CHM 1102 PART 3

Balancing chemical equations

When chemicals react, atoms cannot be either created or destroyed. So there must be the same number of each type of atom on the reactants side of a chemical equation as there are on the products side. A symbol equation is a shorthand way of describing a chemical reaction. It shows the number and type of the atoms in the reactants and the number and type of atoms in the products. If these are the same, we say the equation is balanced. Follow these examples to see how we balance an equation.

Balancing an equation

Example

Step 1: Write down the formulae of all the reactants and products. For example:

$$H_2 + O_2 \longrightarrow H_2O$$

Step 2: Count the number of atoms of each reactant and product.

$$H_2 + O_2 \longrightarrow H_2O$$
$$2[H] + 2[O] \qquad 2[H] + 1[O]$$

Step 3: Balance one of the atoms by placing a number in front of one of the reactants or products. In this case the oxygen atoms on the right-hand side need to be balanced, so that they are equal in number to those on the left-hand side. Remember that the number in front multiplies everything in the formula. For example, $2H_2O$ has 4 hydrogen atoms and 2 oxygen atoms.

$$H_2 + O_2 \longrightarrow 2H_2O$$
$$2[H] \quad 2[O] \qquad 4[H] + 2[O]$$

Step 4: Keep balancing in this way, one type of atom at a time until all the atoms are balanced.

$$2H_2 + O_2 \longrightarrow 2H_2O$$
$$4[H] \quad 2[O] \qquad 4[H] + 2[O]$$

NB: When you balance an equation you must not change the formulae of any of the reactants or products.

Example: Write a balanced equation for the reaction of iron(III) oxide with carbon monoxide to form iron and carbondioxide.

Step1: formulae $\quad Fe_2O_3 + CO \longrightarrow Fe + CO_2$

Step 2: count the number of atoms $\quad Fe_2O_3 + CO \longrightarrow Fe + CO_2$

$$2[Fe] + 3[O] \quad 1[C] + 1[O] \qquad 1[Fe]\ 1[C] + 2[O]$$

Step 3: balance the Iron $\quad Fe_2O_3 + CO \longrightarrow 2Fe + CO_2$

$$2[Fe] + 3[O] \quad 1[C] + 1[O] \qquad 2[Fe] + 1[C] + 2[O]$$

Step 4: balance the Oxygen $\quad Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$

$$2[Fe]+3[O] \quad 3[C]+3[O] \qquad 2[Fe] + 3[C] + 6[O]$$

In step 4 the oxygen in the CO_2 comes from two places, the Fe_2O_3 and the CO. In order to balance the equation, the same number of oxygen atoms (3) must come from the iron oxide as come from the carbon monoxide

Practice questions: Write balanced equations for the following reactions.

a Iron reacts with hydrochloric acid to form iron(II) chloride, $FeCl_2$, and hydrogen.

b Aluminium hydroxide, $Al(OH)_3$, decomposes on heating to form aluminium oxide, Al_2O_3, and water.
c Hexane, C_6H_{14}, burns in oxygen to form carbon dioxide and water.

Using state symbols

We sometimes find it useful to specify the physical states of the reactants and products in a chemical reaction. This is especially important where chemical equilibrium and rates of reaction are being discussed. We use the following state symbols: (s) solid, (l) liquid,(g) gas, (aq) aqueous (a solution in water). State symbols are written after the formula of each reactant and product.

For example:
$ZnCO_{3(s)} + H_2SO_{4(aq)}\ ZnSO_{4(aq)} + H_2O_{(l)} + CO_{2(g)}$

STOICHIOMETRY

Mole calculations and Reacting masses
When reacting chemicals together we may need to know what mass of each reactant to use so that they react exactly and there is no waste. To calculate this we need to know the chemical equation. This shows us the ratio of moles of the reactants and products – the stoichiometry of the equation. The balanced equation shows this stoichiometry.
For example, in the reaction

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

1 mole of iron(III) oxide reacts with 3 moles of carbon monoxide to form 2 moles of iron and 3 moles of carbon dioxide.

The stoichiometry of the equation is 1 : 3 : 2 : 3.

The large numbers that are included in the equation (3, 2 and 3) are called stoichiometric numbers.

In order to find the mass of products formed in a chemical reaction we use:

- the mass of the reactants
- the molar mass of the reactants
- the balanced equation.

The relative atomic mass or relative molecular mass of a substance in grams is called a mole of the substance. So a mole of sodium (Relative atomic mass Ar = 23.0) weighs 23.0 g. The abbreviation for a mole is mol. We define the mole in terms of the standard carbon-12 isotope

We often refer to the mass of a mole of substance as its molar mass (abbreviation *M*). The units of molar mass are g mol^{-1}.

The number of atoms in a mole of atoms is very large: 6.02×10^{23} atoms. This number is called the Avogadro constant (or Avogadro number). The symbol for the Avogadro constant is L or N_A.

The Avogadro constant applies to atoms, molecules, ions and electrons. So in 1 mole of sodium there are 6.02×10^{23} sodium atoms and in 1 mole of sodium chloride (NaCl) there are 6.02×10^{23} sodium ions and 6.02×10^{23} chloride ions.

It is important to make clear what type of particles we are referring to. If we just state ‘moles of chlorine’, it is not clear whether we are thinking about chlorine atoms or chlorine molecules. A mole of chlorine molecules, Cl_2, contains 6.02×10^{23} chlorine molecules but twice as many chlorine atoms, as there are two chlorine atoms in every chlorine molecule.

You can find the number of moles of a substance by using the mass of substance and the relative atomic mass (*A*r) or relative molecular mass (*M*r).

$$\text{number of moles (mol)} = \frac{\text{mass of substance in grams(g)}}{\text{molar mass (g mol}^{-1})}$$

Example: How many moles of sodium chloride are present in 117.0 g of sodium chloride, NaCl?
(*A*r values: Na = 23.0, Cl = 35.5)

Solution:

Molar mass of NaCl = 23.0 + 35.5 = 58.5 g mol^{-1}

$$\text{number of moles} = \frac{\text{mass of substance in grams(g)}}{\text{molar mass (g mol}^{-1})}$$

$$= \frac{117.0}{58.5} = 2.0 \text{ mol}$$

Practice exercise: Use these *A*r values: C = 12.0, Fe = 55.8, H = 1.0, O = 16.0, Na = 23.0.
Calculate the mass of the following:

a 0.20 moles of carbon dioxide, CO_2

b 0.050 moles of sodium carbonate, Na_2CO_3

c 5.00 moles of iron(II) hydroxide, $Fe(OH)_2$

To find the mass of a substance present in a given number of moles, you need to rearrange the equation:

mass of substance (g) = number of moles (mol) × molar mass (g mol^{-1})

Example: What mass of sodium hydroxide, NaOH, is present in 0.25 mol of sodium hydroxide?
(*A*r values: H = 1.0, Na = 23.0, O = 16.0)

Solution:

molar mass of NaOH = 23.0 + 16.0 + 1.0
= 40.0 g mol^{-1}

mass = number of moles × molar mass
= 0.25 × 40.0 g
= 10.0 g NaOH

Example: Iron(III) oxide reacts with carbon monoxide to form iron and carbon dioxide.

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

Calculate the maximum mass of iron produced when 798 g of iron(III) oxide is reduced by excess carbon monoxide. (*A*r values: Fe = 55.8, O = 16.0)

Solution

Step 1 $Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$

Step 2 1 mole iron(III) oxide $\longrightarrow$ 2 moles iron

$(2 \times 55.8) + (3 \times 16.0) \longrightarrow 2 \times 55.8$

159.6 g Fe_2O_3 $\longrightarrow$ 111.6 g Fe

Step 3 798 g $\longrightarrow$ $\dfrac{111.6 \times 798}{159.6}$

= 558 g Fe