PowerPoint Lectures
to accompany
Physical Science, 8e

Chapter 4
Heat and Temperature

New Symbols for this Chapter

T-Temperature
Q-Heat
C-Heat capacity

$$T_F = \frac{9}{5}T_C + 32°$$

$$T_c = \frac{5}{9}\left(T_F - 32°\right)$$

$$T_K = T_C + 273$$

$$Q = mc\Delta T$$

Core Concepts

A relationship exists between heat, temperature, and the motion and position of molecules.

Overview

Thermodynamics
- Study of macroscopic processes involving heat, mechanical and other forms of energy
- Applications - systems with energy inputs and outputs: heat engines, heat pumps, refrigerators, …
- Based upon but not concerned with microscopic details

Approach here
- Discuss underlying microscopic processes
- Relate microscopic and macroscopic views
- Study the laws of thermodynamics

Kinetic Molecular Theory

- Collective hypotheses about the particulate nature of matter and the surrounding space
- Greeks - earliest written ideas on atoms
- Current view
  - Matter comprised of microscopic particles - atoms
  - Atoms combine to form molecules
  - Many macroscopic phenomena can be traced to interactions on this level.

Atoms

Greek philosopher Democritus called these smallest pieces **atomos** the Greek word for indivisible. Today we call this smallest piece of an element an **Atom** but they are not indivisible.

The Parts of an Atom

It turns out that an atom is made up of three smaller particles

In the center of the atom (called the **Nucleus**) there are two types of particles **Protons** and **Neutrons**

Quarks

Protons and Neutrons are themselves made up of even smaller particles called **Quarks**. Each Proton and Neutron is composed of 3 Quarks.

Molecules

- Chemical elements - defined by each unique type of atom
- Compounds - pure substances made up of two or more atoms chemically bonded
- Molecules
  – Smallest unit retaining the properties of a compound
  – Shorthand here: "molecules" can stand for either atoms (monatomic molecules) or molecules

Molecular interactions

- Usually attractive, causing materials to cling together
- Cohesion - attractive forces between like molecules
- Adhesion
  – Attractive forces between unlike molecules
  – Water wetting skin
  – Glue mechanism; adhesives
- Interactions can also be repulsive
  – Water beading on wax

Phases of Matter - Solids

- Definite shape and volume
- Rigid 3-D structure
- Atoms/molecules bonded in place
- Allowed motions restricted to vibration in place only

Phases of Matter - Liquids

- Definite volume, indefinite shape
- Only weak cohesive bonds between component molecules
- Constituent molecules mostly in contact
- Allowed motions
  - Vibration
  - Rotation
  - Limited translation

Phases of Matter - Gases

- Indefinite volume and shape
- Molecules mostly not in contact
- Allowed motions
  - Vibration and rotation (molecules with more than one atom)
  - Translation on random, mostly free paths

Temperature

- A measure of the internal energy of an object
- Thermometers
  - Used to measure temperature
  - Rely on thermometric properties
  - Example: bimetallic strips and thermostats

Temperature Scales

- Defined with respect to various reference points
- Fahrenheit
- Celsius
- Kelvin

Temperature Scales

- Conversion formulas
  - Fahrenheit to Celsius
  - Celsius to Fahrenheit
  - Celsius to Kelvin

$$T_F = \frac{9}{5}T_C + 32°$$

$$T_C = \frac{5}{9}(T_F - 32°)$$

$$T_K = T_C + 273$$

Example 1 (Parallel Exercise Group B #1)

1) The Fahrenheit temperature reading is 98° on a hot summer day. What is this reading on the Kevin scale?

Heat

- A form of energy transfer between two objects
- External energy - total potential and kinetic energy of an everyday-sized object
- Internal energy - total kinetic energy of the molecules in that object
- External can be transferred to internal, resulting in a temperature increase

Heat versus Temperature

Temperature

- A measure of hotness or coldness of an object
- Based on average molecular kinetic energy

Heat

- Based on total internal energy of molecules
- Doubling amount at same temperature doubles heat

Heat

Definition
- A measure of the internal energy that has been absorbed or transferred from another object
- Two related processes
  - "Heating" = increasing internal energy
  - "Cooling" = decreasing internal energy

Heating methods
1. Temperature difference: Energy always moves from higher temperature regions to lower temperature regions
2. Energy-form conversion: Transfer of heat by doing work

Measures of Heat

Metric units
- calorie (cal) - energy needed to raise temperature of 1 g of water 1 degree Celsius
- kilocalorie (kcal, Calorie, Cal) - energy needed to raise temperature of 1 kg of water 1 degree Celsius

English system
- British thermal unit (BTU) - energy needed to raise the temperature of 1 lb of water 1 degree Fahrenheit

Mechanical equivalence
- 4.184 J = 1 cal

Specific Heat

The **Specific Heat** is a constant which tells us the amount of heat needed to change the temperature of one kilogram of a substance by 1°C.

Different materials will have different specific heats.

$$Q = mc\Delta T$$

Example 2 (Parallel Exercise Group B #6)

2) A 50.0 g silver spoon at 20°C is placed in a cup of coffee at 90°C. How much heat does the spoon absorb from the coffee to reach a temperature of 89°C

Heat Flow

Three mechanisms for heat transfer due to a temperature difference

1. Conduction
2. Convection
3. Radiation

Natural flow is always from higher temperature regions to cooler ones

Conduction

- Heat flowing through matter
- Mechanism
  - Hotter atoms collide with cooler ones, transferring some of their energy
  - Direct physical contact required; cannot occur in a vacuum
- Poor conductors = insulators (Styrofoam, wool, air…)

Convection

- Energy transfer through the bulk motion of hot material
- Examples
  - Space heater
  - Gas furnace (forced)
- Natural convection mechanism - "hot air rises"

Radiation

- Radiant energy - energy associated with electromagnetic waves
- Can operate through a vacuum
- All objects emit and absorb radiation
- Temperature determines
  - Emission rate
  - Intensity of emitted light
  - Type of radiation given off
- Temperature determined by balance between rates of emission and absorption
  - Example: Global warming

Energy, Heat, and Molecular Theory

Two responses of matter to heat

1. Temperature increase within a given phase
   - Heat goes mostly into internal kinetic energy
   - Specific heat

Energy, Heat, and Molecular Theory

Two responses of matter to heat

2. Phase change at constant temperature
   - Related to changes in internal potential energy
   - Latent heat

Phase Changes

	Solid/liquid	Liquid/gas	Solid/gas
Latent heat	Fusion	Vaporization	Sublimation
Temperature (Direction ->)	Melting point	Boiling point	Sublimation
Temperature (Direction <-)	Freezing point	Condensation point	Sublimation

Evaporation and Condensation

- Individual molecules can change phase any time
- Evaporation:
  - Energy required to overcome phase cohesion
  - Higher energy molecules near the surface can then escape
- Condensation:
  - Gas molecules near the surface lose KE to liquid molecules and merge

A song about Evaporation

Since the molecules that make up a fluid are moving in random directions there will always be some moving upwards.

If these upwardly mobile molecules are moving fast enough they can leave the fluid behind.
This is **Evaporation**.

Thermodynamics

- The study of heat and its relationship to mechanical and other forms of energy
- Thermodynamic analysis includes
  - System
  - Surroundings (everything else)
  - Internal energy (the total internal potential and kinetic energy of the object in question)
- Energy conversion
  - Friction - converts mechanical energy into heat
  - Heat engines - devices converting heat into mechanical energy
  - Other applications: heat pumps, refrigerators, organisms, hurricanes, stars, black holes … virtually any system with energy inputs and outputs

The First Law of Thermodynamics

- Conservation of energy-

The energy you get out of a device will never be greater then the energy you put in.

- Components
  - Internal energy
  - Heat
  - Work
- Stated in terms of changes in internal energy
- Application: heat engines

The Second Law of Thermodynamics

Equivalent statements:

- No process can solely convert a quantity of heat to work (heat engines)
- Heat never flows spontaneously from a cold object to a hot object (refrigerators)
- Natural processes tend toward a greater state of disorder (entropy)

Two reference scales:

1. An object's external energy
   - Energy of global, coherent motion
   - Associated with work
2. An object's internal energy
   - Energy of microscopic, chaotic, incoherent motion
   - Associated with heat

Refrigerators

A **Refrigerator** is a heat engine in reverse where mechanical energy is used to "pump" thermal energy from a low temperature reservoir (the inside of the refrigerator) to a high temperature reservoir (the back of the refrigerator).

Second Law, First Statement

Conservation of energy, heat engine

- Input energy = output energy

Efficiency of a heat engine

- Work done per unit input energy

Second law:

- Efficiency cannot equal 1
- Some energy always degraded

Second Law, Second Statement

Conservation of energy, heat pump

- Energy arriving in high temperature region = energy from low temperature region + work needed to move it
- Upgrading of energy by heat pump accompanied by greater degradation of energy elsewhere

Second Law, Third Statement

- Real process = irreversible process
- Measure of disorder = entropy

Second law, in these terms:

- The total entropy of the Universe continually increases

- Natural processes degrade coherent, useful energy
  - Available energy of the Universe diminishing
  - Eventually: “heat death” of the Universe
- Direction of natural processes
  - Toward more disorder
  - Spilled milk will never “unspill” back into the glass!

Entropy

Entropy is what we use to measure the disorder of an object.

The more disorder an object has the greater the object’s entropy is.

When you heat an object you are increasing the disorder of the object and also increasing the objects entropy.