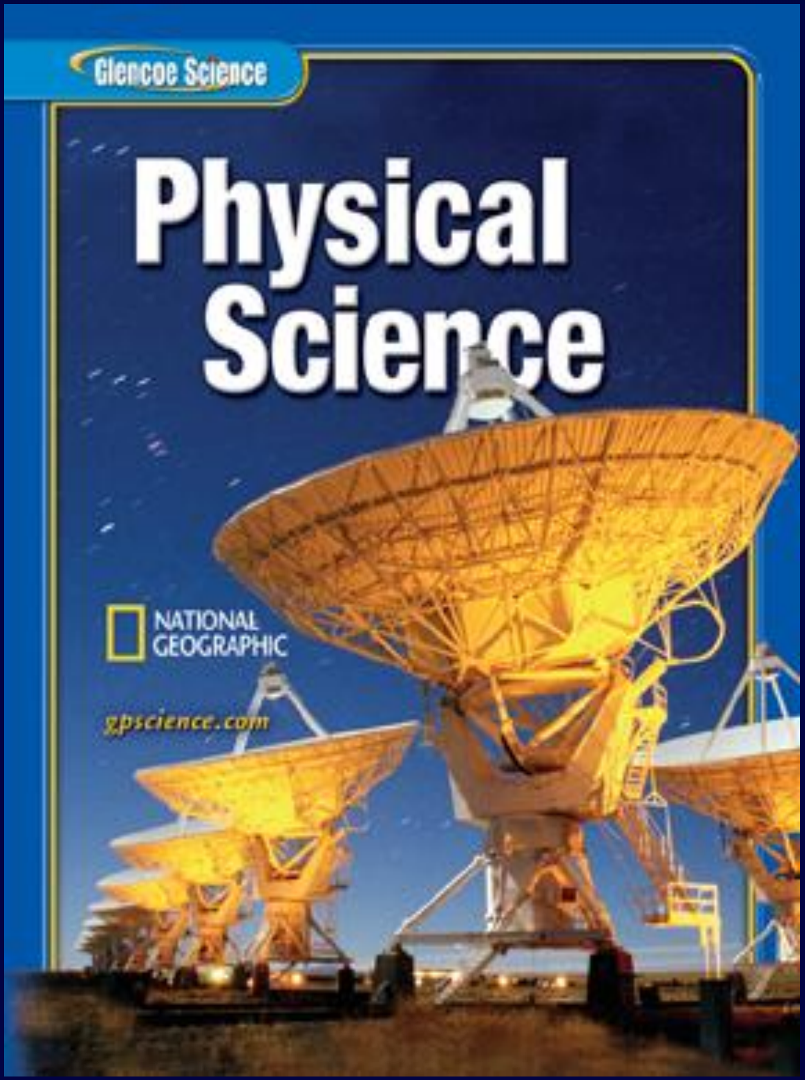
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6

# Unit 1: Energy and Motion

## Chapter 6: Thermal Energy


6.1: Temperature and Heat

6.2: Transferring Thermal Energy

6.3: Using Heat

# Temperature

- You use the words hot and cold to describe temperature.
- Something is hot when its temperature is high.
- When you heat water on a stove, its temperature increases.
- How are temperature and heat related?

6.1

# Matter in Motion

- The matter around you is made of tiny particles—atoms and molecules.
- In all materials these particles are in constant, random motion; moving in all directions at different speeds.

# Matter in Motion

- The faster they move, the more kinetic energy they have.
- This figure shows that particles move faster in hot objects than in cooler objects.

# Temperature

- The **temperature** of an object is a measure of the average kinetic energy of the particles in the object.

- As the temperature of an object increases, the average speed of the particles in random motion increases.

# Temperature

- In SI units, temperature is measured in kelvins (K).
- A more commonly used temperature scale is the Celsius scale.


- One kelvin is the same as one degree Celsius.

6.1

# Thermal Energy

- If you let cold butter sit at room temperature for a while, it warms and becomes softer.

- Because the air in the room is at a higher temperature than the butter, particles in air have more kinetic energy than butter particles.

6.1

# Thermal Energy

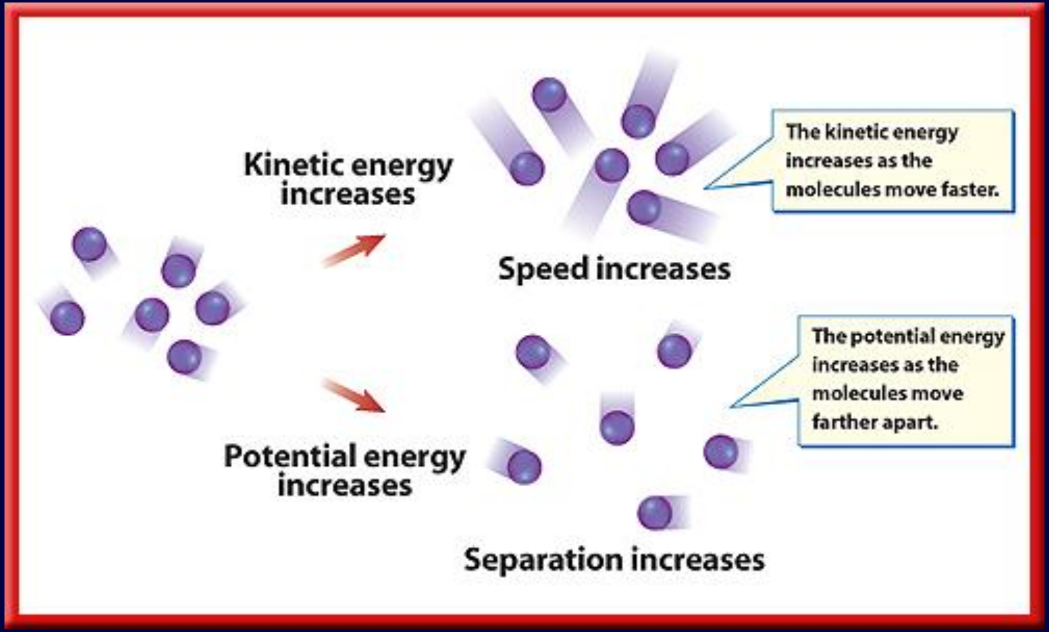
- Collisions between particles in butter and particles in air transfer energy from the faster-moving particles in air to the slower-moving butter particles.

- The butter particles then move faster and the temperature of the butter increases.

6.1

# Thermal Energy

- The sum of the kinetic and potential energy of all the particles in an object is the **thermal energy** of the object.



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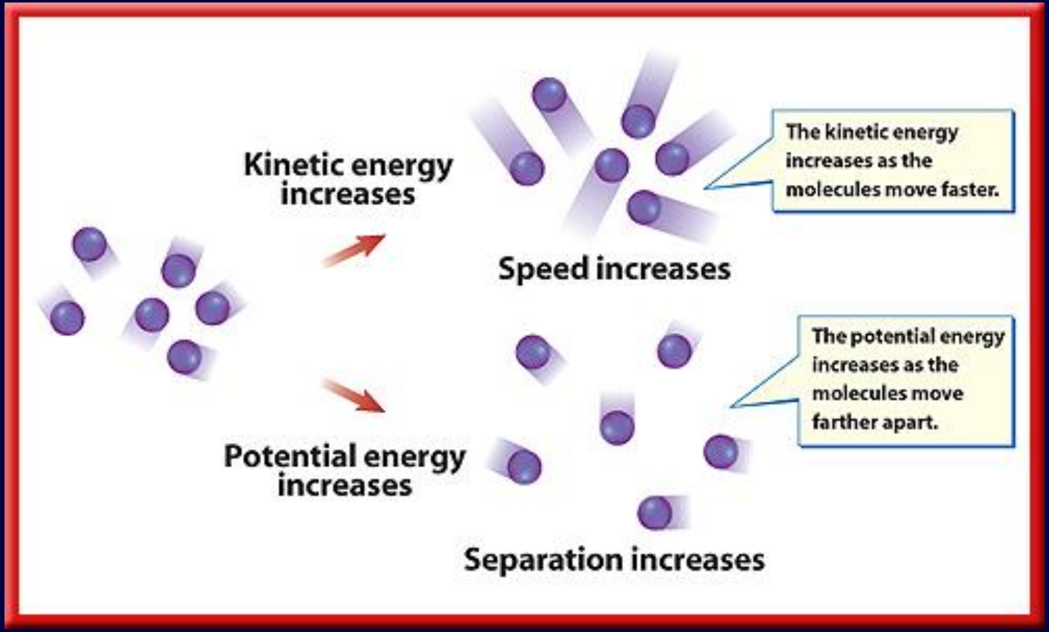
# Thermal Energy

- Because the kinetic energy of the butter particles increased as it warmed, the thermal energy of the butter increased.



6.1

# Thermal Energy and Temperature

- When the temperature of an object increase, the average kinetic energy of the particles in the object increases.

- Because thermal energy is the total kinetic and potential energy of all the particles in an object, the thermal energy of the object increases when the average kinetic energy of its particles increases.

# Thermal Energy and Mass

- Suppose you have a glass and a beaker of water that are at the same temperature.
- The beaker contains twice as much water as the glass.


- The water in both containers is at the same temperature, so the average kinetic energy of the water molecules is the same in both containers.

# Thermal Energy and Mass

- There are twice as many water molecules in the beaker as there are in the glass. So the total kinetic energy of all the molecules is twice as large for the water in the beaker.

6.1

# Thermal Energy and Mass

- As a result, the water in the beaker has twice as much thermal energy as the water in the glass does.


- If the temperature doesn't change, the thermal energy in an object increases if the mass of the object increases.

6.1

# Heat

- **Heat** is thermal energy that flows from something at a higher temperature to something at a lower temperature.
- Heat is a form of energy, so it is measured in joules—the same units that energy is measured in.
- Heat always flows from warmer to cooler materials.

6.1

# Specific Heat

- As a substance absorbs heat, its temperature change depends on the nature of the substance, as well as the amount of heat that is added.
- The amount of heat that is needed to raise the temperature of 1 kg of some material by 1°C is called the **specific heat** of the material.
- Specific heat is measured in joules per kilogram Kelvin [J/(kg °C)].

6.1

# Water as a Coolant

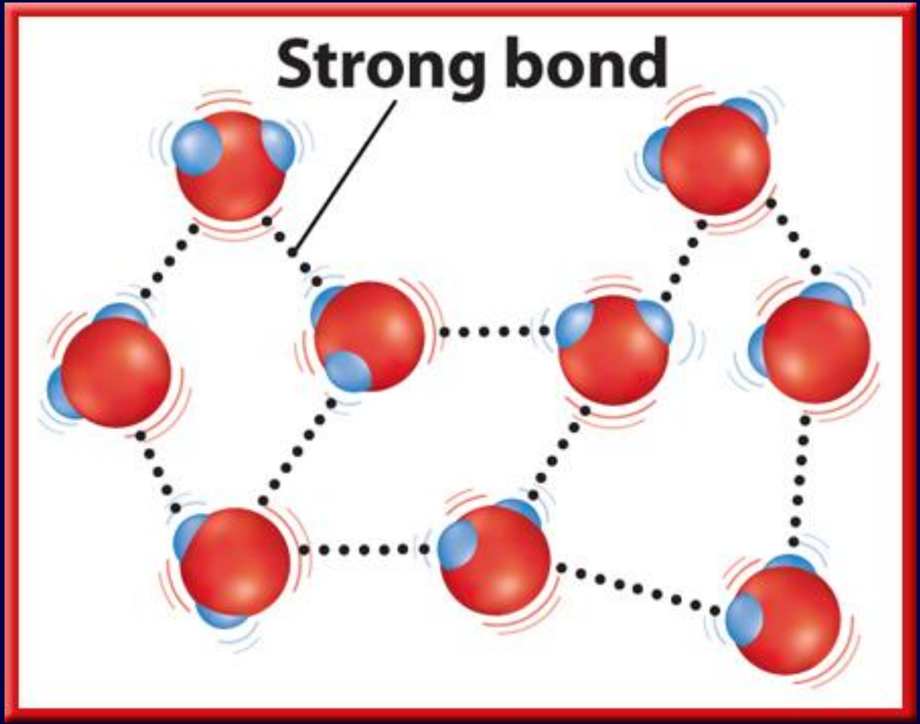
- Compared with the other common materials in the table, water has the highest specific heat.

| Specific Heat of Some Common Materials | |
|---|---|
| Substance | Specific Heat [J/(kg/°C)] |
| Water | 4,184 |
| Wood | 1,760 |
| Carbon (graphite) | 710 |
| Glass | 664 |
| Iron | 450 |

- The specific heat of water is high because water molecules form strong bonds with each other.

# Water as a Coolant

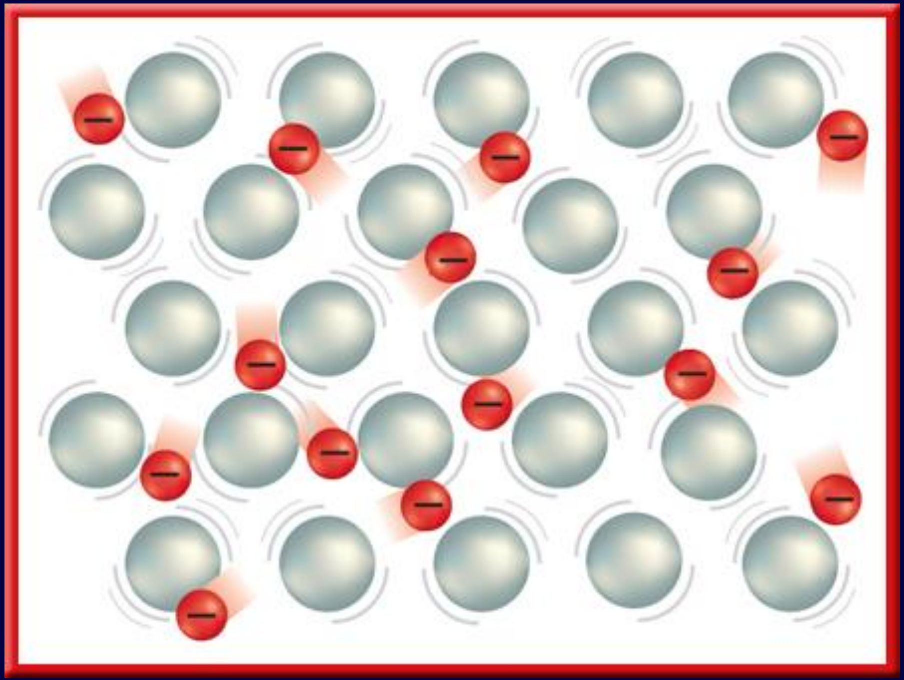
- When heat is added, some of the added heat has to break some of these bonds before the molecules can start moving faster.



# Water as a Coolant

- Because water can absorb heat without a large change in temperature, it is useful as a coolant.
- A coolant is a substance that is used to absorb heat.
- Compared to other materials, the temperature of water will increase less.

# Water as a Coolant



- In metals, electrons can move freely. When heat is added, no strong bonds have to be broken before the electrons can start moving faster.

# Changes in Thermal Energy

- The thermal energy of an object changes when heat flows into or out of the object.
- If *Q* is the change in thermal energy and *C* is specific heat, the change in thermal energy can be calculated from the following equation:

**Thermal Energy Equation**

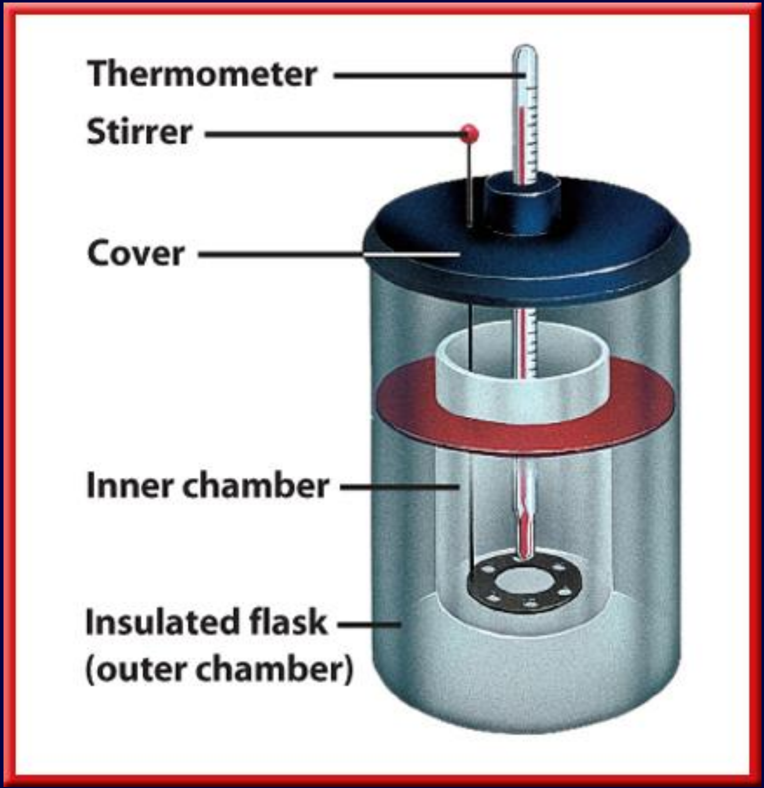
**change in thermal energy** (J) =
**mass** (kg) × **change in temperature** (°C) × **specific heat** $\left(\frac{\text{J}}{\text{kg°C}}\right)$

$$Q = m(T_t - T_i)C$$

6.1

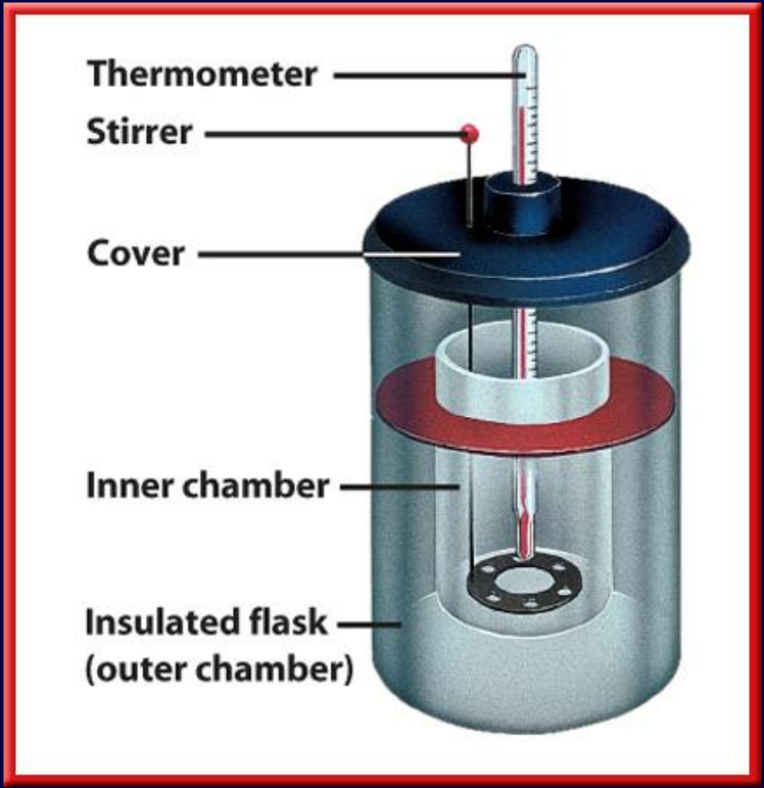
# Measuring Specific Heat

- The specific heat of a material can be measured using a device called a calorimeter.
- In a calorimeter, a heated sample transfers heat to a known mass of water.



# Measuring Specific Heat

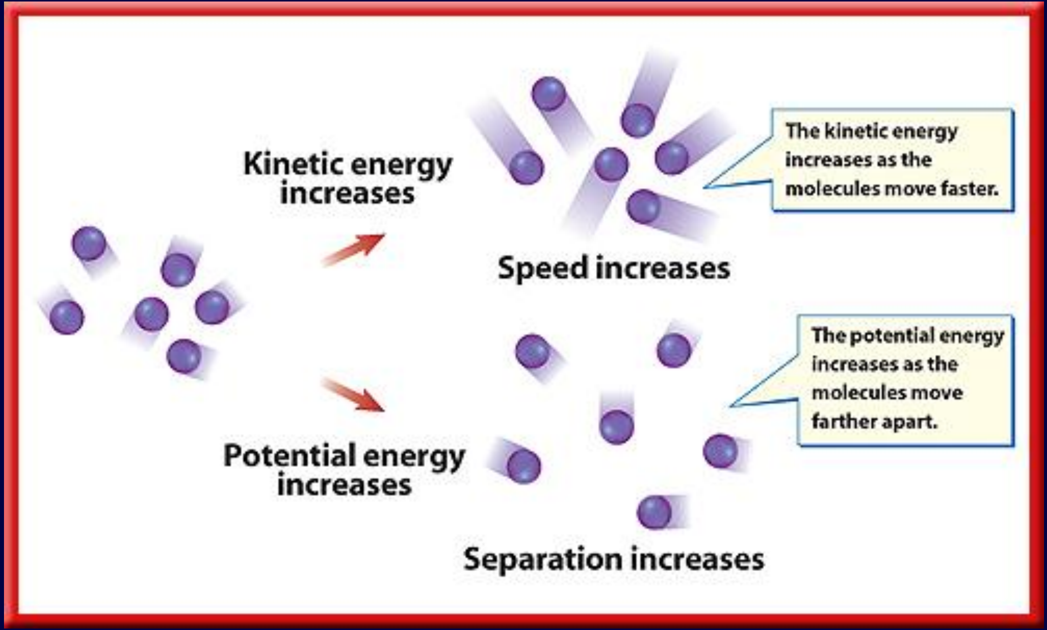
- The energy absorbed by the water can be calculated by measuring the water's temperature change.
- Then the thermal energy released by the sample equals the thermal energy absorbed by the water.



# Question 1

How is temperature related to kinetic energy?

# Answer




Temperature is a measure of the average kinetic energy of the particles in an object or material. As the temperature increases, the average speed of the particles increases.

## Question 2

How is temperature related to kinetic energy?

## Answer

Thermal energy is the sum of the kinetic and potential energy of all the particles in an object.

# Question 3

The amount of heat that is needed to raise the temperature of 1 kg of a material by 1° C is called the ____________ of the material.

A. density
B. mass
C. specific heat
D. thermal energy

## Answer

The answer is C. Specific heat is measured in joules/kilogram °C

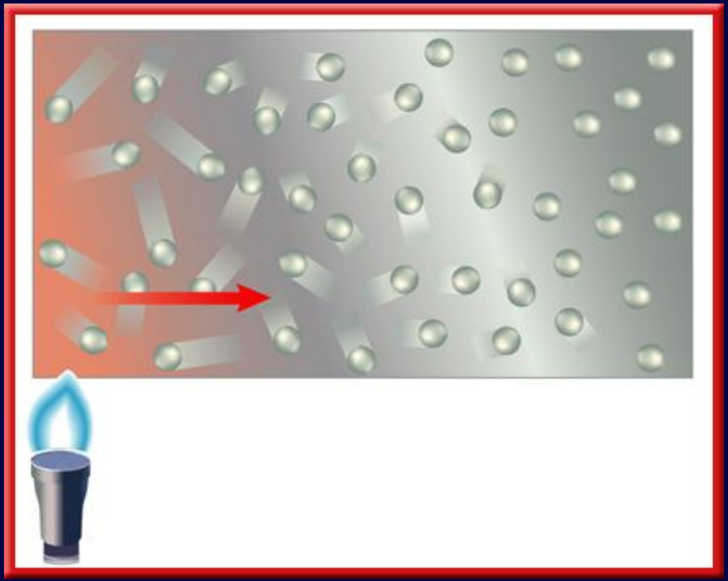
# Conduction

- Thermal energy is transferred from place to place by conduction, convection, and radiation.
- **Conduction** is the transfer of thermal energy by collisions between particles in matter.
- Conduction occurs because particles in matter are in constant motion.

6.2

# Collisions Transfer Thermal Energy

- Thermal energy is transferred when one end of a metal spoon is heated by a Bunsen burner.

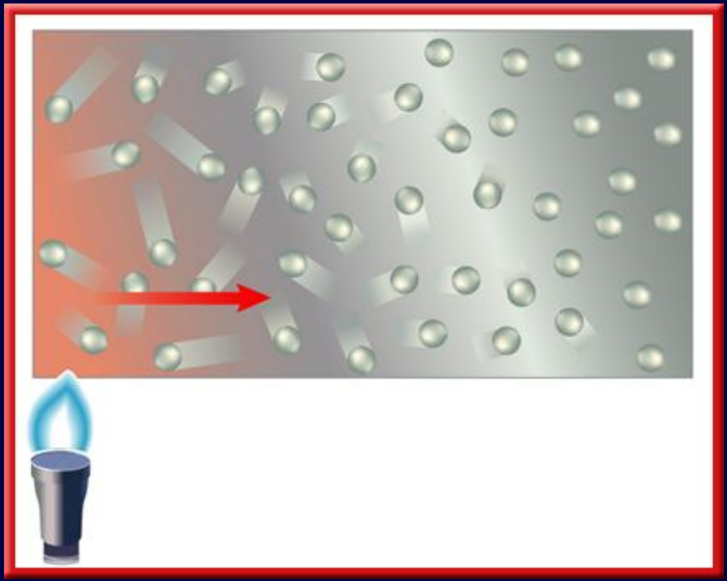


- The kinetic energy of the particles near the flame increases.

6.2

# Collisions Transfer Thermal Energy

- Kinetic energy is transferred when these particles collide with neighboring particles.

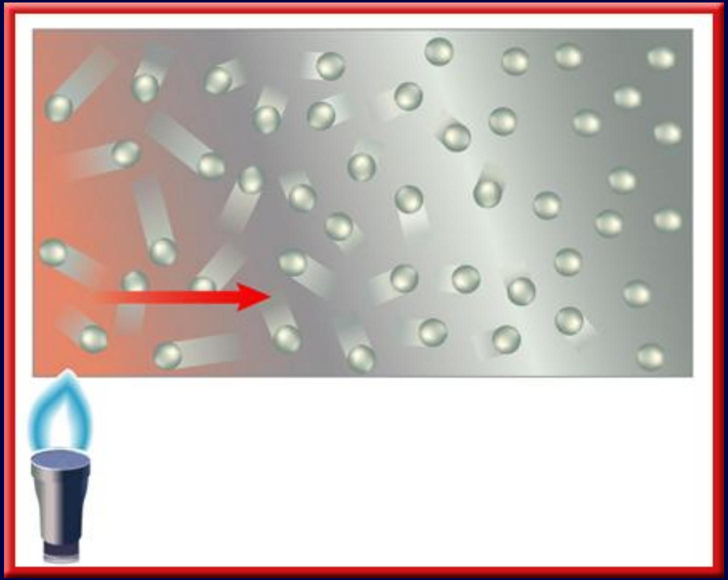


- As these collisions continue, thermal energy is transferred from one end of the spoon to the other end of the spoon.

6.2

# Collisions Transfer Thermal Energy

- When heat is transferred by conduction, thermal energy is transferred from place to place without transferring matter.



- Thermal energy is transferred by the collisions between particles, not by movement of matter.

# Heat Conductors

- The rate at which heat moves depends on the material.
- Heat moves faster by conduction in solids and liquids than in gases.
- In gases, particles are farther apart, so collisions with other particles occur less frequently than they do in solids or liquids.

6.2

# Heat Conductors

- The best conductors of heat are metals.

- In a piece of metal, there are electrons that are not bound to individual atoms, but can move easily through the metal.

# Heat Conductors

- Collisions between these electrons and other particles in the metal enable thermal energy to be transferred more quickly than in other material.

# Convection

- Liquids and gases can flow and are classified as fluids.
- In fluids, thermal energy can be transferred by convection.
- **Convection** is the transfer of thermal energy in a fluid by the movement of warmer and cooler fluid from place to place.

# Convection

- When conduction occurs, more energetic particles collide with less energetic particles and transfer thermal energy.
- When convection occurs, more energetic particles move from one place to another.
- As the particles move faster, they tend to be farther apart.
- As a result, a fluid expands as its temperature increases.

# Convection

- When a fluid expands, its volume increases, but its mass doesn't change.
- As a result, its density decreases.
- The same is true for parts of a fluid that have been heated.
- The density of the warmer fluid, therefore, is less than that of the surrounding cooler fluid.

6.2

# Heat Transfer by Currents

- Convection currents transfer heat from warmer to cooler parts of the fluid.
- In a convection current, both conduction and convection transfer thermal energy.

# Desert and Rain Forests

- Earth's atmosphere is made of various gases and is a fluid.
- The atmosphere is warmer at the equator than it is at the north and south poles.
- These temperature differences create convection currents that carry heat to cooler regions.

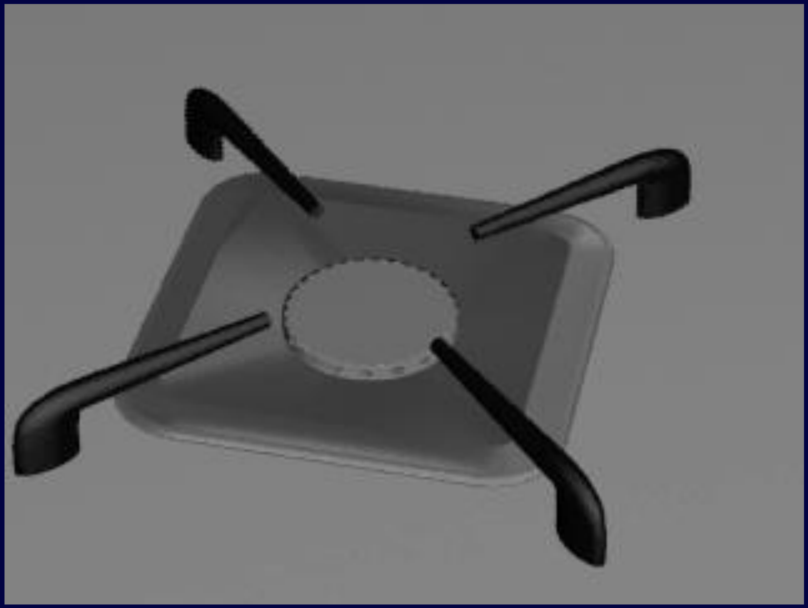
## Radiation

- Almost no matter exists in the space between Earth and the Sun, so heat cannot be transferred by conduction or convection. Instead, the Sun's heat reaches Earth by radiation.

6.2

# Radiation

- **Radiation** is the transfer of energy by electromagnetic waves.



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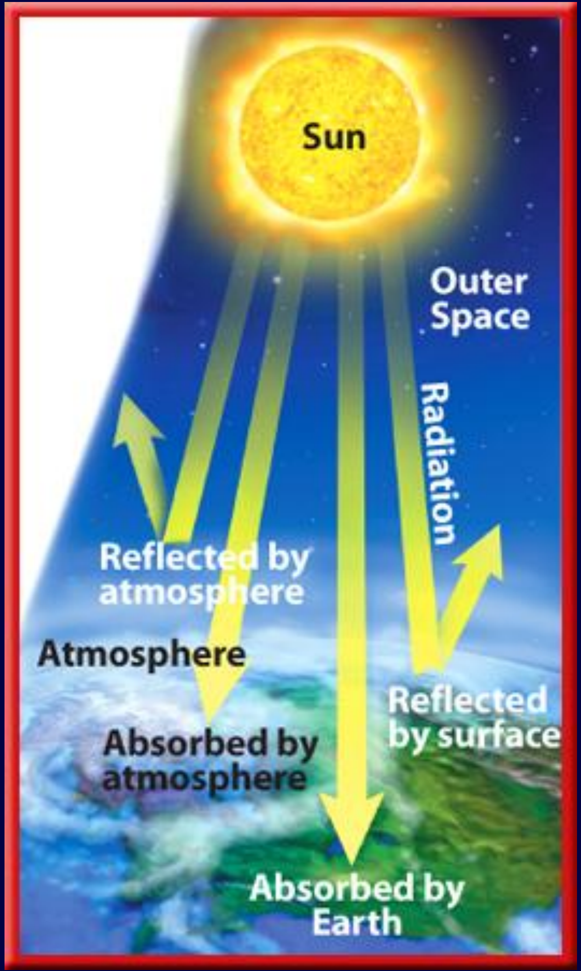
# Radiation

- These waves can travel through space even when no matter is present.
- Energy that is transferred by radiation often is called radiant energy.

# Radiant Energy and Matter

- When radiation strikes a material, some of the energy is absorbed, some is reflected, and some may be transmitted through the material.



# Radiant Energy and Matter

- The amount of energy absorbed, reflected, and transmitted depends on the type of material.
- Materials that are light-colored reflect more radiant energy, while dark-colored materials absorb more radiant energy.

# Radiant Energy and Matter

- When radiant energy is absorbed by a material, the thermal energy of the material increases.

# Radiation in Solids, Liquids, and Gases

- The transfer of energy by radiation is most important in gases.
- In a solid, liquid or gas, radiant energy can travel through the space between molecules.
- Molecules can absorb this radiation and emit some of the energy they absorbed.

# Radiation in Solids, Liquids, and Gases

- This energy then travels through the space between molecules, and is absorbed and emitted by other molecules.
- Because molecules are much farther apart in gases than in solids or liquids, radiation usually passes more easily through gases than through solids or liquids.

6.2

# Controlling Heat Flow

- Almost all living things have special features that help them control the flow of heat.
- For example, the Antarctic fur seal's thick coat helps keep it from losing heat. This helps them survive in a climate in which the temperature is often below freezing.

6.2

# Controlling Heat Flow

- In the desert the scaly skin of the desert spiny lizard has just the opposite effect.

- It reflects the Sun's rays and keeps the animal from becoming too hot.

# Insulators

- A material in which heat flows slowly is an **insulator**.
- Examples of materials that are insulators are wood, some plastics, fiberglass, and air.
- Material, such as metals, that are good conductors of heat are poor insulators.

# Insulators

- Gases, such as air, are usually much better insulators than solids or liquids.

- Some types of insulators contain many pockets of trapped air.

- These air pockets conduct heat poorly and also keep convection currents from forming.

# Insulating Buildings

- Building insulation is usually made of some fluffy material, such as fiberglass, that contains pockets of trapped air.

- The insulation is packed into a building's outer walls and attic, where it reduces the flow of heat between the building and the surrounding air.

# Reducing Heat Flow in a Thermos

- A thermos bottle reduces the flow of heat into and out of the liquid in the bottle, so that the temperature of the liquid hardly changes over a number of hours.
- To do this, a thermos bottle has two glass walls.

6.2

# Reducing Heat Flow in a Thermos

- The air between the two walls is removed so there is a vacuum between the glass layers.
- Because the vacuum contains almost no matter, it prevents heat transfer by conduction or radiation between the liquid and the air outside the thermos.

# Reducing Heat Flow in a Thermos

- To further reduce the flow of heat into or out of the liquid, the inside and outside glass surface of a thermos bottle is coated with aluminum to make each surface highly reflective.
- This causes electromagnetic waves to be reflected at each surface.

# Reducing Heat Flow in a Thermos

- The inner reflective surface prevents radiation from transferring heat out of the liquid.

- The outer reflective surface prevents radiation from transferring heat into the liquid.

# Question 1

Describe the difference between conduction and convection.

## Answer

Conduction transfers thermal energy without transferring matter. In convection, the more energetic particles move from one place to another.

6.2

## Question 2

__________ is the transfer of energy by electromagnetic waves.

## Answer

The transfer of energy by electromagnetic waves is radiation. Radiation is how Earth gets heat from the Sun.

## Question 3

Which of the following is the least effective insulator?

A. air
B. fiberglass
C. metal
D. wood

## Answer

The answer is C. Metals are good conductors of heat.