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

<u>Types of Energy</u> - 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.

Units of Thermal Energy: joule (J) or calorie (c).

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

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

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.

<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.

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

$$H_{products} < H_{reactants}\text{ , }\Delta H\text{ is negative}$$
$$H_{products} > H_{reactants}\text{ , }\Delta H\text{ is positive}$$

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.

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

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

<u>Write the equation for the heat of formation of $C_2H_6(g)$</u>

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

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

ΔH°_{rxn} = [-84.7 kJ/mol] – [226.7 kJ/mol] = -331.4 kJ/mol

Endothermic/ Exothermic equations

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°C) (10°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°C) (ΔT)

23.5 °C = ΔT

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

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

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.

$-Q_1 = -(175\text{ g})(0.900\text{ J/g°C})(T_f - 100°\text{C})$ for aluminum
$Q_2 = (40.0\text{ g})(4.184\text{ J/g°C})(T_f - 0.0°\text{C})$ 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

$$-157.5\,(T_f - 100°\text{C}) = 167.4\,(T_f - 0.0°\text{C})$$

$$-157.5\,T_f + 15750°\text{C} = 167.4\,T_f$$

$$15750°\text{C} = 324.9\,T_f \quad \therefore \quad T_f = 48.5°\text{C}$$