PHYS11 CH:11 The Hidden Energy

Temperature, Heat, and Phase Change

Mr. Gullo

December 2025

Outline

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

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
- **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

11.1 What Is Temperature?

The Illusion

You think: Temperature measures heat
Reality: Temperature measures average kinetic energy of molecules

The Source Code

Temperature = what we measure on a thermometer
Heat = transfer of energy due to temperature difference

11.1 What Is Temperature?

The Illusion

You think: Temperature measures heat
Reality: Temperature measures average kinetic energy of molecules

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.

11.1 Thermal Energy: The Invisible Motion

The Mental Model

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

Thermal energy = average kinetic energy of particles in a substance

11.1 Thermal Energy: The Invisible Motion

The Mental Model

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

Thermal energy = average kinetic energy of particles in a substance

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

11.1 Thermal Energy: The Invisible Motion

The Mental Model

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

Thermal energy = average kinetic energy of particles in a substance

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

Higher speed → greater kinetic energy → higher temperature

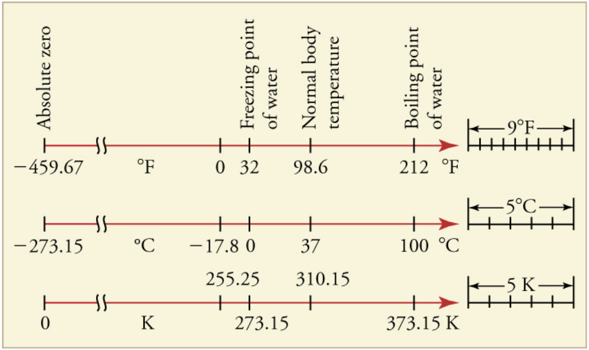

Figure: Fahrenheit, Celsius, and Kelvin scales compared

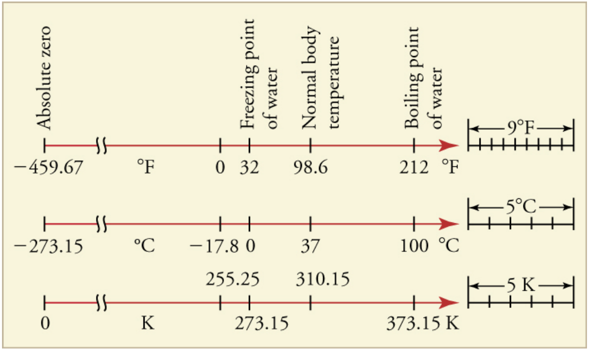

Figure: Fahrenheit, Celsius, and Kelvin scales compared

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

Absolute zero = 0 K = -273.15 C

The temperature at which all molecular motion ceases.

11.1 Absolute Zero: The Coldest Possible

The Ultimate Limit

Absolute zero = 0 K = -273.15 C
The temperature at which all molecular motion ceases.

Can we reach it?

- Theoretically possible

11.1 Absolute Zero: The Coldest Possible

The Ultimate Limit

Absolute zero = 0 K = -273.15 C
The temperature at which all molecular motion ceases.

Can we reach it?

- Theoretically possible
- Never achieved in practice

11.1 Absolute Zero: The Coldest Possible

The Ultimate Limit

Absolute zero $= 0$ K $=$ -273.15 C
The temperature at which all molecular motion ceases.

Can we reach it?

- Theoretically possible
- Never achieved in practice
- Coldest lab temperature: 1.0×10^{-10} K (Helsinki)

11.1 Absolute Zero: The Coldest Possible

The Ultimate Limit

Absolute zero = 0 K = -273.15 C
The temperature at which all molecular motion ceases.

Can we reach it?

- Theoretically possible
- Never achieved in practice
- Coldest lab temperature: 1.0×10^{-10} K (Helsinki)

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

11.1 Converting Temperature Scales

Key Conversion Equations

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

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

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

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

11.1 Converting Temperature Scales

Key Conversion Equations

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

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

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

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

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:

- $T_{\circ F} = 98.6$ 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?

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?

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

Reveal: Decoding Body Temperature

Self-correct in a different color:

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

Substitute: $T_{\circ C} = \frac{5}{9}(98.6 - 32) = \frac{5}{9}(66.6)$

Reveal: Decoding Body Temperature

Self-correct in a different color:

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

Substitute: $T_{\circ C} = \frac{5}{9}(98.6 - 32) = \frac{5}{9}(66.6)$

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

Reveal: Decoding Body Temperature

Self-correct in a different color:

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

Substitute: $T_{\circ C} = \frac{5}{9}(98.6 - 32) = \frac{5}{9}(66.6)$

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

Step 2: Convert C to K using $T_K = T_{\circ C} + 273.15$

Reveal: Decoding Body Temperature

Self-correct in a different color:

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

Substitute: $T_{\circ C} = \frac{5}{9}(98.6 - 32) = \frac{5}{9}(66.6)$

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

Step 2: Convert C to K using $T_K = T_{\circ C} + 273.15$

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

Reveal: Decoding Body Temperature

Self-correct in a different color:

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

Substitute: $T_{\circ C} = \frac{5}{9}(98.6 - 32) = \frac{5}{9}(66.6)$

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

Step 2: Convert C to K using $T_K = T_{\circ C} + 273.15$

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

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

Learning Objectives

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

- **11.2:** Explain heat, heat capacity, and specific heat

Learning Objectives

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

- **11.2:** Explain heat, heat capacity, and specific heat
- **11.2:** Distinguish between conduction, convection, and radiation

Learning Objectives

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

- **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

The Universal Law

Heat = transfer of thermal energy from hot to cold

Key insights:

- Heat is NOT a substance - it's energy in transit

The Universal Law

Heat = transfer of thermal energy from hot to cold

Key insights:

- Heat is NOT a substance - it's energy in transit
- Heat always flows from high to low temperature

11.2 Heat: Energy on the Move

The Universal Law

Heat = transfer of thermal energy from hot to cold

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

11.2 Heat: Energy on the Move

The Universal Law

Heat = transfer of thermal energy from hot to cold

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

$$\boxed{Q = mc\Delta T}$$

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

Nature's Rule for Temperature Change

$$\boxed{Q = mc\Delta T}$$

Heat transferred = mass × specific heat × 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

The Mental Model

Specific heat = how much energy needed to raise 1 kg of material by 1 C

11.2 Specific Heat: Material Stubbornness

The Mental Model

Specific heat = how much energy needed to raise 1 kg of material by 1 C

Common values:

- Water: 4186 J/kg·C (very high!)

11.2 Specific Heat: Material Stubbornness

The Mental Model

Specific heat = how much energy needed to raise 1 kg of material by 1 C

Common values:

- Water: 4186 J/kg·C (very high!)
- Aluminum: 900 J/kg·C

11.2 Specific Heat: Material Stubbornness

The Mental Model

Specific heat = how much energy needed to raise 1 kg of material by 1 C

Common values:

- Water: 4186 J/kg·C (very high!)
- Aluminum: 900 J/kg·C
- Iron: 450 J/kg·C

11.2 Specific Heat: Material Stubbornness

The Mental Model

Specific heat = how much energy needed to raise 1 kg of material by 1 C

Common values:

- Water: 4186 J/kg·C (very high!)
- Aluminum: 900 J/kg·C
- Iron: 450 J/kg·C
- Copper: 387 J/kg·C

11.2 Specific Heat: Material Stubbornness

The Mental Model

Specific heat = how much energy needed to raise 1 kg of material by 1 C

Common values:

- Water: 4186 J/kg·C (very high!)
- 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!

11.2 Why Metal Feels Colder

The Paradox

Wood and metal at room temperature.

Why does metal feel colder when you touch it?

The Paradox

Wood and metal at room temperature.
Why does metal feel colder when you touch it?

The answer:

- Both are same temperature

The Paradox

Wood and metal at room temperature.
Why does metal feel colder when you touch it?

The answer:

- Both are same temperature
- Metal conducts heat faster than wood

11.2 Why Metal Feels Colder

The Paradox

Wood and metal at room temperature.
Why does metal feel colder when you touch it?

The answer:

- Both are same temperature
- Metal conducts heat faster than wood
- Metal pulls heat from your hand rapidly

11.2 Why Metal Feels Colder

The Paradox

Wood and metal at room temperature.
Why does metal feel colder when you touch it?

The answer:

- Both are same temperature
- 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

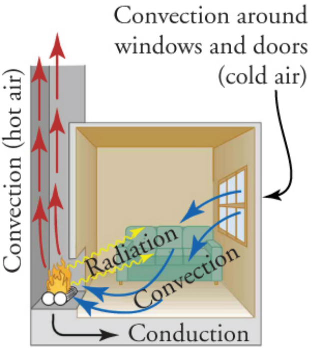

Figure: Fireplace: all three modes at once

11.2 Three Modes of Heat Transfer

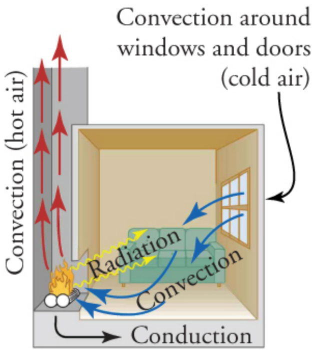

Figure: Fireplace: all three modes at once

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

11.2 Conduction: Touch Transfer

The Mental Model

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

11.2 Conduction: Touch Transfer

The Mental Model

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

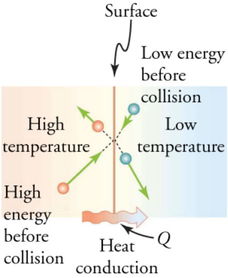

Figure: Energy transfers through collisions

11.2 Conduction: Touch Transfer

The Mental Model

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

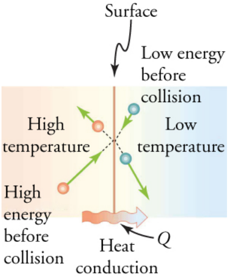

Figure: Energy transfers through collisions

Good conductors: metals (copper, aluminum, gold)
Poor conductors: wood, plastic, rubber (insulators)

11.2 Convection: Fluid Flow

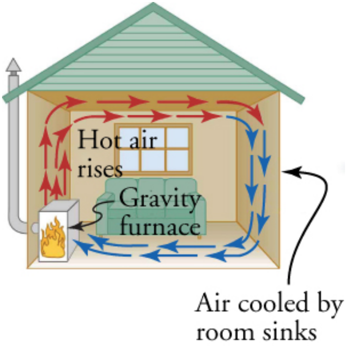

Figure: Heated air rises, cool air sinks

11.2 Convection: Fluid Flow

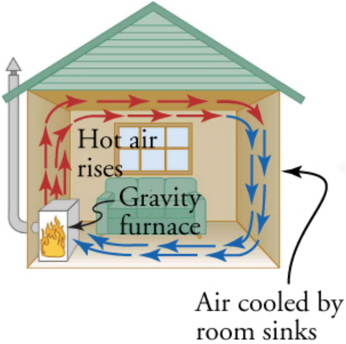

Figure: Heated air rises, cool air sinks

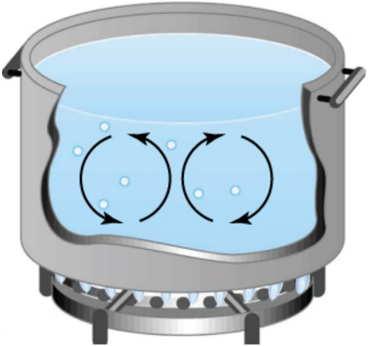

Figure: Water circulation in pot

11.2 Convection: Fluid Flow

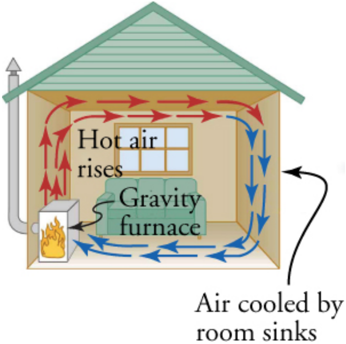

Figure: Heated air rises, cool air sinks

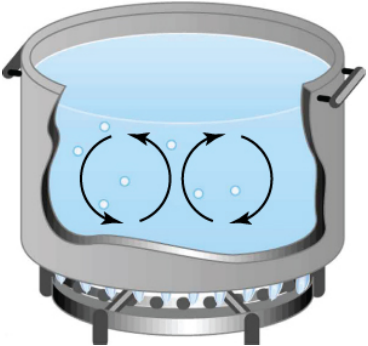

Figure: Water circulation in pot

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?

11.2 Radiation: No Medium Needed

The Mystery

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

The Source Code

Radiation = energy transfer by electromagnetic waves
No physical medium required!

11.2 Radiation: No Medium Needed

The Mystery

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

The Source Code

Radiation = energy transfer by electromagnetic waves
No physical medium required!

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

Color affects absorption and emission:

- **Black:** best absorber AND radiator
- **White:** worst absorber AND radiator

11.2 Color and Radiation

Color affects absorption and emission:

- **Black:** best absorber AND radiator
- **White:** worst absorber AND radiator
- **Shiny:** reflects radiation like mirror

11.2 Color and Radiation

Color affects absorption and emission:

- **Black:** best absorber AND radiator
- **White:** worst absorber AND radiator
- **Shiny:** reflects radiation like mirror

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:

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

Find: Heat energy required (Q)

Can you calculate energy needed? Work silently.

Turn and talk (2 min):

1. What equation did you use?
2. How did you calculate ΔT?
3. What units did you get for Q?

Compare: Heat Calculation

Turn and talk (2 min):

1. What equation did you use?
2. How did you calculate ΔT?
3. What units did you get for Q?

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

Reveal: Energy to Heat Water

Self-correct in a different color:

Step 1: Calculate temperature change

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

Reveal: Energy to Heat Water

Self-correct in a different color:

Step 1: Calculate temperature change

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

Step 2: Use $Q = mc\Delta T$

Reveal: Energy to Heat Water

Self-correct in a different color:

Step 1: Calculate temperature change

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

Step 2: Use $Q = mc\Delta T$

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

Reveal: Energy to Heat Water

Self-correct in a different color:

Step 1: Calculate temperature change

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

Step 2: Use $Q = mc\Delta T$

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

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

Reveal: Energy to Heat Water

Self-correct in a different color:

Step 1: Calculate temperature change

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

Step 2: Use $Q = mc\Delta T$

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

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

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

Learning Objectives

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

- **11.3:** Explain changes in heat during changes of state

Learning Objectives

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

- **11.3:** Explain changes in heat during changes of state
- **11.3:** Describe latent heats of fusion and vaporization

Learning Objectives

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

- **11.3:** Explain changes in heat during changes of state
- **11.3:** Describe latent heats of fusion and vaporization
- **11.3:** Solve problems involving phase changes

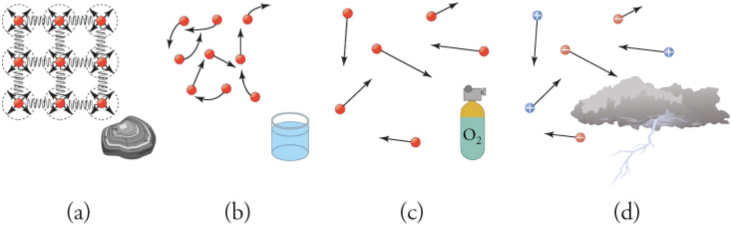

Figure: Solid, liquid, gas, and plasma

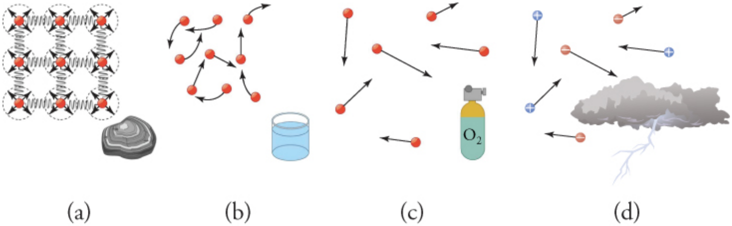

Figure: Solid, liquid, gas, and plasma

Energy ranking: Solid ¡ Liquid ¡ Gas ¡ Plasma

11.3 Phase Changes: Energy In/Out

Adding energy (heating):

- Melting: solid $\rightarrow$ liquid

11.3 Phase Changes: Energy In/Out

Adding energy (heating):

- Melting: solid $\rightarrow$ liquid
- Vaporization: liquid $\rightarrow$ gas

11.3 Phase Changes: Energy In/Out

Adding energy (heating):

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

11.3 Phase Changes: Energy In/Out

Adding energy (heating):

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

Removing energy (cooling):

- Freezing: liquid $\rightarrow$ solid

11.3 Phase Changes: Energy In/Out

Adding energy (heating):

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

Removing energy (cooling):

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

11.3 Phase Changes: Energy In/Out

Adding energy (heating):

- Melting: solid $\rightarrow$ liquid
- Vaporization: liquid $\rightarrow$ gas
- 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

You heat ice at 0 C. Temperature stays at 0 C even as you add energy.
Where does the energy go?

11.3 Latent Heat: The Hidden Energy

The Paradox

You heat ice at 0 C. Temperature stays at 0 C even as you add energy.
Where does the energy go?

The Revelation

Energy breaks bonds between molecules, not increase speed.
No temperature change during phase transition!

11.3 Latent Heat: The Hidden Energy

The Paradox

You heat ice at 0 C. Temperature stays at 0 C even as you add energy.
Where does the energy go?

The Revelation

Energy breaks bonds between molecules, not increase speed.
No temperature change during phase transition!

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

11.3 Phase Diagram: Ice to Steam

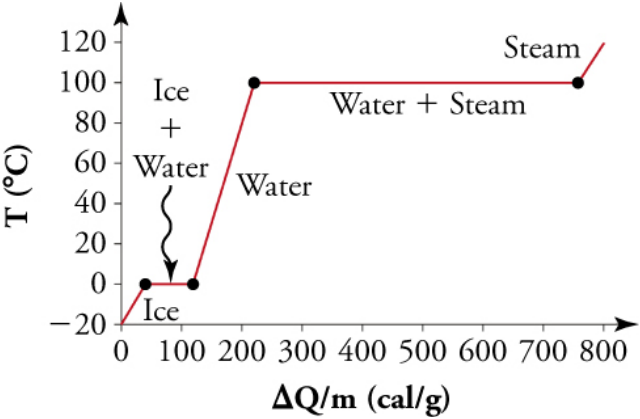

Figure: Temperature vs energy for water

11.3 Phase Diagram: Ice to Steam

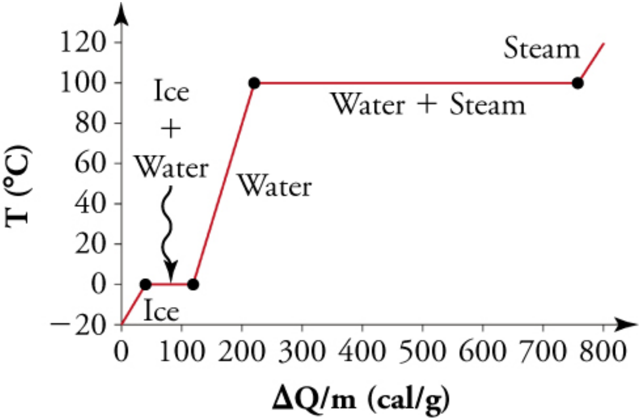

Figure: Temperature vs energy for water

Flat regions = phase changes (temp constant)
Sloped regions = temperature increasing

11.3 Latent Heat Equations

Nature's Rules for Phase Change

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

11.3 Latent Heat Equations

Nature's Rules for Phase Change

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

For water:

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

11.3 Latent Heat Equations

Nature's Rules for Phase Change

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

For water:

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

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:

- $m = 0.50$ kg
- $L_f = 334$ 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?

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?

Name wheel: One pair share your reasoning.

Reveal: Energy to Melt Ice

Self-correct in a different color:

Key insight: Phase change, so use $Q = mL_f$

Reveal: Energy to Melt Ice

Self-correct in a different color:

Key insight: Phase change, so use $Q = mL_f$

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

Reveal: Energy to Melt Ice

Self-correct in a different color:

Key insight: Phase change, so use $Q = mL_f$

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

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

Reveal: Energy to Melt Ice

Self-correct in a different color:

Key insight: Phase change, so use $Q = mL_f$

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

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

Check: That's enough energy to raise 1 kg of water by 40 C!
Phase changes require enormous energy.

Real-World Application

When sweat evaporates:

1. Water absorbs 2256 kJ/kg from your skin

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

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

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!

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.

11.3 Condensation Releases Heat

The Reverse Process

Condensation releases same energy that vaporization absorbed.
Gas $\rightarrow$ liquid releases 2256 kJ/kg for water.

Why hurricanes are so powerful:

- Water vapor condenses in storm

11.3 Condensation Releases Heat

The Reverse Process

Condensation releases same energy that vaporization absorbed.
Gas $\rightarrow$ liquid releases 2256 kJ/kg for water.

Why hurricanes are so powerful:

- Water vapor condenses in storm
- Releases enormous latent heat

11.3 Condensation Releases Heat

The Reverse Process

Condensation releases same energy that vaporization absorbed.
Gas $\rightarrow$ liquid releases 2256 kJ/kg for water.

Why hurricanes are so powerful:

- Water vapor condenses in storm
- Releases enormous latent heat
- Heats surrounding air

11.3 Condensation Releases Heat

The Reverse Process

Condensation releases same energy that vaporization absorbed.
Gas $\rightarrow$ liquid releases 2256 kJ/kg for water.

Why hurricanes are so powerful:

- Water vapor condenses in storm
- Releases enormous latent heat
- Heats surrounding air
- Creates powerful updrafts and winds

What You Now Know

1. Temperature = average molecular kinetic energy

The Revelations of Thermal Physics

What You Now Know

1. Temperature = average molecular kinetic energy
2. Heat = energy transfer from hot to cold

The Revelations of Thermal Physics

What You Now Know

1. Temperature = average molecular kinetic energy
2. Heat = energy transfer from hot to cold
3. $Q = mc\Delta T$ for temperature changes

The Revelations of Thermal Physics

What You Now Know

1. Temperature = average molecular kinetic energy
2. Heat = energy transfer from hot to cold
3. $Q = mc\Delta T$ for temperature changes
4. Three transfer modes: conduction, convection, radiation

What You Now Know

1. Temperature = average molecular kinetic energy
2. Heat = energy transfer from hot to cold
3. $Q = mc\Delta T$ for temperature changes
4. Three transfer modes: conduction, convection, radiation
5. $Q = mL$ for phase changes (no temp change!)

The Revelations of Thermal Physics

What You Now Know

1. Temperature = average molecular kinetic energy
2. Heat = energy transfer from hot to cold
3. $Q = mc\Delta T$ for temperature changes
4. Three transfer modes: conduction, convection, radiation
5. $Q = mL$ for phase changes (no temp change!)
6. Water's high specific heat stabilizes climate

What You Now Know

1. Temperature = average molecular kinetic energy
2. Heat = energy transfer from hot to cold
3. $Q = mc\Delta T$ for temperature changes
4. Three transfer modes: conduction, convection, radiation
5. $Q = mL$ for phase changes (no temp change!)
6. Water's high specific heat stabilizes climate
7. Phase changes require enormous energy

Key Equations

Temperature Conversions:

$$T_{^\circ F} = \frac{9}{5} T_{^\circ C} + 32 \tag{1}$$

$$T_{^\circ C} = \frac{5}{9}(T_{^\circ F} - 32) \tag{2}$$

$$T_K = T_{^\circ C} + 273.15 \tag{3}$$

Heat Transfer:

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

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

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

Water Constants:

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

Homework

Complete the assigned problems

posted on the LMS