SECTION 2

CHEMICAL REACTIONS AND EQUATIONS

This section introduces the language of chemical equations, the method of representing the changes which occur in a chemical reaction in which substances are consumed and new ones formed.

Chemical reaction: A chemical reaction occurs when a substance or a mixture of substances undergoes a change which produces new substances.

Reactants: The initial substances of a reaction.

Products: The new substances produced in a chemical reaction.

Chemical equation: A symbolic representation of a chemical reaction using chemical formulae.
[e.g. When gaseous dihydrogen, H_2, and dioxygen, O_2, are mixed at room temperature nothing happens, but when the mixture is sparked a large amount of heat is given out and water is formed. *Equation*: $H_2 + O_2 \rightarrow H_2O$
reactants product]
An arrow, normally from left to right shows the direction of the reaction. In a chemical reaction the atoms of the reactants rearrange to give new substances. **Chemical bonds** are broken and new chemical bonds made.

Chemical bonds: The forces holding atoms together in matter. (see *section 4*)

Balanced chemical equation: A chemical equation in which the numbers of atoms of each element is the same on both sides

[e.g. $2H_2 + O_2 \rightarrow 2H_2O$].

Stoichiometry: The relative proportions in which elements form compounds or in which substances react. (From the Greek word for element, *stoikheion.*)

Stoichiometric coefficient: The number immediately in front of the formula of the chemical substances in the balanced equation. The coefficients may be interpreted as the relative number of particles of reactants and products [e.g. For the above equation two molecules of dihydrogen react with one molecule of dioxygen to form two molecules of water].

Balancing chemical equations: Deriving the stoichiometric coefficients of reactants and products such that the equation is balanced. Although this can always be done by the mathematical method of linear equations, most equations can be balanced by inspection using the following hints.

1. If the number of atoms of one kind happen to be balanced when the formulae of reactants and products are written down keep this so by placing 1 in front of these formulae.
2 Leave formulae containing only one kind of atom for the last.
3 Start with a kind of atom appearing in only two formulae.

Two examples:
Ostwald combustion of ammonia. (**Combustion** is a reaction with dioxygen.) The products are nitric oxide and water. Write the formulae for reactants and products,

$$NH_3 + O_2 \rightarrow NO + H_2O$$

Hint 1 $1NH_3 + O_2 \rightarrow 1NO + H_2O$

Hint 2 Leave O until last

Hint 3 This is H. Balance H by writing 3/2 in front of H_2O. 3H on left, therefore (3/2) x 2 on right $1NH_3 + O_2 \rightarrow NO + {}^3/_2H_2O$

Now O $1NH_3 + {}^5/_4O_2 \rightarrow 1NO + {}^3/_2H_2O$

One cannot have ½ or ¼ molecules. Multiply all coefficents by 4 to have only whole numbers

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

The combustion of ethane: The products are carbon dioxide and water. Write the formulae for reactants and products, $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$

Hint 1 Not applicable.

Hint 2 Leave O until last

Hint 3 Could balance C or H next. Balance carbon, C, by writing 2 in front of CO_2.

$$C_2H_6 + O_2 \rightarrow 2CO_2 + H_2O$$

(2 C on both sides; 2 atoms in one molecule of ethane, C_2H_6, and one atom in each of 2 molecules of carbon dioxide, CO_2.) Now balance H. There are 6 H atoms on the left, so write 3 in front of H_2O.

$$C_2H_6 + O_2 \rightarrow 2CO_2 + 3H_2O$$

(6 H atoms in ethane and 2 H atoms in each of 3 water molecules.) Balance O. There are 2 O atoms on left and 7 O atoms on right. Write 7/2 in front of O_2.

$$C_2H_6 + {}^7/_2O_2 \rightarrow 2CO_2 + 3H_2O$$

This would be interpreted as one molecule of ethane reacting with 3½ molecules of dioxygen to give 2 molecules of CO_2 and 3 molecules of water. But one cannot have half a molecule. This problem is overcome by multiplying all coefficients by two.

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

2 molecules of ethane react with 7 molecules of dioxygen to form 4 molecules of carbon dioxide and 6 molecules of water.

(In *section 8* another interpretation of the stoichiometric coefficient is given.)

Summary: A balanced chemical equation is a concise expression for conveying much information.

[e.g. the equation $S_8 + 8O_2 \rightarrow 8SO_2$

implies
(i) a molecule of sulfur contains 8 atoms of sulfur
(ii) a molecule of oxygen contains 2 atoms of oxygen
(iii) sulfur and oxygen react to form sulfur dioxide, each molecule of which contains one atom of S and 2 atoms of O (as the name suggests)
(iv) one molecule of sulfur requires 8 molecules of dioxygen for a complete reaction.]

Nett ionic equation: A chemical equation for a reaction occurring in aqueous solution between ionic compounds, but showing only the reacting ions. [e.g. When solutions of silver nitrate, $AgNO_3$, and sodium chloride, NaCl, are mixed a precipitate of silver chloride forms:

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

The Na^+ and NO_3^- ions present in solution are not shown because they are not reacting. Such ions are sometimes called spectator ions. The (aq) and (s) in the equation stand for aqueous and solid respectively and make the equation more meaningful.]

Nuclear equation: An equation for a nuclear change or reaction. [e.g. the production and decay of cobalt-60:

$$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ^{0}_{-1}e + \gamma\text{-photon}$$

Normal cobalt, ^{59}Co, absorbs a neutron (n) in a nuclear reactor to give ^{60}Co which decays with elimination of an electron from the nucleus to give ^{60}Ni with excess energy and this is lost as a gamma-photon.] Note that the mass numbers (superscripts) balance and the atomic numbers or charge (subscripts) balance.

EXERCISES

Balance the following chemical equations:

1. *Example*: $N_2 + H_2 \rightarrow NH_3$ (ammonia)

   Balance N by writing 2 in front of NH_3

   $$N_2 + H_2 \rightarrow 2NH_3$$

   Balance H by writing 3 in front of H_2

   $$N_2 + 3H_2 \rightarrow 2NH_3$$

2. $C_6H_6 + O_2 \rightarrow CO_2 + H_2O$ (benzene)

3. $H_2 + Cl_2 \rightarrow HCl$

4. $CH_4 + H_2O \rightarrow CO + H_2$

5. $Fe_3O_4 + C \rightarrow Fe + CO$

6. $NO + O_2 \rightarrow NO_2$

7. $NaNO_3 \rightarrow NaNO_2 + O_2$

8. $NH_3 + O_2 \rightarrow N_2 + H_2O$

9. $NH_3 + O_2 \rightarrow N_2O + H_2O$

10. $CO_2 + H_2 \rightarrow CO + H_2O$

Write nett ionic equations for the following reactions on mixing aqueous solutions of the following soluble ionic compounds (salts).

11. Solutions of thallium nitrate, $TlNO_3$ and potassium fluoride, KF, to give a precipitate of thallium fluoride.

12. Solutions of copper sulfate, $CuSO_4$, and sodium carbonate, Na_2CO_3, to give a precipitate of copper carbonate.

13. Solutions of calcium nitrate, $Ca(NO_3)_2$, and sodium phosphate, Na_3PO_4, to give a precipitate of calcium phosphate.

14. Solutions of magnesium sulfate, $MgSO_4$, and barium hydroxide, $Ba(OH)_2$, to give a precipitates of barium sulfate and magnesium hydroxide.