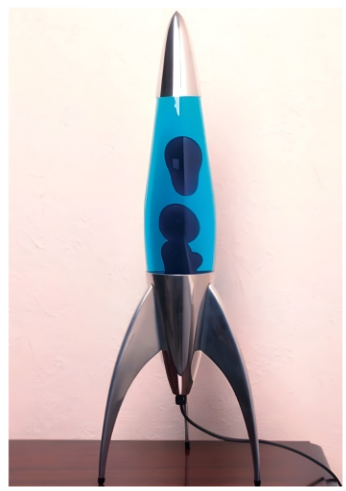


Figure 1.10: Lava lamp demonstrating convection currents.

Convection in Gases

When air near the ground is heated, it becomes lighter and rises. As it moves upward, it cools because it expands in lower pressure areas. Cooler air, which is denser and heavier, then sinks to replace the rising warm air. This continuous movement of warm air rising and cool air sinking creates convection currents as shown in Fig.1.11. These currents are the key feature of convection and show how heat is transferred through the movement of air in the atmosphere.

Black marks on walls or ceilings above lamps or radiators happen because dust is carried up by convection currents. The heat from the lamp or radiator warms the air, making it rise and carry dust with it.

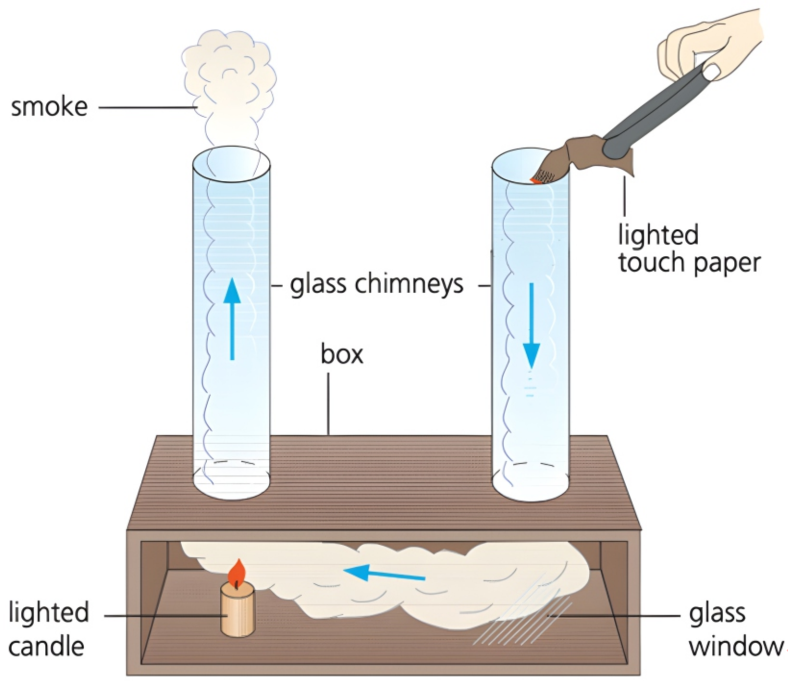


Figure 1.11: Convection currents demonstrated with glass chimneys: warm air rises, drawing cooler, smoky air down.

To see convection currents in air, you can do a simple experiment. Light a candle to create heat. Use touch paper (brown paper soaked in a potassium nitrate solution and dried) to produce smoke. The smoke shows the movement of air. Warm air rises, and cooler air moves in to replace it. This experiment clearly shows how convection works in air.

Coastal breezes

Convection currents in the atmosphere, caused by uneven heating of Earth's surface, produce winds. For example, at the seashore, temperature differences between land and sea drive **sea and land breezes.**

During the day, the land heats up faster than the sea due to its lower specific heat capacity, causing warm air over the land to rise. Cooler, denser air from the sea moves in to replace it, forming a sea breeze as shown in Fig.1.12(a). At night, the land cools more quickly, while the sea retains its heat longer, making the air over the sea warmer. This warmer air rises, and cooler air from the land flows toward the **sea, creating a land breeze** as shown in Fig.1.12(b). These air movements are driven by **convection**, resulting from temperature-induced changes in air density.

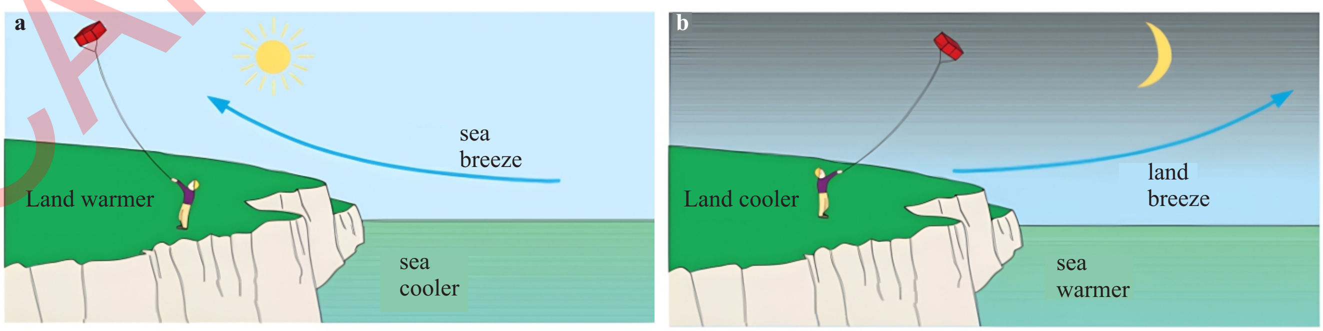


Figure 1.12: Convection drives coastal breezes: **(a)** sea breeze by day, **(b)** land breeze by night.

THINK

- You can hold your fingers beside the candle flame without harm, but not above the flame. Why?

Convection plays a vital role in both nature and human-made systems. It helps regulate weather patterns, ocean currents, and the movement of tectonic plates in Earth's mantle. In everyday life, convection is used in heating systems, ovens, and appliances to efficiently distribute heat, helping to improve energy management and the design of heating and cooling systems.

Role of Convection in Seawater to Support Marine Life

Convection in seawater occurs as the sun heats the surface water, making it warmer and lighter, causing it to rise. While some of this warm water may evaporate, most of it remains as liquid and spreads out across the surface. As the warm water moves upward, cooler water from below rises to take its place. This cooler water then gets heated by the sun, and the cycle continues. The mixing of warm and cool water allows heat to be transferred downward into the ocean, creating a convection current. This process ensures that heat, oxygen, and nutrients are distributed throughout the ocean. These convection currents are vital for marine life, as they transport nutrients to the surface for plankton growth and oxygen to deeper waters, supporting marine ecosystems. This continuous cycle maintains a balance and helps the ocean sustain life.

Use of Thermal Currents by Birds and Gliders for Sustained Flight

Convection is important not only in seawater but also in the atmosphere, enabling birds and gliders to remains aloft for long periods without much effort. Both rely on thermal currents, which are created when the sun heats the Earth's surface, causing warm air to rise in columns called thermals. Birds glide into these rising air columns, which lift them higher without the need to flap their wings, saving energy as shown in Fig.1.13(a). Similarly, gliders, like hang-gliders, use thermals to stay airborne as shown in Fig.1.13(b). Once in the air, a pilot can move from one thermal to another, maintaining altitude and prolonging flight without an engine. This efficient use of convection currents allows both birds and gliders to sustain long and energy-saving flights.

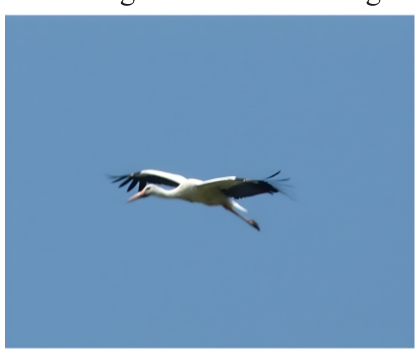


Figure 1.13 (a): Birds use thermal currents for hours of flight.

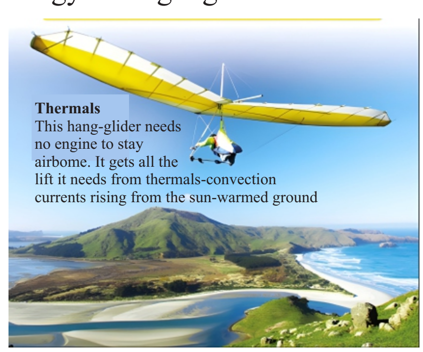
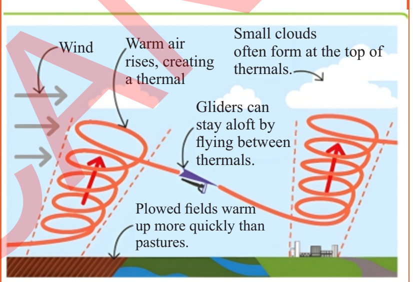


Figure 1.13 (b): A hang-glider uses thermals, rising convection currents from sun-warmed ground, for lift.

Do You Know?

How thermals work

Darker surfaces like roads, buildings, and plowed fields absorb heat from the Sun more quickly than vegetated areas. This heat warms the air above, causing it to rise in columns called thermals, often marked by fluffy cumulus clouds at the top. Gliders use these thermals to remain airborne by circling within them to gain altitude and following the clouds to locate the next thermal.



Multiple Choice Question

1. Convection currents in liquids and gases are primarily driven by changes in what property of the fluid?

a) Pressure b) Temperature
c) Volume d) Color

2. How do land and sea breezes moderate coastal climates?
   a) Increase coastal temperature.
   b) Stabilize air pressure.
   c) Redistribute heat, balancing temperature.
   d) Reduce moisture, cooling the region.
3. The ability of birds to fly for hours without flapping their wings relies on what natural phenomenon?
   a) Wind currents
   b) Thermal convection currents
   c) Atmospheric pressure zones
   d) Temperature regulation through respiration
4. How do convection currents support marine life?
   a) Bring cold water to the surface.
   b) Distribute oxygen in deep waters.
   c) Regulate temperature and move nutrients.
   d) Prevent water layer mixing.

Test Yourself

Short answer-based questions

1 Describe the relationship between convection in liquids and gases and its impact on heat transfer in natural systems such as the atmosphere and oceans.

2 Analyze the role of convection in seawater and its effect on marine ecosystems, focusing on nutrient distribution and temperature regulation.

3 What is the advantage of placing an electric immersion heater in a tank of water:
a. Near the top?
b. Near the bottom?

4 Why does hot air rise?

Skill:1.2

Objective:

- Explain convection in liquids and gases through density changes and justify experiments demonstrating convection.
- Analyze the role of convection in coastal climates, marine life, and sustained flight in birds and gliders.

D1.3 Knowledge

Thermal Energy Transfer by Radiation

Thermal energy can travel in three ways: conduction, convection, and radiation. Unlike conduction and convection, which need matter to transfer heat, **radiation** does not require any medium. This means radiation can occur even in a vacuum, where there are no particles of matter. The most common example of radiation is how thermal energy from the **Sun** reaches Earth.

Radiation travels in the form of **electromagnetic waves**, just like light, and moves at the **speed of light**. The type of radiation we are concerned with here is **infrared radiation**, which is a form of thermal radiation. All objects emit some level of thermal radiation. When this radiation hits an object, part of it is reflected, part passes through the object (transmitted), and part is absorbed. The absorbed radiation increases the object's temperature.

For example, buildings in hot countries are often painted white because white surfaces are **good reflectors** of radiation as shown in Fig.1.14. This helps to keep the buildings cooler by reflecting much of the sun's heat away, rather than absorbing it.

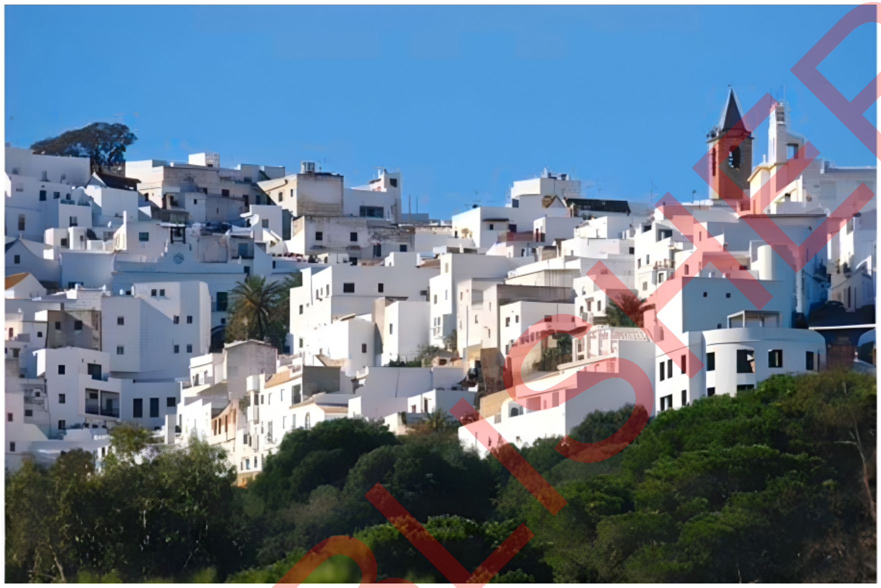


Figure 1.14: White-painted buildings reduce heat absorption, helping to keep homes cool in hot climates.

Dependence of Rate of Emission of Radiation on Temperature and Surface Area

Radiation is emitted by all bodies above absolute zero, primarily as infrared radiation, though light and ultraviolet radiation are emitted if the object is very hot, like the Sun. The rate at which an object emits radiation depends on its temperature and surface area.

The temperature of an object plays a key role in determining how much radiation it emits. The hotter an object is, the more radiation it gives off. For an object to maintain a constant temperature, the amount of energy it radiates must be equal to the amount of energy it absorbs from its surroundings.

When the surface temperature of an object is higher than its surroundings, it emits radiation at a faster rate than it absorbs radiation. This causes the object to lose heat and cool down. As it cools, the rate at which it emits radiation decreases until it matches the rate at which it absorbs energy. At this point, the object reaches a constant temperature.

The greater the difference between the object's temperature and the temperature of its surroundings, the faster it will cool. Additionally, the larger the surface area of the object, the more radiation it can emit, which further increases its rate of cooling. For example, a larger object or surface will release more heat and cool faster than a smaller one.

Effect of surface color and texture on the emission, absorption and reflection of infrared radiation

The color and texture of a surface have a significant impact on its ability to absorb, emit, and reflect infrared radiation, which is important for understanding how heat interacts with different materials.

1. Color:

- Dark surfaces are good absorbers and emitters of infrared radiation. For example, asphalt absorbs more heat from the sun due to its dark color and rough texture, making it a good emitter when it heats up.
- Light surfaces, like white or shiny metal, are better reflectors of infrared radiation. These surfaces reflect much of the infrared radiation away, preventing them from absorbing too much heat. This is why buildings in hot climates are often painted white-to reflect the sun's radiation and stay cooler.

2. Texture:

- Rough or matte surfaces are more effective at absorbing and emitting infrared radiation. For example, rough concrete or dull black metal has a larger surface area due to tiny irregularities, which allows it to absorb and release heat more efficiently.
- Smooth or shiny surfaces are better at reflecting infrared radiation. A polished metal surface, for example, reflects much of the heat away rather than absorbing it, which helps keep it cooler.

In summary, dark, rough surfaces are better at absorbing and emitting infrared radiation, while light, smooth surfaces are better at reflecting radiation. Understanding these properties is important for designing objects and system to manage heat effectively.

Justifying Experiments to Distinguish Between Good and Bad Absorbers and Emitters of Infrared Radiation

Some surfaces are better at absorbing and emitting infrared radiation than others, and this can be clearly demonstrated through simple experiments. For example, two lids, one shiny and the other dull black, are used in an experiment where coins are stuck on the outside of each lid with candle wax as shown in Fig.1.15(a). When a heater is placed midway between the lids, both lids receive the same amount of radiation. After a few minutes, the wax on the black lid melts, causing the coin to fall off, while the shiny lid remain cool and the wax does not melt. This experiment shows that dull black surfaces are better absorbers of infrared radiation than shiny surfaces, which reflect most of the heat.

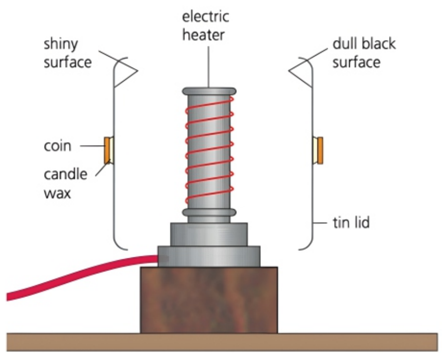


Figure 1.15 (a): Comparing radiation absorption by shiny and dull black surfaces.

Another experiment focuses on the ability of surfaces to emit radiation when they are hot. If you touch both sides of a hot copper sheet shown in Fig. 1.15(b), one side polished and the other blackened, you will feel that the blackened side is warmer. This is because the dull black surface is a better emitter of infrared radiation compared to the shiny polished side.

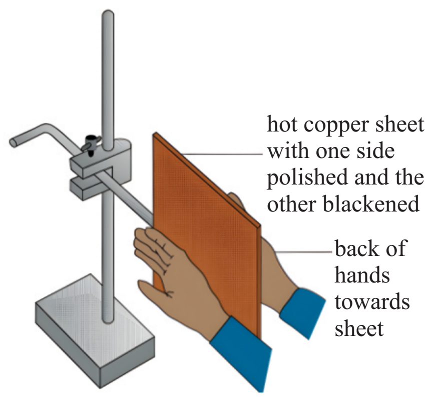


Figure 1.15 (b): Comparing radiation emission from polished and blackened sides of a hot copper sheet.

These experiments show that dark, rough surfaces are more effective at both absorbing and emitting infrared radiation, while shiny surfaces are poor at absorbing and excellent at reflecting radiation. This understanding is key to how materials interact with heat in various real-world applications. For example, cooling fins on refrigerators are painted black because black surfaces are excellent emitters, allowing them to lose heat quickly. In contrast, polished saucepans are poor emitters and retain heat longer, which is why they remain hot for a longer time after being removed from the heat source.

The Greenhouse Effect and Its Impact on Global Warming

The greenhouse effect is a natural process that helps keep the Earth warm enough to support life. It works similarly to how a greenhouse traps heat.

1. Heat Trapping in a Greenhouse:

In a greenhouse, sunlight and short-wavelength infrared radiation from the Sun pass through the glass and heat up the plants and soil inside. These surfaces, being cooler than the Sun, emit infrared radiation with a longer wavelength. However, this longer-wavelength radiation cannot pass through the glass and gets trapped inside, causing the temperature to rise.

2. Heat Trapping in Earth's Atmosphere:

Similarly, the Earth's atmosphere traps heat. The Sun's radiation reaches the Earth as short wavelength light and infrared radiation, which easily passes through the atmosphere. The Earth's surface absorbs this energy and then emits it as long-wavelength infrared radiation. However, gases like carbon dioxide (CO_2) and methane (CH_4) in the atmosphere trap this long-wavelength radiation, preventing it from escaping into space. This is how the Earth's atmosphere acts like the glass of a greenhouse, keeping heat inside and maintaining a temperature suitable for life as shown in Fig.1.16.

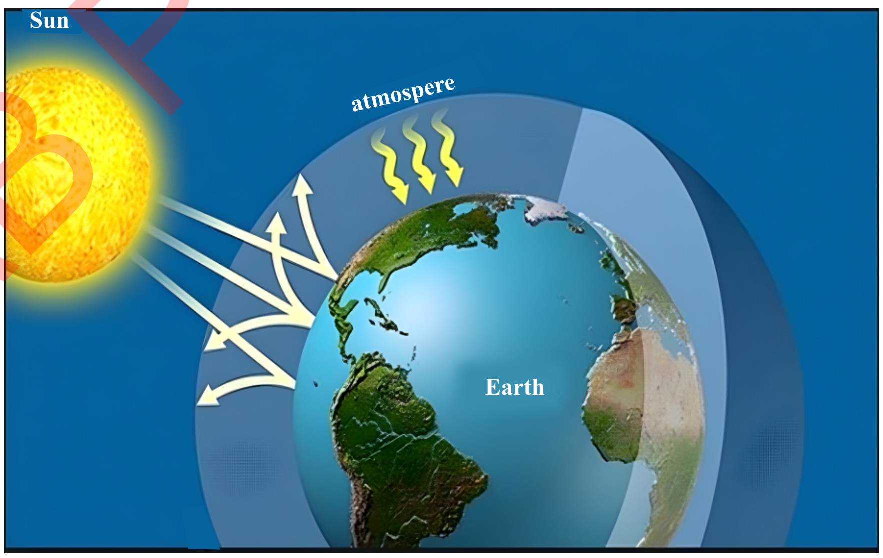


Figure 1.16: Illustrates the greenhouse effect, showing how solar radiation heats the Earth and is trapped by the atmosphere.

Consequences of Greenhouse Effect

The **greenhouse effect** is important for keeping the Earth warm, but an increase in heat-trapping gases like **CO** and **methane** from human activities disrupts this balance. These gases trap more heat, causing the Earth's temperature to rise, which leads to **global warming**. As a result, we face harmful consequences such as melting ice caps, rising sea levels, and extreme weather events like heatwaves, storms, and floods. This imbalance in the Earth's temperature harms ecosystems and human life. In summary, while the greenhouse effect is essential, excess heat trapped by increased gases causes **global warming**, leading to dangerous environmental changes.

Skill:1.1

Objective:

- Explain thermal energy transfer by radiation and analyze factors affecting emission, absorption, and reflection.
- Justify experiments on radiation properties and evaluate its role in the greenhouse effect and global warming.

Multiple Choice Question

1. Which of the following is the main factor influencing the rate of radiation emitted by a surface?
   a) Surface area of the object
   b) The object's color and texture
   c) The distance from the sun
   d) The type of medium surrounding the object
2. Which surface would be most effective at absorbing infrared radiation?
   a) A white, smooth surface
   b) A black, rough surface
   c) A shiny, metallic surface
   d) A transparent surface
3. In the context of the greenhouse effect, which of the following best describes how heat is trapped in the Earth's atmosphere?
   a) Water vapor absorbs visible light
   b) Greenhouse gases absorb infrared radiation and prevent it from escaping
   c) Clouds reflect all radiation back to space
   d) The Earth's surface emits more ultraviolet radiation than it absorbs

Test Yourself

Short answer-based questions

1. Describe how the surface color of an object affects its ability to emit and absorb infrared radiation.
2. Why does the temperature of an object directly affect the amount of infrared radiation it emits?
3. Describe the role of the atmosphere in the greenhouse effect and its impact on global temperatures. What is the significance of infrared radiation in this process?

D1.4 Knowledge

Applications of Heat Transfer

Heat transfer occurs in three main ways: conduction, convection, and radiation. Each of these methods plays a critical role in everyday activities, helping us understand how heat moves and how we can use it in various applications. Here are some examples:

Heating Objects (Kitchen Pans):

When a pan is heated on a stove as shown in Fig.1.17, infrared radiation from the burner warms the pan's surface. The heat then spreads throughout the pan via conduction, ensuring it becomes uniformly warm. The heat from the pan is transferred to the food or liquid through conduction, cooking it efficiently.

Metals like aluminium, iron, and copper, which are good conductors, are used in saucepans, boilers, and radiators to transfer thermal energy quickly.

Figure 1.17: Heat transfer by conduction in a metal pan placed over a gas flame.

Heating Room By Convection

Modern central heating systems use convection to warm the air inside homes. Hot water in radiators transfers heat to the air, causing it to warm up and become less dense. The warm air then rises, and cooler air moves in to take its place. As the warm air cools, it sinks back down, completing the cycle. This continuous movement of air forms a convection current that evenly distributes heat throughout the room as indicted in Fig.1.18.

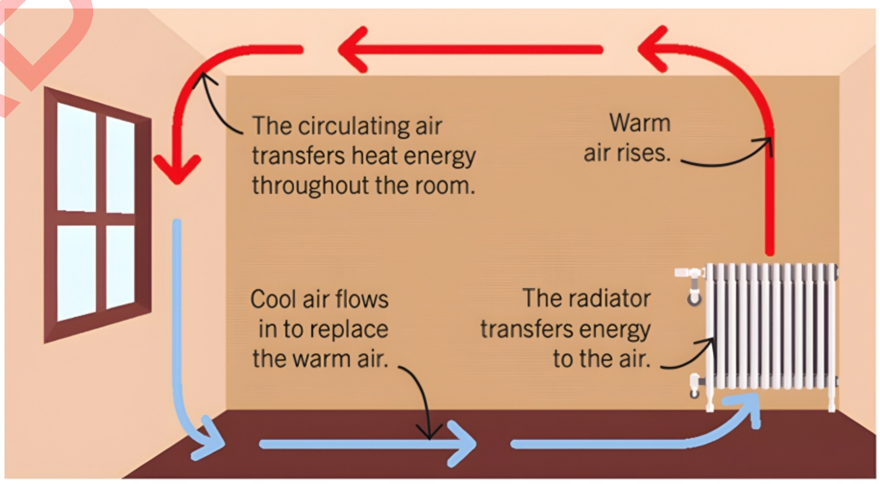


Figure 1.18: Heat distribution in a room through convection currents created by a radiator.

Measurement of temperature using an infrared thermometer

An infrared thermometer measures the heat radiation emitted by an object and turns it into an electrical signal. This signal is used to calculate the object's temperature, which is then displayed on a digital screen. The best part is that it works without touching the object, allowing you to measure the temperature from a distance. Infrared thermometers are commonly used in places like airports to check the body temperature of passengers for health monitoring as shown in Fig.1.19.

Figure 1.19: Infrared thermometer measuring body temperature without physical contact.

Use of Thermal insulation to maintain the temperature

Thermal insulation is widely used in everyday objects and buildings to maintain temperature and reduce energy loss. Here is how it works in two common applications: the vacuum flask and in building construction.

Vacuum Flask

A vacuum flask, also known as a Thermos, keeps liquids hot or cold by reducing heat transfer as shown in Fig.1.20. It minimizes heat loss through conduction and convection by having double-walled glass with a vacuum between the walls. The vacuum prevents heat transfer through conduction or convection. To further reduce heat loss, the inner and outer walls are coated with silver, which reflects radiation. For example, when a hot liquid is inside, the silver coating reflects the small amount of radiation from the hot liquid back into the flask. Any slight heat loss that does occur happens through conduction along the glass walls and through the stopper.

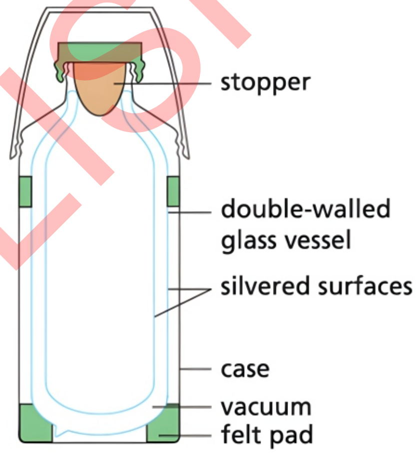


Figure 1.20: Structure of a vacuum flask minimizing heat transfer by conduction, convection, and radiation.

Using Thermal Insulation to Maintain Temperature and Reduce Energy Transfer in Buildings

In buildings, thick insulation in the roof and walls prevents heat transfer by conduction, keeping the space warm in winter and cool in summer as shown in Fig.1.21(a).

Figure 1.21 (a). Installing thermal insulation to reduce heat loss through the roof.

Double-glazed windows and tight-fitting doors reduce heat loss by preventing drafts and minimizing heat transfer as shown in Fig.1.21(b). Cavity walls with insulation materials like foam or mineral wool further reduce heat loss by blocking convection as shown in figure 1.21(c). These methods of thermal insulation help keep the temperature steady and reduce the need for additional heating or cooling, making buildings more energy efficient.

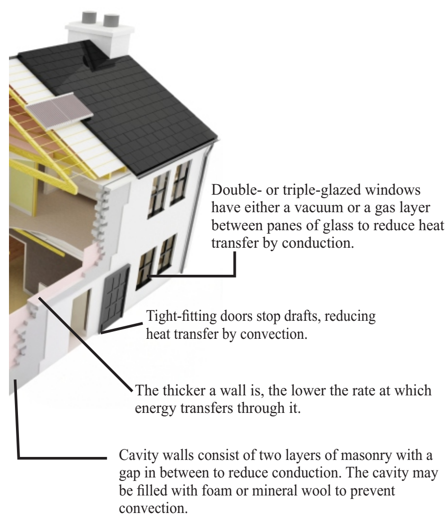


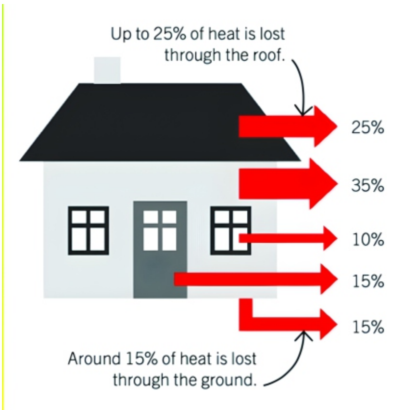
Figure 1.21 (b): Energy-efficient house minimizing heat transfer through insulation and design.

Important Information

Important Information on Heat Loss in Buildings

A house loses most of its energy through the roof and walls, but heat is also lost through windows, doors, and the ground. The greater the temperature difference between the inside and outside of the house, the faster the rate of energy loss.

Do You Know?



Important Information

Air is one of the worst conductors of heat, making it an excellent insulator, but vacuum is even a better insulator than air. A vacuum, with no particles to transfer heat, has almost no thermal conductivity, making it ideal for preventing heat transfer. This property is used in applications like vacuum flasks, where the vacuum between double walls reduces heat loss or gain. Similarly, double-glazed windows and cavity walls trap air to improve energy efficiency, while materials like down feathers and foam trap air to keep warmth close to the body or prevent heat loss in insulated clothing and water pipes.

Figure 1.21 (c): Cavity wall insulation reduces heat loss.

Mechanism of a household hot-water system

A household hot-water system typically works by heating water and distributing it throughout the house for use in taps, showers, and appliances. The water is heated in a water heater, which can be powered by electricity, gas, or even solar energy. In a tank-based system, water is heated in an insulated tank and stored to maintain a constant temperature. When hot water is needed, it flows from the tank through pipes to the required location. Tankless systems, on the other hand, heat water on demand without storing it. Some systems use circulating pumps to maintain a steady supply of hot water by keeping it moving through the pipes, ensuring it's immediately available when needed. Insulated pipes help minimize heat loss as the water travels to various points in the house as shown in Fig.1.22.

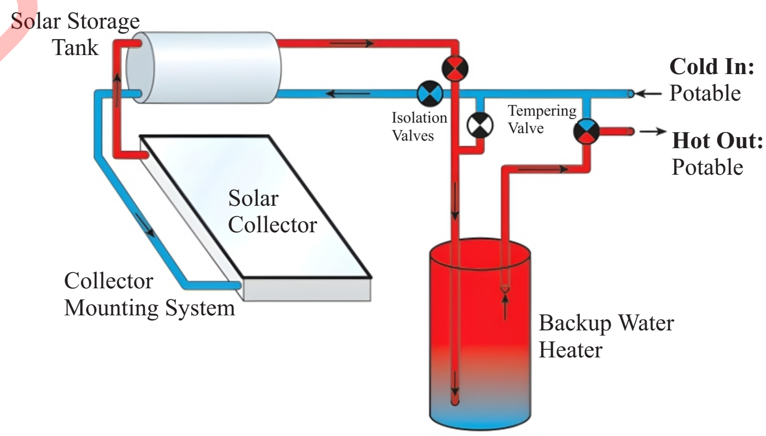


Figure 1.22: Schematic of a solar water heating system with a backup heater.

Multiple Choice Question

1. Which of the following is primarily responsible for heating a room through a radiator system?
   a) Conduction, as the heat moves directly through solid objects
   b) Convection, as warm air rises and circulates in the room

c) Radiation, as infrared heat radiates directly from the heater
d) Evaporation, as water evaporates from the radiator's surface

2. When using an infrared thermometer, which principle of heat transfer is being applied?
a) Conduction, as the thermometer directly contacts the object
b) Convection, as heat flows through the air to the thermometer
c) Radiation, as the thermometer detects infrared radiation emitted by the object
d) Absorption, as the thermometer absorbs the heat from the object

Skill:1.3

Objective:

- Analyze real-life applications of conduction, convection, and radiation in heating objects, room heating, infrared thermometers, thermal insulation, and household hot-water systems.

Key Points

- Heat transfer occurs through lattice vibrations and free electron movement, especially in metals.
- Metals like copper are good conductors due to free electrons, while materials like wood and plastic are poor conductors.
- Insulating materials such as wood and plastic slow down heat transfer because they rely on phonon movement.
- Materials with more free electrons (e.g., metals) conduct heat faster.
- Copper is an excellent conductor compared to materials like aluminum and iron.
- Simple experiments like heating metal rods or placing hands on different surfaces (metal vs. wood) show which materials are good or bad conductors.
- Good conductors allow heat to travel quickly, while bad conductors slow down the process.
- Convection occurs when heated fluid becomes less dense and rises, while cooler fluid sinks, creating a convection current.
- Changes in fluid density due to temperature variations drive convection.
- In seawater, convection currents distribute heat and nutrients, supporting marine life by facilitating plankton growth and oxygen distribution.
- Air rises when heated, cooling as it expands in lower pressure areas, forming convection currents.
- Land and sea breezes regulate coastal climates by redistributing heat.
- Thermal energy transfer by radiation does not require a medium and occurs through electromagnetic waves.
- The rate of radiation emission depends on the temperature and surface area of an object.
- Dark, rough surfaces absorb and emit more infrared radiation compared to light, smooth surfaces that reflect radiation. This principle is applied in everyday items like cooking utensils, building materials, and heat control devices.
- Greenhouse gases trap infrared radiation, warming the Earth and supporting life.
- Excessive greenhouse gases lead to global warming, causing harmful environmental impacts.

Exercise

After completing the chapter students practice SLO based exercise to prepare for examination. Each SLO include three types of question: Multiple choice question (MCQs), Short response question (SRQs), Extended response question (ERQs) and detailed exercise solution available in QR code.

Explain thermal conduction in all solids. (Understanding)

Multiple-Choice Questions

1. Which of the following best explains the mechanism of thermal conduction in metallic conductors?
 a) Free electrons move through the lattice, transferring energy

b) Atoms vibrate in place, transferring energy through collisions
c) The molecules form bonds, which transmit heat
d) Heat is transferred through the movement of gas molecule

2. In non-metallic solids, how does heat transfer occur?
a) Through the movement of free electrons
b) Through molecular vibrations in the solid lattice
c) By the transfer of light waves
d) Through the expansion of the solid material

Short Response Questions

1. Describe the role of free electrons in thermal conduction in metallic conductors.
2. How do molecular lattice vibrations contribute to thermal conduction in non-metallic solids?

Extended Response Questions

Describe the process of thermal conduction in solids, focusing on the role of both atomic vibrations and free electrons. How do these mechanisms differ between metals and non-metals?

Justify experiments to distinguish between good and bad thermal conductors. (Application)

Multiple-Choice Questions

1. What distinguishes good thermal conductors from bad ones?
a) The ability to transfer free electrons
b) The size of the atoms
c) The material's density
d) The color of the material

2. Which of the following materials would be the best choice for the handle of a frying pan?
a) Copper
b) Wood
c) Aluminum
d) Steel

Short Response Questions

1. Justify why insulating materials like wool and plastic are poor conductors of heat.
2. Describe the process of thermal conduction in metals and non-metals.

Extended Response Questions

Design an experiment to distinguish between good and bad thermal conductors. What factors would you control, and what measurements would you take to draw conclusions?

Explain convection in liquids and gasses [in terms of density changes]. Justify experiments to illustrate convection. (Understanding + Application)

Multiple-Choice Questions

1. How does convection contribute to the regulation of coastal climates?
a) By raising the overall temperature of the land
b) By redistributing heat and moderating temperature fluctuations
c) By increasing humidity levels
d) By causing air pressure to stabilize

Short Response Questions

1. Describe the role of convection currents in heating a room through radiators.
2. Why metal feels colder than wood at the same temperature.

Extended Response Questions

1. Analyze how convection in liquids and gases, such as in heating systems and the atmosphere, influences heat transfer and temperature regulation.
2. Discuss the role of convection in maintaining coastal climates, with a focus on land and sea breezes. How does this phenomenon help moderate temperature fluctuations between land and sea?

Describe the role of land breezes and sea breezes in maintaining moderate coastal climates. (Understanding)

Multiple-Choice Questions

1. Which phenomenon causes land breezes at night?
a) The land cools faster than the sea, increasing air pressure over the land
b) The sea cools faster than the land, creating low pressure over the land
c) Both land and sea heat up equally, causing wind currents
d) The land heats up faster than the sea, creating low pressure over the land

2. What is the main factor driving the sea breeze during the day?
a) The cooling of the land at night
b) The unequal heating of the land and sea, causing air to rise over the land
c) The warming of the ocean currents
d) The movement of the Earth's atmosphere

Short Response Questions

1. Describe how land breezes and sea breezes contribute to moderate temperatures along coastlines.
2. How does the difference in heat capacity between land and water affect the formation of land and sea breezes

Extended Response Questions

Describe the formation of land and sea breezes and explain their role in maintaining moderate coastal climates. How do these breezes influence weather patterns and local temperatures?

Explain convection in seawater to support marine life. (Understanding)

Multiple-Choice Questions

1. How does convection in seawater support marine life?
a) It helps circulate nutrients and oxygen throughout the water
b) It prevents the water from becoming too warm for marine organisms
c) It causes all marine organisms to move toward the surface
d) It increases the salinity of seawater
2. Which factor most influences convection currents in seawater?
a) The speed of ocean currents
b) The differences in water temperature and salinity
c) The wind blowing over the surface
d) The movement of fish in the ocean

Short Response Questions

1. How do convection currents in seawater help distribute nutrients and oxygen, benefiting marine life?
2. How does the density of seawater change with temperature and salinity to create convection currents?

Extended Response Questions

Explain how convection in seawater contributes to the distribution of nutrients, oxygen, and heat, which supports marine ecosystems.

Explain how birds are able to fly for hours without flapping their wings and gliders are able to rise by riding on thermal currents. (Understanding)

Multiple-Choice Questions

1. How do birds stay airborne without flapping their wings?
a) Using thermal currents
b) Using wind speed
c) Using flapping power
d) By creating lift with their wings
2. What allows gliders to rise without an engine?
a) Engine power b) Thermal currents c) Magnetic fields d) Wind resistance

Short Response Questions

1. How do birds use thermal currents to conserve energy during long flights?
2. How do gliders utilize thermal currents to gain altitude without an engine?

Extended Response Questions

Describe the role of thermal currents in flight. How do they provide lift for birds and gliders, and how does this reduce their need to flap wings or use engines?

Describe the process of thermal energy transfer by radiation [and know that it does not require a medium]. (Understanding)

Multiple-Choice Questions

1. Which of the following is an example of thermal radiation?
a) The heat you feel when standing near a fire
b) The warmth of a stove heating a pan
c) The heating of air by a fan
d) The transfer of heat from a hot cup to your hand
2. Why is a vacuum an excellent insulator?
a) It reduces thermal energy transfer through conduction
b) It prevents heat from escaping due to radiation

c) It eliminates convection currents
d) It reflects heat back to the source

Short Response Questions

1. Why radiation does not require a medium for thermal energy transfer. Provide an example where this is observed in everyday life.
2. Describe how the Sun's heat reaches Earth through radiation. Why can this process occur despite the vacuum of space?

Extended Response Questions

1. Describe the process of thermal energy transfer by radiation, and how do temperature and surface area affect radiation emission? Give daily life examples.
2. Analyze how thermal energy transfer by radiation is different from conduction and convection, and provide examples of each in real-world applications.

Justify qualitatively how the rate of emission of radiation depends on the surface temperature and surface area of an object. (Application)

Multiple-Choice Questions

1. In the process of thermal radiation, which factor primarily affects the rate of emission?
a) The surface area of the object
b) The color of the object
c) The material's density
d) The temperature of the object
2. How does surface temperature affect the rate of radiation emission?
a) Higher temperature increases the emission rate
b) Higher temperature decreases the emission rate
c) Temperature has no effect on emission rate
d) Emission rate remains constant regardless of temperature

Short Response Questions

1. Why does a larger surface area result in a higher rate of emission of radiation? Provide an example in everyday life.
2. How does increasing the temperature of an object affect the amount of infrared radiation it emits?

Extended Response Questions

Explain how both surface temperature and surface area contribute to the rate of emission of radiation.

Describe the effect of surface color and texture on the emission, absorption and reflection of infrared radiation. (Understanding)

Multiple-Choice Questions

1. Which surface color is most effective at absorbing infrared radiation?
a) White
b) Black
c) Shiny metallic
d) Transparent
2. How does texture affect infrared radiation reflection?
a) Smooth surfaces reflect more than rough surfaces
b) Rough surfaces reflect more than smooth surfaces
c) Both reflect the same amount
d) Texture has no effect

Short Response Questions

1. Why do black, matte surfaces emit more infrared radiation than white, smooth surfaces?
2. How does a shiny metallic surface affect the absorption and reflection of infrared radiation?

Extended Response Questions

Describe how surface color and texture influence the efficiency of infrared radiation absorption and emission. How would these properties impact the design of materials for energy-efficient buildings?

Justify Experiments to distinguish between good and bad emitters and absorbers of infrared radiation. (Application)

Multiple-Choice Questions

1. Which of the following materials is most likely to be a good absorber of infrared radiation?
a) Polished metal
b) Black, matte surface
c) Transparent glass
d) Shiny white surface
2. Which of the following materials is most likely to be a good absorber of infrared radiation?
a) Polished metal
b) Black, matte surface
c) Transparent glass
d) Shiny white surface

Short Response Questions

1. Describe how surface color affects the emission and absorption of infrared radiation.
2. Why a dark, rough surface is better at both absorbing and emitting infrared radiation than a shiny, smooth surface.

Extended Response Questions

Design an experiment to compare the infrared radiation emission of different materials. Identify the factors to control and predict the results based on the materials' properties.

Analyze the consequence of heat radiation in the greenhouse effect and its effect in global warming. (Application)

Multiple-Choice Questions

1. In the greenhouse effect, what is the primary role of greenhouse gases like CO_2?
   a) To absorb visible light
   b) To prevent infrared radiation from escaping
   c) To block all types of radiation
   d) To reflect the Sun's heat
2. What is the consequence of increased heat radiation in the atmosphere due to human activities?
   a) Decrease in Earth's average temperature
   b) Increased reflection of sunlight
   c) Rise in global temperatures, leading to global warming
   d) Decrease in solar radiation reaching Earth

Short Response Questions

1. How does the greenhouse effect lead to global warming.
2. Justify why the understanding of heat radiation is important for solving environmental issues such as global warming.

Extended Response Questions

1. Analyze the consequences of heat radiation in the greenhouse effect. How does the increase in greenhouse gases affect Earth's temperature and climate systems?
2. What is the greenhouse effect, and how does it relate to global warming? How do human activities affect greenhouse gas concentrations, and what are the long-term environmental consequences?

Analyze everyday applications of conduction, convection and radiation. (Application)

Multiple-Choice Questions

1. What type of heat transfer occurs when an infrared thermometer measures the temperature of an object?
   a) Conduction
   b) Convection
   c) Radiation
   d) Absorption
2. Which of the following methods is used to heat a kitchen pan on a stove?
   a) Convection, through the movement of air
   b) Radiation, from the heat emitted by the burner
   c) Conduction, through direct contact with the burner
   d) Absorption, through the transfer of light energy

Short Response Questions

1. How do thermal insulators help reduce energy loss in buildings and systems?
2. Justify the use of thermal insulation in hot water systems.

Extended Response Questions

1. Describe how conduction is used in heating kitchen pans, and how materials with high and low conductivity affect the efficiency of cooking.
2. Analyze how the principles of conduction, convection, and radiation are applied in the design of a household heating system. How do these methods work together to maintain a comfortable temperature?

CHAPTER 2

Waves

2.1 Knowledge

Wave Motion and Types of Waves

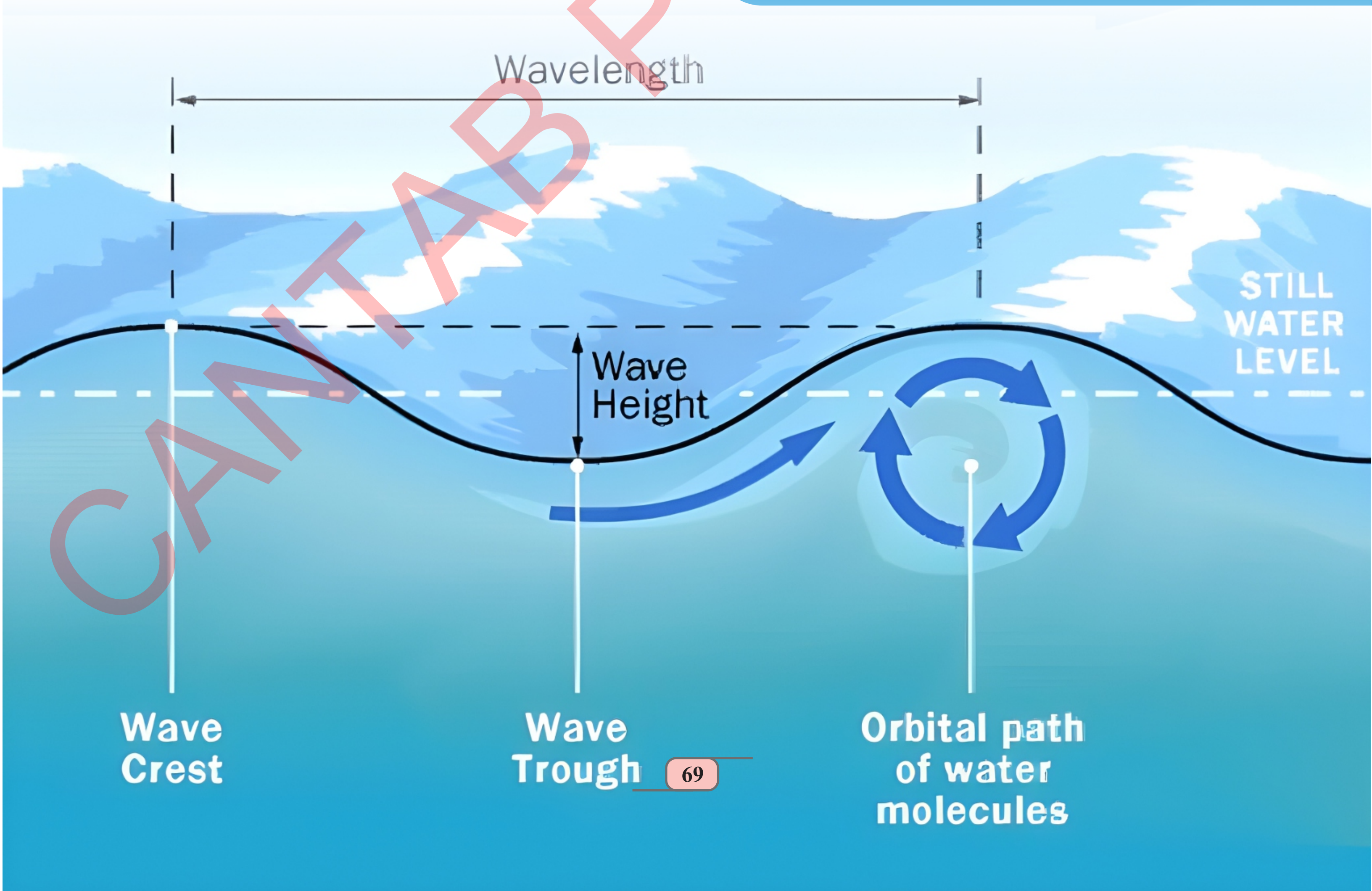
Student Learning Outcomes

[SLO: P-10-D-01]: *Prove that waves transfer energy without transferring matter*

[SLO: P-10-D-02]: *Describe what is meant by wave motion [as illustrated by vibrations in ropes and springs and by experiments using water waves.]*

[SLO: P-10-D-06]: *Illustrate that for a transverse wave, the direction of vibration is at right angles to the direction of the energy transfer [including giving examples such as electromagnetic radiation, waves on the surface of water, and seismic S-waves (secondary)]*

[SLO: P-10-D-07]: *Illustrate that for a longitudinal wave, the direction of vibration is parallel to the direction of the energy transfer [including give examples such as sound waves and seismic P-waves(primary)]*



2.2 Knowledge

Wave Characteristics & Speed Equation

Student Learning Outcomes

SLO: P-10-D-03]: *Describe the features of a wave [in terms of wavefront, wavelength, frequency, time period, crest (peak), trough, compression, rarefaction, amplitude and wave speed]*

[SLO: P-10-D-04]: *Define the terms frequency, wavelength, and amplitude.*

[SLO: P-10-D-05]: *Recall and apply the equation wave speed = frequency × wavelength ($v = f\lambda$)*

2.3 Knowledge

Wave Properties: Reflection, Refraction & Diffraction

Student Learning Outcomes

[SLO: P-10-D-08]: *Describe how waves can undergo reflection, refraction and diffraction.*

[SLO: P-10-D-09]: *Describe how wavelength affects diffraction at an edge.*

[SLO: P-10-D-11]: *Describe how wavelength and gap size affect diffraction through a gap.*

2.4 Knowledge

Tsunami Formation and Effects

Student Learning Outcomes

[SLO: P-10-D-10]: *Analyse the phenomenon of tsunamis generated under the surface of water [in terms of underwater earthquakes/volcanic activity generating waves that increase in frequency and amplitude as they encounter increasingly shallow water]*

Introduction

When a stone is dropped into a pond, ripples spread outward, transferring energy across the water. However, a leaf floating on the surface only moves up and down as the wave passes, demonstrating that waves transfer energy without moving matter. In this chapter, you will explore waves as disturbances that carry energy from one point to another. Some waves, like sound waves, vibrate parallel to their direction of travel, while others, like water waves, vibrate perpendicular to their motion. You will also learn to describe waves using their general properties, including wavelength, frequency, amplitude, and wave speed, which apply to light, sound, seismic, and water waves.

Additionally, you will investigate how ripple tank experiments demonstrate reflection, refraction, and diffraction, where waves bounce off surfaces, change speed in new mediums, and spread through gaps. Additionally, you will analyze how wavelength affects diffraction and how tsunamis form from underwater earthquakes or volcanic activity, increasing in frequency and amplitude in shallow water.

2.1 Knowledge

Wave Motion and Types of Waves

A wave is a disturbance that propagates through a medium or space, transferring energy without transporting matter. Waves are fundamental in nature and technology, enabling the transmission of sound, light, radio signals, and water waves. They originate from an oscillating or vibrating source, creating a disturbance that spreads outward. This motion is characterized by oscillations, where particles or fields undergo repetitive movement in fixed intervals of time.

Types of Waves

Waves are classified into two main types based on their propagation:

1. **Mechanical Waves -** These waves require a medium (such as air, water, or solids) for propagation. They are generated by the oscillation of particles within the medium. Examples include sound waves, water waves, and waves on a rope or a spring.
2. **Electromagnetic Waves -** Unlike mechanical waves, these do not need a medium and can propagate through a vacuum. Examples include light waves, radio waves, X-rays, and microwaves.

Wave Energy Transfer Without Transporting Matter

To understand how waves transfer energy without carrying matter, consider an experiment with a floating ball on the surface of still water. When a disturbance, such as a dropped stone, generates waves, the ball moves up and down instead of traveling with the wave. This confirms that water molecules oscillate in place rather than moving forward. The energy from the disturbance propagates outward through the water, but the individual particles return to their original positions. This demonstrates that the wave carries energy forward while the medium itself remains in place.

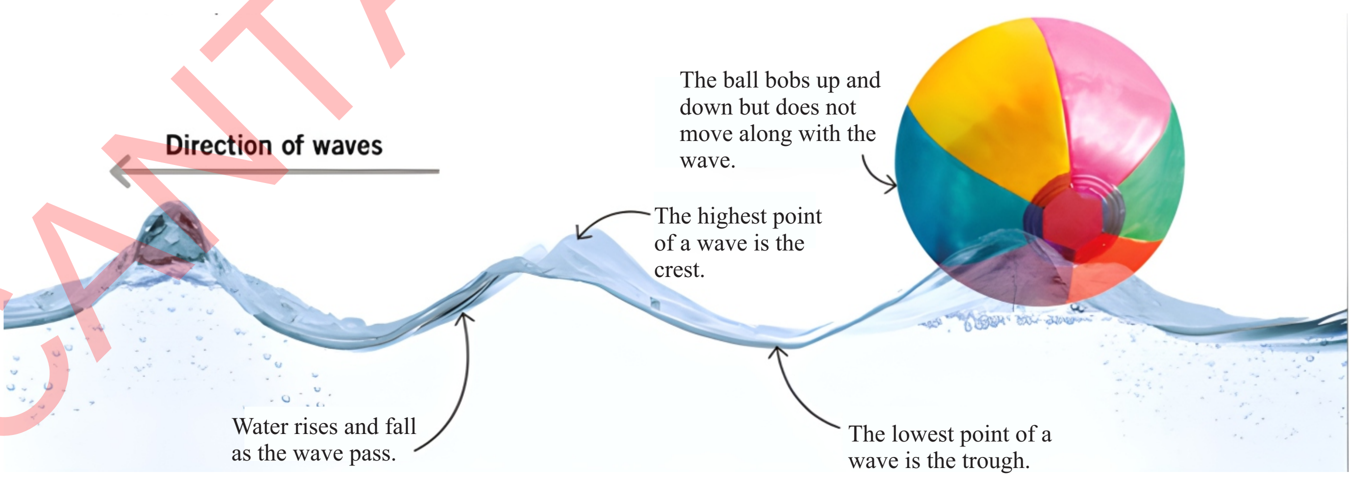


Figure 2.1: Depicts that how waves transfer energy without transporting matter, as shown by the movement of a floating ball that oscillates up and down without traveling with the wave.

Types of Wave Motion

Several kinds of wave motion occur in physics. Wave motion is the transfer of energy through a medium by the mechanism of oscillations. In mechanical waves, particles in the medium oscillate, causing the wave to propagate. The source of continuous waves must be a periodic vibrator that generates regular oscillations in the medium's particles. Wave motion can be understood by examining the progressive or travelling waves, which carry energy by moving away from the source of disturbance. In a progressive wave, particles of the medium can either oscillate perpendicular or parallel to the direction of transfer of energy. So, we can classify them into two types.

Transverse Waves

In these waves, the disturbance occurs at right angles to the direction of wave propagation i.e., oscillations are perpendicular to the wave motion. For example, when one end of a rope is moved up and down, a transverse wave is generated, with the disturbance traveling along the rope as shown in Fig. 2.2.

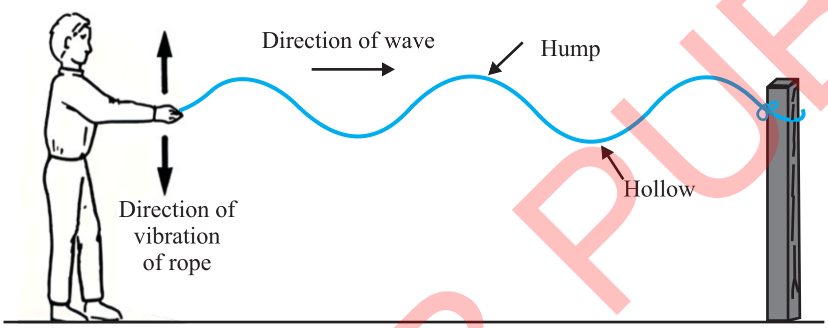


Figure 2.2: Transverse wave

In the figure, the hump represents the maximum upward displacement of a particle, called amplitude, forming the crest of the transverse wave. Similarly, the hollow represents the maximum downward displacement (amplitude), forming the trough. A transverse wave consists of a series of crests and troughs.

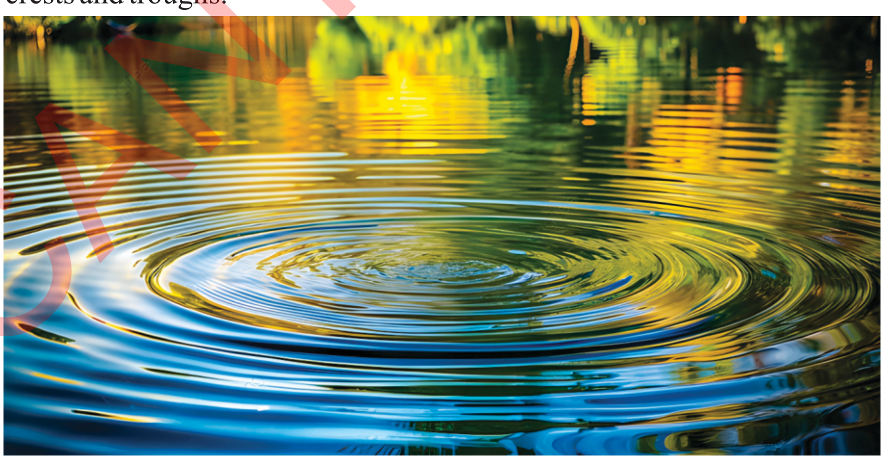


Figure 2.3: Water waves

Water ripples waves are the examples of transverse waves. These waves can be produced if we drop a stone into still water. This will create circular ripples that spread outward as shown in Fig 2.3. The water particles oscillate up and down or in small circular motions but return to their original positions after the wave passes.

S-waves are also a type of transverse wave produced by earthquakes, move side-to-side at right angles to the direction of travel, similar to waves on a rope. They cannot pass through liquids, which is why they do not travel through the Earth's outer core as shown in Fig 2.4.

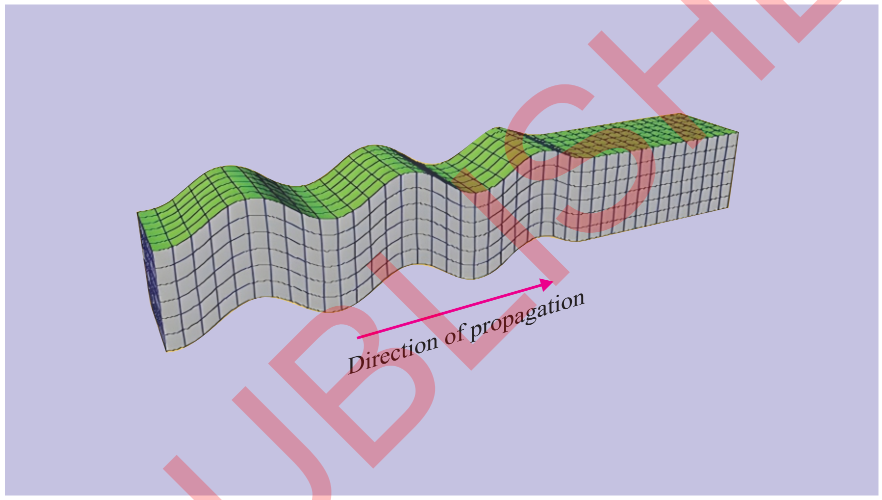


Figure 2.4: Earth interior structure due to S Seismic waves generated by earthquake

All the electromagnetic waves (radio waves, microwaves, visible light, infrared waves, ultraviolet waves, x-rays and gamma rays) are transverse in nature. In these types of waves electric and magnetic fields oscillate perpendicular to the direction of propagation of wave as indicated in the Fig. 2.5 further discussed in chapter 11.

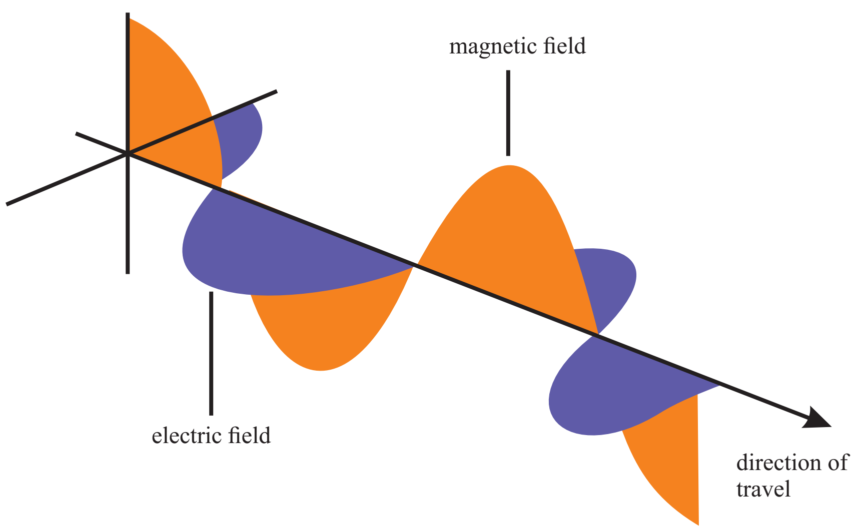


Figure 2.5: An electromagnetic wave

Longitudinal Waves

In these waves, the particles of the medium oscillate parallel to the direction of wave propagation. A longitudinal wave can be demonstrated by moving the free end of a stretched spring back and forth, creating compressions C (where particles are close together) and rarefactions R (where particles are spread apart) as shown in Fig. 2.6.

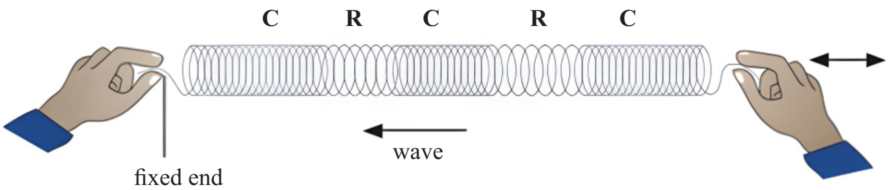


Figure 2.6: Longitudinal waves

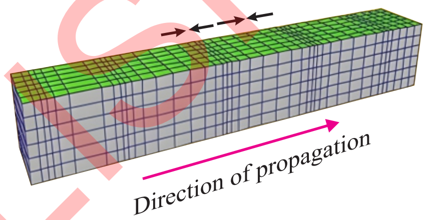


Figure 2.7: Earth interior structure due to P Seismic waves generated by earthquake

Another example of longitudinal waves is the P- Seismic waves produced by earthquake as indicated in Fig.2.7. They move by compressing and expanding the material they pass through, similar to how a slinky spring moves back and forth. They travel through the Earth at speeds of up to 13,000 m s^{-1}.

Sound waves are examples of longitudinal waves which are shown in the Fig. 2.8. Sound waves cause air molecules to vibrate along the direction of propagation, creating regions of low pressure (rarefaction) and high pressure (compression). These waves can be detected by a microphone and displayed on an oscilloscope as a transverse curve, making it easy to interpret.

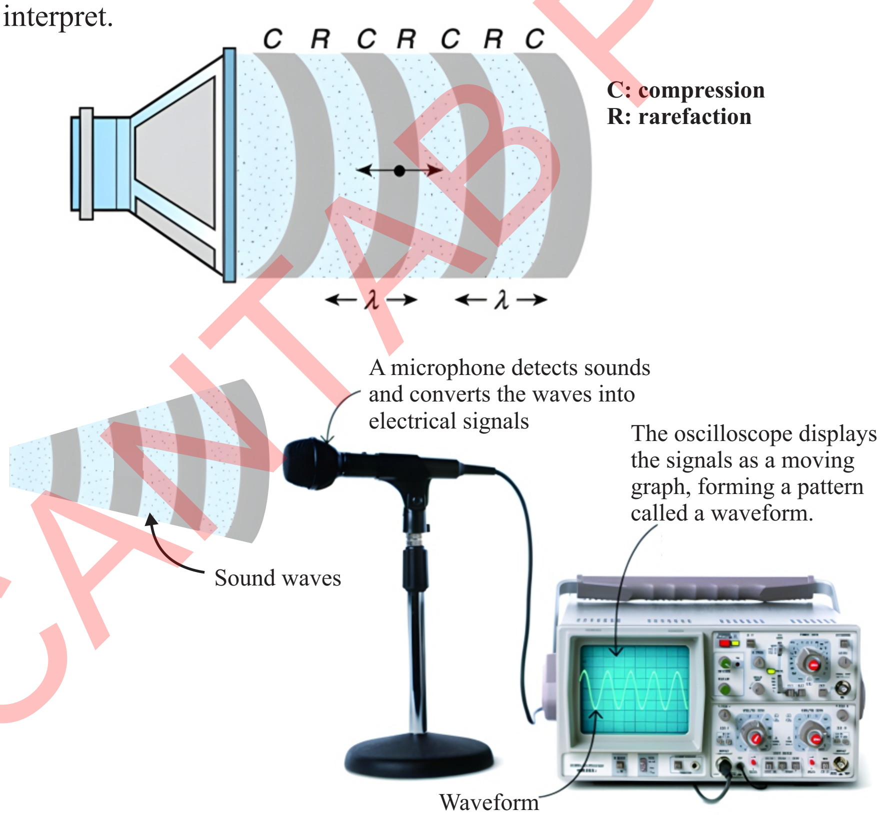


Figure 2.8: Sound waves are generated by a speaker, detected by a microphone, and displayed as a waveform on an oscilloscope.

Seismic Waves

Earthquakes produce two types of waves: P-waves (primary waves) and S-waves (secondary waves). P-waves are an example of longitudinal waves, while S-waves are an example of transverse waves.

- P-waves (Longitudinal Waves): These waves are the fastest, traveling by compressing and expanding the box material through which they move.
- S-waves (Transverse Waves): These waves are slower than P-waves and travel at lower speeds. They move in a side-to-side motion, which is at right angles to the direction of travel, similar to the way waves move on a rope. S-waves cannot travel through liquids, which is why they are not observed passing through the Earth's outer core.

  When these seismic waves travel through the Earth and reach the surface, they can cause damage to buildings and structures. If an earthquake occurs under the sea, it can transfer energy to the water and generate tsunami waves, which can travel long distances across the ocean. As these tsunami waves approach shallow coastal waters, they slow down, and their amplitude (height) increases, often causing massive destruction.

For example, the 2004 Sumatra-Andaman earthquake triggered tsunami waves that traveled across the ocean to Sri Lanka and Thailand, causing devastation. The arrival time of the tsunami can be predicted if the speed of the waves and the distance from the earthquake's epicenter are known.

Multiple Choice Question

1. Which example best demonstrates that waves transfer energy without moving matter?
   a) A ball rolling down a hill
   b) A person hearing a sound from a distance.
   c) A car moving on a road
   d) A rock being thrown into a lake
2. In an experiment, a student shakes a rope up and down. What type of wave is produced?
   a) Longitudinal wave   b) Transverse wave
   c) Electromagnetic wave   d) Sound wave
3. What is the crest of a wave?
   a) The lowest point of a wave
   b) The highest point of a wave
   c) The distance between two waves
   d) The speed at which the wave moves
4. Which of the following is an example of a longitudinal wave?
   a) Light waves   b) Water waves
   c) Sound waves   d) Radio waves
5. Why are electromagnetic waves transverse?

a) They need a medium
b) Electric and magnetic fields oscillate perpendicular to wave travel
c) They compress air particle.
d) They travel only in straight lines

Skill:2.1

Analyze wave motion by proving that waves transfer energy without moving matter, describing wave behavior through experiments, and illustrating the differences between transverse and longitudinal waves with real-world examples.

Test Yourself

Short answer-based questions

1. Differentiate between mechanical and electromagnetic waves in terms of how they transfer energy without moving matter.
2. A student says, "In a longitudinal wave, particles move in the same direction as the energy transfer". Is this statement correct? Why?
3. A cork is floating on the surface of a pond. When a water wave passes through, the cork moves up and down but does not travel forward. What does this tell us about wave motion?

2.2 Knowledge

Wave Characteristics & Speed Equation

Waves, both transverse and longitudinal, have key features that describe their motion: wavefront, wavelength, frequency, time period, crest, trough, compression, rarefaction, amplitude, and wave speed. To explain these features, we use a displacement-distance graph, which shows the position of different parts of the medium from its undisturbed state at a specific moment as indicated in Fig. 2.9. This graph captures how the displacement of parts of the medium varies along its length.

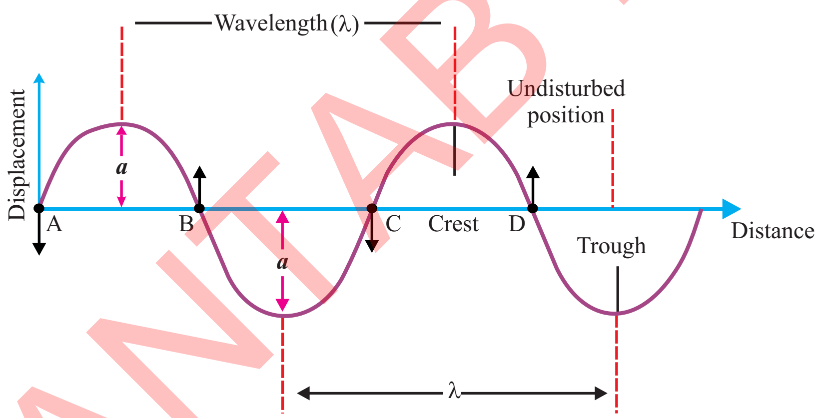


Figure 2.9: Graph showing displacement vs. distance for a wave at a specific moment in time.

Phase

In the figure, the short arrows at points A, B, C, and D show the direction of motion of different parts of the medium. The parts at A and C move in the same direction and at the same speed, so they are in phase. Similarly, the parts at B and D are in phase with each other. However, the parts at A and B, as well as C and D, move in opposite directions at the same speed, so they are out of phase.

Key Facts

The lines that join the points along the troughs of the waves are also wavefronts.

Crest (Peak)

In a transverse wave, the crest is the highest point of the wave, where the displacement of the parts of the medium is at its maximum value in the upward direction. In the Figure, points X and Y are crest points.

Trough

The trough is the lowest point of the wave in a transverse wave, where the displacement of parts of the medium is at its maximum value in the downward direction. In the Figure, points M and N are the trough points.

Compression

In longitudinal waves, compression refers to regions where particles of the medium are closely packed, representing areas of high pressure. These occur at the points where the wave's energy is concentrated. In Fig 2.7, region C represents compression

Rarefaction

It is the opposite of compression in longitudinal waves. It is the region where particles are spread apart, leading to a decrease in pressure. In the Fig 2.4, region R represents rarefaction (low pressure region).

Important Information

It is important to remember that the direction in which the wave moves is always perpendicular to the wavefront. This means that the direction of the wave's travel is at a right angle to the tangent at any point on the wavefront. This perpendicular direction is called ray of light. Understanding this helps us visualize how waves spread out from their source in different directions.

Wavelength

Wavelength is the distance between two consecutive points in the wave that are in the same phase, such as two crests or two troughs. In the graph, it is the distance between two consecutive crests (high points) or two consecutive troughs (low points). The wavelength is denoted by the Greek letter λ (lambda)

In the case of longitudinal waves, wavelength refers to the distance between two consecutive compressions (C) or two consecutive rarefactions (R). This can be understood from Fig. 2.7.

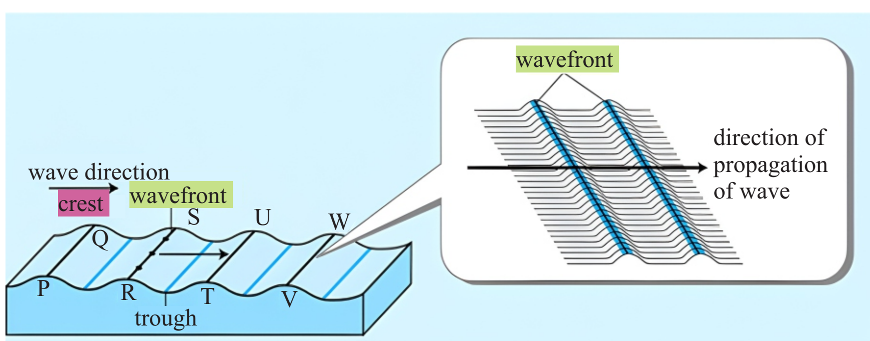
Wavefront

A wavefront is a line or surface where every point on it vibrates in phase, meaning they vibrate in the same direction and with the same speed from their rest position. This line or surface is always equidistant from the source of the wave.

There are two main types of wavefronts: plane and circular.

1. Plane Wavefronts:

In plane waves, the wavefronts are straight lines that move outward from the source in parallel, like the ripples created when a wooden bar vibrates vertically on the surface of water.



In Fig. 2.10, we can see these plane waves, where the lines PQ, RS, TU, and VW represent the wavefronts along the crests of the waves. These wavefronts are parallel to each other and move in the same direction as the wave.

2. Circular Wavefronts:

When you repeatedly touch the surface of water with your fingertip, circular waves are created, as shown in Fig. 2.11. The wavefronts in this case are circles centered on the point where the wave originates. Each circle represents a wavefront, and the direction in which the wave propagates is always at a right angle (perpendicular) to these circles. The normal drawn at a right angle to the wavefront at a point, representing the direction of wave propagation, is called the ray of light

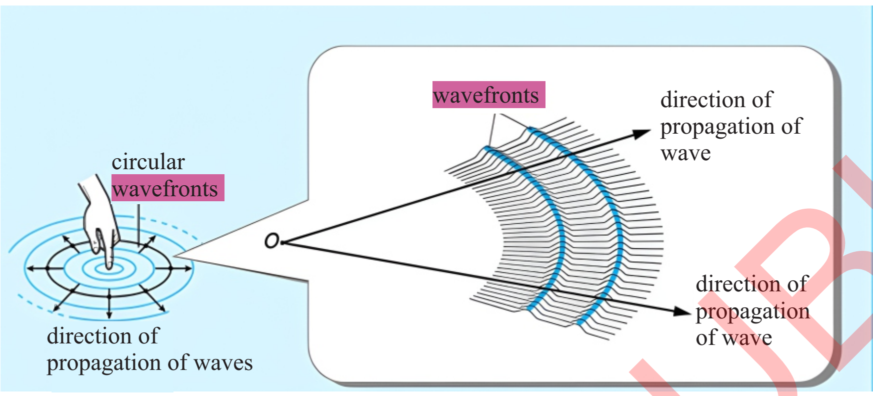


Figure 2.11: Circular wavefront

Frequency

The frequency (f) refers to the number of complete waves generated per second. For example, if the end of a rope is moved up and down twice in one second, two waves are produced. This means the frequency of the wave is two vibrations per second, or 2 hertz (2 Hz), where hertz is the unit used to measure frequency. The frequency of the wave is the same as the frequency of the source's motion. In other words, the number of waves passing a particular point per second is also the frequency of the wave.

Wave Speed

The wave speed (v) is the distance traveled by a crest or any point on the wave in the direction of wave propagation in 1 second. The speed at which a wave propagates depends on the properties of the medium, such as its elasticity and inertia. In mediums where particles are tightly bound, they respond quickly to disturbances, allowing waves to travel faster.

Amplitude

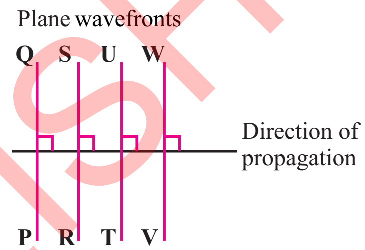
The amplitude (a) is the height of a crest or depth of a trough, measured from the undisturbed position of the medium, like a rope, as shown in Fig 2.7. Note that the amplitude of the wave is determined by the vibrating source and is equal to the amplitude of the source.

Time Period

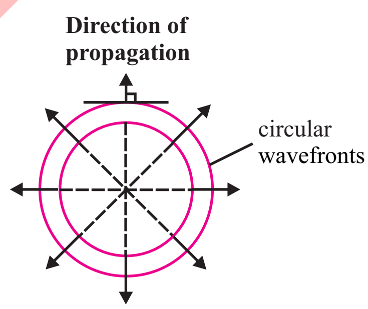
The time period of a wave is the time taken by the source of disturbance (vibrating source) to complete one cycle (vibration). In this time, one

Important Information

It is important to remember that the direction in which the wave moves is always **perpendicular** to the wavefront. This means that the direction of the wave's travel is at a **right angle** to the tangent at any point on the wavefront. This perpendicular direction is called ray of light. Understanding this helps us visualize how waves spread out from their source in different directions.



(a) Plane wavefronts



(b) Circular wavefronts

complete wave is generated and passes through a particular point. Thus, the time period can also be defined as the time taken by one wave to pass through a specific point in the medium. It is denoted by T.

Additionally, time period and frequency are reciprocals of each other. Therefore, we can write $T = \frac{1}{f}$

Wave Equation $v = f\lambda$

The faster the end of a rope is vibrated, the shorter the wavelength of the wave produced. In other words, a higher frequency results in a smaller wavelength. There is an important relationship between frequency (f), wavelength λ, and wave speed (v), which applies to all types of waves.

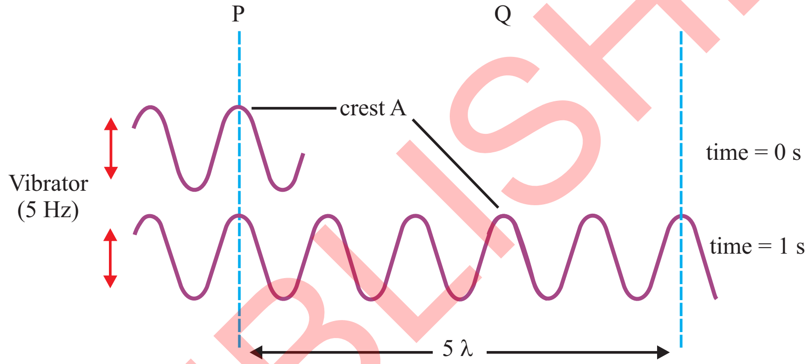


Figure 2.12: Illustration of determination of wave speed

For example, if waves with a wavelength of $\lambda = 30$ cm travel along a rope and five crests pass a specific point every second, the frequency (f) is 5 Hz. If Fig. 2.12 represents this wave motion, at a given time, if crest A is at point P, after one second it will be at point Q. The distance between P and Q is five wavelengths, or 5×30 cm $= 150$ cm $= 1.5$ m.

Thus, the speed of the wave (v) is 150 cm per second, which can also found by multiplying the frequency (f) by the wavelength (λ). This gives the wave equation:

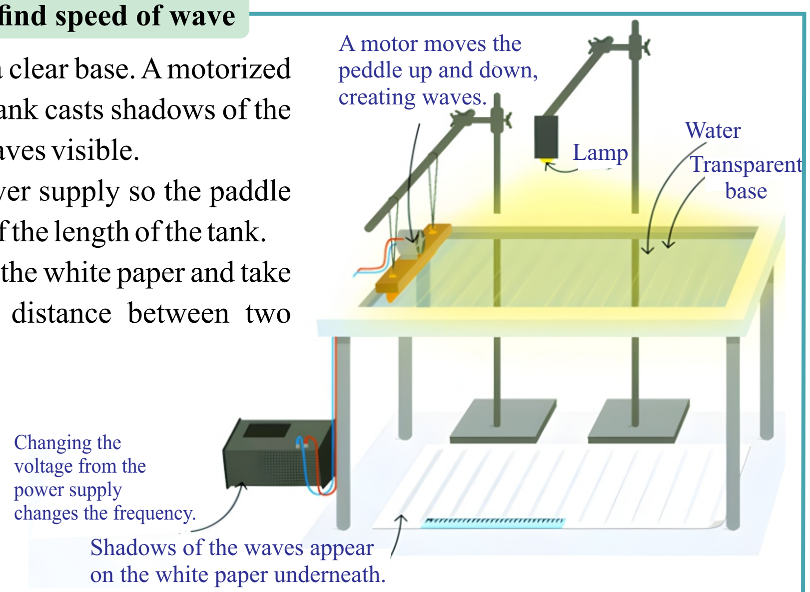
$$v = f\lambda$$

This equation shows the connection between wave speed, frequency, and wavelength.

Ripple Tank Experiment to find speed of wave

A ripple tank is a shallow tray of water with a clear base. A motorized paddle creates waves, and a light above the tank casts shadows of the waves onto white paper below, making the waves visible.

- Set up the ripple tank and adjust the power supply so the paddle creates waves with wavelengths about half the length of the tank.
- Measure the wavelength: Place a ruler on the white paper and take a photo of the shadows. Measure the distance between two consecutive waves to find the wavelength.
- Measure the frequency: Mark a point on the paper and use a timer to count how many waves pass it in 10 seconds. Divide by 10 to find the frequency in waves per second (Hz).



- Calculate the wave speed: Use the formula:

$$\text{speed} = \text{frequency} \times \text{wavelength}$$

to find the speed of the waves.

- Verify the result: Time how long one wave takes to pass between two measured points on the paper, then use the formula: $\text{speed} = \dfrac{\text{distance}}{\text{time}}$ to check the speed again.

2.1 EXAMPLE

The speed of a wave is 4 cm s^{-1}. If its frequency is 2 Hz, calculate its wavelength.

Solution:

Using the formula:

$$v = f\lambda$$

$$\lambda = \frac{v}{f} = \frac{4 \text{ cm s}^{-1}}{2 \text{ Hz}} = 2 \text{ cm}$$

The wavelength is 2 cm.

2.2 EXAMPLE

A wave traveling at 10 m/s has a wavelength of 25 cm. Calculate its frequency.

Solution:

First, convert the wavelength to meters:

$$\lambda = 25 \text{ cm} = 0.25 \text{ m}$$

Using the formula:

$$v = f\lambda$$

$$f = \frac{v}{\lambda} = \frac{10 \text{ m s}^{-1}}{0.25 \text{ m}} = 40 \text{ Hz}$$

The frequency is 40 Hz.

Multiple Choice Question

1. How does amplitude affect the energy of a wave?
   a) Higher amplitude means lower energy
   b) Amplitude does not affect energy
   c) Higher amplitude means higher energy
   d) Energy depends only on frequency, not amplitude
2. How is wave speed calculated?
   a) $v = f \times \lambda$ b) $v = \lambda \div f$
   c) $v = f \div \lambda$ d) $v = f \times T$
3. If the frequency of a wave is doubled while the wavelength remains the same, what happens to the wave speed?
   a) Halved b) Same
   c) Doubles. d) Zero
4. A wave has a speed of 300 m/s and a frequency of 150 Hz. What is its wavelength?
   a) 2 m b) 0.5 m
   c) 450 m d) 150 m

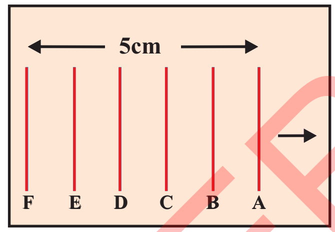
Skill:2.2

Describe wave features, define frequency, wavelength, and amplitude, and apply v = f λ to solve wave motion problems.

Test Yourself

Short answer-based questions

1. The lines in figure represent the crests of straight ripples.



   (a) What is the wavelength of the ripples?
   (b) If ripple A was at the position of ripple F 5 s ago, what is the frequency of the ripples?
   (c) What is the speed of the ripples?
2. Compare the terms crest and trough in a transverse wave.

2.3 Knowledge

Wave Properties: Reflection, Refraction & Diffraction

The behavior of water waves in a ripple tank can show how different wave properties like reflection, refraction, and diffraction work.

Reflection at a plane surface

Reflection of waves occurs when waves strike a surface and bounce back. In Fig.2.13(a), straight water waves in ripple tank, approach a metal strip at angle of 60°. This angle is the angle between the direction of wave propagation and the normal (an imaginary line perpendicular to the plane of metal strip at a point where light ray strikes), known as the angle of incidence (i). The wavefronts, represented by straight lines, are the crests of the waves, and they are at right angles to the direction of travel (i.e., the rays). The angle between the wavefront and the metal strip is also 60°, the same as the angle of incidence.

When the wave reflects off the surface, the reflected ray makes an angle (*r*) with the normal, called the angle of reflection. It has been observed that the angle of incidence is exactly equal to the angle of reflection. This is known as the law of reflection. In simple terms, the wave bounces back at the same angle at which it approached the surface.

This principle applies to all types of waves, including light and sound waves. Reflection of radio waves from ionosphere is illustrated in Fig. 2.13(b) The key takeaway is that the angle between the incident wavefront and the surface is the same as the angle between the reflected wavefront and the surface, reinforcing that the angle of incidence and angle of reflection are always equal.

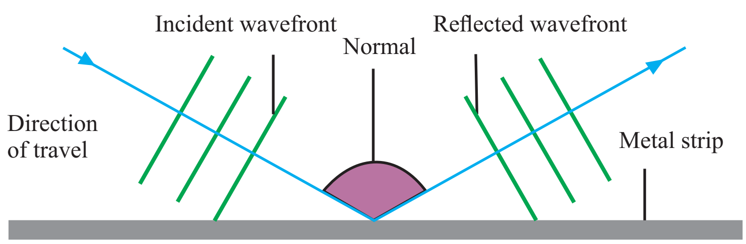


Figure 2.13: (a) Reflection of waves at plane surface

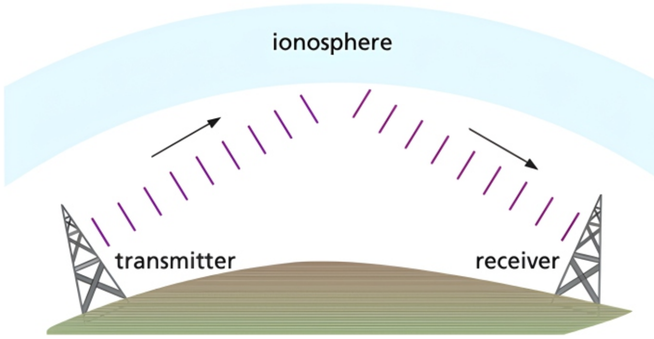


Figure 2.13: (b) Reflection of radio waves

Refraction

Refraction occurs when waves change direction as they pass from one medium to another. For water waves, this happens when they move from deep water (higher speed) to shallow water (lower speed). In shallow water, the movement of water particles is more restricted, causing the wave to slow down, similar to walking on soft mud. As the wave slows, the wavefronts (crests) get closer together, as shown in Fig. 2.14, indicating a decrease in wavelength. Both speed and wavelength decrease as waves transition from deep to shallow water.

Figure 2.14: Waves in shallower water have a shorter wavelength.

Waves bend during this process because, when waves strike the boundary at an angle, the part in shallow water slows first, while the part in deep water moves faster as indicated. This causes the wave to bend towards the normal, a process known as refraction, as seen in Fig. 2.15.

Figure 2.15: Waves are refracted at the boundary between deep and shallow region

Fig. 2.16 (a) shows Side view of water waves transitioning from deep to shallow water. Fig. 2.16 (b) shows the wave refraction explained using wavefronts and rays.

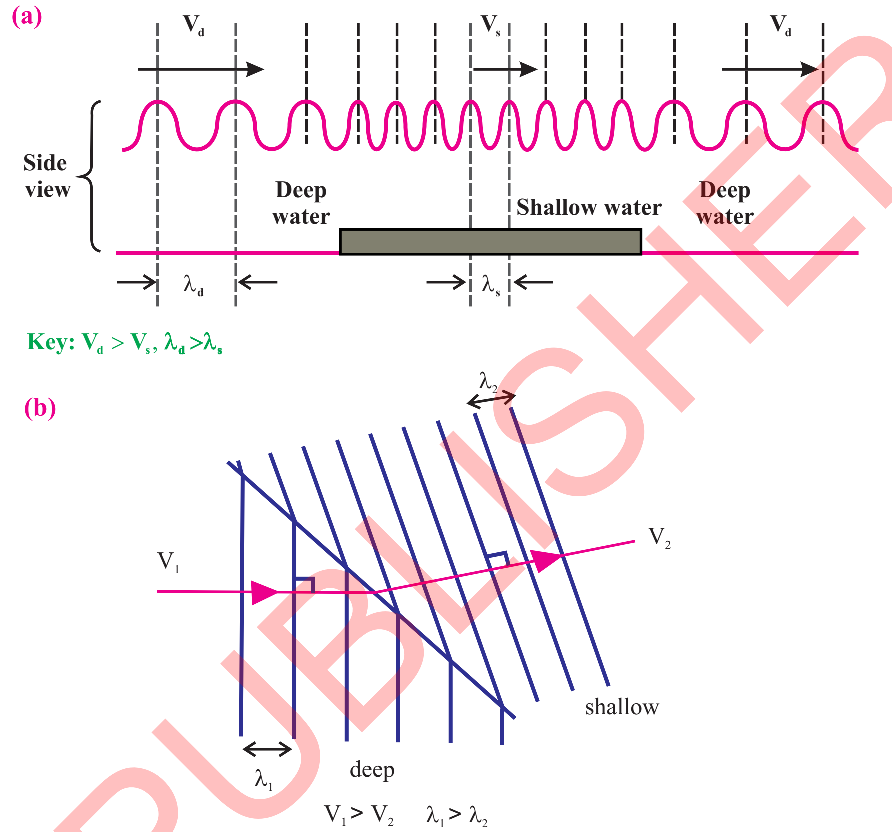


Figure 2.16: Water waves slow down and refract in shallow water, reducing wavelength. (a) Shows sideview water waves behavior, while (b) illustrates wavefront and ray refraction.

Refraction also occurs when waves pass between other media, such as light waves moving from air to glass, bending towards the normal as their speed decreases.

Diffraction of Waves

Diffraction through a Narrow Gap

When straight water waves in ripple tank pass through a narrow gap, they spread out and change direction. In Fig.2.17(a), the gap is narrow, and as the waves pass through, they bend around the edges of the gap, creating circular wavefronts. This bending and spreading of waves as they pass through an opening or around obstacles is known as diffraction.

Figure 2.17: (a) Water waves are spreading after passing through a narrow gap.

Diffraction through a Wide Gap

In Fig.2.17(b), the gap is wider (10 cm) compared to the wavelength of the waves. When the waves pass through this larger gap, they continue to move forward with some spreading at the edges, but the waves mostly maintain their direction. The spreading at the edges is less noticeable compared to when the gap is narrow.

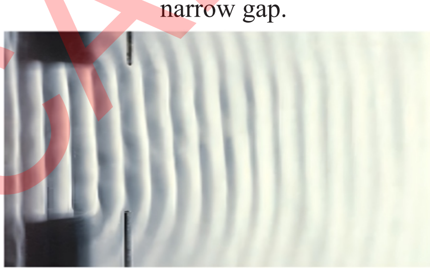


Figure 2.17: (b) Water waves are spreading after passing through a wide gap.

Effect of Wavelength and Gap Size on Diffraction

The amount of diffraction depends on the relationship between the wavelength of the waves and the size of the gap. In Fig. 2.17(a), where the gap width is about the same as the wavelength of the waves (1 cm), the waves bend sharply and spread out in all directions after passing through the gap. In Fig. 2.17(b), where the gap is much wider than the wavelength (10 cm), the waves continue in their original direction but spread slightly at the edges, causing a less noticeable diffraction effect.

Engineers study diffraction when designing harbours, as waves interacting with obstacles like piers or breakwaters can behave differently depending on the size of the gaps and the wavelength. Fig. 2.18 shows a model of a harbour used to study how waves diffract and how this affects the harbour's design.

Figure 2.18: Harbour model demonstrating wave behavior analysis.

Diffraction at an Edge

When waves encounter a single edge, such as the boundary of a pier (raised structure extending from the shore into water, supported by pillars, used for docking, fishing, and recreation), diffraction occurs at the edge. The wavefronts spread out and curve around the edge. This effect is more pronounced when the wavelength of the waves is longer. The longer the wavelength, the more the waves bend around the edge, which can affect the distribution of wave energy in the area. Diffraction of radio waves around an obstacle is shown in Fig. 2.19.

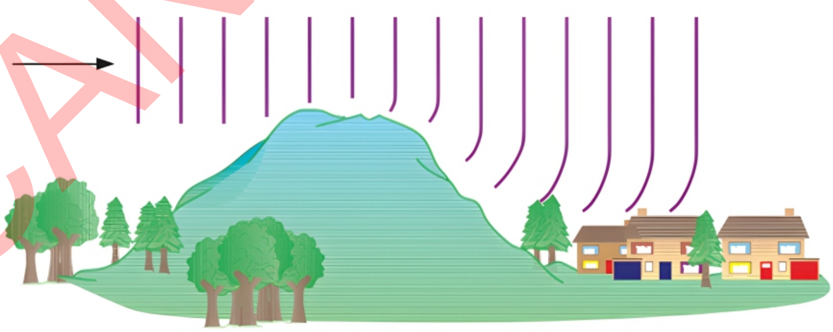


Figure 2.19: Diffraction of radio waves

Multiple Choice Question

1. What happens when a wave undergoes reflection?
   a) Bends in a new medium
   b) Bounces back in the same medium
   c) Spreads through a gap
   d) Disappears after hitting a surface
2. Which real-life scenario is an example of diffraction at an edge?
   a) Mirror reflecting light
   b) Pencil appearing bent in water
   c) Ocean waves bending around a rock
   d) Light passing through glass
3. Which of the following conditions causes maximum diffraction?
   a) Gap much larger than wavelength
   b) Gap same size as wavelength
   c) Gap much smaller than wavelength
   d) Wavelength is zero

Skill:2.3

Describe how waves undergo reflection, refraction, and diffraction, explaining how wavelength affects diffraction at edges and how both wavelength and gap size influence diffraction through a gap.

Test Yourself

Short answer-based questions

1. Describe how refraction affects the speed and direction of a wave when it moves from air to water.
2. What would happen if radio waves had very short wavelengths? How would this affect their ability to diffract around buildings?
3. Define diffraction and describe how it occurs when a wave passes through a gap.

2.4 Knowledge

Tsunami Formation and Effects

Tsunamis are large, powerful waves caused by sudden disturbances beneath the ocean surface. Unlike typical ocean waves driven by wind, tsunamis result from shifts in the ocean floor due to underwater earthquakes, volcanic activity, or underwater landslides, which displace large volumes of water.

Formation of Tsunamis and its Wave Behavior in Shallow Waters:

The most common cause of tsunamis is underwater earthquakes. When an earthquake occurs beneath the ocean floor, the tectonic plates along the fault line (fractures in the Earth's crust where two blocks of the Earth's surface move relative to each other) suddenly move, causing the seafloor to uplift. The movement of tectonic plates, either vertically or horizontally, displaces a large amount of water above them, generating waves that propagate outward across the ocean.

Similarly, volcanic eruptions and underwater landslides can also displace water, generating waves. However, underwater earthquakes are the primary cause of tsunamis. These waves travel at extremely high speeds-500-800 kilometers per hour-in deep ocean waters. Despite their high speed, tsunami waves have long wavelengths and small amplitudes in deep water, making them barely detectable. The wave height in the deep ocean is often only about 5 meters (15 feet) or less.

As tsunami waves approach the coast and enter shallower waters, their behavior changes. The wave speed decreases as the water depth becomes shallower. According to the relationship $v = f \times \lambda$, when the wave slows down, its energy becomes more concentrated, causing the amplitude to increase. The wavefronts (crests) become closer together, and the waves grow in height from 5 meters (15 feet) to 30 meters (100 feet) or more, as shown in the Fig. 2.20. This significant increase in wave height and frequency makes tsunamis extremely dangerous when they reach coastal areas. They cause fast-moving surges of water that can inundate vast areas of land.

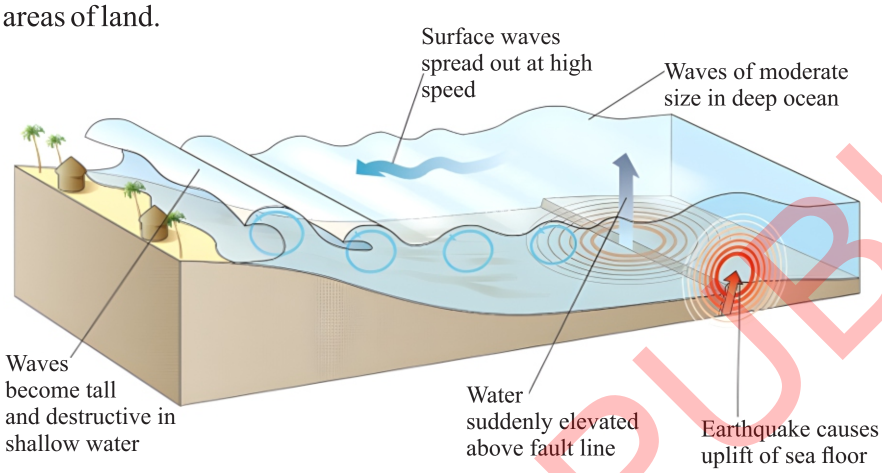


Figure 2.20: Shows how an earthquake uplifts the seafloor, generating tsunami waves that increase in height in shallow water.

Multiple Choice Question

1. Why are tsunamis more dangerous near coastlines?
   a) Ocean absorbs wave energy
   b) Wave energy spreads and weakens
   c) Wave slows down but grows taller
   d) Tsunami disappears before landfall
2. How can tsunami damage be reduced?
   a) Build stronger shore buildings
   b) Use satellites to stop waves
   c) Use warning systems and evacuation plans
   d) Add shoreline rocks to break waves

Test Yourself

Short answer-based questions

1. How does an underwater earthquake generate a tsunami?
2. How do scientists detect and monitor tsunamis before they reach land?

Skill:2.4

Analyze how underwater earthquakes and volcanic activity generate tsunamis, causing changes in wave frequency, amplitude, and speed as they move from deep to shallow water, leading to coastal impacts

Important Information

Tectonic plates are large, rigid pieces of the Earth's outer layer, called the lithosphere, that move slowly over the semi-fluid asthenosphere beneath them. Earthquakes occur at the boundaries where these plates meet, due to stress and pressure. There are three main types of plate boundaries: convergent (plates move toward each other), divergent (plates move apart), and transform (plates slide past each other). When the pressure at these boundaries is released, it causes an earthquake. Tectonic plate movements are therefore the main cause of earthquakes.

Do You Know?

The 2004 Indian Ocean earthquake, which took place on December 26, 2004, off the coast of Sumatra, Indonesia, was one of the deadliest natural disasters in history, resulting in the deaths of more than 225,000 people across 11 countries.

Key Points

- Waves transfer energy through particle oscillation, not by moving matter. Particles vibrate in place rather than traveling with the wave.
- Wave motion is the movement of energy through a medium, demonstrated by vibrations in ropes, springs, and water waves.
- Transverse waves vibrate perpendicular to the direction of energy transfer, like light waves, water waves, and seismic S-waves.
- Longitudinal waves vibrate parallel to the direction of energy transfer, such as sound waves and seismic P-waves.
- Waves have key features like wavelength (distance between crests or troughs), frequency (number of waves per second), amplitude (height of the wave), wavefronts, and speed.
- Wave speed is calculated using the equation $v = f\lambda$, where v is speed, f is frequency, and λ is wavelength.
- Waves undergo reflection, refraction, and diffraction. Reflection occurs when waves bounce off surfaces, refraction bends waves as they pass through different mediums, and diffraction spreads waves when they pass edges or gaps.
- Wavelength affects diffraction; longer wavelengths bend more around edges, while shorter wavelengths bend less.
- Diffraction depends on the size of the gap and the wavelength. When the gap is about the same size as the wavelength, the diffraction is stronger, causing the wave to spread out more.
- Tsunamis are caused by underwater earthquakes or volcanic eruptions. These waves increase in frequency and amplitude as they reach shallow water, leading to massive destruction.

Exercise

After completing the chapter students practice SLO based exercise to prepare for examination. Each SLO include three types of question: Multiple choice question (MCQs), Short response question (SRQs), Extended response question (ERQs) and detailed exercise solution available in QR code.

[SLO: P-10-D-01]: *Prove that waves transfer energy without transferring matter. (Application)*

Multiple-Choice Questions

1. Which of the following is not an example of wave energy transfer without matter movement?
   a) Sound waves in air   b) Surfer moving forward
   c) Ripples on water   d) Light waves in space

2. A cork is floating on water. When a wave passes, what will happen to the cork?
   a) Moves forward   b) Moves up and down
   c) Sinks   d) Moves in a straight line

Short Response Questions

1. A student says, "In a sound wave, air particles move from the speaker to the listener". Describe why this statement is incorrect.

2. Describe an experiment using a slinky that shows how waves transfer energy without moving the entire slinky forward.

3. If ocean waves carried water forward instead of energy, what would happen to objects floating on the surface? Describe your reasoning.

Extended Response Questions

1. Explain why waves transfer energy without transferring matter, using real-life examples and particle motion analysis.

[SLO: P-10-D-02]: *Describe what is meant by wave motion [as illustrated by vibrations in ropes and springs and by experiments using water waves]. (Understanding)*

Multiple-Choice Questions

1. Which of the following best demonstrates wave motion?
   a) Moving rope up and down   b) Rolling ball

c) Pushed book
d) Walking on treadmill

2. A slinky is stretched and compressed back and forth. What type of wave motion does this demonstrate?
   a) Transverse wave
   b) Longitudinal wave
   c) Surface wave
   d) Standing wave

Short Response Questions

1. Describe how a slinky can be used to illustrate both transverse and longitudinal waves.
2. What happens to the motion of water particles in a wave? How does this support the idea of wave motion?

Extended Response Questions

1. Describe wave motion using scientific reasoning and real-life examples.

***[SLO: P-10-D-06]:** Illustrate that for a transverse wave, the direction of vibration is at right angles to the direction of the energy transfer. (Understanding)*

Multiple-Choice Questions

1. Why do seismic S-waves not travel through liquids?
   a) Liquids do not allow perpendicular motion
   b) Liquids block all waves
   c) S-waves are too slow
   d) S-waves lose energy
2. Which of the following is not an example of a transverse wave?
   a) Light waves
   b) Water waves
   c) Sound waves
   d) Seismic S-waves

Short Response Questions

1. Describe how waves on the surface of water demonstrate transverse wave motion.
2. How do seismic S-waves help scientists understand the Earth's interior?

1. Illustrate that in a transverse wave, the direction of vibration is at right angles to the direction of energy transfer.

***[SLO: P-10-D-07]:** Illustrate that for a longitudinal wave, the direction of vibration is parallel to the direction of the energy transfer. (Understanding)*

Multiple-Choice Questions

1. In a longitudinal wave, how do the particles move relative to the direction of energy transfer?
   a) Perpendicular
   b) Circular motion
   c) Parallel
   d) Random
2. What are the regions of high and low pressure in a longitudinal wave called?
   a) Crests and troughs
   b) Amplitude and frequency
   c) Compressions and rarefactions
   d) Peaks and valleys
3. What happens to air particles as a sound wave moves through them?
   a) Move forward permanently
   b) Oscillate back and forth
   c) Move in circles
   d) Do not move

Short Response Questions

1. Describe how sound waves demonstrate longitudinal wave motion.
2. Why can seismic P-waves travel through both solids and liquids, while seismic S-waves cannot?
3. A student pushes and pulls a slinky back and forth. How does this demonstrate longitudinal wave motion?

Extended Response Questions

1. Illustrate that in a longitudinal wave, the direction of vibration is parallel to the direction of energy transfer.

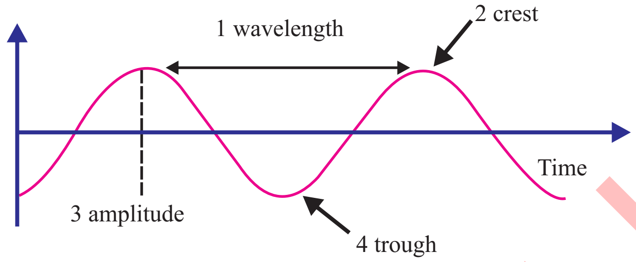
SLO: P-10-D-03]: *Describe the features of a wave [in terms of wavefront, wavelength, frequency, time period, crest (peak), trough, compression, rarefaction, amplitude and wave speed]. (Understanding)*

Multiple-Choice Questions

1. In a longitudinal wave, what are the regions where particles are close together called?
a) Troughs b) Crests c) Compressions d) Rarefactions

2. For a wave with speed v, frequency f and wavelength λ, which statement is correct?
a) Always proportional to frequency b) Always proportional to wavelength
c) Inversely proportional to $\frac{1}{T}$ d) Depends on the properties of the medium

3. Figure shows a wave graph with labeled points. Which of the following labels are correct?



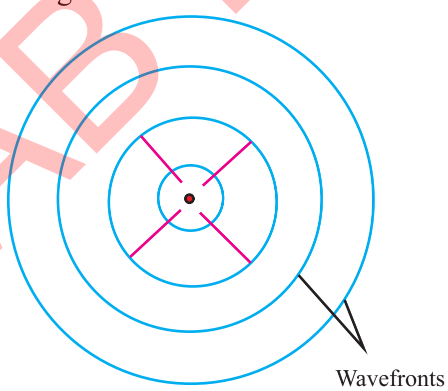
a) 1 and 3 only b) 2 and 4 only c) 1, 2, and 4 only d) All labels are correct

Short Response Questions

1. In the two scenarios below, describe why each student's statement is incorrect and how you would rephrase it to make it more accurate.
(a) A student claims that a wavelength is the shortest distance between two crests.
(b) Another student states that a wave's amplitude is half the distance between a crest and a trough.

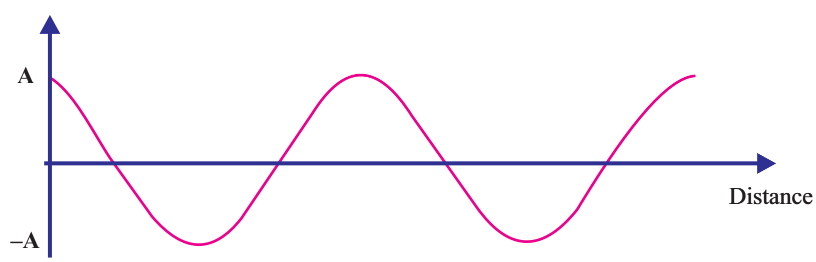
2. How does increasing the amplitude of a wave affect its energy?

3. A series of regularly spaced, outward-spreading wavefronts is created by dipping the tip of a rod in and out of the water surface as shown in figure below.



(a) Define a wavefront.
(b) What is the term for the shortest distance between two consecutive wavefronts?

4. The displacement-distance graph of a wave is shown in figure below. Draw the waveform $\frac{3}{4}$ of a period later.



[SLO: P-10-D-04]: *Define the terms frequency, wavelength, and amplitude. (knowledge)*

Multiple-Choice Questions

1. If a wave has a frequency of 10 Hz, what does this mean?
a) Takes 10 sec per cycle b) 10 cycles per second
c) Wavelength is 10m d) Speed is 10 m s^{-1}.

2. What is the relationship between wavelength and frequency in a wave?
a) Directly proportional b) No relation
c) Inversely proportional d) Both increase together

3. Which unit is used to measure wavelength?
a) Hertz (Hz) b) Meters (m) c) Seconds (s) d) Joules (J)

Short Response Questions

1. What is wavelength, and how is it different from amplitude?

2. How does increasing the frequency of a wave affect its wavelength?

[SLO: P-10-D-05]: *Recall and apply the equation wave speed = frequency × wavelength ($v = f\lambda$). (Application)*

Multiple-Choice Questions

1. A wave traveling at 500 m s^{-1} has a wavelength of 5 m. What is its frequency?
a) 50 Hz b) 100 Hz c) 250 Hz d) 500 Hz

2. Which of the following correctly defines frequency in the equation $v=f\lambda$?
a) Time for one cycle b) Waves per second
c) Distance between crests/trough d) Total wave energy

Short Response Questions

1. A wave has a speed of 340 m s^{-1} and a wavelength of 0.85 m. Calculate its frequency.

2. How does changing the frequency of a wave affect its wavelength if the speed remains constant?

3. A radio wave has a frequency of 100 MHz and a wavelength of 3 m. Calculate its speed.

Extended Response Questions

1. A wave moves forward by 30 m in 5 s for each oscillation. Calculate:(a) The wavelength of the wave. (b) The speed of the wave. (c) The frequency of the wave. **[30 m, 6 m s^{-1}, 0.2 Hz]**

2. A sound wave in the air has a frequency of 256 Hz and a wavelength of 1.35 m.
a. Calculate the speed of the wave.
b. If the frequency increases to 512 Hz, assuming the wave speed remains the same, calculate the new wavelength. **[345.6 m s^{-1}, 0.675 m]**

[SLO: P-10-D-08]: *Describe how waves can undergo reflection, refraction and diffraction. (Understanding)*

Multiple-Choice Questions

1. Which of the following is an example of refraction?
a) Mirror reflecting light b) Pencil appearing bent in water
c) Echo off a wall d) Wave spreading around a rock

2. Which statement about wave behavior is true?
a) Only sound waves diffract.
b) Only light waves reflect.
c) Refraction occurs when waves change speed between mediums.
d) Waves reflect only off smooth surfaces.

3. Why do ocean waves bend as they approach the shore?
a) Because of diffraction b) Because of reflection
c) Because of refraction d) Because of absorption

Short Response Questions

1. Differentiate between reflection and refraction .
2. Why do we sometimes hear sounds from around a corner, even when we cannot see the source?
3. Describe an experiment to demonstrate the reflection of water waves in a ripple tank.

Extended Response Questions

1. As a wave enters a second medium, describe what happens to its:
   (a) Wavelength (b) Frequency (c) Speed
2. Describe how diffraction occurs and what factors affect it.

***[SLO: P-10-D-09]:** Describe how wavelength affects diffraction at an edge. (Understanding)*

Multiple-Choice Questions

How does wavelength affect diffraction at an edge?
a) Longer wavelengths diffract more
b) Shorter wavelengths diffract more
c) No effect on diffraction
d) Only light diffracts

Short Response Questions

1. Why do sound waves experience more notice able diffraction than light waves?
2. Give an example of diffraction at an edge in daily life and how does wavelength influences it.

Extended Response Questions

1. A person standing behind a wall can hear a speaker playing music but cannot see the speaker. Explain why this occurs.

***[SLO: P-10-D-11]:** Describe how wavelength and gap size affect diffraction through a gap. (Understanding)*

Multiple-Choice Questions

1. What happens when a wave passes through a narrow gap?
   a) Absorbed
   b) Bends and spreads out
   c) Disappears
   d) Speeds up, moves straight
2. If a wave's wavelength is much shorter than the gap size, what happens?
   a) Spreads widely
   b) Passes with little diffraction
   c) Stops moving
   d) Travels back

Short Response Questions

1. Why does a narrow doorway allow sound waves to spread into another room but not light waves?
2. Compare the diffraction of a wave when the gap is much larger than the wavelength versus when the gap is similar to the wavelength.

Extended Response Questions

1. Describe how wavelength and gap size affect diffraction.

***[SLO: P-10-D-10]:** Analyse the phenomenon of tsunamis generated under the surface of water [in terms of underwater earthquakes/volcanic activity generating waves that increase in frequency and amplitude as they encounter increasingly shallow water]. (Understanding)*

Multiple-Choice Questions

1. As a tsunami approaches shallow water, what happens to its speed and amplitude?
   a) Speed increases, amplitude decreases
   b) Speed decreases, amplitude increases
   c) Both increase
   d) Both decrease
2. What best describes a tsunami's frequency?

a) High frequency, short wavelength

b) Low frequency, long wavelength in deep water

c) High frequency, large height

d) No specific pattern

Short Response Questions

1. Why do tsunamis have such long wavelengths in deep water?
2. Describe why people on boats in the deep ocean may not notice a tsunami passing underneath them.

Extended Response Questions

1. Analyze how tsunamis are formed and how they behave as they approach land.