Hewitt/Lyons/Suchocki/Yeh

Conceptual Integrated Science

Chapter 6

HEAT

The Kinetic Theory of Matter

Kinetic Theory of Matter:

Matter is made up of tiny particles (atoms or molecules) that are always in motion.

Thermal Energy:

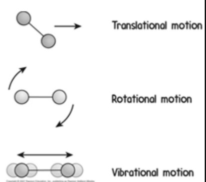
The total energy (kinetic and potential) of the submicroscopic particles that make up a substance.

Temperature

Temperature

is defined as the measure of hotness or coldness of an object (degrees Celsius, or degrees Fahrenheit, or kelvins).

Temperature is related to the average translational kinetic energy per molecule in a substance.



Temperature

A **Thermometer** is an instrument that measures temperature by comparing the expansion and contraction of a liquid as it gains or loses thermal energy.

An infrared thermometer measures temperature by the radiation a substance emits.

Temperature

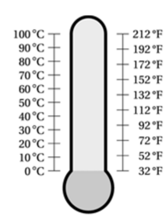
Temperature has no upper limit.

Temperature of a substance is registered on a liquid-base thermometer when the substance has reached thermal equilibrium with the thermometer.

Temperature

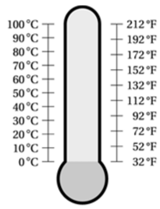
Three different temperature scales differ in zero point and divisions:

- Celsius scale
  freezing point of water: 0°C
  boiling point of water: 100°C
  division: 100 degree units

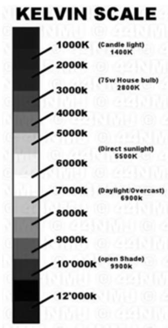


Temperature

- Fahrenheit scale
  freezing point of water: 32° F
  boiling point of water: 212° F
  division: 180 degree units



Temperature

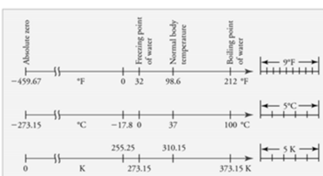


- Kelvin scale (used in scientific research)
  freezing point of water: 273 K
  boiling point of water: 373 K
  division: same-size increments as Celsius scale

Absolute Zero

Absolute zero or zero K is the lowest limit of temperature at –273°C where molecules have lost all available kinetic energy.

A substance cannot get any colder.



What Is Heat?

Heat is defined as a flow of thermal energy due to a temperature difference.

The direction of heat flow is from a *higher-temperature substance to a lower-temperature substance*.

Quantity of Heat

Heat is measured in units of energy—joules or calories.

The **calorie** is defined as the amount of heat needed to raise the temperature of 1 gram of water by 1 Celsius degree.

4.18 joules = 1 calorie

so 4.18 joules of heat will change the temperature of 1 gram of water by 1 Celsius degree.

Quantity of Heat

Energy rating of food and fuel is measured by energy released when they are metabolized.

Kilocalorie: Heat unit for labeling food

One kilocalorie or Calorie (with a capital C) is the heat needed to change the temperature of 1 kilogram of water by 1 degree Celsius.

The Laws of Thermodynamics

First Law of Thermodynamics:

Whenever heat flows into or out of a system, the gain or loss of thermal energy equals the amount of heat transferred.

When thermal energy transfers as heat, it does so without net loss or gain.

The Laws of Thermodynamics

Second Law of Thermodynamics:

Heat never spontaneously flows from a lower-temperature substance to a higher-temperature substance.

Heat can be made to flow the opposite way only when work is done on the system or by adding energy from another source.

The Laws of Thermodynamics

Third Law of Thermodynamics:

No system can reach absolute zero.

Entropy

Entropy is a measure of the disorder of a system.

Whenever energy freely transforms from one form to another, the direction of transformation is toward a state of greater disorder and, ***therefore, toward one of greater entropy***.

The greater the disorder ⇒ the higher the entropy.

Entropy

Second law of thermodynamics — restatement:

Natural systems tend to disperse from concentrated and organized-energy states toward diffuse and disorganized states.

Energy tends to degrade and disperse with time.

The total amount of entropy in any system tends to increase with time.

Specific Heat Capacity

Specific heat capacity is defined as

- the quantity of heat required to change the temperature of 1 unit mass of a substance by 1 degree Celsius.
- thermal inertia that indicates the resistance of a substance to a change in temperature.

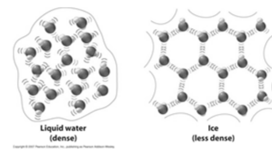
Thermal Expansion

When the temperature of a substance is increased, its particles jiggle faster and move farther apart.

All forms of matter generally expand when heated and contract when cooled.

Expansion of Water

When water becomes ice, it expands. Ice has open-structured crystals resulting from strong bonds at certain angles that increase its volume. This make ice less dense than water.



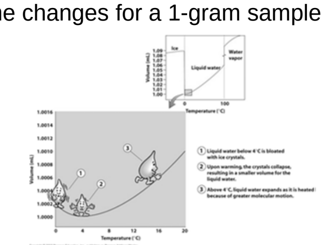
Expansion of Water

Water between 0°C and 4°C does not expand with temperature. As the temperature of 0° water rises, it contracts until it reaches 4°C. Thereafter, it expands.

Water is at its smallest volume and greatest density at **<u>4°C</u>**. When 0°C water freezes to become ice, however, it has its largest volume and lowest density.

Expansion of Water

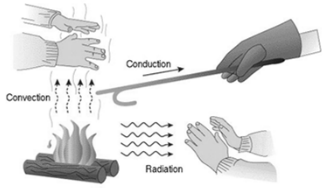
Volume changes for a 1-gram sample of water.



Heat Transfer

Processes of thermal energy transfer:

- conduction
- convection
- radiation



Heat Transfer: Conduction

Conduction occurs predominately in solids where the molecules remain in relatively restricted locations.

Heat Transfer: Conduction

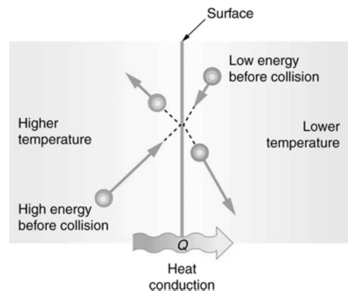
Example of conduction:

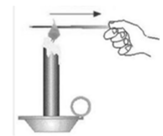
a) When one end of a solid is placed near a heat source, electrons and adjacent molecules gain kinetic energy and start to move faster and farther.

b) They collide with neighboring molecules and transfer some of their kinetic energy to them.

c) These molecules then interact with other neighboring molecules, and thermal energy is gradually transferred along the solid.

Heat Transfer: Conduction





Heat Transfer: Conduction

Good conductors are

- composed of atoms with “loose” outer electrons
- known as poor insulators
- examples—all metals to varying degrees

Poor conductors:

- delay the transfer of heat
- known as good insulators
- examples—wood, wool, straw, paper, cork, Styrofoam, liquid, gases, air, or materials with trapped air

Heat Transfer: Conduction

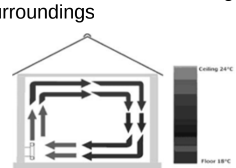
No insulator can totally prevent heat from getting through it.

An insulator reduces the rate at which heat penetrates.

Heat Transfer: Convection

Convection:

- occurs in liquids and gases
- involves the movement of warmer gases or liquids to cooler surroundings

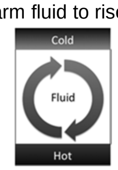


Radiator System and heat gradient.

Heat Transfer: Convection

Two characteristics of convection:

- the ability of flow—carrying thermal energy with the fluid
- the ability of warm fluid to rise in cooler surroundings

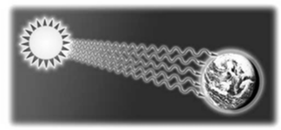


Heat Transfer: Radiation

Radiation is the process by which thermal energy is transferred by electromagnetic waves.

Heat Transfer: Radiation

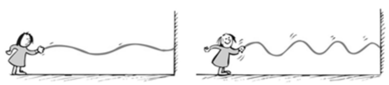
A thermal energy source such as the Sun converts some of its energy into electromagnetic waves. These waves carry energy, which converts back into thermal energy when absorbed by a receiver. The energy source radiates energy, and a receiver absorbs it.



Heat Transfer: Radiation

The wavelength of radiation is related to the frequency of vibration.

Low-frequency vibrations ⇒ long waves
High-frequency vibrations ⇒ short waves



Emission of Radiant Energy

Emission of Radiant Energy

All substances at any temperature above absolute zero emit radiant energy.

Average frequency ($\bar{f}$) of radiant energy is directly proportional to the absolute temperature T of the emitter:

$$\bar{f} \sim T$$

Absorption of Radiant Energy

The ability to absorb and radiate thermal energy is indicated by the color of the material.

Good absorbers and good emitters are dark in color.

Poor absorbers and poor emitters are reflective or light in color.

Absorption of Radiant Energy

The surface of any material both absorbs and emits radiant energy.

When a surface absorbs more energy than it emits, it is a net absorber, and temperature rises.

When a surface emits more energy than it absorbs, it is a net emitter, and temperature falls.

Absorption of Radiant Energy

Whether a surface is a net absorber or net emitter depends on whether its temperature is above or below that of its surroundings.

A surface hotter than its surroundings will be a net emitter and will cool.

A surface colder than its surroundings will be a net absorber and will warm.