

PHYS11 CH:11 The Hidden Energy

Temperature, Heat, and Phase Change

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Outline

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

The Mystery of the Welder



The Mystery of the Welder



How does thermal energy travel from the arc to your skin meters away?

Learning Objectives

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

- **11.1:** Explain that temperature is a measure of internal kinetic energy

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- **11.1:** Explain that temperature is a measure of internal kinetic energy
- **11.1:** Interconvert temperatures between Celsius, Kelvin, and Fahrenheit scales

11.1 What Is Temperature?

The Illusion

You think: Temperature measures heat

Reality: Temperature measures average kinetic energy of molecules

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The Source Code

Temperature = what we measure on a thermometer

Heat = transfer of energy due to temperature difference

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You think: Temperature measures heat

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The Source Code

Temperature = what we measure on a thermometer

Heat = transfer of energy due to temperature difference

Heat and temperature are NOT the same thing.

11.1 Thermal Energy: The Invisible Motion

The Mental Model

Atoms and molecules are constantly bouncing around in random directions.
Faster motion = higher temperature.

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Thermal energy = average kinetic energy of particles in a substance

$$KE = \frac{1}{2}mv^2$$

Higher speed → greater kinetic energy → higher temperature

11.1 Temperature Scales

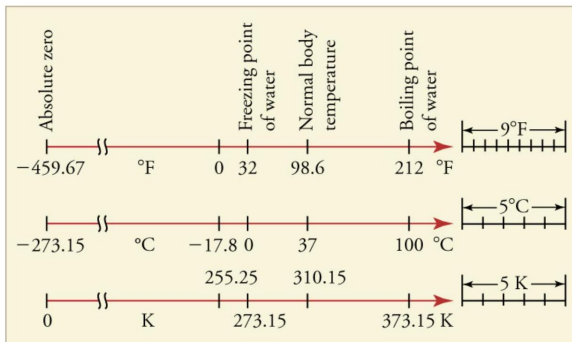


Figure: Fahrenheit, Celsius, and Kelvin scales compared

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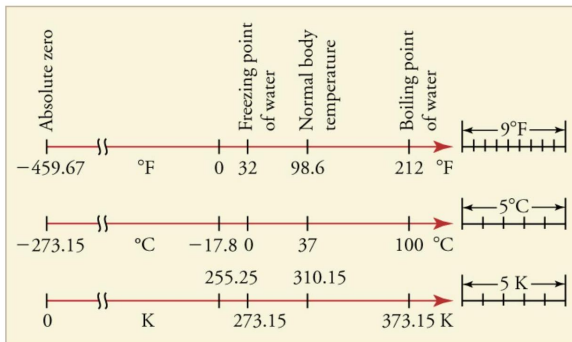


Figure: Fahrenheit, Celsius, and Kelvin scales compared

Three scales, same physics:

- Celsius: water freezes at 0, boils at 100
- Fahrenheit: water freezes at 32, boils at 212
- Kelvin: absolute zero at 0, water freezes at 273.15

11.1 Absolute Zero: The Coldest Possible

The Ultimate Limit

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The temperature at which all molecular motion ceases.

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At absolute zero, particles have minimum possible energy (quantum zero-point energy).

11.1 Converting Temperature Scales

Key Conversion Equations

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

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

$$T_K = T_{\circ C} + 273.15$$

$$T_{\circ C} = T_K - 273.15$$

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Quick Check

Room temperature: 25 C = ? F = ? K

Attempt: Temperature Conversion

The Challenge (3 min, silent)

Your body temperature is normally 98.6 F.

Given:

- $T_{oF} = 98.6 \text{ F}$

Find: Body temperature in Celsius and Kelvin

Can you decode your body's thermal state? Work silently.

Compare: Temperature Conversion

Turn and talk (2 min):

- 1 Which equation did you use to convert F to C?
- 2 Did you subtract 32 before or after multiplying by $5/9$?
- 3 How did you convert C to K?

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Name wheel: One pair share your approach (not your answer).

Reveal: Decoding Body Temperature

Self-correct in a different color:

Step 1: Convert F to C using $T_{\circ C} = \frac{5}{9}(T_{\circ F} - 32)$

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$$T_{\circ C} = \boxed{37.0 \text{ C}}$$

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$$T_K = 37.0 + 273.15 = \boxed{310.2 \text{ K}}$$

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Check: 37 C is normal body temp. Makes sense!

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- **11.2:** Explain heat, heat capacity, and specific heat
- **11.2:** Distinguish between conduction, convection, and radiation
- **11.2:** Solve problems involving specific heat and heat transfer

11.2 Heat: Energy on the Move

The Universal Law

Heat = transfer of thermal energy from hot to cold

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Key insights:

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Key insights:

- Heat is NOT a substance - it's energy in transit
- Heat always flows from high to low temperature
- Heat stops flowing when temperatures equalize
- Heat is measured in joules (J), like all energy

11.2 The Heat Equation

Nature's Rule for Temperature Change

$$Q = mc\Delta T$$

Heat transferred = mass \times specific heat \times temperature change

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Heat transferred = mass \times specific heat \times temperature change

What each variable means:

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

11.2 Specific Heat: Material Stubbornness

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- Aluminum: 900 J/kg·C
- Iron: 450 J/kg·C

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- Aluminum: 900 J/kg·C
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- Copper: 387 J/kg·C

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- Aluminum: 900 J/kg·C
- Iron: 450 J/kg·C
- Copper: 387 J/kg·C

Water requires 5× more energy than iron to heat the same amount!

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The Paradox

Wood and metal at room temperature.

Why does metal feel colder when you touch it?

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- Metal conducts heat faster than wood
- Metal pulls heat from your hand rapidly
- You sense rate of heat loss, not temperature!

11.2 Three Modes of Heat Transfer

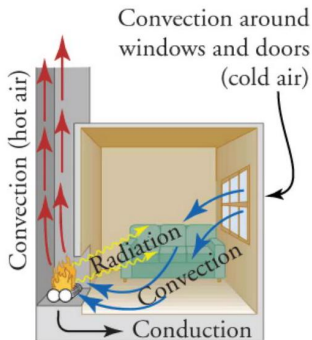


Figure: Fireplace: all three modes at once

11.2 Three Modes of Heat Transfer

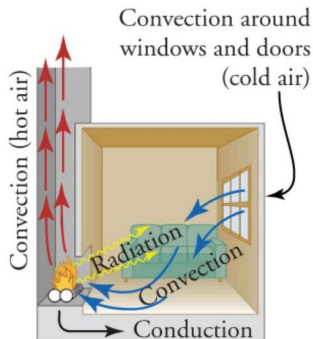


Figure: Fireplace: all three modes at once

- **Conduction:** through physical contact
- **Convection:** by fluid movement
- **Radiation:** by electromagnetic waves

11.2 Conduction: Touch Transfer

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Molecules vibrating faster bump into slower neighbors, sharing energy.
Like dominoes falling in sequence.

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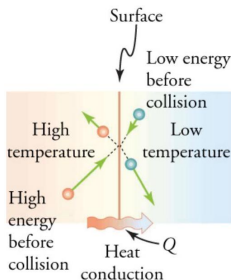


Figure: Energy transfers through collisions

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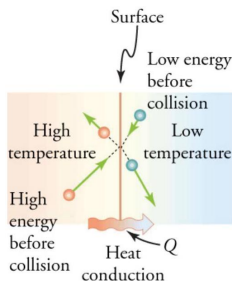


Figure: Energy transfers through collisions

Good conductors: metals (copper, aluminum, gold)

Poor conductors: wood, plastic, rubber (insulators)

11.2 Convection: Fluid Flow

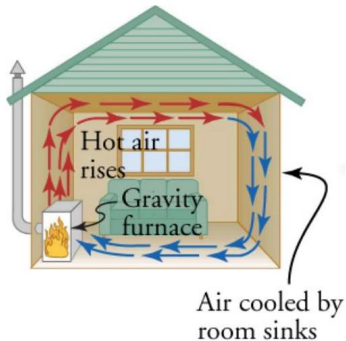


Figure: Heated air rises, cool air sinks

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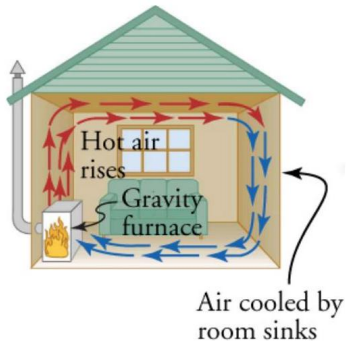


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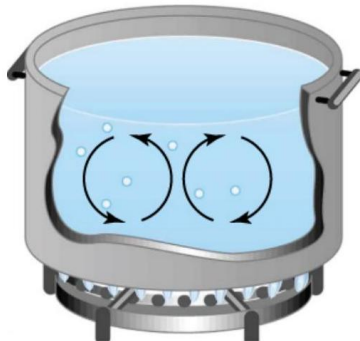


Figure: Water circulation in pot

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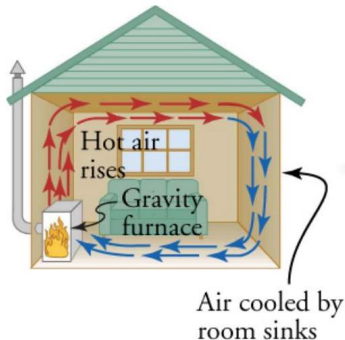


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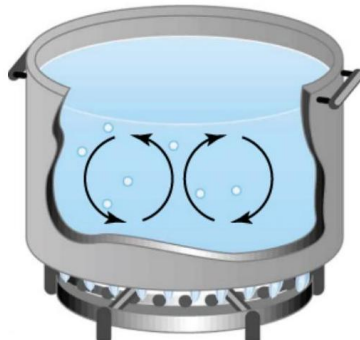


Figure: Water circulation in pot

Key idea: Hot fluid expands, becomes less dense, rises

11.2 Radiation: No Medium Needed

The Mystery

How does Sun's energy reach Earth through vacuum of space?

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No physical medium required!

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Examples:

- Feel warmth from fire without touching
- Microwave oven heating food
- Infrared heat lamps
- Sun warming Earth

11.2 Color and Radiation

Color affects absorption and emission:

- **Black:** best absorber AND radiator

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Real-World Application

Hot climates: wear white to reflect heat

Cold nights: black asphalt radiates heat faster than grass

Space blankets: shiny surface reflects body heat back

Attempt: Heating Water

The Challenge (4 min, silent)

You heat 2.0 kg of water from 20 C to 80 C.

Given:

- $m = 2.0 \text{ kg}$
- $c_{\text{water}} = 4186 \text{ J/kg}\cdot\text{C}$
- $T_i = 20 \text{ C}, T_f = 80 \text{ C}$

Find: Heat energy required (Q)

Can you calculate energy needed? Work silently.

Compare: Heat Calculation

Turn and talk (2 min):

- 1 What equation did you use?
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- 3 What units did you get for Q ?

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Reveal: Energy to Heat Water

Self-correct in a different color:

Step 1: Calculate temperature change

$$\Delta T = T_f - T_i = 80 - 20 = 60 \text{ C}$$

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Substitute: $Q = (2.0 \text{ kg})(4186 \text{ J/kg}\cdot\text{C})(60 \text{ C})$

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$$Q = 502,320 \text{ J} = \boxed{502 \text{ kJ}}$$

Reveal: Energy to Heat Water

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$$Q = 502,320 \text{ J} = \boxed{502 \text{ kJ}}$$

Check: About 500 kJ to heat 2 L water by 60 degrees. Reasonable!

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- **11.3:** Describe latent heats of fusion and vaporization
- **11.3:** Solve problems involving phase changes

11.3 The Four Phases of Matter

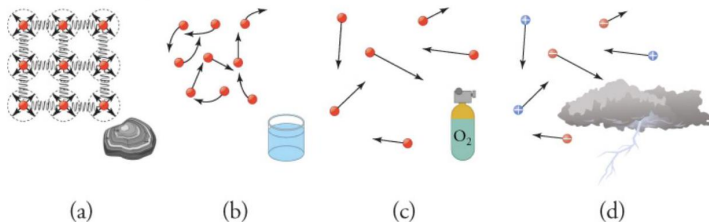


Figure: Solid, liquid, gas, and plasma

11.3 The Four Phases of Matter

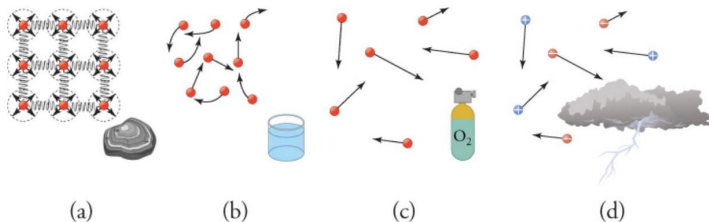


Figure: Solid, liquid, gas, and plasma

Energy ranking: Solid | Liquid | Gas | Plasma

11.3 Phase Changes: Energy In/Out

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- Melting: solid \rightarrow liquid
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- Sublimation: solid \rightarrow gas (skips liquid!)

Removing energy (cooling):

- Freezing: liquid \rightarrow solid
- Condensation: gas \rightarrow liquid
- Deposition: gas \rightarrow solid

11.3 Latent Heat: The Hidden Energy

The Paradox

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Where does the energy go?

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Energy breaks bonds between molecules, not increase speed.

No temperature change during phase transition!

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Latent heat = hidden energy used to change phase without changing temperature

11.3 Phase Diagram: Ice to Steam

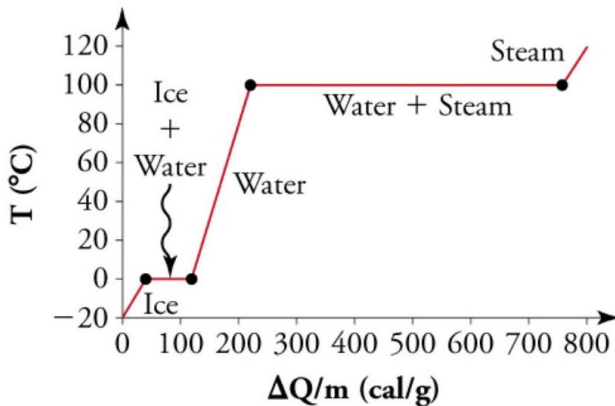


Figure: Temperature vs energy for water

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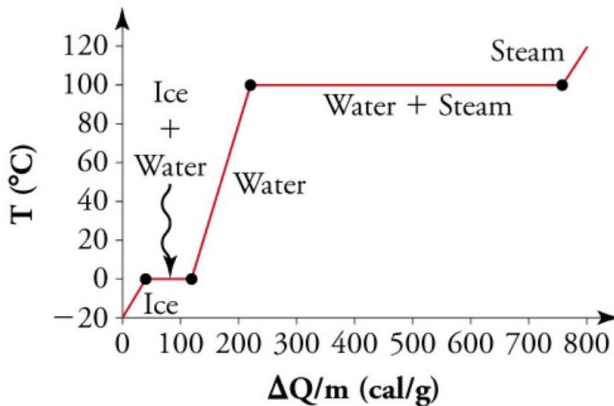


Figure: Temperature vs energy for water

Flat regions = phase changes (temp constant)

Sloped regions = temperature increasing

11.3 Latent Heat Equations

Nature's Rules for Phase Change

$$Q = mL_f \quad (\text{melting/freezing})$$

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For water:

- $L_f = 334 \text{ kJ/kg}$ (latent heat of fusion)
- $L_v = 2256 \text{ kJ/kg}$ (latent heat of vaporization)

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For water:

- $L_f = 334 \text{ kJ/kg}$ (latent heat of fusion)
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Note: No ΔT in these equations - temperature doesn't change!

Attempt: Melting Ice

The Challenge (3 min, silent)

How much energy is needed to melt 0.50 kg of ice at 0 C?

Given:

- $m = 0.50 \text{ kg}$
- $L_f = 334 \text{ kJ/kg}$
- Ice already at 0 C (melting point)

Find: Heat energy Q required

Can you calculate the hidden energy? Work silently.

Compare: Latent Heat

Turn and talk (2 min):

- 1 Which equation did you choose?
- 2 Why didn't you use $Q = mc\Delta T$?
- 3 What value did you use for latent heat?

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Substitute: $Q = (0.50 \text{ kg})(334 \text{ kJ/kg})$

$$Q = \boxed{167 \text{ kJ}}$$

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$$Q = \boxed{167 \text{ kJ}}$$

Check: That's enough energy to raise 1 kg of water by 40 C!

Phase changes require enormous energy.

11.3 Why Sweating Cools You

Real-World Application

When sweat evaporates:

- 1 Water absorbs 2256 kJ/kg from your skin

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- 3 Your skin temperature drops

Evaporation is most effective cooling method for your body!

11.3 Why Sweating Cools You

Real-World Application

When sweat evaporates:

- 1 Water absorbs 2256 kJ/kg from your skin
- 2 Undergoes phase change: liquid \rightarrow gas
- 3 Your skin temperature drops

Evaporation is most effective cooling method for your body!

On humid days: Less evaporation \rightarrow less cooling \rightarrow you feel hotter

11.3 Condensation Releases Heat

The Reverse Process

Condensation releases same energy that vaporization absorbed.

Gas \rightarrow liquid releases 2256 kJ/kg for water.

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- Creates powerful updrafts and winds

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- 6 Water's high specific heat stabilizes climate
- 7 Phase changes require enormous energy

Key Equations

Temperature Conversions:

$$T_{oF} = \frac{9}{5} T_{oC} + 32 \quad (1)$$

$$T_{oC} = \frac{5}{9} (T_{oF} - 32) \quad (2)$$

$$T_K = T_{oC} + 273.15 \quad (3)$$

Heat Transfer:

$$Q = mc\Delta T \quad (\text{temperature change}) \quad (4)$$

$$Q = mL_f \quad (\text{melting/freezing}) \quad (5)$$

$$Q = mL_v \quad (\text{vaporization/condensation}) \quad (6)$$

Water Constants:

- $c_{\text{water}} = 4186 \text{ J/kg}\cdot\text{C}$
- $L_f = 334 \text{ kJ/kg}$
- $L_v = 2256 \text{ kJ/kg}$

Complete the assigned problems
posted on the LMS