# Chemistry – Chapter 11

Thermochemistry

Goals : To gain an understanding of :

1. Energy changes in chemical reactions.

NOTES:

Heat energy is the sum of the kinetic energy of the particles of a substance, whereas temperature is the average kinetic energy of the particles of a substance. To illustrate this imagine the two blocks of brass below, one is 2.0 kg, the other is 0.5 kg, and both are at 300.0 K. They both have the same temperature (average kinetic energy), but the larger block, due to a greater number of particles, has a greater total kinetic energy (more heat energy).

2.0 kg   0.5 kg
300.0 K   300.0 K
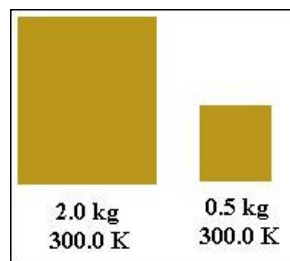
Thermochemistry is the study of energy changes in chemical reactions.

Energy is the capacity to do work or to transfer heat energy. Kinetic energy is the energy of motion ex. heat energy - the energy of the moving particles of a substance) and potential energy is energy that is stored (ex. chemical energy - the energy stored in the chemical bonds of a substance).

Heat is the total kinetic energy of the particles of a substance or object while temperature is the average kinetic energy of the particles of a substance. To understand the difference think about getting splashed by a very small drop of boiling water. It is hot, but doesn't do any real damage to your skin. Compare that to getting splashed by a cup of boiling water - same temperature as the drop of boiling water, but with a lot more heat energy

Exothermic reactions are reactions which release heat energy (heat is produced) and can be shown as :

$$A + B \rightarrow C + 2.2 \text{ kJ}$$

where the heat energy is shown as 2.2 kJ.

Endothermic reactions absorb heat energy and can be shown as :

$$A + 2.2 \text{ kJ} \rightarrow B + C$$

Two units of heat energy :

 - joule (J) - SI unit of heat energy
 - calorie (cal) = the amount of heat needed to raise 1 gram of water 1 Celsius degree. (A food calorie (Cal) is equal to 1,000 calories (or 1 kcal).

 Heat capacity - the amount of heat needed to raise an object's temperature by one Celsius degree. The heat capacity of an object depends on its mass and the chemical composition of the object.

Specific heat capacity (or just "specific heat") - the amount of heat needed to raise one gram of a substance by one Celsius degree. Since the mass is specified specific heat depends only on the chemical composition and is therefore a more useful quantity.

Heat (Q) can be calculated by the following equation : $Q = m \cdot c \cdot \triangle T$, where m is mass (in g), c is the specific heat of the substance (units are cal/g · °C), and $\triangle T$ is the change in temperature.

Example : How much heat is required to raise 20.0 g of iron from 22.0 °C to 44.0 °C? (c for iron = 0.11 cal/g · °C)

$Q = m \cdot c \cdot \triangle T = (20.0g)(0.11 \text{ cal/g} \cdot °C) (44.0 °C - 22.0 °C) = 48$ cal

Specific heat can be calculated by the following equation : $c = Q/(m \times \triangle T)$ where c = specific heat, Q = heat energy, m = mass and T = temperature. The specific heat of water equals 1.00 cal/(g · °C).

Example : What is the specific heat of aluminum (in joules) if it takes 250.0 joules to raise 10.0 grams from 22.0 °C to 49.7 °C ?

$c = Q/(m \times \triangle T) = 250.0$ J/ $(10.0g \times 27.7 °C) = .903$ J/g · °C

To calculate change in temperature use the above equations rearranged to solve for $\triangle T$.

Thermochemical equations are chemical equations which show heat energy being absorbed or released.

The standard conditions for thermochemical equations are 25 °C and 1 atm of pressure.

Calorimetry is the measuring of changes in heat energy in units of calories. Heat is the total kinetic energy of the particles of a substance. This cannot be measured directly, but its effects on the temperature of water can be observed and measured. A calorie is the amount of heat energy it takes to raise 1 gram of water one °C. A substance is put into a calorimeter and allowed to undergo an energy change (in the case of foods they are usually burned to release heat energy) and the energy that is released or absorbed changes the temperature of the water in the calorimeter and the number of calories can then be calculated by the equation :

$$Q = (m)(c)(\triangle T)$$

where m = mass of water, c = the specific heat of water (1.00 cal/g x °C), and $\triangle T$ = change in temperature

For example if 5.0 g of cocoa puff cereal were put into a calorimeter and burned completely and the surrounding 15.0 g of water were raised 20.0 °C we can then calculate the number of calories per gram of cocoa puff cereal : (values are not accurate -just made up for purposes of illustration)

Calculation of total number of calories :

$$Q = 15.0\cancel{g} \left(\frac{1.00 \text{ cal}}{\cancel{g} \times \cancel{°C}} \right) 20.0 °\cancel{C} = 3.00 \times 10^2 \text{cal}$$

Calculation of calories per gram of cocoa puff cereal :

$$\left(\frac{3.00 \times 10^2 \text{cal}}{5.0 \text{ g}} \right) = 6.0 \times 10^1 \text{cal/g}$$

Enthalpy is a measure of the heat content of a substance at a given temperature and pressure. The symbol for enthalpy is H and for change in enthalpy : $\triangle$ (reads "delta H").

The enthalpy of a substance is measure by the amount of energy absorbed or released during a chemical reaction. The standard conditions for measuring enthalpy are 25 °C and 1 atm of pressure.

The heat of reaction is the amount of heat energy absorbed or released by a chemical reaction and is equivalent to $\triangle H$.

Exothermic reactions always have a negative $\triangle H$ because the enthalpy of the products is less than that of the reactants since heat is being released.

Endothermic reactions always have a positive △H because the enthalpy of the products is greater than that of the reactants since heat is being absorbed.

Heat of combustion is the amount of heat released when one mole of a substance is completely burned.

A phase change is a change from one state of matter (solid, liquid or gas) to another. For pure substances the temperature remains constant as phase change occurs. The temperature will change while a substance is in a particular phase. For a phase change to occur or for a substance in a particular phase to change to have a change of temperature energy must be added or taken away. This can be observed in the following graph showing the phase changes of pure water at one atm of pressure. During melting and freezing the temperature is constant at 0 °C (at 100 °C for vaporization and condensation) but energy is being added or taken away. During the liquid phase both temperature and energy change from point to point along the line.
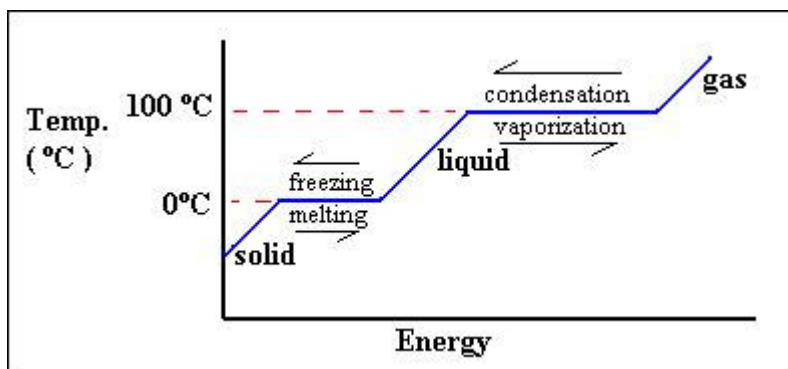
Sublimation is the process by which a solid substance changes directly into a gaseous substance without going through the liquid phase. the most common example of sublimation is dry ice. Dry ice is solid (frozen) carbon dioxide which sublimes into gaseous carbon dioxide.

- Heat of fusion - the heat energy required to melt one gram of a solid at its melting point.
- Heat of solidification - the heat energy lost as one gram of a liquid freezes to a solid at its freezing point.
- Heat of vaporization - the heat energy required to vaporize one gram of a liquid at its normal boiling point.
- Heat of condensation - the heat energy released when one gram of a liquid forms from its vapor at its normal boiling point.

To calculate the amount of heat of fusion (solidification, vaporization or condensation) multiply the mass of the substance by its value. Here are two examples :

Ex. 1. How much heat will be released when 12.0 g of water condenses on an object at 100.0 °C ? (ht of condensation = 540.0 cal/g)

$$12.0 \text{ g} \left(\frac{540.0 \text{ cal}}{\text{g}} \right) = 6\,480 \text{ cal}$$

Ex. 2. How much heat is needed to melt 500.0 g of ice at 0 °C ? (ht of fusion = 80.0 cal/g)

$$500.0 \text{ g} \left(\frac{80.0 \text{ cal}}{\text{g}} \right) = 4.00 \times 10^4 \text{ cal}$$

Phase Changes

    Evaporation (liquid → gas)   (below the boiling point)
    Vaporization (liquid → gas) (at the boiling point)
    Boiling (liquid → gas)
    Condensation (gas → liquid)
    Melting (fusion) (solid → liquid)
    Freezing (or Solidification) (liquid → solid)
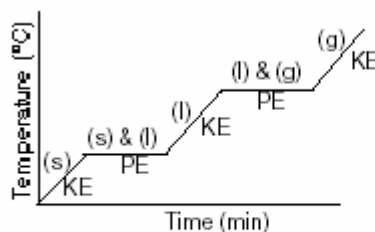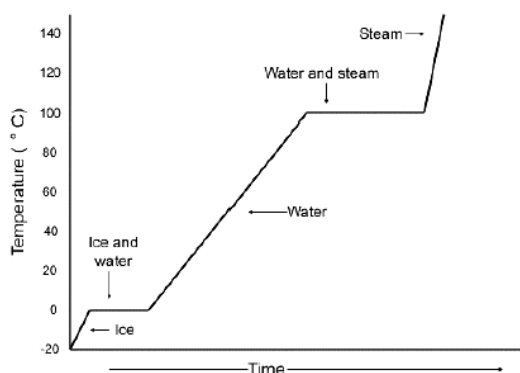   Sublimation (solid → gas)
    Deposition (gas → solid)
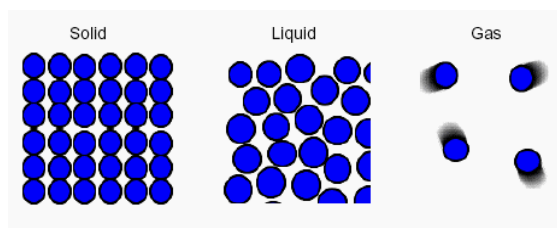
NRG is REQUIRED	NRG is RELEASED
solid → liquid melting or fusion	liquid → solid freezing
liquid → gas vaporization evaporation or boiling	gas → liquid condensation
solid → gas sublimation	gas → solid solidification

Changes of State
  1. Heating curve

KE = kinetic energy changes which are times when the heat energy speeds up the molecules.

PE = potential energy changes which are times when the heat energy separates the molecules from solid to liquid or liquid to gas.

a. Note that the temperature remains constant during a phase change
b. Chemical bonds are being broken or formed during phase changes

Thermochemistry - The study of the changes in heat energy that accompany chemical reactions and physical changes

The Nature of Energy
  A. Definition
     1. Energy is the capacity to do work (or to produce heat*)
       a. Work is a force acting over a distance (moving an object)
       b. *Heat is actually a form of energy.
         (1) chemicals may store potential energy in their bonds that can be released as heat energy
  B. Law of Conservation of Energy
     1. Energy can be converted from one form to another, but cannot be created or destroyed
       a. Potential energy (chemical potential energy)
         (1) energy due to the position or composition of chemical bonds in a compound
       b. Kinetic energy
         (1) energy due to the motion of molecules

$$KE = \frac{1}{2}m v^2$$

Temperature vs Heat (or Heat Energy)

Temperature is a measure of the average kinetic energy of the particles in a sample of matter. It is the sum total of the kinetic energies of the particles in a sample of matter. Heat flows spontaneously from matter at higher temperatures to matter at lower temperatures Heat is usually measured in joules, J. Heat cannot be measured directly, but is measured by temperature changes when heat energy is transferred from one object to another

Unit of Heat:

$$1 \ J = N \cdot m = \frac{kg \cdot m^2}{s^2}$$

C. Heat and Temperature
   1. Temperature reflects the random motion of particles in a substance
   2. Temperature indicates the direction in which heat energy will flow (heat flows from high to low temperatures)
   3. Heat is a measure of energy content (heat is what flows when objects of different temperatures come in contact)
   4. Heat is what is transferred during a temperature change
D. Chemical Energy
   1. Exothermic reactions
      a. Reactions that give off energy as they progress
      b. Some of the potential energy stored in the chemical bonds is converted to thermal energy (random KE) through heat transfer.
      c. Products are generally more stable (stronger bonds) than reactants (products have lower PE than reactants)
   2. Endothermic reactions
      a. Reactions in which energy is absorbed from the surroundings
      b. Energy flows into the system to increase the potential energy of the system
      c. Products are generally less stable (weaker bonds) than the reactants (products have greater PE than reactants)
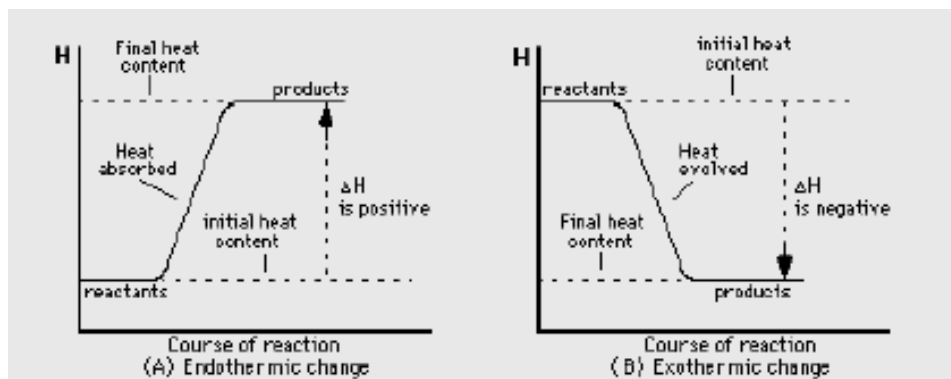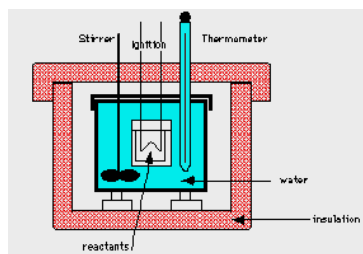

Heat Calculations

Heat and Temperature
   A. Calorimeter
      1. Heat given off or absorbed is determined from the temperature of a known mass of water

Heat Capacity and Specific Heat
   A. Specific Heat
      1. The amount of heat required to raise the temperature of one gram of substance by one Celsius degree (1°C) or
         one kelvin (1 K)
      2. Every substance has a different specific heat capacity depending on the arrangement and nature of its chemical
         bonds.
      3. Specific Heat symbol = *(c)* sometimes *(cp)*   Units of specific heat = J/g°C

Heat Calculations
    A. change in heat = mass x specific heat capacity x change in temperature
          1. $\Delta H = mc\Delta T$
          2.   Units:
                 a.   Units of heat = J
                 b.   Units of mass = g
                 c.   Units of specific heat = J/g°C
                 d.   Units of temperature = °C
          3. Memorize the specific heat of water = 4.184 J/g°C

Heat of Reaction
   A. Heat of Reaction
      1. Quantity of heat released or absorbed during a chemical rxn
   B. Thermochemical Equation
      1. An equation that includes the quantity of heat released or absorbed during the reaction as written
$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g) + 483.6 \text{ kJ}$$
   C. Heat Change (ΔH)
      1. The amount of heat absorbed or lost by a system during a process
        a. $\Delta H$is positive for an endothermic rxn (heat is written as a reactant in the chemical equation)
         (1) Heat content of products is greater than the heat content of the reactants
        b. ΔH is negative for an exothermic rxn (heat is written as a product in the chemical equation)
         (1) Heat content of the reactants is greater than the heat content of the products
      2. ΔH is proportional to the number of moles of reactant or product in the chemical equation