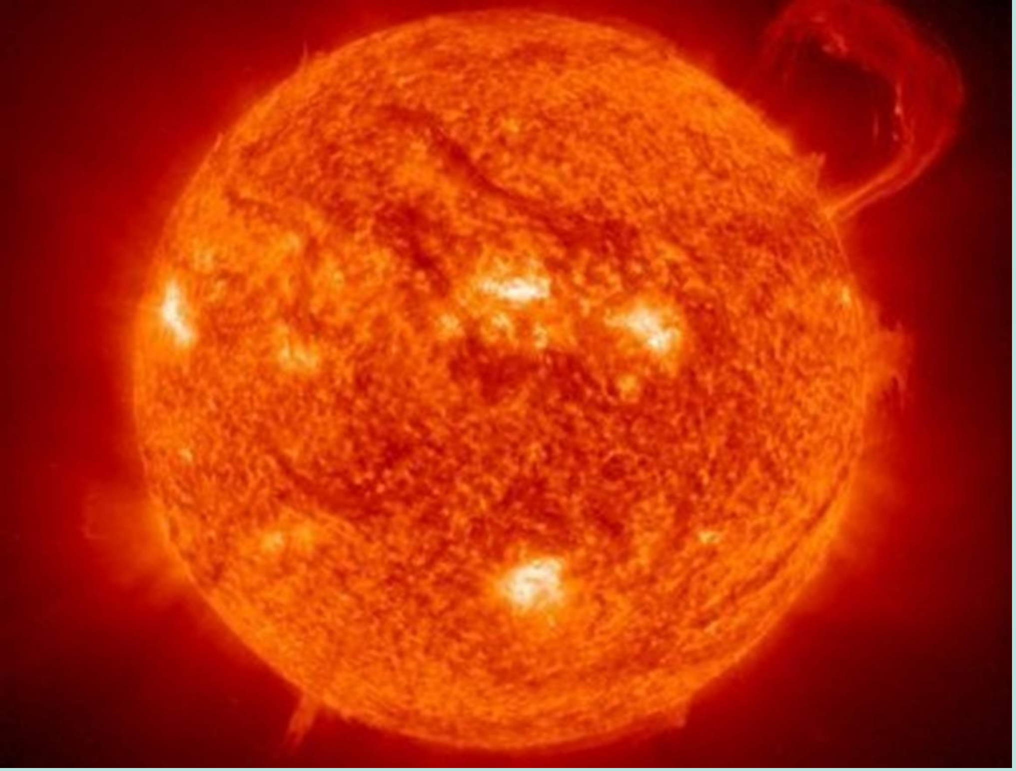
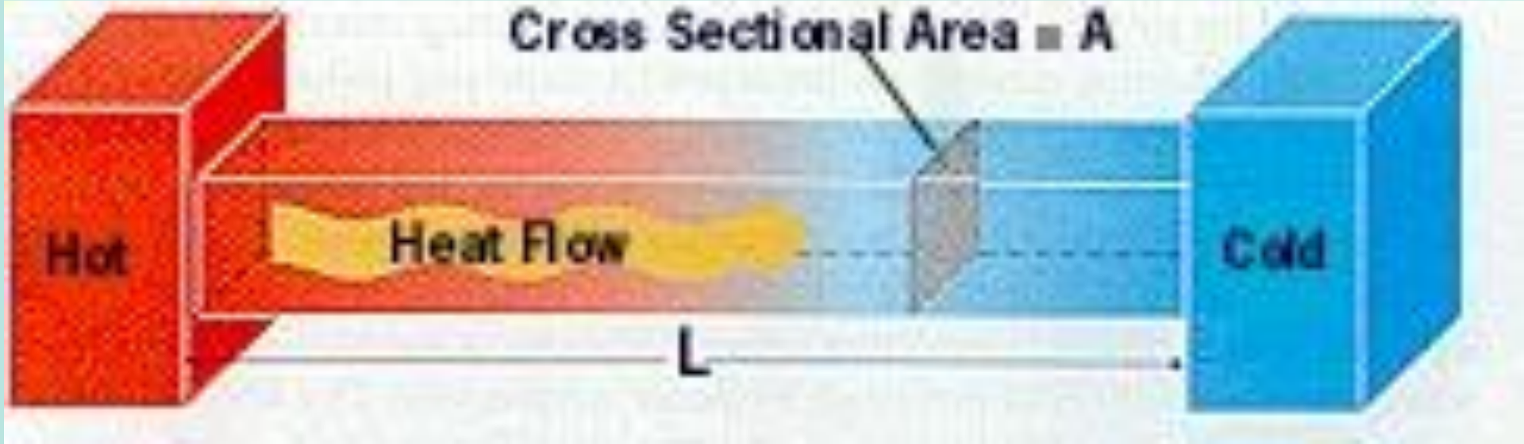


Thermal Energy (Heat)

Chapter 16



WARM-UP

Name the major forms of energy.

Each form of energy has:

WARM-UP

Name the major forms of energy.

Chemical energy

Mechanical energy

Electrical energy

Light energy (electromagnetic **radiation**)

Sound energy

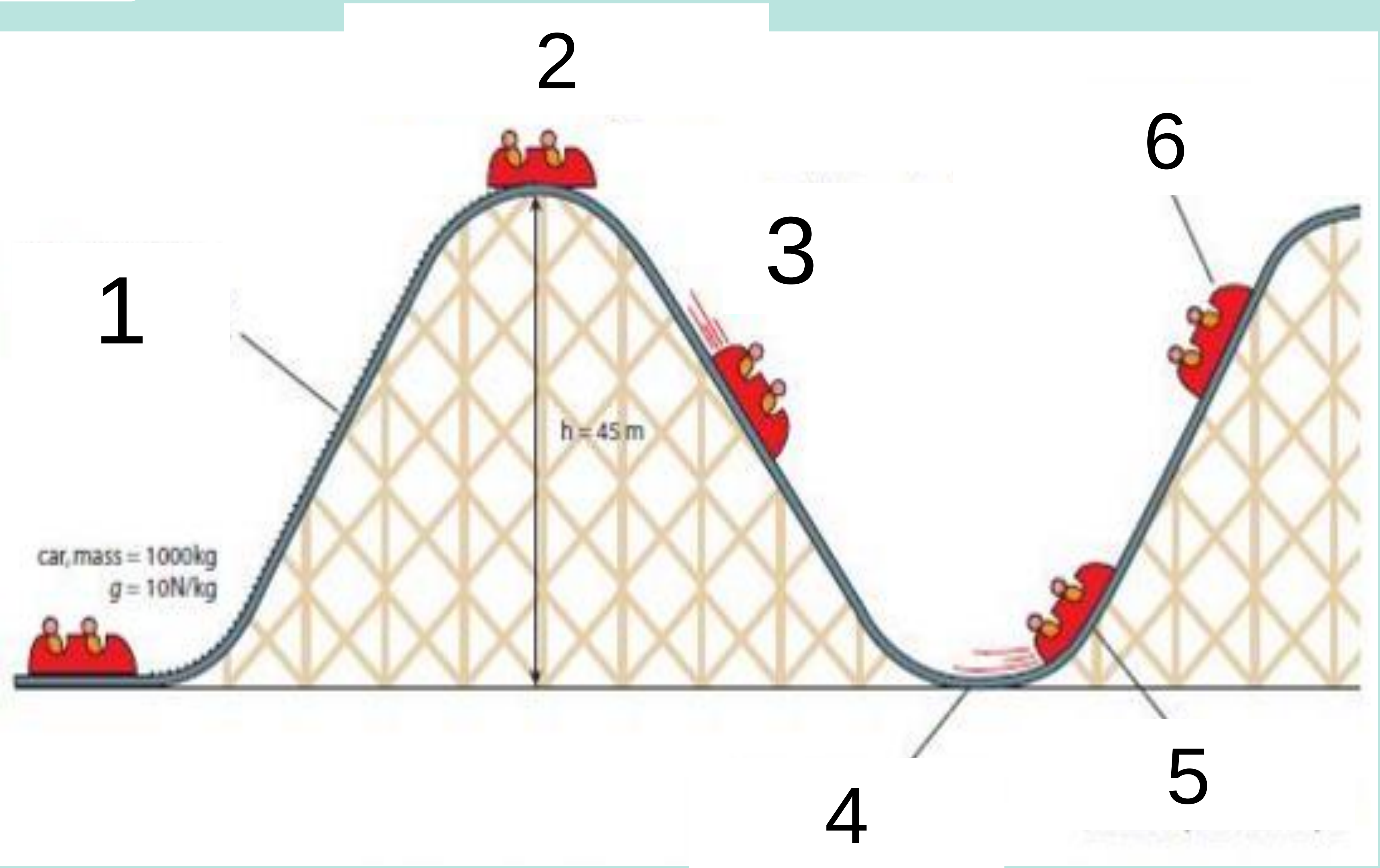
Magnetic energy

Heat energy

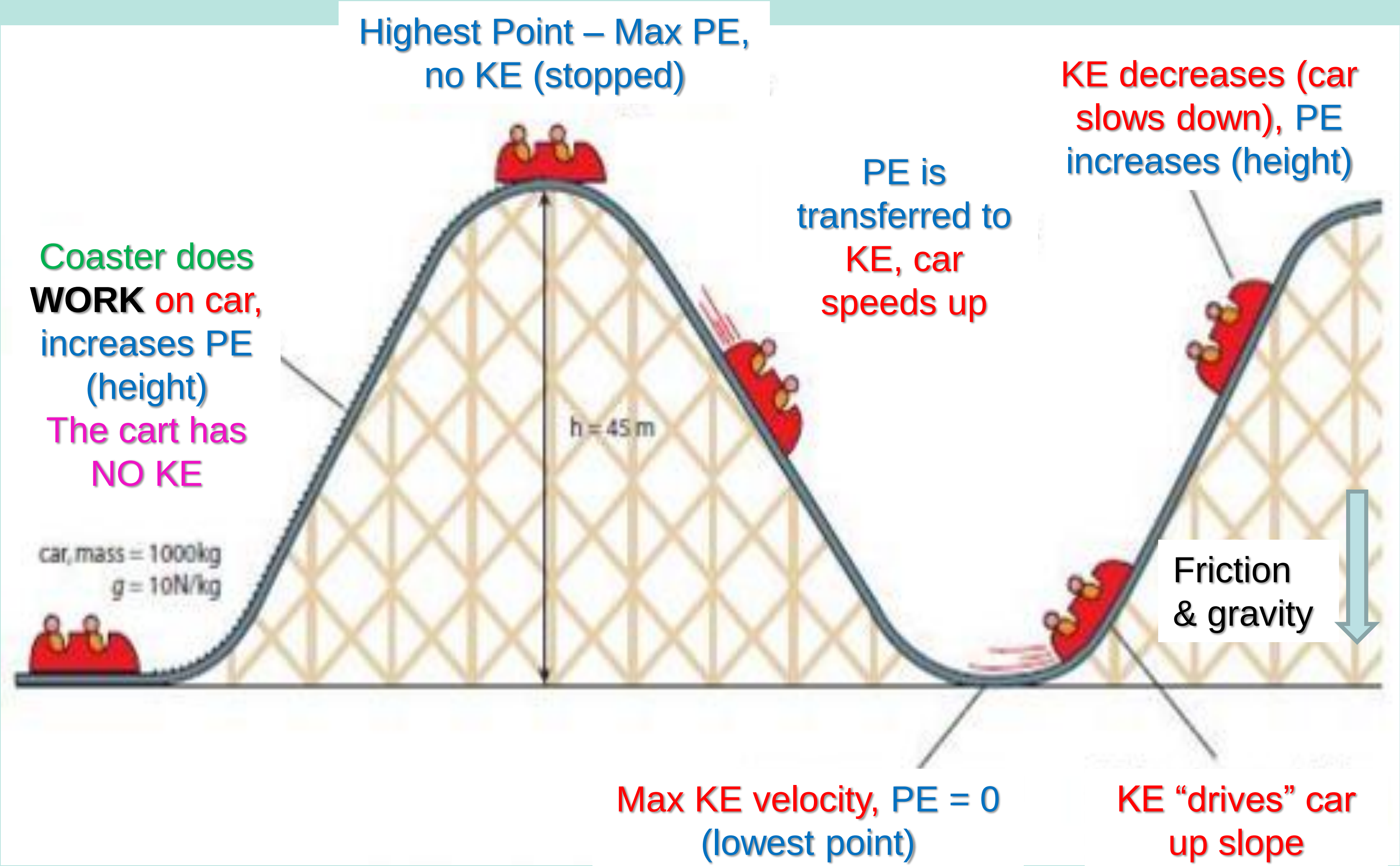
Nuclear Energy

Each form of energy has: PE & KE

Describe PE & KE at each point.



Describe PE & KE at each point.

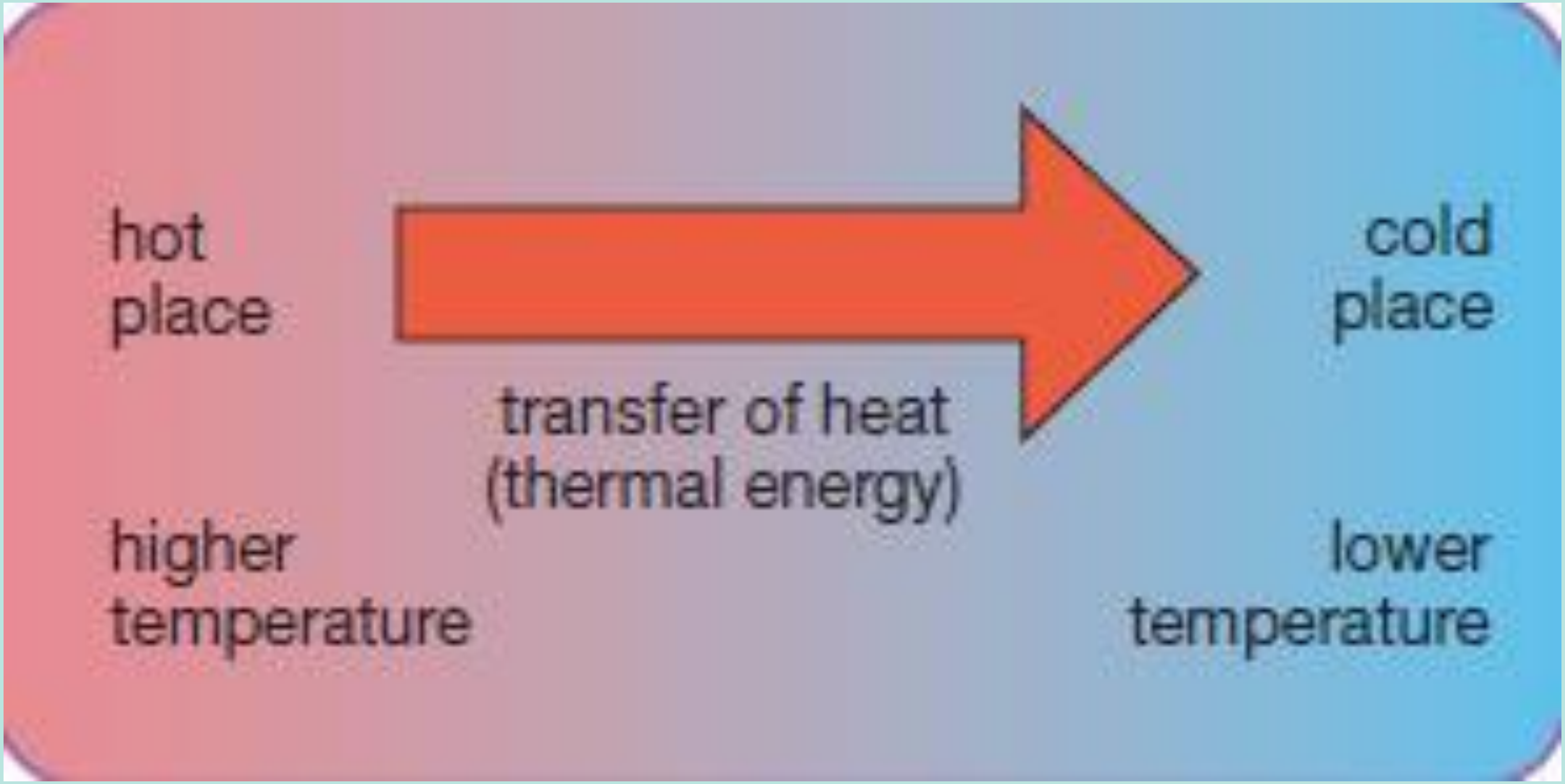


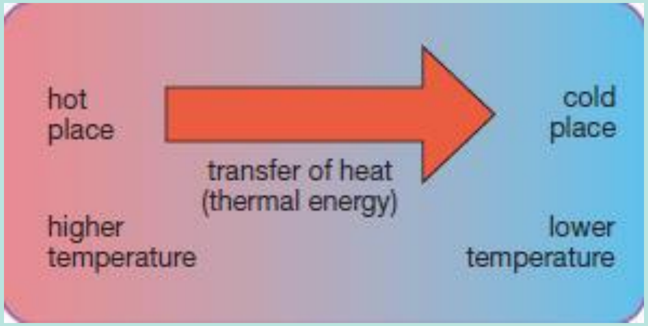
Focus Questions

LESSON QUESTION

1. Define heat flow and its direction.
2. Name two variables thermal energy related to?
3. Explain thermal expansion.
4. Define and calculate specific heat, showing how it relates to a change in temperature.
5. List and describe heat transfer and three modes of heat transfer.
6. Explain the three laws of thermodynamics.
7. **Describe heating and cooling systems in terms of how they distribute thermal energy.**

Heat Flow


hot
place
cold
place
transfer of heat
(thermal energy)
higher
temperature
lower
temperature



Heat Flow

- **Heat flows spontaneously from hot objects to cold objects.**
- **The second law of thermodynamics (entropy) states that thermal energy can flow from colder objects to hotter objects only if work is done on the system.**
  - This is because matter goes from order to disorder spontaneously. Hotter objects have particles moving much faster (more random) than cooler objects. Therefore, hotter objects spread out faster than cooler objects.

Heat Flow

Thermal energy depends on the mass, temperature, and phase (solid, liquid, or gas) of an object.

e.g. A cup of tea and a teapot full of tea can have the same temperature, but the number of particles (related to mass) and the phase (s, l, g) affect the heat flow.

On the Kelvin scale, **absolute zero** is defined as a temperature of 0 kelvins.

Thermal Energy

Thermal energy depends on mass and temperature.

A. The tea is at a higher temperature than the lemonade.

B. The lemonade has more thermal energy because it has many more particles.

Temperature

A measure of the average kinetic energy (motion) of molecules in a substance.

Most people equate temperature with how “hot” or “cold” an object is. *But an Alaskan or an Egyptian would define hot and cold differently than you and I.*

80 ºF (27 ºC) would be “hot” to an Alaskan But “cool” to an Egyptian

Temperature

A measure of the average kinetic energy (motion) of molecules in a substance.

Most substances expand with an increase in temperature and contract as the temperature decreases. (e.g. sidewalks in winter versus summer).

This explains how thermometers work (*the liquid inside expands & contracts*).

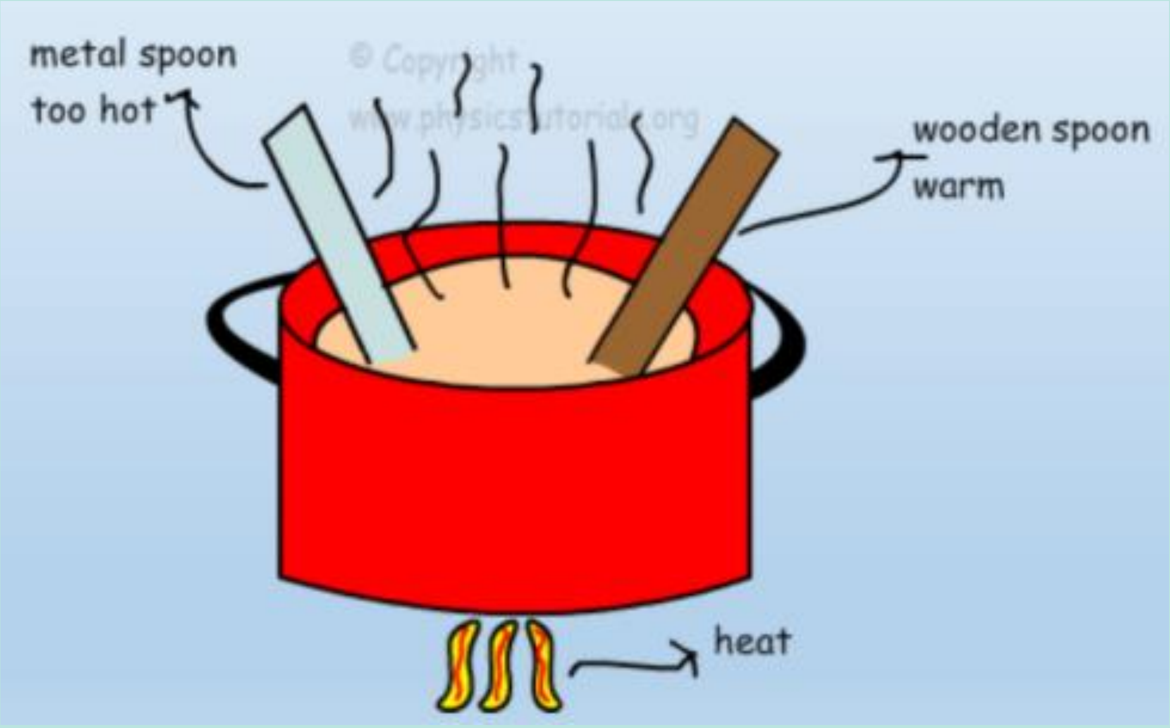
Heat Flow

- Thermal **expansion** occurs when particles of matter move farther apart as temperature increases, therefore, **volume increases**.

- As temperature decreases, there is thermal **contraction** of particles, therefore, **volume decreases**, because they slow down, collide less, and exert less force.

Heat Flow

- Temperature relates to the **specific heat** of a substance.



- The metal spoon heats up faster than the wooden spoon.

Specific Heat of Water

The **specific heat capacity**, or simply the specific heat (C) of a substance, is the amount of heat it takes to raise the temperature of 1 g of the substance 1º C.

- Water has the second highest specific heat of all liquids.
- Metals generally have low specific heats.

Specific Heats of Some Common Substances		
Substance	Specific heat (c_p)	
	J/(g·ºC)	cal/(g·ºC)
Liquid water	4.18	1.00
Ethanol	2.4	0.58
Ice	2.1	0.50
Steam	1.9	0.45
Chloroform	0.96	0.23
Aluminum	0.90	0.21
Iron	0.46	0.11
Silver	0.24	0.057

Specific Heat (C)

Some things heat up or cool down faster than others.

e.g. Michigan stays warmer in the winter due to the heat from the lakes (*e.g. hot vegetables stay hot a long time because of their high water content*)

Specific heat is ability of a substance to "hold" heat.

C_{water} = 4.184 J / g°C

C_{sand} = 0.664 J / g°C

This is why land heats up quickly during the day and cools quickly at night and why water takes longer.

Specific heat

Specific Heat

$$Q = m \times c \times \Delta T$$

Heat is in joules, mass is in grams, specific heat is in J/g•°C, and the temperature change is in degrees Celsius

QUICK CHECK

An iron skillet has a mass of 500.0 grams. The specific heat of iron is 0.449 J/g• ºC. How much heat must be absorbed to raise the skillet's temperature by 95.0 ºC?

A

G

E

S

QUICK CHECK

An iron skillet has a mass of 500.0 grams. The specific heat of iron is 0.449 J/g• ºC. How much heat must be absorbed to raise the skillet's temperature by 95.0 ºC?

A **Heat (Q)**

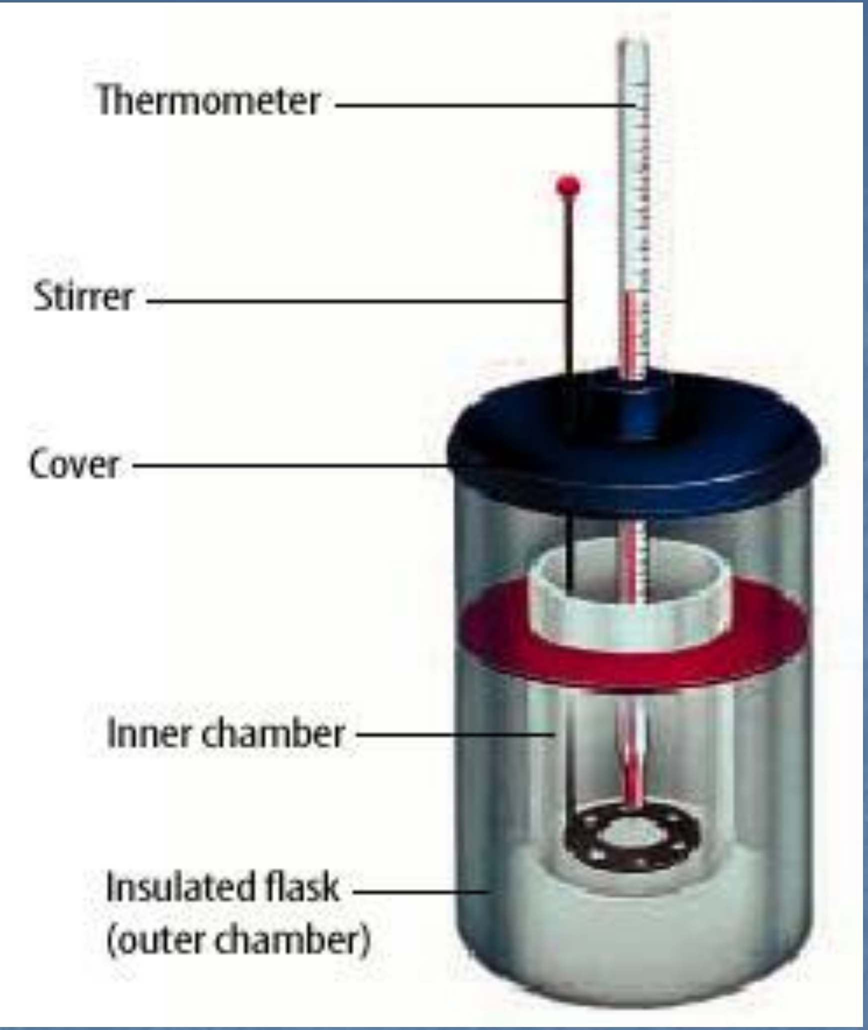
G **m = 500 g; c = 0.449 J/g• ºC; T = 95.0 ºC**

E **$Q = m\ c\ \Delta T$**

S **Q = 500 g x 0.449 J/g• ºC x 95.0 ºC = 21, 375 J**

Q = 21.4 kJ

A **calorimeter** is used to measure the specific heat of a substance.

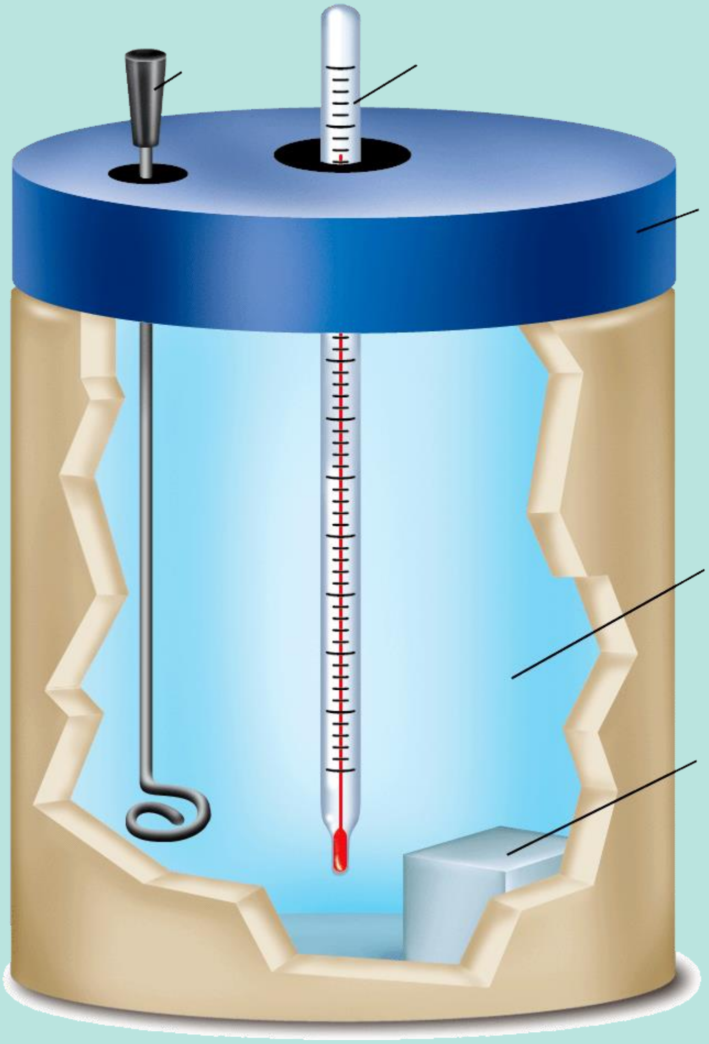


Rearrange $q = mc\Delta T$ to solve for c:

$$c = \frac{q}{m \times \Delta T} = \frac{\text{heat (J or cal)}}{\text{mass (g)} \times \text{change in temperature (°C)}}$$

Specific Heat

A **calorimeter** is used to measure specific heat. A sample is heated and placed in the calorimeter. The **temperature** change is observed.



QUICK CHECK

1. What is the thermal energy of an object?
    a. the total number of atoms or molecules
    b. the total kinetic energy of the atoms or molecules
    c. the average kinetic energy of the atoms or molecules
    d. the average mechanical energy of the atoms or molecules

2. What causes a gas to expand when its temperature is increased?
    a. The number of particles increases as temperature increases.
    b. Each particle expands as its temperature increases, so the total volume increases.
    c. As temperature increases, more electrons leave atoms and move separately.
    d. As gas particles move faster, they overcome some forces of attraction.

QUICK CHECK

1. What is the thermal energy of an object?
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   d. As gas particles move faster, they overcome some forces of attraction.

Heat flows from

a. Warm to cold
b. Cold to warm
c. Along an equal temperature

What property of matter can be measured using a calorimeter?

a. temperature
b. thermal expansion
c. specific heat
d. Mass

Heat depends on:

Heat flows from

a. **Warm to cold**
b. Cold to warm
c. Along an equal temperature

What property of matter can be measured using a calorimeter?

a. temperature
b. thermal expansion
c. **specific heat**
d. mass

Heat depends on:

Mass
Temperature
Phase of substance (s, l, g)

Specific Heat

Math Practice

1. How much heat is needed to raise the temperature of 100.0 g of water by 85.0°C?

Answer:

$Q = m * c * \Delta T$

$= (100.0\ g)(4.18\ J/g{\bullet}°C)(85.0°C)$

$= 35.5\ kJ$

Specific Heat

Math Practice

2. How much heat is absorbed by a 750-g iron skillet when its temperature rises from 25°C to 125°C?

Answer:

Specific Heat

Math Practice

2. How much heat is absorbed by a 750-g iron skillet when its temperature rises from 25°C to 125°C?

Answer:

$Q = m * c * \Delta T$

$= (750\ g)(0.449\ J/g•°C)(125°C – 25°C)$

$= (750\ g)(0.449\ J/g•°C)(100°C)$

$= 34\ kJ$

Specific Heat

Math Practice

3. In setting up an aquarium, the heater transfers 1200 kJ of heat to 75,000 g of water. What is the increase in the water's temperature? (*Hint:* Rearrange the specific heat formula to solve for ΔT.)

Answer:

Specific Heat

Math Practice

3. In setting up an aquarium, the heater transfers 1200 kJ of heat to 75,000 g of water. What is the increase in the water's temperature? (*Hint:* Rearrange the specific heat formula to solve for ΔT.)

Answer:

$\Delta T = Q / (m \times c)$

$= 1{,}200{,}000\ \text{J}/(75{,}000\ \text{g} \times 4.18\ \text{J/g} \bullet {}^\circ\text{C})$

$= 3.8^\circ\text{C}$

Specific Heat

Math Practice

5. What mass of water will change its temperature by 3.0°C when 525 J of heat is added to it?

Answer:

Specific Heat

Math Practice

5. What mass of water will change its temperature by 3.0°C when 525 J of heat is added to it?

Answer:

$m = Q / (\Delta T \times c)$

$= 525 \text{ J}/(3.0°\text{C} \times 4.18 \text{ J/g}\bullet°\text{C})$

$= 42 \text{ g}$

Thermal (Heat) Energy Transfer

Like matter, energy can be transformed from one form to another AND can move from one sphere to another

Thermal (Heat) Energy is transferred in one of three ways:

Conduction

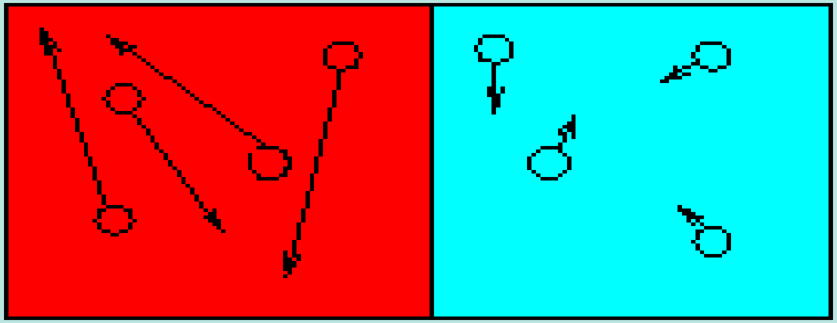
Convection

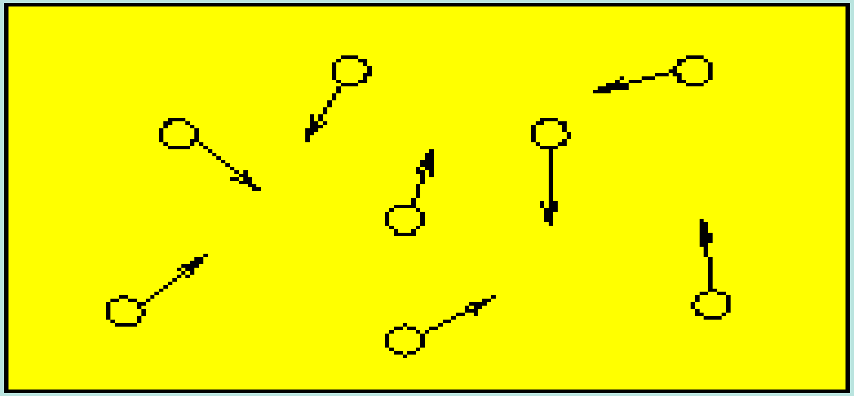
Radiation

Conduction

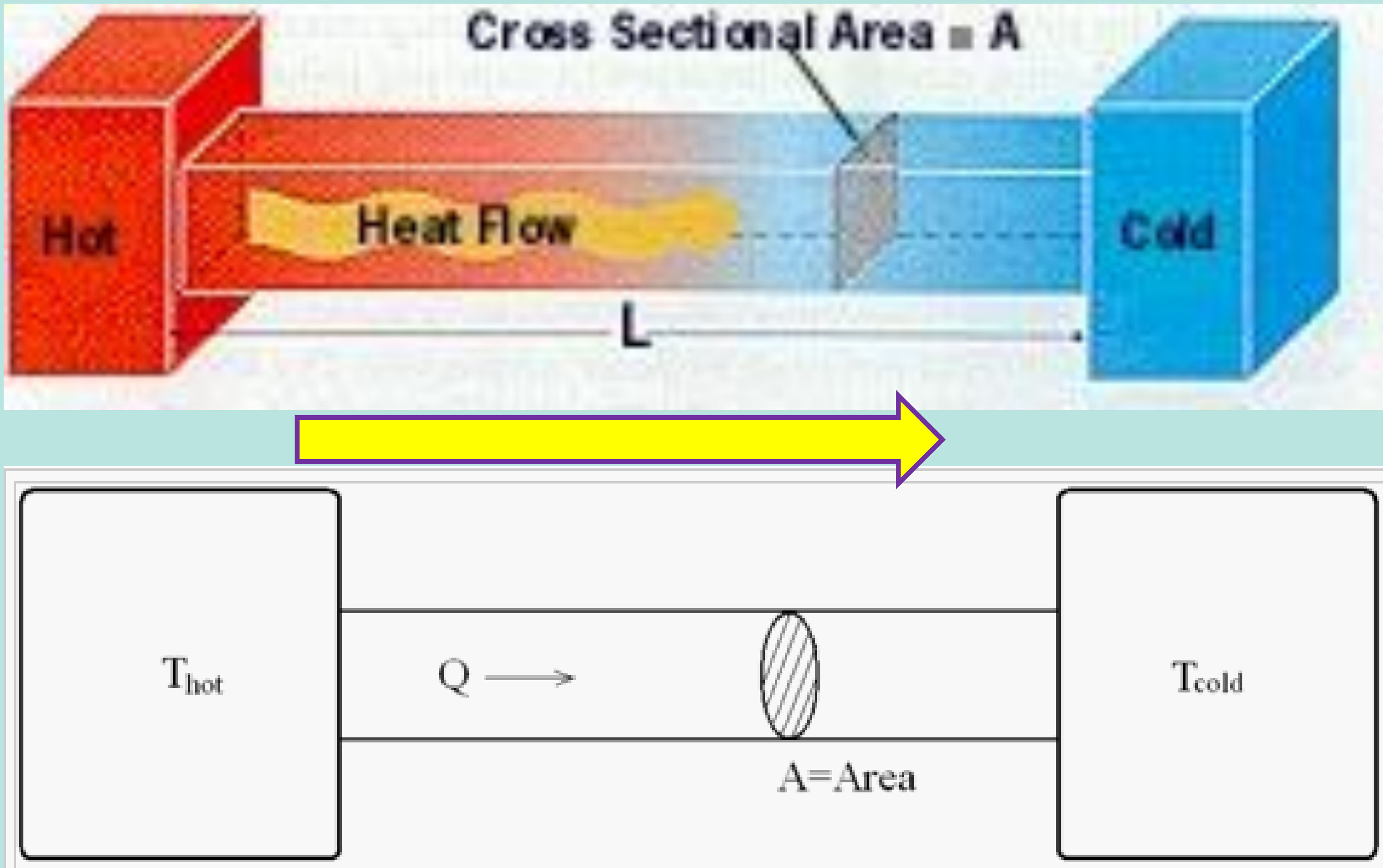
<u>Conduction</u> – the transfer of heat by contact between molecules.

Conduction requires matter for the transfer



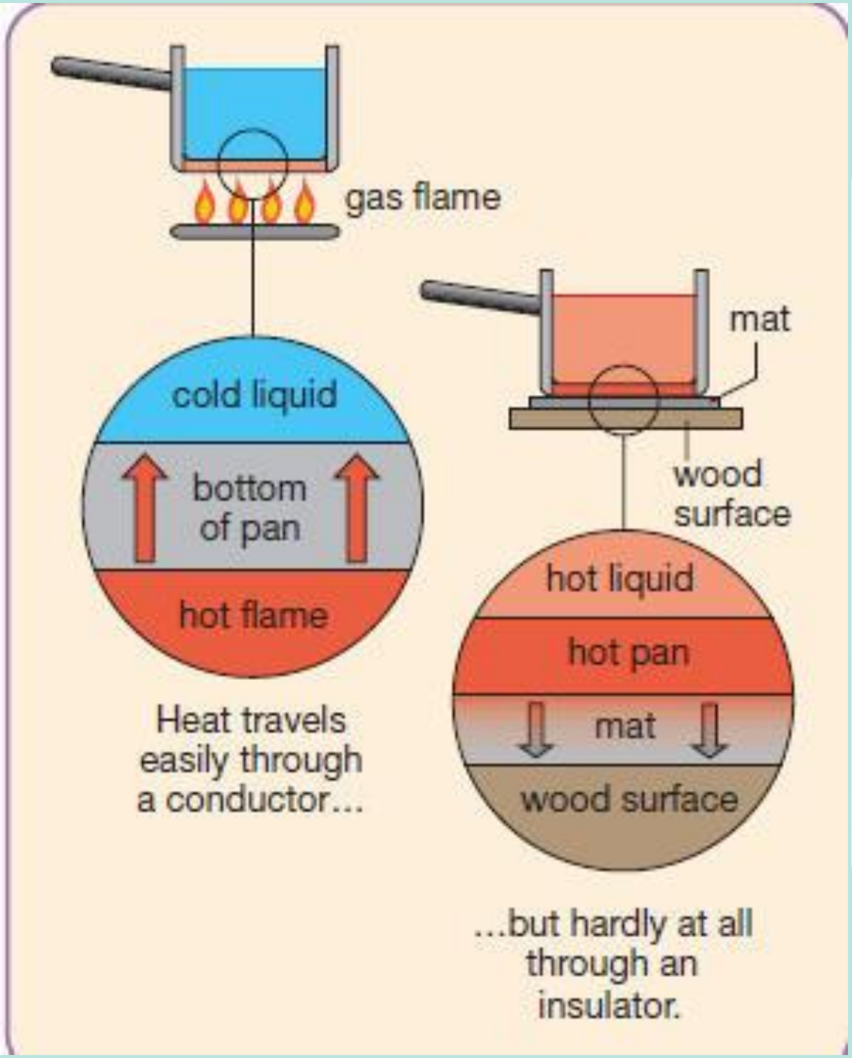


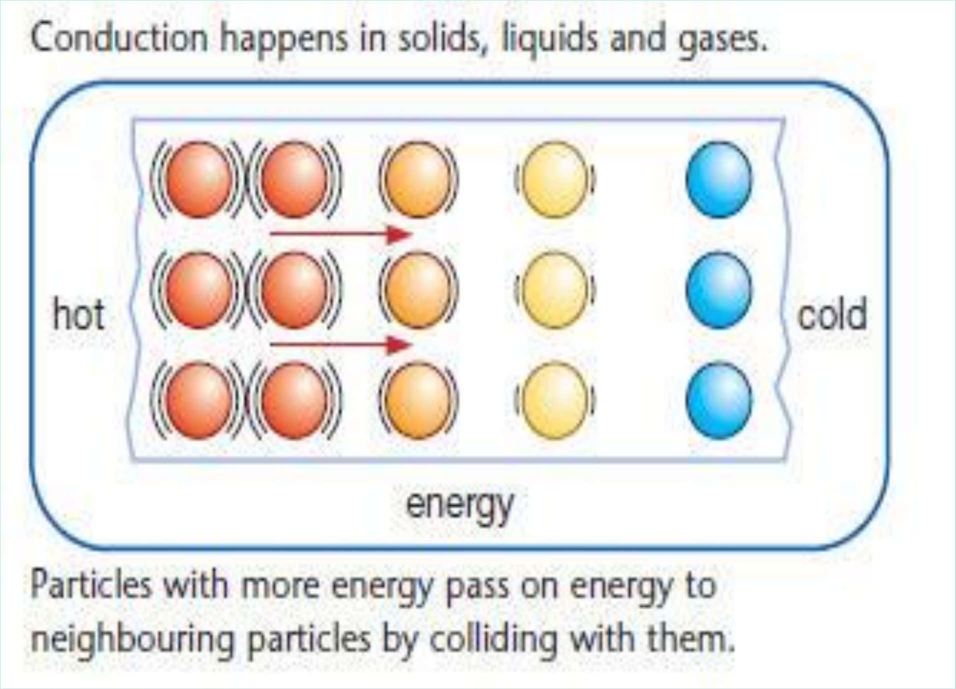
Conduction



Cross Sectional Area = A
Hot
Heat Flow
Cold
L
T_{hot}
Q
T_{cold}
A=Area

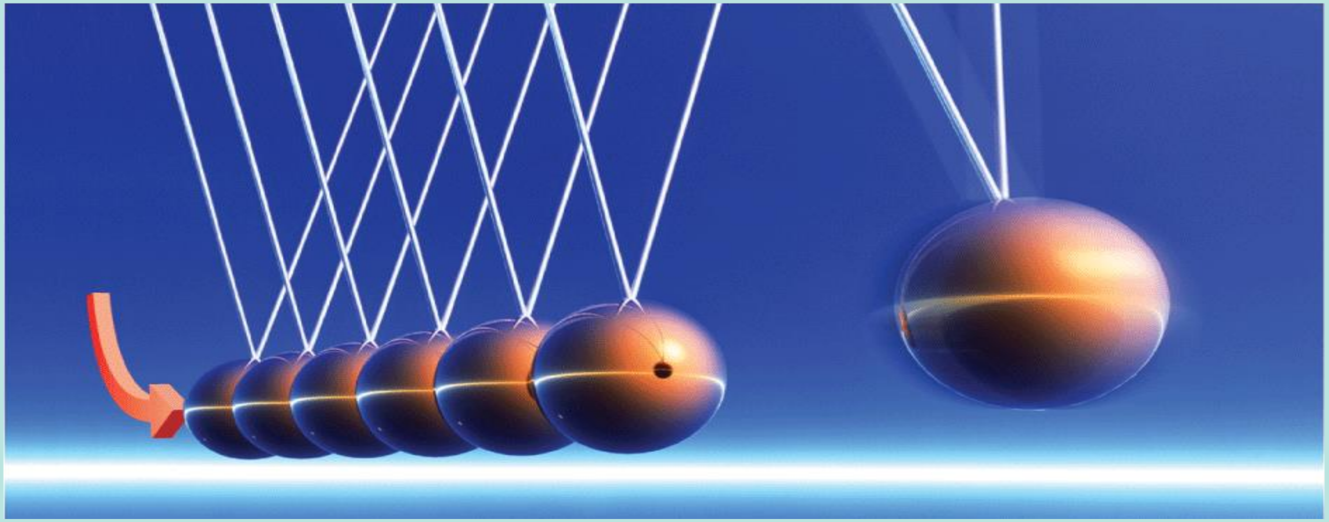
Conduction


gas flame
mat
cold liquid
bottom of pan
hot flame
wood surface
hot liquid
hot pan
mat
wood surface
Heat travels easily through a conductor...
...but hardly at all through an insulator.


Conduction happens in solids, liquids and gases.
hot
cold
energy
Particles with more energy pass on energy to neighbouring particles by colliding with them.

Conduction

- **Conduction in gases is slower than in liquids and solids because the particles in a gas collide less often.**
- Newton's cradle helps to visualize conduction. One ball strikes the rest, and most of the kinetic energy is transferred to one ball on the end.

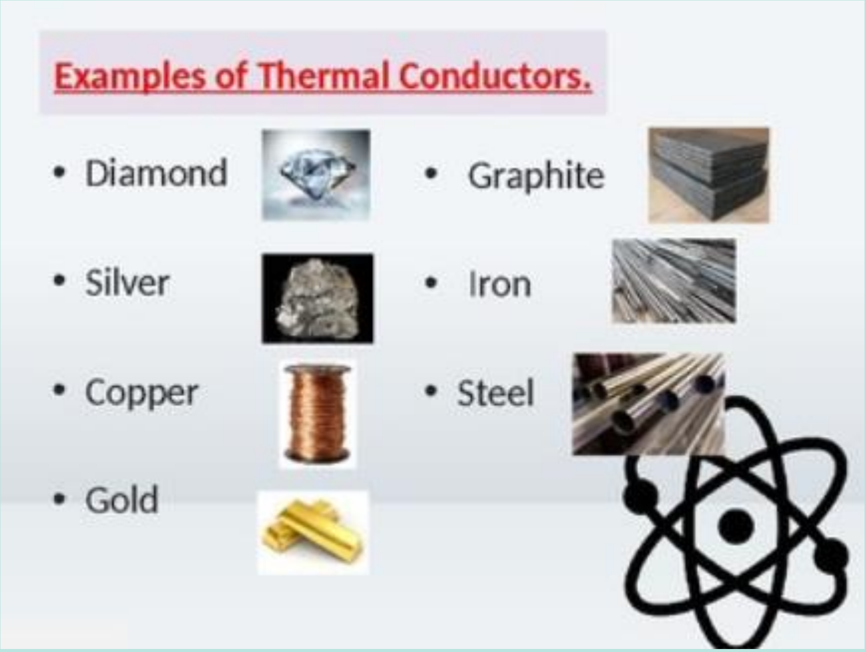


Conduction

Thermal Conductors

A **thermal conductor** is a material that conducts thermal energy well.

- Metals are good thermal conductors.



Conduction

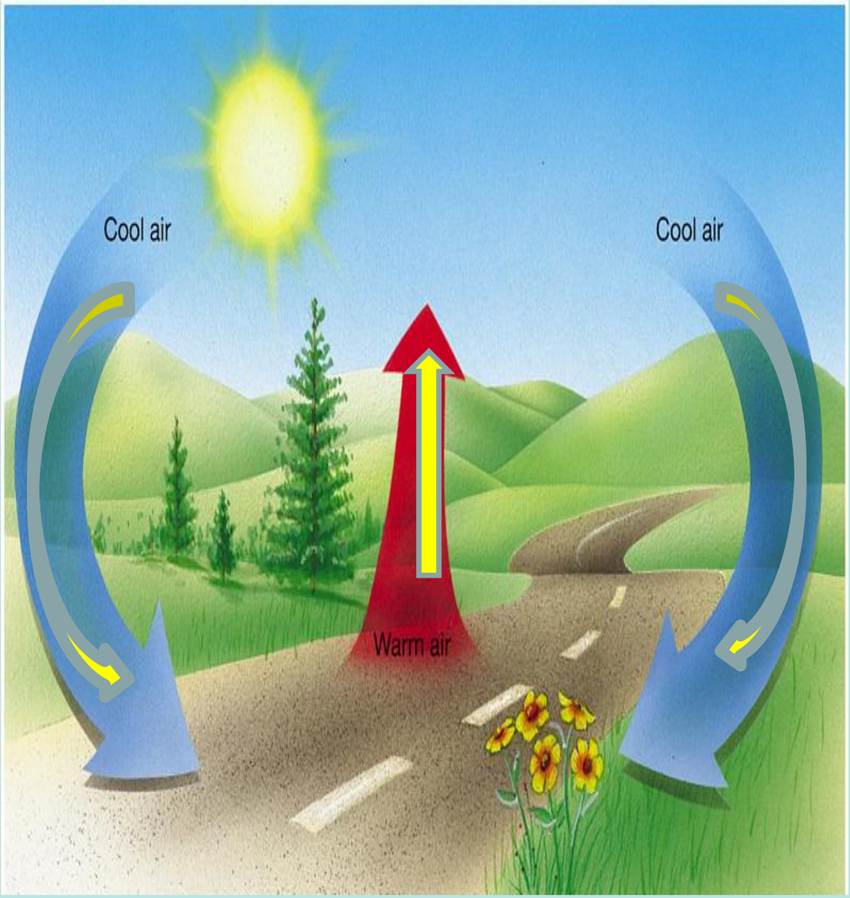
Thermal Insulators

A material that conducts thermal energy poorly is called a **thermal insulator.**

Air is a very good insulator. Wool garments and plastic foam cups use trapped air to slow down conduction.

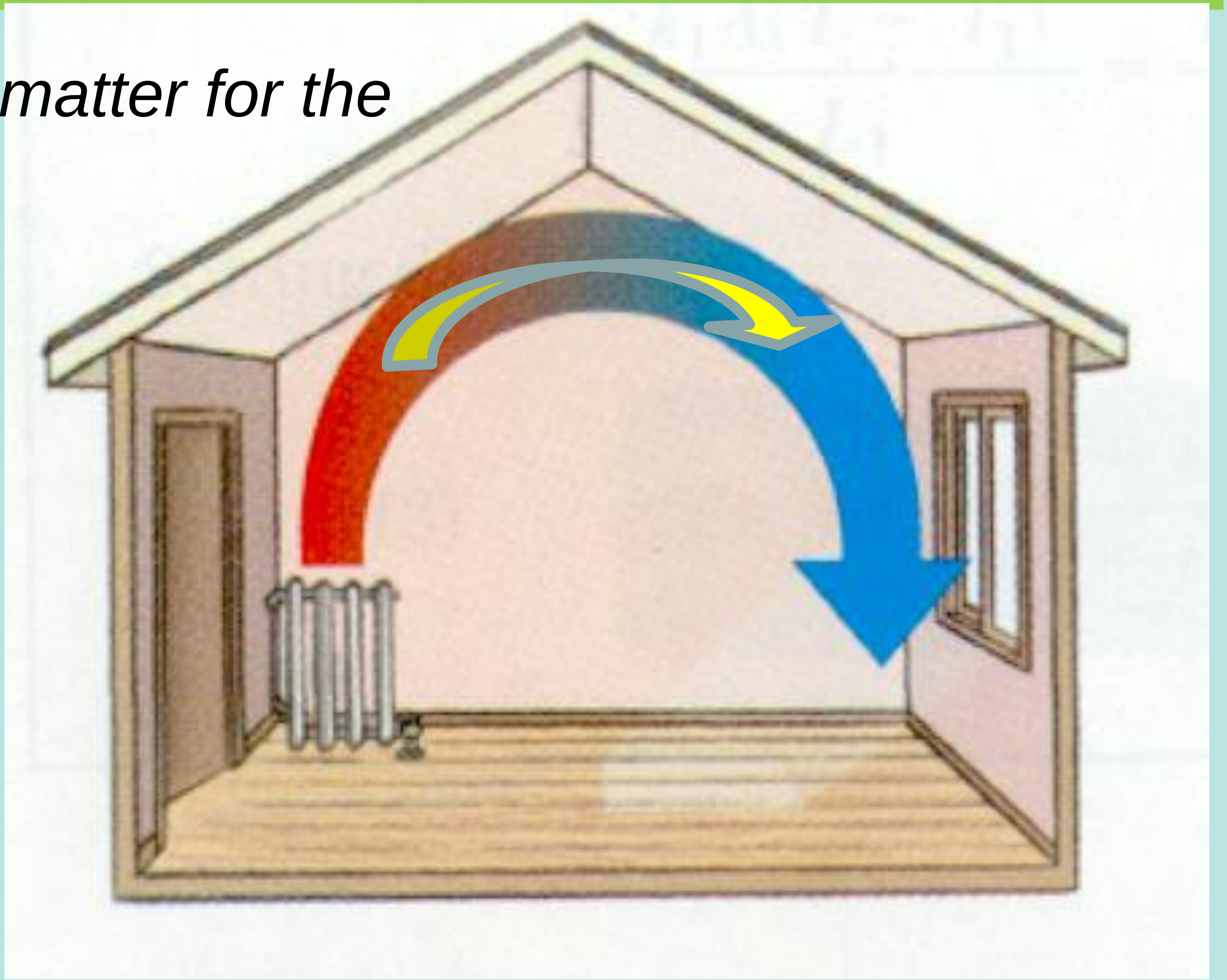
Convection

- Energy is transferred due to differences in density or temperature.
- The cooler material will sink, warmer material will rise
- This is true for heat <u>IN</u> and <u>ON</u> the Earth.



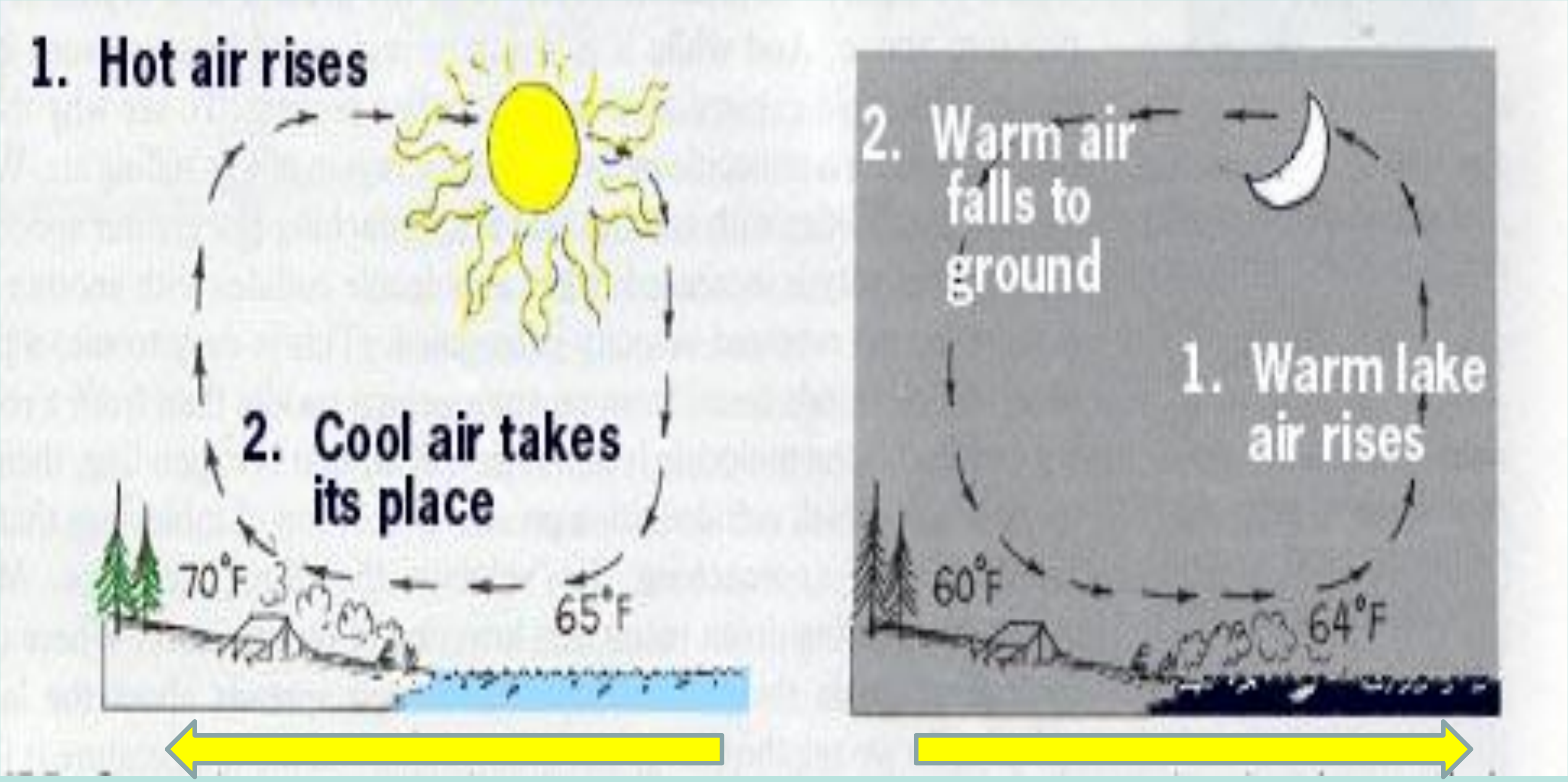
Convection

Requires matter for the transfer

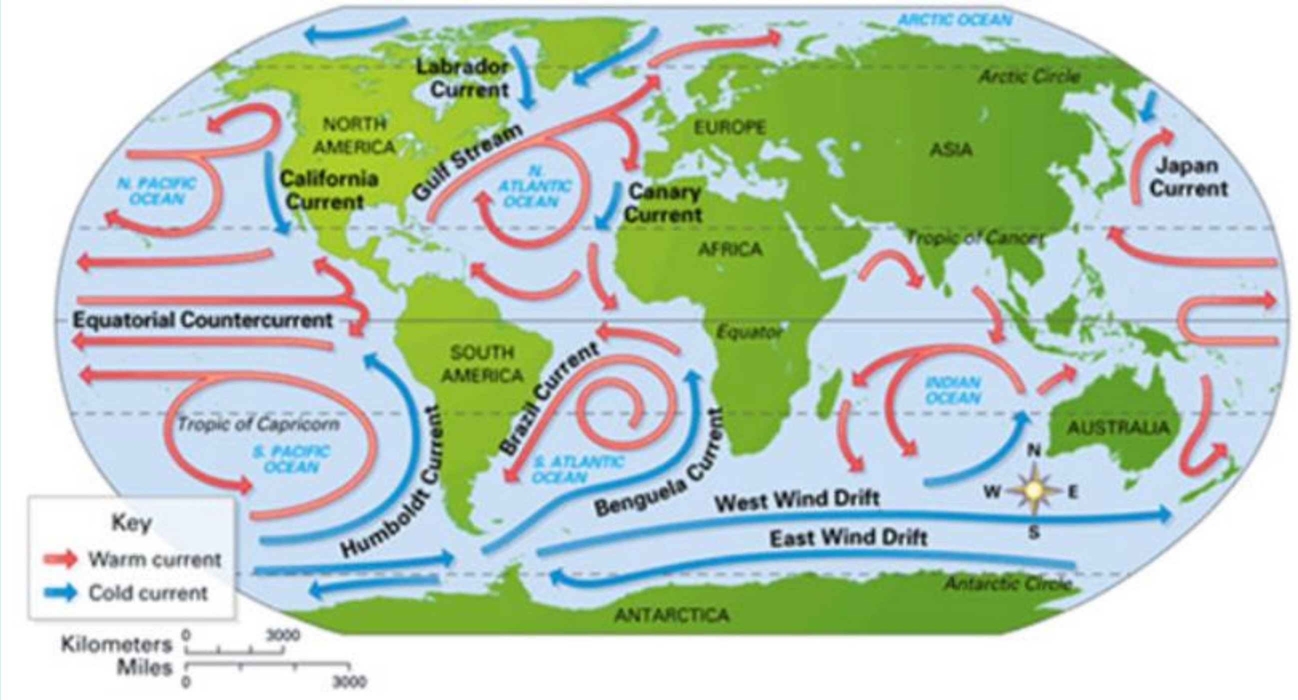


Convection

Convection

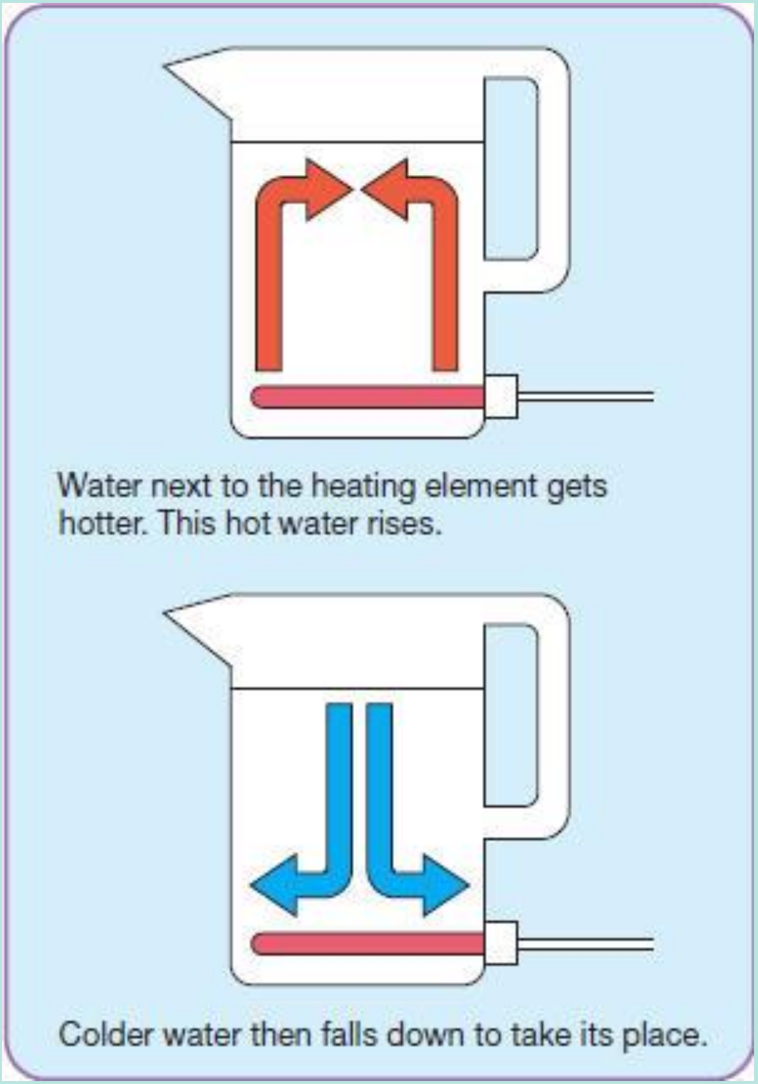

1. Hot air rises
2. Cool air takes its place
70°F
65°F
2. Warm air falls to ground
1. Warm lake air rises
60°F
64°F

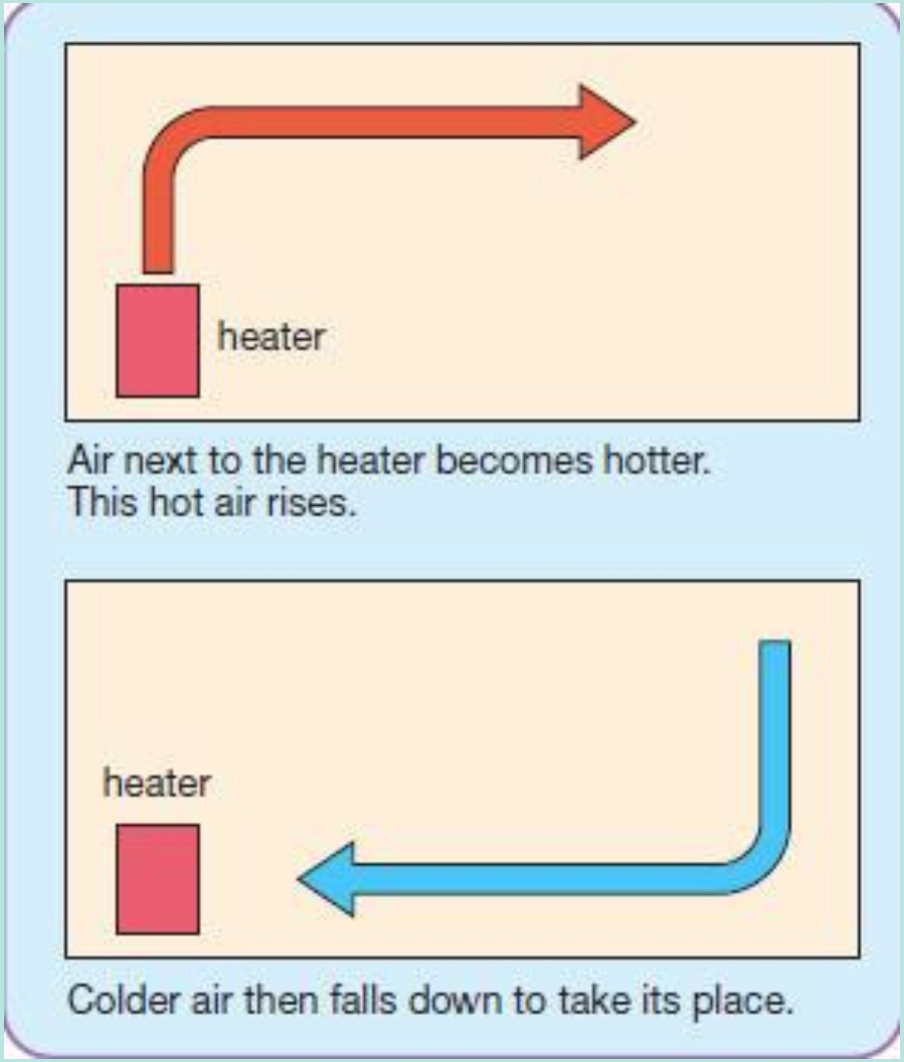
Convection



Ocean currents, Global wind patterns, and movement in the earth's crust all occur due to convection.

Convection

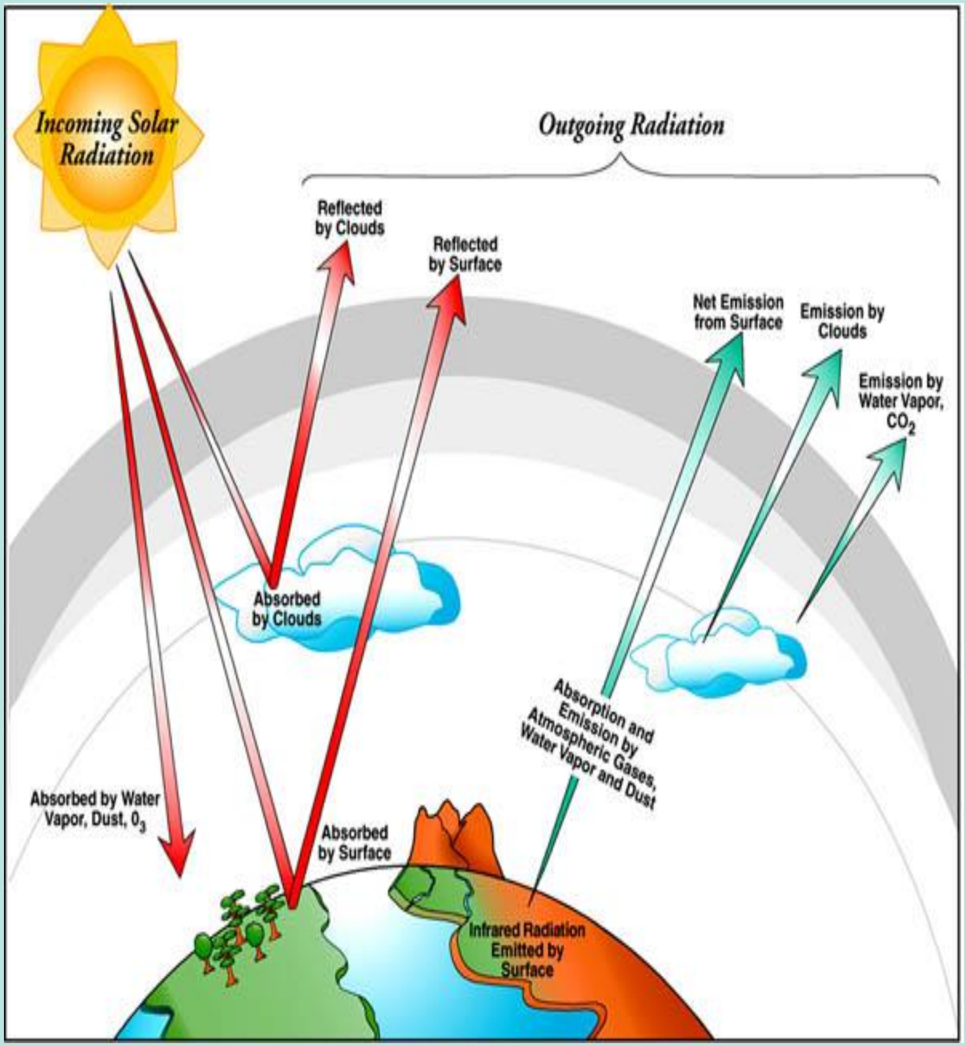

Water next to the heating element gets hotter. This hot water rises.
Colder water then falls down to take its place.


heater
Air next to the heater becomes hotter. This hot air rises.
heater
Colder air then falls down to take its place.

Radiation

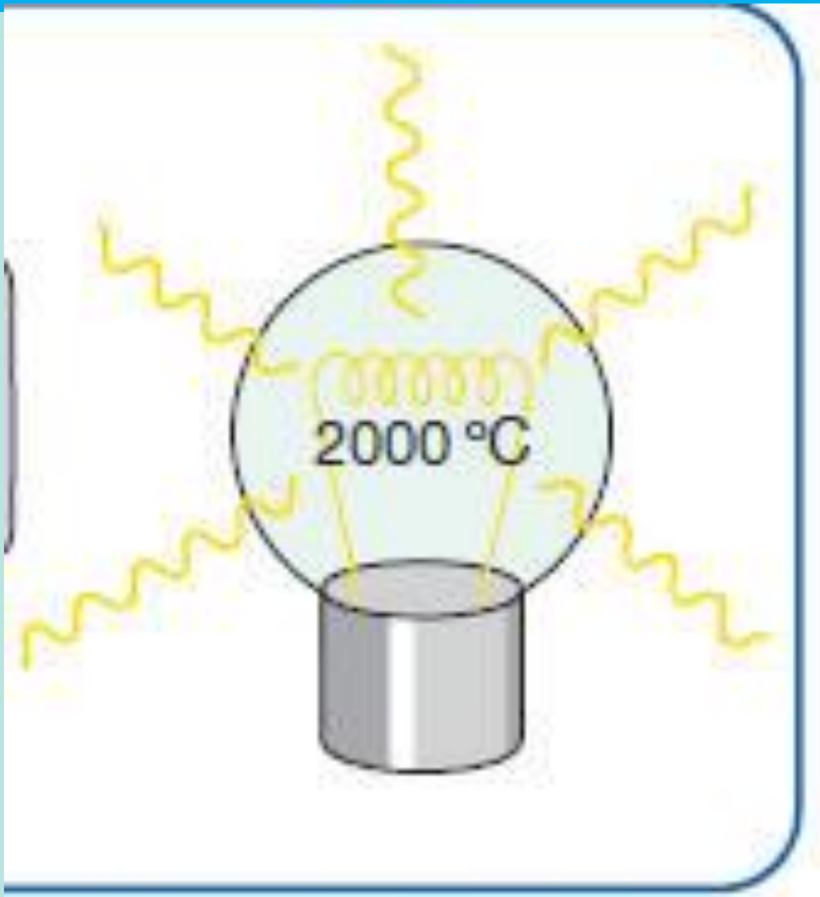
Energy that is "given off" by an object AND ***does NOT require matter*** *for the transfer*.

The Earth is most affected by the Sun's radiation (the heat the Sun gives off (radiates)).



Radiation

Radiation



A very hot lamp filament emits light as well as thermal radiation.

Examples of Radiation

- The warmth of a bonfire
- Stoves / Ovens radiate heat
- A “radiator” in a house
- Our bodies radiate heat

Radiation

Thermal energy is transferred from the fire to your face by radiation. No substance (solid, liquid or gas) is needed so the radiation can travel through empty space.

Thermal (Heat) Energy Transfer

Conduction

(*requires matter for the transfer*)

Convection

(*requires matter for the transfer*)

Radiation

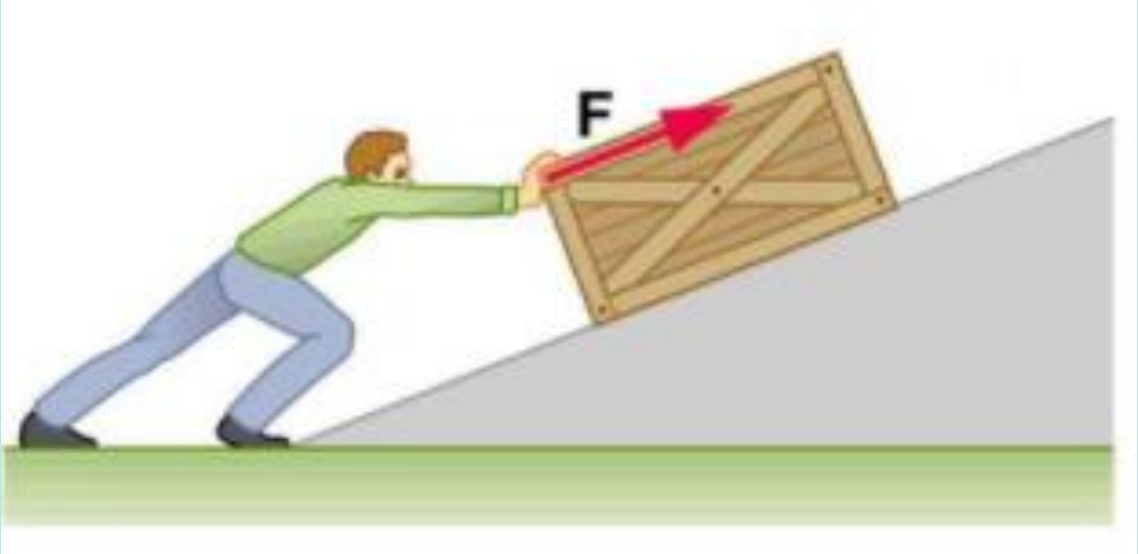
(*does NOT require matter for the transfer*)

Laws of Thermodynamics

- The first law of thermodynamics states that energy is conserved. Energy cannot be created or destroyed, but it can be converted into different forms.
- **The second law of thermodynamics states that thermal energy can flow from colder objects to hotter objects only if work is done on the system.**
- The third law of thermodynamics states that absolute zero cannot be reached.

First Law of Thermodynamics

- Energy is never lost, but transferred or converted to other forms of energy.
- Machines never have 100% efficiency because of friction (some energy is converted to heat).



Second Law of Thermodynamics

- A refrigerator must do work to transfer thermal energy from the cold food compartment to the warm room air.
- The thermal energy is released by coils at the bottom or in the back of the refrigerator.

Third Law of Thermodynamics

The third law of thermodynamics states that absolute zero cannot be reached.

This physicist uses a laser to cool rubidium atoms to 3 billionths of a Kelvin above absolute zero.

What form of energy transfer requires the motion of particles of a fluid?

Conduction … convection … radiation … insulation

QUICK CHECK

What happens in every case in which energy is added to a system?

a. Temperature increases.
b. Work is done on the system.
c. All of the energy can be accounted for as work or heat.
d. An identical amount of energy is removed from the system.

Thermal energy can move from a cooler object to a warmer object when

a. the warmer object is larger.
b. the cooler object has more thermal energy.
c. energy is transferred by radiation.
d. work is done on the system.

What form of energy transfer requires the motion of particles of a fluid?

conduction … **convection** … radiation … insulation

QUICK CHECK

What happens in every case in which energy is added to a system?

a. Temperature increases.
b. Work is done on the system.
c. **All of the energy can be accounted for as work or heat.**
d. An identical amount of energy is removed from the system.

Thermal energy can move from a cooler object to a warmer object when

a. the warmer object is larger.
b. the cooler object has more thermal energy.
c. energy is transferred by radiation.
d. **work is done on the system. (2nd law of thermodynamics)**

Heat Engines

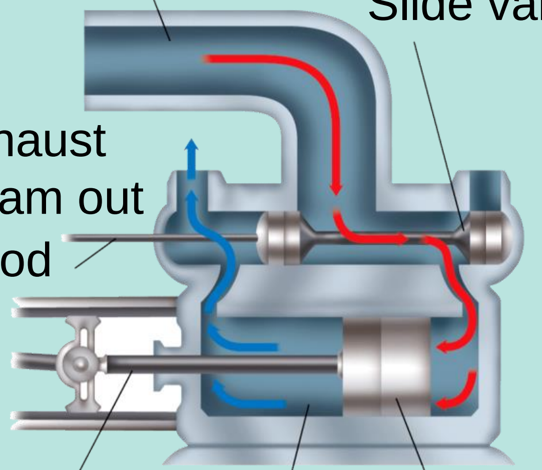
Heat engines played a key role in the development of the modern industrial world.

Steam locomotives were an important early use of the steam engine.

Electric power plants today use steam turbines.

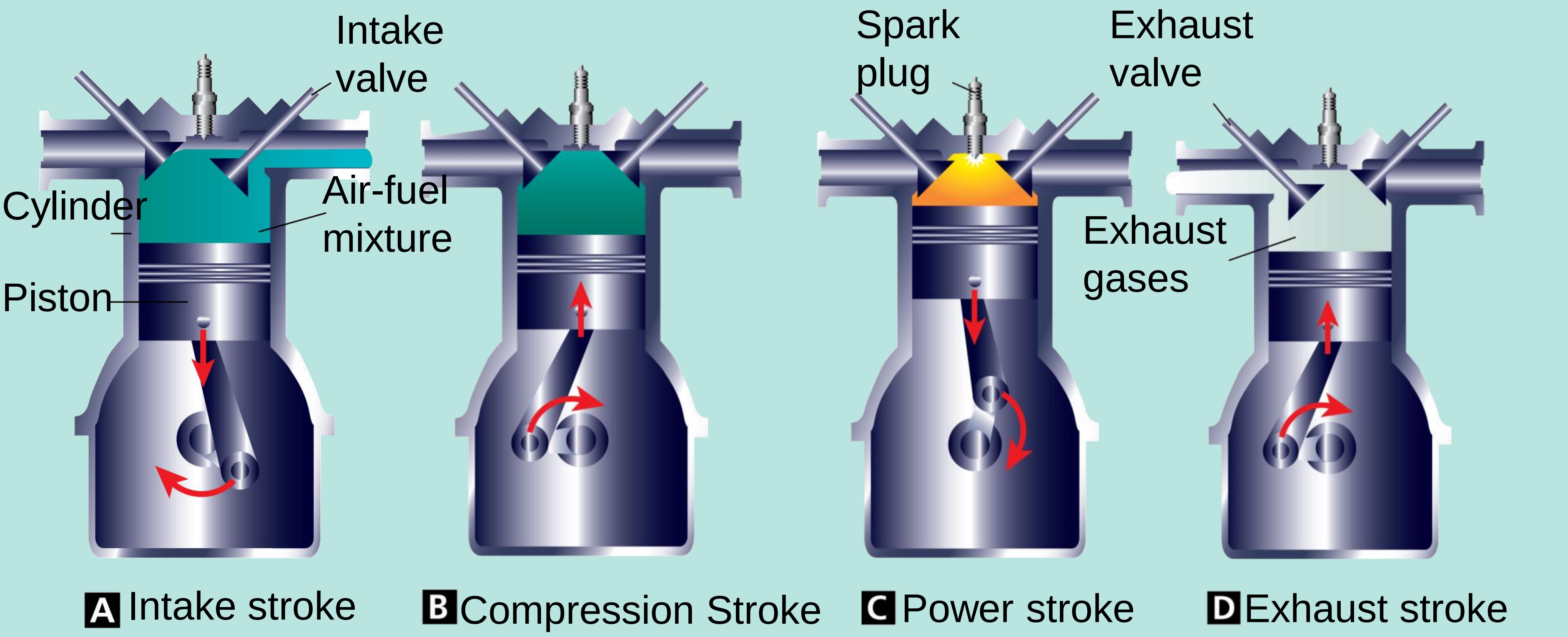
External Combustion Engine

A steam engine is an **external combustion engine**—an engine that burns fuel outside the engine.



Heat Engines

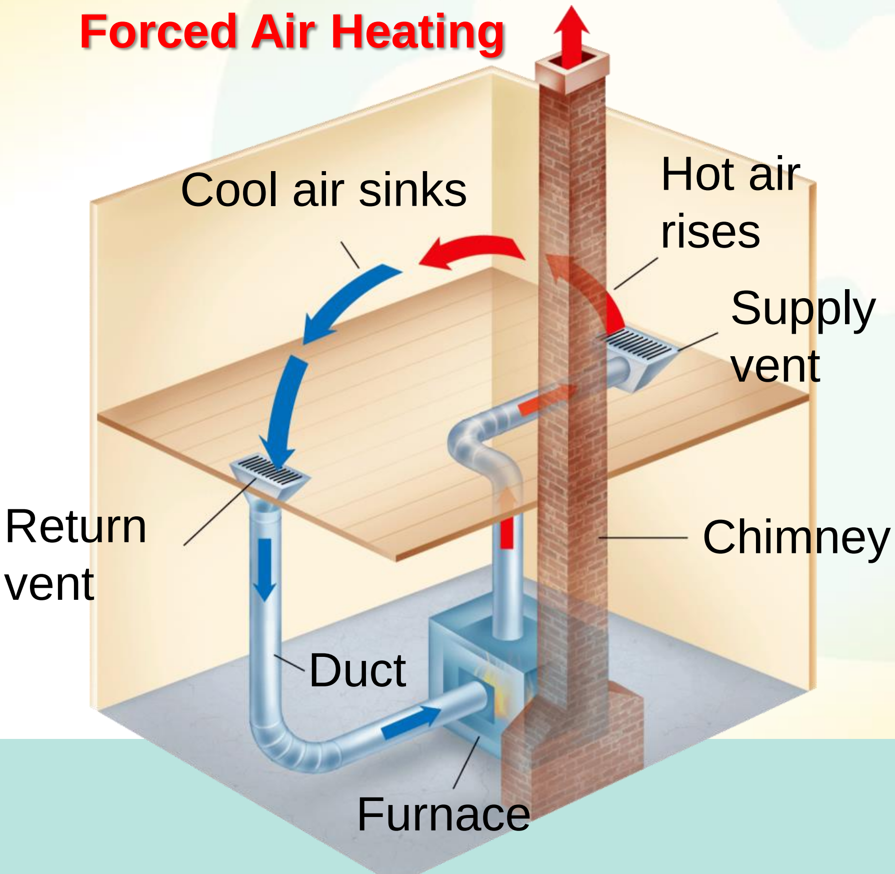
Most cars have a four-stroke **internal combustion engine**. This diagram shows only one of the cylinders during each stroke.



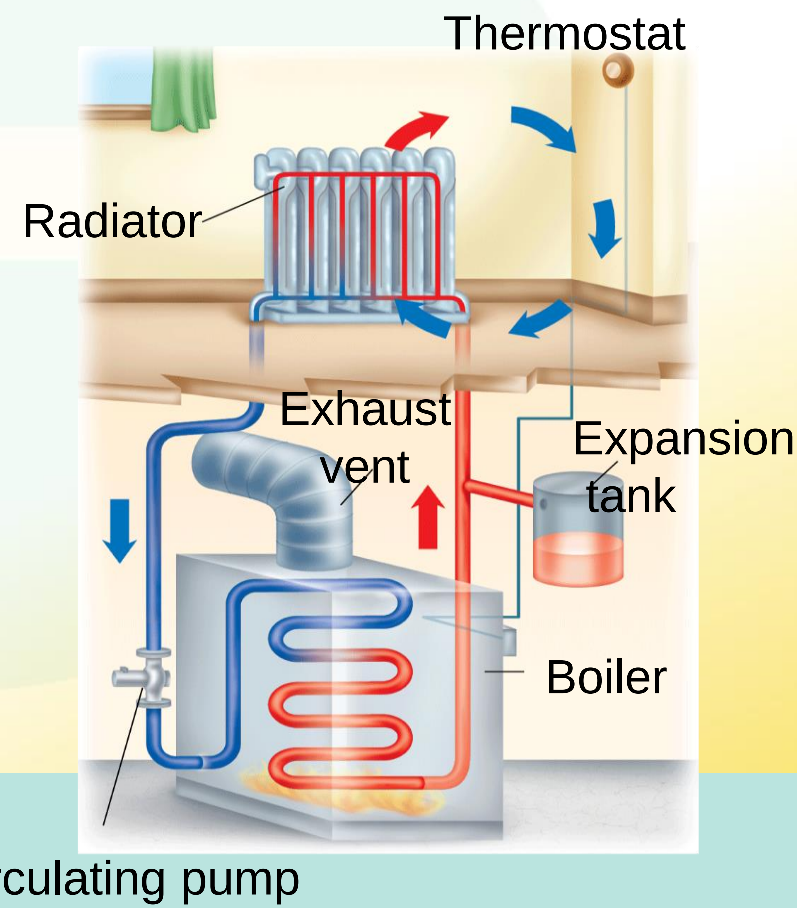
Heating Systems

Most heating systems use convection to distribute thermal energy.

Central heating system
Steam Heating
Baseboard Heating
Forced Air Heating

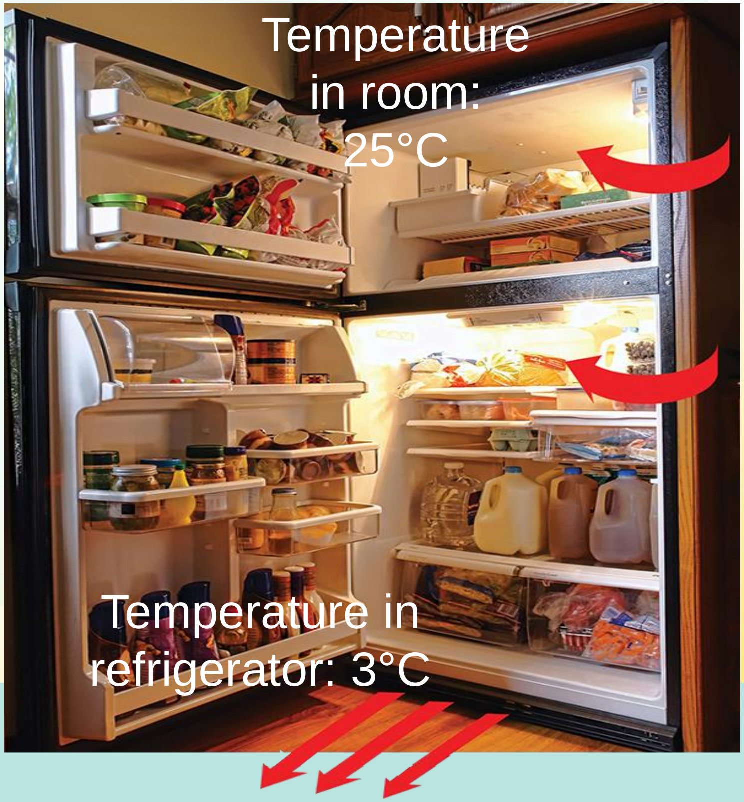


Hot-Water Heating



Cooling Systems

- A **heat pump** is a device that reverses the normal flow of thermal energy.
- **Heat pumps must do work on a refrigerant in order to reverse the normal flow of thermal energy.**



Cooling Systems

A **refrigerant** is a fluid that vaporizes and condenses inside the tubing of a heat pump.

- When the refrigerant absorbs heat, it vaporizes, or turns into a gas.
- When the refrigerant gives off heat, it condenses, or turns back into a liquid.

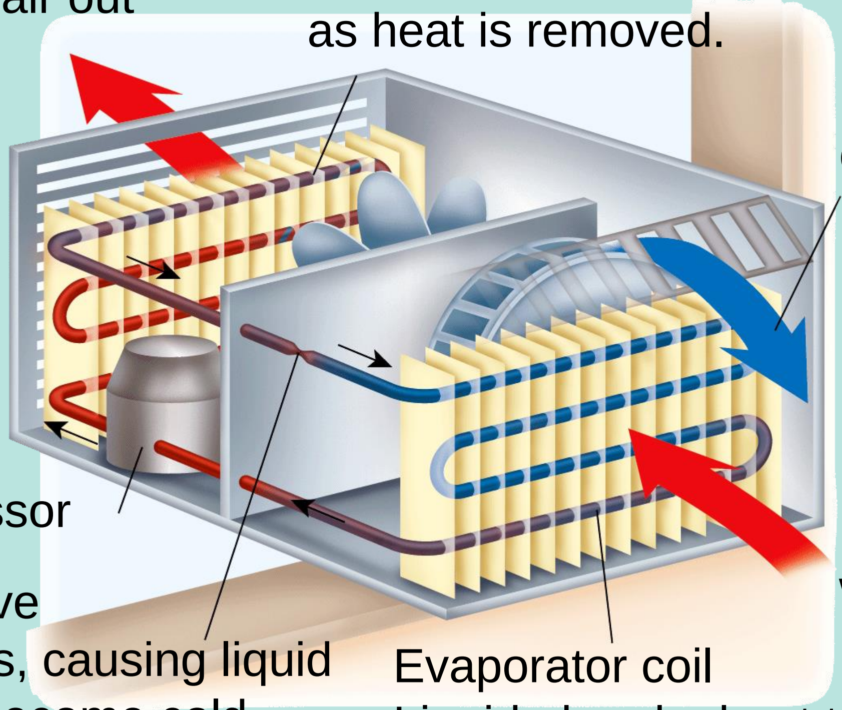
Air Conditioners

- The compressor in a room air conditioner raises the temperature and pressure of the refrigerant, turning it into a hot, high-pressure gas.
- The condenser coil is hotter than the outside air, so heat flows spontaneously to the outside air.
- The refrigerant cools and condenses into a liquid.

Cooling Systems

Air Conditioners

- Outside air is heated as a fan blows it through the condenser coil



Only about one-third of the energy in gasoline is converted to work in an internal combustion engine. The rest of the chemical energy is

a. lost as unused mechanical energy.
b. destroyed by the engine.
c. converted to potential energy.
d. discharged as waste heat.

QUICK CHECK

How is a room heated by an electric baseboard heating system?

a. conduction and convection only
b. conduction and radiation only
c. convection and radiation only
d. conduction, convection, and radiation

____ systems are often used to heat many buildings from a central location.

Only about one-third of the energy in gasoline is converted to work in an internal combustion engine. The rest of the chemical energy is

QUICK CHECK

a. lost as unused mechanical energy.
b. destroyed by the engine.
c. converted to potential energy.
d. discharged as waste heat.

How is a room heated by an electric baseboard heating system?

a. conduction and convection only
b. conduction and radiation only
c. **convection and radiation only**
d. conduction, convection, and radiation

Steam systems are often used to heat many buildings from a central location.

Thermodynamics

First Law of Thermodynamics

The first law of thermodynamics states that energy is conserved.

Energy cannot be created or destroyed, but it can be converted into different forms.

Added energy increases the thermal energy of a system or does work on the system. In either case, energy is conserved.

Thermodynamics

Pushing on the pump does work on the system.

Some of the work is converted into thermal energy, which heats the air in the pump and the tire.

Thermodynamics

Second Law of Thermodynamics

The second law of thermodynamics states that thermal energy can flow from colder objects to hotter objects only if work is done on the system.

Thermodynamics

Thermal energy flows spontaneously only from hotter to colder objects.

- A refrigerator must do work to transfer thermal energy from the cold food compartment to the warm room air.
- The thermal energy is released by coils at the bottom or in the back of the refrigerator.

Thermodynamics

A **heat engine** is any device that converts heat into work.

- The efficiency of a heat engine is always less than 100 percent.
- Thermal energy that is not converted into work is called **waste heat.**
- Waste heat is lost to the surrounding environment.

Thermodynamics

Third Law of Thermodynamics

The third law of thermodynamics states that absolute zero cannot be reached.

Thermodynamics

The efficiency of a heat engine increases with a greater difference between the high temperature inside and the cold temperature outside the engine.

A heat engine could be 100 percent efficient if the cold outside environment were at absolute zero (0 Kelvin). This would violate the third law of thermodynamics.

Assessment Questions

1. What form of energy transfer requires the motion of particles of a fluid?
   a. conduction
   b. convection
   c. radiation
   d. insulation

Assessment Questions

1. What form of energy transfer requires the motion of particles of a fluid?
   a. conduction
   b. convection
   c. radiation
   d. insulation

   ANS: B

Assessment Questions

2. What happens in every case in which energy is added to a system?
   a. Temperature increases.
   b. Work is done on the system.
   c. All of the energy can be accounted for as work or heat.
   d. An identical amount of energy is removed from the system.

Assessment Questions

2. What happens in every case in which energy is added to a system?
   a. Temperature increases.
   b. Work is done on the system.
   c. All of the energy can be accounted for as work or heat.
   d. An identical amount of energy is removed from the system.

   ANS: C

Assessment Questions

3. Thermal energy can move from a cooler object to a warmer object when
   a. the warmer object is larger.
   b. the cooler object has more thermal energy.
   c. energy is transferred by radiation.
   d. work is done on the system.

Assessment Questions

3. Thermal energy can move from a cooler object to a warmer object when
   a. the warmer object is larger.
   b. the cooler object has more thermal energy.
   c. energy is transferred by radiation.
   d. work is done on the system.

   ANS: D

Assessment Questions

4. According to the third law of thermodynamics, it is impossible
   a. to cool an object to absolute zero.
   b. transfer thermal energy from a cooler object to a warmer object.
   c. convert energy from one form to another.
   d. account for all of the energy in a system.

Assessment Questions

4. According to the third law of thermodynamics, it is impossible
    a. to cool an object to absolute zero.
    b. transfer thermal energy from a cooler object to a warmer object.
    c. convert energy from one form to another.
    d. account for all of the energy in a system.

ANS: A

Assessment Questions

1. All metals are good thermal insulators.

   True

   False

Assessment Questions

1. All metals are good thermal insulators.

   True
   False

   ANS: F, conductors