PHYS11 CH:11

Temperature, Heat, and Phase Changes

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Overview

Learning Objectives

By the end of this lesson, you will be able to:

- Define temperature and explain its relationship to molecular motion
- Convert between temperature scales (Celsius, Fahrenheit, and Kelvin)
- Explain the difference between heat and temperature
- Calculate heat transfer using $Q = mc\Delta T$
- Identify the three mechanisms of heat transfer
- Describe phase changes and calculate energy using latent heat

Temperature and Thermal Energy

- **Temperature:** Quantity measured by a thermometer
- Related to the average kinetic energy of atoms and molecules
- **Absolute zero:** Temperature at which there is no molecular motion
- Three main temperature scales:
  - Celsius (°C)
  - Fahrenheit (°F)
  - Kelvin (K)

[Thermometer scales diagram showing comparison of the three temperature scales] comparison-three-temperature-scales-vector-16434650-2

Temperature Scales and Conversion

Temperature Conversion Formulas

$$\begin{aligned} T_{^\circ\mathrm{F}} &= \frac{9}{5} T_{^\circ\mathrm{C}} + 32 \\ T_{^\circ\mathrm{C}} &= \frac{5}{9}(T_{^\circ\mathrm{F}} - 32) \\ T_{\mathrm{K}} &= T_{^\circ\mathrm{C}} + 273.15 \\ T_{^\circ\mathrm{C}} &= T_{\mathrm{K}} - 273.15 \end{aligned}$$

Examples

- Room temperature: $20^\circ\mathrm{C} = 68^\circ\mathrm{F} = 293.15\ \mathrm{K}$
- Freezing point of water: $0^\circ\mathrm{C} = 32^\circ\mathrm{F} = 273.15\ \mathrm{K}$
- Absolute zero: $-273.15^\circ\mathrm{C} = -459.67^\circ\mathrm{F} = 0\ \mathrm{K}$

Heat and Specific Heat

Definitions

- **Heat (Q):** Thermal energy transferred due to a temperature difference
- **Specific heat (c):** Amount of heat needed to raise the temperature of 1 kg of a substance by 1°C

Heat Transfer Equation

$$Q = mc\Delta T$$

where:

- Q = heat transferred (J)
- m = mass (kg)
- c = specific heat (J/kg·°C)
- ΔT = change in temperature (°C or K)

Specific Heat of Common Materials

Material	**Specific Heat (J/kg·°C)**
Water	4,186
Ice (at 0°C)	2,090
Steam (at 100°C)	2,010
Aluminum	900
Copper	385
Gold	129
Wood	$\approx$ 1,700

Note

Water has an unusually high specific heat, which is why bodies of water moderate climate.

Heat Transfer Methods

- **Conduction:** Transfer between objects in direct contact
  - Metals are good conductors
  - Wood and air are poor conductors (insulators)
- **Convection:** Transfer by movement of mass
  - Ocean currents, boiling water, air movement
- **Radiation:** Transfer by electromagnetic waves
  - Requires no medium (works in vacuum)
  - How the Sun's energy reaches Earth

[Diagram showing the three heat transfer mechanisms] phys11-thermo-heat-transfer-mechanisms.jpg

Phases of Matter

- Four distinct phases:
  - **Solid:** Particles in fixed positions, vibrating
  - **Liquid:** Particles close together but can move around
  - **Gas:** Particles far apart, moving freely
  - **Plasma:** Ionized gas (very high energy)
- Gas is the most energetic state
- Solid is the least energetic state

[Phase transition diagram showing the four states of matter and the energy relationships between them] phys11-thermo-phases-of-matter.jpg

Phase Changes

- **Melting:** Solid $\rightarrow$ Liquid
- **Freezing:** Liquid $\rightarrow$ Solid
- **Vaporization:** Liquid $\rightarrow$ Gas
- **Condensation:** Gas $\rightarrow$ Liquid
- **Sublimation:** Solid $\rightarrow$ Gas
- **Deposition:** Gas $\rightarrow$ Solid

Important Points

- Phase changes occur at fixed temperatures
- No temperature change during phase change
- Energy breaks bonds between particles
- Increases potential energy, not kinetic energy

Latent Heat

Definition

Latent heat: The energy required to change the phase of a substance without changing its temperature

Heat Transfer Equations for Phase Changes

$$Q_{\text{melting/freezing}} = mL_f$$
$$Q_{\text{vaporization/condensation}} = mL_v$$

where:

- Q = heat transferred (J)
- m = mass (kg)
- L_f = latent heat of fusion (J/kg)
- L_v = latent heat of vaporization (J/kg)

Latent Heat Values

Substance	Latent Heat of Fusion (kJ/kg)	Latent Heat of Vaporiz
Water	334	2,260
Aluminum	380	11,400
Gold	64.5	1,580
Mercury	11.8	296
Tungsten	184	4,810

Note

During phase changes, the temperature remains constant while energy is being added or removed.

"I do" Example

Problem

How much energy would it take to heat 1.00 kg of ice at $0°C$ to water at $15.0°C$?

Solution

1. Energy to melt ice at 0°C to water at 0°C:

$$Q_1 = mL_f = 1.00 \text{ kg} \times 334 \text{ kJ/kg} = 334 \text{ kJ}$$

2. Energy to heat water from 0°C to 15.0°C:

$$\begin{aligned} Q_2 &= mc\Delta T \\ &= 1.00 \text{ kg} \times 4,186 \text{ J/(kg·°C)} \times 15.0 \text{ °C} \\ &= 62,790 \text{ J} = 62.8 \text{ kJ} \end{aligned}$$

3. Total energy required:

$$Q_{\text{total}} = Q_1 + Q_2 = 334 \text{ kJ} + 62.8 \text{ kJ} = 397 \text{ kJ}$$

"We do" Example

Problem

Ice cubes are used to chill a soda with a mass of 0.250 kg at 15.0°C. The ice is at 0°C, and the total mass of the ice cubes is 0.020 kg. Assume that the soda is kept in a foam container so that heat loss can be ignored, and that the soda has the same specific heat as water. Find the final temperature when all ice has melted.

Solution Steps

1. Heat lost by soda = Heat gained by ice
2. Heat lost by soda: $Q_{\text{soda}} = m_{\text{soda}} c_{\text{water}} (T_f - T_i)$
3. Heat gained by ice: $Q_{\text{ice}} = m_{\text{ice}} L_f + m_{\text{ice}} c_{\text{water}} (T_f - 0°\text{C})$
4. Set $Q_{\text{soda}} = Q_{\text{ice}}$ and solve for T_f
5. $T_f = 9.03°\text{C}$

"You do" Example

Problem

A certain quantity of water is given 4.0 kJ of heat. This raises its temperature by 30.0°F. What is the mass of the water in grams?

Hints

- Use the equation $Q = mc\Delta T$
- Remember to convert temperature change from °F to °C
- The specific heat of water is 4,186 J/(kg·°C)

Take some time to work this out. Then we'll discuss the solution.

"You do" Example

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Answer

The mass of water is 57 g.

Key Equations

Temperature Conversions:

$$T_{^\circ\mathrm{F}} = \frac{9}{5}T_{^\circ\mathrm{C}} + 32$$
$$T_{^\circ\mathrm{C}} = \frac{5}{9}(T_{^\circ\mathrm{F}} - 32)$$
$$T_{\mathrm{K}} = T_{^\circ\mathrm{C}} + 273.15$$

Heat Transfer:

$$Q = mc\Delta T$$
$$Q_{\text{melting/freezing}} = mL_f$$
$$Q_{\text{vaporization/condensation}} = mL_v$$

Summary

Temperature and Thermal Energy

- Temperature relates to average kinetic energy of particles
- Three main scales: Celsius, Fahrenheit, Kelvin
- Absolute zero: no molecular motion

Heat, Specific Heat, and Heat Transfer

- Heat is energy transfer due to temperature difference
- $Q = mc\Delta T$ relates heat, mass, specific heat, and temperature change
- Heat transfer methods: conduction, convection, radiation

Phase Change and Latent Heat

- Four phases: solid, liquid, gas, plasma
- Phase changes occur at constant temperature
- Heat added during melting/vaporization, released during freezing/condensation

Thank You!

Questions?

Remember to review the key equations and concepts for the upcoming quiz!