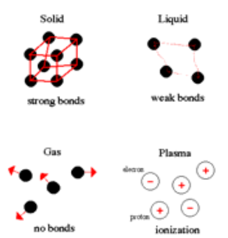
Thermal Concepts

Atomic Theory of Matter

- John Dalton (in 1805) determined that
  - each chemical element is composed of a unique type of atom
  - atoms differed by their masses
  - compounds are made of molecules, and that molecules are composed of atoms in definite proportions

States of Matter

- Matter exists in four states: solid, liquid, gas and plasma
- The state of matter is determined by the strength of the bonds between the atoms that makes up matter



abyss.uoregon.edu/~js/21st_century_science/lectures/lec05.html

Temperature

- In every day life, temperature is a measure of how hot or cold something is
- Temperature is explained in atomic theory as the motion of the atoms
  - Temperature is proportional to the random kinetic energy of the molecules

Temperature Scale

- A temperature scale is created by setting arbitrary values to two readily reproducible temperatures
  - Daniel Gabriel Fahrenheit (1724)
    - freezing point water = 32, boiling point water = 212
  - Anders Celsius (1747)
    - freezing point water = 100, boiling point water = 0
    - (points were switched a year later)

Absolute Temperature

- William Thomson, 1st Baron Kelvin (Irish physicist and engineer), stated in a paper in 1848 that there needed to be a scale where the coldest temperature was zero
  - Kelvin (or absolute temperate) scale
    - Starts at 0, and has increments equal to Celsius degrees

$$T/K = T/°C + 273$$

Heat

- When two objects at different temperatures are put in contact, heat flows spontaneously from the hotter one to the colder one
- Given enough time the temperature of the objects will be come the same (thermal equilibrium) and there will be no heat flow between them

- Heat is the transfer of energy from one body to another as a result of a difference in temperature
- Heat only moves in one direction
  - From a hotter body to a colder one

Internal Energy

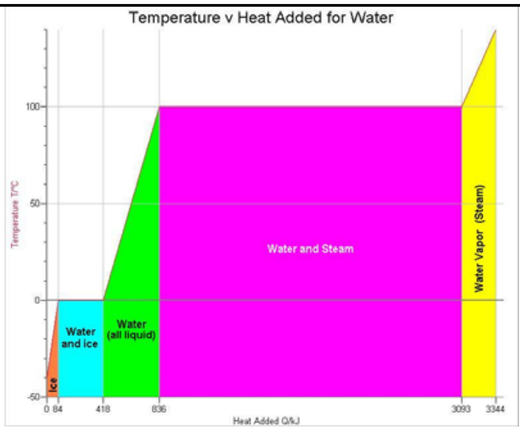
- The particles in a substance are in constant motion (kinetic energy)
- There are also forces between the particles (potential energy)
- The total random kinetic energy of the particles of a substance plus the total inter-particle potential energy of the particles

- If heat flows into an object, work is done on the particles changing the internal energy
- Temperature, in kelvins, is directly proportional to the average kinetic energy of the particles

Phase Changes

- During a phase change, the energy added or removed changes the potential energy of the particles
- Supplied heat does work on the particles separating them (breaking the bonds)
- The temperature does not change during a phase change

Heat Added	**Heat Removed**
Melting (solid to liquid)	Freezing (liquid to solid)
Vaporization (liquid to gas)	Condensation (gas to liquid)
Sublimation (solid to gas)	Deposition (gas to solid)



Specific Heat Capacity

- The energy required to increase the temperature of a unit mass of a body by one kelvin
- Symbol: *c*
- The amount of heat necessary to increase the temperature of a mass, *m*, by ΔT is given by

$$\Delta Q = mc\Delta T$$

Note: ΔT is always positive since heat always flows from hot to cold

Example 1

- If 200cm^3 of tea at 95ºC is poured into a 150g glass cup initially at 25ºC, what will be the final temperature, T, of the mixture when equilibrium is reached, assuming no heat flows to the surroundings.
- c_{water} = 4186 J kg^{-1} ºC^{-1}
- c_{glass} = 840 J kg^{-1} ºC^{-1}

$$Q_{\text{lost by tea}} = Q_{\text{gained by cup}}$$

$$m_{\text{tea}} c_{\text{tea}} \Delta T_{\text{tea}} = m_{\text{cup}} c_{\text{cup}} \Delta T_{\text{cup}}$$

$$m_{\text{tea}} = \rho V = (1.0 \times 10^{-6}\ \text{kgm}^{-3})(200 \times 10^{-6}\ \text{m}^3) = 0.20\ \text{kg}$$

$$(0.20\text{kg})(4186\text{Jkg}^{-1}{}^{\circ}\text{C}^{-1})(95{}^{\circ}\text{C} - T) = (0.150\text{kg})(840\text{Jkg}^{-1}{}^{\circ}\text{C}^{-1})(T - 25{}^{\circ}\text{C})$$

$$T = 86\ {}^{\circ}\text{C}$$

Example 2

- A 0.150kg sample of an unknown metal is heated to 540ºC. It is then quickly place in 400g of water at 10ºC, which is contained in a 200g aluminum calorimeter cup. The final temperature of the mixture is 30.5ºC. Calculate the specific heat of the unknown metal.
- $c_{\text{aluminum}} = 900\ \text{Jkg}^{-1}{}^{\circ}\text{C}^{-1}$

$$Q_{\substack{\text{lost by}\\\text{sample}}} = Q_{\substack{\text{gained by}\\\text{water}}} + Q_{\substack{\text{gained by}\\\text{calorimeter cup}}}$$

$$m_{\text{s}} c_{\text{s}} \Delta T_{\text{s}} = m_{\text{w}} c_{\text{w}} \Delta T_{\text{w}} + m_{\text{cal}} c_{\text{cal}} \Delta T_{\text{cal}}$$

$$c_{\text{s}} = \frac{m_{\text{w}} c_{\text{w}} \Delta T_{\text{w}} + m_{\text{cal}} c_{\text{cal}} \Delta T_{\text{cal}}}{m_{\text{s}} \Delta T_{\text{s}}}$$

$$c_{\text{s}} = \frac{(0.4\,\text{kg})(4186\,\text{Jkg}^{-1}{}^{\circ}\text{C}^{-1})(30.5{}^{\circ}\text{C} - 10{}^{\circ}\text{C}) + (0.2\,\text{kg})(900\,\text{Jkg}^{-1}{}^{\circ}\text{C}^{-1})(30.5{}^{\circ}\text{C} - 10{}^{\circ}\text{C})}{(0.150\,\text{kg})(540{}^{\circ}\text{C} - 30.5{}^{\circ}\text{C})}$$

$$c_{\text{s}} = 500\ \text{Jkg}^{-1}{}^{\circ}\text{C}^{-1}$$

Specific Latent Heat

- The amount of energy required to change the phase of a unit mass at constant temperature
- Symbol: L
- The energy required to change the phase of a mass m is given by

$$Q = mL$$

- The specific latent heat of vaporization (vaporizing or condensing), L_v, is always greater than the specific latent heat of fusion (melting or freezing), L_f
  - The increase in separation of the particles is much larger when going from a liquid to a gas than from a solid to a liquid
  - Therefore, more work is required to separate the particles
  - So, more energy is needed

Example

- You add ice cubes to cool 355 ml of hot coffee (85 °C) to cool it down to 55 °C. What mass of ice cubes at -18.5 °C should be added?
  - Assume there is no thermal energy lost to the surroundings or to the coffee cup.
  - c_{water} = 4186 $Jkg^{-1}°C^{-1}$
  - c_{ice} = 2050 $Jkg^{-1}°C^{-1}$
  - $L_{f\ water}$ = 333 $kJkg^{-1}$

$$Q_{\text{lost by coffee}} = Q_{\text{gained by ice}}$$

$$m_c c_c \Delta T_c = m_i c_i \Delta T_i + m_i L_f + m_w c_w \Delta T_w$$

Coffee is essentially water: m_c = 0.355 kg

The mass of solid ice is the same as the amount of liquid(melted) ice

$$m_i = \frac{m_c c_c \Delta T_c}{c_i \Delta T_i + L_f + c_w \Delta T_w}$$

$$m_i = 0.074\ kg$$