Unit 11 Thermochemistry

Energy - measure of the ability to cause change to occur, i.e. work.
Units of energy: Joule (J) = newton x meter or J = N x m

Types of Energy - five main forms of energy:

Mechanical (Kinetic and Potential)
Chemical
Electromagnetic
Heat (Thermal)
Nuclear

Kinetic energy - energy of motion; depends on both mass and velocity; the faster an object moves, the greater the kinetic energy

Potential Energy- amount of energy that is stored.
3 types **Elastic** e.g. pulling a rubber band back and holding
Chemical e.g. burning a match
Gravitational e.g. boulder resting on top of a hill

Chemical energy - energy stored in the bonds of atoms and molecules

Electromagnetic Energy- a form of energy that is reflected or emitted from objects in the form of electrical and magnetic waves that can travel through space; moving electric charges.

Thermal Energy- internal energy or thermal energy of a substance is determined by the movement of the molecules and the potential energy of the arrangement of molecules.

Temperature - measure of the average kinetic energy of the molecules.

Heat (q) - energy transferred from a warmer substance to a colder one by the collisions of molecules.

calorie - amount of heat needed to raise 1 g of a substance 1 degree Celsius.
Calorie (food calorie, with a capital C) is 1000 cal (1 kcal)
1 cal = 4.18 joules or 1 kcal = 4180 J

$$\text{specific heat capacity } (c_p) = \frac{\mathbf{q}}{\mathbf{m} \times \Delta \mathbf{T}} = \frac{\textbf{heat} \text{ (joules or calories)}}{\textbf{mass (g)} \times \textbf{change in T}^{\circ}\textbf{C}}$$

Nuclear Energy -when the nucleus of an atom splits, nuclear energy is released. Nuclear energy is the most concentrated form of energy.

Law of Conservation of Energy- energy can be converted from one form to another, but it can neither be created nor destroyed.

Heat Energy - if a substance gets hotter, then something else must get colder.

$$heat_{lost} = heat_{gained}$$

Temperature measures the average kinetic energy of the particles in a sample of matter:

$$\text{Kinetic Energy} = \tfrac{1}{2} mv^2$$

<u>Methods of Energy Transfer</u>

Energy transfer as heat can occur in 3 ways:

Conduction- transfer of energy as heat between particles as they collide with a substance or between 2 objects in contact.

Convection- transfer of energy by the movement of fluid with different temperature . **Convection current** - cycle of a heated fluid that rises and then cools and falls.

Radiation- transfer of energy by electromagnetic waves. This energy transfer does not need any matter since it travels in waves.

Main Points

The Law of Conservation of Energy- energy cannot be created or destroyed. It can only be transferred from one form to another.

Heat is the transfer of energy from the particles of one object to those of another object due to a temperature difference between the two objects.

The transfer of energy always takes place from a substance at a higher temperature to a substance at a lower temperature.

<u>Thermochemical Equation</u> - balanced, stoichiometric chemical equation that includes the enthalpy change, ΔH

Enthalpy (ΔH) - transfer of energy in a reaction; change in heat.

$$\Delta H = H_{products} - H_{reactants}$$

$H_{products} < H_{reactants}$, ΔH is negative

$H_{products} > H_{reactants}$, ΔH is positive

Writing Thermochemical Equations
For example, Burning one mole of wax releases 20,000 kJ of heat energy.

This could be written as:
$C_{40}H_{82} + 60.5\ O_2 \rightarrow 40\ CO_2 + 41\ H_2O + 20{,}000\ kJ$

Instead we usually write:
$C_{40}H_{82} + 60.5\ O_2 \rightarrow 40\ CO_2 + 41\ H_2O$ $\Delta H = -20{,}000\ kJ$

Example 1
Reacting 2 moles of solid sodium with 2 moles of water to produce 2 mole of aqueous sodium hydroxide and 1 mole of hydrogen gas will release 367 kJ of energy.

$2Na\ (s) + 2\ H_2O\ (l) \rightarrow 2\ NaOH\ (aq) + H_2\ (g) + 367\ kJ$

or

$2Na\ (s) + 2\ H_2O\ (l) \rightarrow 2\ NaOH\ (aq) + H_2\ (g)$ $\Delta H = -367\ kJ$

Example 2
184.6 kJ of energy is needed to produce 1 mole of hydrogen gas and 1 mole of chlorine gas from 2 moles of hydrogen chloride gas.

$2\ HCl\ (g) + 184.6\ kJ \rightarrow H_2\ (g) + Cl_2\ (g)$

or

$2\ HCl\ (g) \rightarrow H_2\ (g) + Cl_2\ (g)$ $\Delta H = +184.6\ kJ$

How to write Thermochemical equations using Standard Heat of Formations

$C_2H_2(g) + 2\ H_2(g) \rightarrow C_2H_6\ (g)$

	ΔH^o_f (in kJ / mol)
$C_2H_2(g)$	226.7
$C_2H_6(g)$	- 84.7

Write the equation for the heat of formation of $C_2H_6(g)$

$C_2H_2(g) + 2\ H_2(g) \rightarrow C_2H_6(g)$

1 mol of $C_2H_2(g)$ and 1 mol $C_2H_6(g)$

And

$$\Delta H^\circ_{rxn} = [\Delta H^\circ_{f\ \text{products}}] - [\Delta H^\circ_{f\ \text{reactants}}]$$

$$\Delta H^\circ_{rxn} = [C_2H_6(g)] - [C_2H_2(g)]$$

Therefore

$$\Delta H^\circ_{rxn} = [-84.7\ \text{kJ/mol}] - [226.7\ \text{kJ/mol}] = -331.4\ \text{kJ/mol}$$

Endothermic/ Exothermic equations

Depending on the sign of ΔH°, the reaction can either be exothermic or endothermic.

Exothermic reactions release heat from the system to the surroundings so the temperature will rise.

ΔH° will be **negative** because the reaction loses heat.

ΔH° can be written into the chemical equation as a **product**.

Endothermic reactions absorb heat from the surroundings into the system so the temperature will decrease.

ΔH° will be **positive** because the reaction absorbs heat.

ΔH° can be written into the chemical equation as a **reactant**.

Example 3

How much energy does it take to raise the temperature of 50 g of aluminum (c_p = 0.9025 J/g°C) by 10°C?

Using $Q = m \times c_p \times (T_f - T_i)$

$Q = (50g)\ (0.9025\ J/g^\circ C)\ (10^\circ C)$

$Q = 451.3\ J$

Example 4

If we add 30 J of heat to lead (c_p = 0.1276 J/g°C) with a mass of 10 g, how much will its temperature increase?

Using $Q = m \times c_p \times \Delta T$

$30J = (10g)\ (0.1276\ J/g^\circ C)\ (\Delta T)$

$23.5\ ^\circ C = \Delta T$

Calorimetry - science of measuring the heat of chemical reactions or physical changes. To do calorimetry, heat of combustion and mass must be given OR during a calorimetry procedure, the heat released during a chemical or physical change is transferred to another substance, such as water, which undergoes a temperature change.

Example 5

Propane is a commonly used fuel. 1 mol of C_3H_8 releases 2,220 kJ of heat during combustion. The molar mass of C_3H_8 is 44.1 g/mol. How much heat is released if a firework contains 67.8 g of C_3H_8?

1st step: convert grams C_3H_8 to moles C_3H_8

$$67.8\text{ g } C_3H_8 \times \frac{1\text{ mol } C_3H_8}{44.1\text{ g } C_3H_8} = 1.54\text{ mol } C_3H_8$$

2nd step: use the heat of combustion of propane to calculate energy (heat) released

$$1.53\text{ mol } C_3H_8 \times \frac{2{,}220\text{ kJ}}{1\text{ mol}} = 3413.06\text{ kJ} \quad \therefore \; >3410\text{ kJ released}$$

For heat transferred to another object, the equation is: $-Q_1 = Q_2$

One will be losing energy ($-Q_1$), the other will be gaining energy (Q_2).

Example 6

175 grams of hot aluminum (100°C) is dropped into an insulated cup that contains 40.0 mL of ice cold water (0°C). Determine the final temperature, T_f.

1st set up expressions for energy released and energy absorbed.

$$-Q_1 = -(175\text{ g})(0.900\text{ J/g°C})(T_f - 100°\text{C}) \quad \text{for aluminum}$$

$$Q_2 = (40.0\text{ g})(4.184\text{ J/g°C})(T_f - 0.0°\text{C}) \quad \text{for cold water}$$

2nd put the expressions together, i.e. $-Q_1 = Q_2$

$$-(175\text{ g})(0.900\text{ J/g°C})(T_f - 100°\text{C}) = (40.0\text{ g})(4.184\text{ J/g°C})(T_f - 0°\text{C})$$

3rd solve for T_f

$$-157.5\,(T_f - 100^oC) = 167.4\,(T_f - 0.0^oC)$$

$$-157.5\,T_f + 15750^oC = 167.4\,T_f$$

$$15750^oC = 324.9\,T_f \qquad \therefore\; T_f = 48.5^oC$$