

# PHYS11 CH:11

## Temperature, Heat, and Phase Changes

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# Overview

- 1 Temperature and Thermal Energy
- 2 Heat, Specific Heat, and Heat Transfer
- 3 Phase Change and Latent Heat
- 4 Examples and Applications
- 5 Summary

# 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 ( $^{\circ}\text{C}$ )
  - Fahrenheit ( $^{\circ}\text{F}$ )
  - Kelvin (K)

[Thermometer scales diagram showing comparison of the three temperature scales]

comparison-three-temperature-scales-vector-16434650-29

# Temperature Scales and Conversion

## Temperature Conversion Formulas

$$T_{\text{°F}} = \frac{9}{5} T_{\text{°C}} + 32$$

$$T_{\text{°C}} = \frac{5}{9} (T_{\text{°F}} - 32)$$

$$T_{\text{K}} = T_{\text{°C}} + 273.15$$

$$T_{\text{°C}} = T_{\text{K}} - 273.15$$

## Examples

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

# 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  $1^{\circ}\text{C}$

## Heat Transfer Equation

$$Q = mc\Delta T$$

where:

- $Q$  = heat transferred (J)
- $m$  = mass (kg)
- $c$  = specific heat ( $\text{J/kg}\cdot^{\circ}\text{C}$ )
- $\Delta T$  = change in temperature ( $^{\circ}\text{C}$  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	≈ 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 Vaporization (kJ/kg)
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  $0^{\circ}\text{C}$  to water at  $15.0^{\circ}\text{C}$ ?



## Solution

- ① Energy to melt ice at  $0^{\circ}\text{C}$  to water at  $0^{\circ}\text{C}$ :

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

- ② Energy to heat water from  $0^{\circ}\text{C}$  to  $15.0^{\circ}\text{C}$ :

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

- 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:  $Q_{\text{ice}} = m_{\text{ice}} L_f + m_{\text{ice}} c_{\text{water}} (T_f - 0^\circ\text{C})$
- 4 Set  $Q_{\text{soda}} = Q_{\text{ice}}$  and solve for  $T_f$
- 5  $T_f = 9.03^\circ\text{C}$

# "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.

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## Answer

The mass of water is 57 g.

# Key Equations

## Temperature Conversions:

$$T_{\circ\text{F}} = \frac{9}{5} T_{\circ\text{C}} + 32$$

$$T_{\circ\text{C}} = \frac{5}{9} (T_{\circ\text{F}} - 32)$$

$$T_{\text{K}} = T_{\circ\text{C}} + 273.15$$

## 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

## Questions?

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