

## THE MOLE CONCEPT AND CALCULATIONS

A large number of calculations that appear in examination papers rely up on the knowledge of the mole concept. This study includes calculations of different kinds which one ought to study.

### A. DEFINITIONS.

The **relative atomic mass (RAM)** of an atom is the number of times an atom is heavier than one twelfth of a carbon-12 atom. It is calculated by adding together the number of protons and neutrons in an atom.

The atomic mass is usually a whole number unless where an element occurs in a number of isotopes. Here the atomic mass is the average atomic weight of the isotopes in the ratio of their existence.

**Example 1.** Chlorine exist in two isotopic forms;  $^{35}\text{Cl}$  and  $^{37}\text{Cl}$  in percentage compositions of 75% and 25% respectively.

Calculate the relative atomic mass of chlorine.

Every 100 atoms of chlorine there is 75 atoms of  $^{35}\text{Cl}$  and 25 atoms of  $^{37}\text{Cl}$

Total mass of 100 atoms  
of chlorine

$$= 75 \times 35 + 25 \times 37$$

$$= 3550$$

$$\text{Average atomic mass} = \frac{3550}{100}$$

$$= 35.5$$

∴ The RAM of chlorine is 35.5

### Exercise 1a

1. A sample of ordinary neon is found to consist of  $^{20}\text{Ne}$ ,  $^{21}\text{Ne}$  and  $^{22}\text{Ne}$  in percentage  $^{20}\text{Ne} = 90.22\%$ ,  $^{21}\text{Ne} = 0.26\%$  and  $^{22}\text{Ne} = 8.82\%$ . Calculate the actual atomic weight of neon.
2. Copper has a relative atomic mass of 63.55 and consists of two isotopes of mass number 63 and 65. Calculate the percentage composition of the isotopes. (1993/1/4)
3. The two isotopes of hydrogen having mass number 1 and 2 have atomic weight equal to 1.007825 and 2.01473 as determined by mass spectrograph. These isotopes are present in ordinary hydrogen in ratio of 6400 to 1. Determine the mean-atomic weight of hydrogen atoms.
4. 2002/1/2, The mass spectrum of chlorine shows peaks at masses 70, 72, and 74. the heights of the peaks are in ratio of 9:6:1  
Calculate
  - a. The average atomic mass of chlorine (2marks)
  - b. The relative abundance of  $^{35}\text{Cl}$  and  $^{37}\text{Cl}$ . (3 marks)
5. 2001/2/1,
  - a. Define the term relative atomic mass (2mark)
  - b. Explain how the relative atomic mass can be determined by the mass spectrometer (10 marks)
  - c. The mass spectrum of an element, A, contained four lines at mass/charge of 54, 56, 57, and 58 with relative intensities of 5.84, 91.68, 2.17 and 0.31 respectively

- i. Explain what the term relative intensities means
- ii. Calculate the relative atomic mass of A

6. 2004/1/03,(b) An element Y has three naturally occurring isotopes with isotopic masses and relative abundances' as shown below:

Isotopic mass	Relative abundance (%)
23.98	78.60
24.98	10.11
25.98	11.29

Calculate the relative atomic mass of Y (2 marks)

### Formula masses (relative formula mass or Molecular mass)

This is the number of times a molecule is heavier than one twelfth of a carbon-12 atom. It is calculated by addition of the individual RAM of the constituent atoms in a molecules, Relative formula mass has no units

#### Example 2.

What is the formula mass of Ozone,  $O_3$ ?

The Ozone molecule contains three oxygen atoms, each of which weighs 16 grams.

$\therefore$  the formula mass of Ozone is  $3 \times 16 = 48$

#### Example 3. What is the formula mass of Ammonia, $NH_3$ ?

RAM of nitrogen atom is 14 and that of hydrogen atom is 1. There are three hydrogen atoms in the molecule and one nitrogen atom;

$\therefore$  the formula mass of ammonia is:  $14 + (3 \times 1) = 17$  grams.

#### Example 4. What is the formula mass of Glucose, $C_6H_{12}O_6$ ?

( $C=12$ ,  $H=1$ , and  $O=16$ )

$\therefore$  The formula mass of Glucose is

$$\begin{aligned}
 &= 6 \times 12 + (12 \times 2) + (6 \times 16) \\
 &= 72 + 24 + 96 \\
 &= 180
 \end{aligned}$$

## Exercise Ib

- (1) Calculate the formula mass of
  - (a) Ammonium sulphate,  $(NH_4)_2SO_4$
  - (b) Sodium carbonate decahydrate,  $Na_2CO_3 \cdot 10H_2O$ .
  - (c) Oxalic acid,  $HOOC-COOH$
  - (d) Maleic acid  $HOOC-CH=CH-COOH$

## B. THE MOLE

A mole is the AMOUNT of a substance which contain as many elementary units (particles, i.e., molecules, atoms, ions etc) as there are in 12 g of carbon-12 isotope ( $^{12}_6C$ ). A mole of any substance contains  $6.02 \times 10^{23}$  particles.

The number of particles in any mole of a substance ( $6.02 \times 10^{23}$ ) is called **AVOGADRO'S NUMBER, L**.

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**Molar Mass** is the mass in grams of 1 mole of a substance. It is numerically equal to its relative atomic mass or its relative formula mass. e.g., One mole of carbon weighs 12 g, 1 mole of oxygen molecule weighs 32 g, and 1 mole of ammonium sulphate weighs 132 g.

### CALCULATIONS USING THE AVOGADRO NUMBER

The Avogadro number,  $L$ , is taken as  $6.0 \times 10^{23}$  in the following examples.

**Example 5.** How many C atoms are there in a carbon rod weighing 8 g ( $C=12$ ).

12 g (RAM of carbon in g or 1 mole) of carbon have  
 $6.0 \times 10^{23}$  atoms.

$$\therefore 8 \text{ g of carbon has } \frac{8 \times 6.0 \times 10^{23}}{12} \text{ atoms}$$

$$= 4.0 \times 10^{23} \text{ atoms}$$

**Example 6.** How many grams of copper ( $Cu=64$ ) contain  $4.5 \times 10^{23}$  atoms?

$6.0 \times 10^{23}$  atoms are in 1 mole of copper i.e. 64 g

$$\therefore 4.5 \times 10^{23} \text{ atoms are in } \frac{4.5 \times 10^{23} \times 64}{6.0 \times 10^{23}}$$

$$= 48 \text{ g}$$

**Example 7.** How many (i) molecules (ii) atoms are there in 35.5 g of gaseous chlorine  $Cl_2$ ?

(i) Mass of 1 mole of chlorine molecule,  $Cl_2 = 71$  g

i.e. 71 g of chlorine contain  $6.0 \times 10^{23}$  molecules.

$$\therefore 35.5 \text{ g of chlorine contains } \frac{35.5 \times 6.0 \times 10^{23}}{71}$$

$$= 3.0 \times 10^{23} \text{ molecules}$$

(ii) Each chlorine molecule contains 2 atoms. Hence there are  
 $2 \times 3.0 \times 10^{23}$  atoms in 35.5 g of gaseous chlorine,  $Cl_2$

$\therefore$  No. of atoms in 35.5 g of chlorine gas =  $6.0 \times 10^{23}$  atoms.

**Example 8.** How many ions are there in 13.5 g of copper (II) chloride,  $CuCl_2$ ?

$$\text{Mass of 1 mole of } CuCl_2 = 64 + (2 \times 35.5)$$

$$= 135 \text{ g}$$

There are 3 ions (one copper and two chloride ions) in  $CuCl_2$  molecule.

i.e. 1 mole or 135 g of  $CuCl_2$  contain  $3 \times 6.0 \times 10^{23}$  ions.

$$\therefore 13.5 \text{ g of CuCl}_2 \text{ contain } \frac{4 \times 13.5 \times 36.0 \times 10^{23}}{135}$$

$$= 1.8 \times 10^{23} \text{ ions.}$$

[NB. it contains  $0.6 \times 10^{23}$  copper ions and twice that i.e.  $1.2 \times 10^{23}$  chloride ions.]

## The 'mole' concept in calculations

### To convert Mass of a substance into moles

$$\text{No. of moles} = \frac{\text{Mass of substance}}{\text{Mass of 1 mole}}$$

### To convert moles of a substance in grams

$$\text{Mass in grams} = \text{No. of moles} \times \text{mass of 1 mole.}$$

**Example 9.** How many moles of carbon dioxide molecules are present in 11 g of carbon dioxide,  $\text{CO}_2$ ?

$$\text{Mass of 1 mole of CO}_2 = 12 + (2 \times 16) = 44 \text{ g}$$

$$\begin{aligned} \text{No. moles of CO}_2 &= \frac{\text{Mass in grams}}{\text{Mass of 1 mole}} \\ &= \frac{11}{44} \text{ moles} = 0.25 \text{ moles} \end{aligned}$$

**Example 10.** What is the mass of 3 mole of carbon monoxide?

$$\text{The Molar mass of CO} = (12 + 16) = 28 \text{ g}$$

$$\text{Mass in grams} = \text{No. of moles} \times \text{mass of 1 mole.}$$

$$= 3 \times 28$$

$$= 84 \text{ g}$$

**Example 11.** What mass of magnesium ( $\text{Mg}=24$ ) would contain the same number of atoms as 4 g of carbon. ( $\text{C}=12$ )

$$\begin{aligned} \text{No. of moles of carbon} &= \frac{\text{Mass in grams}}{\text{Mass of 1 mole}} = \frac{4}{12} \text{ moles} \\ &= 0.333 \text{ mol} \end{aligned}$$

A mole of any element contains the same number of atoms.

Hence 0.333 moles of magnesium contain the same number of atoms as 4 g of carbon.

$$\text{Mass of 0.333 moles magnesium} =$$

$$\begin{aligned} &\text{No. of moles} \times \text{Mass of 1 mole} \\ &= 0.333 \times 24 \end{aligned}$$

$$\frac{5}{6.0 \times 10^{23}} = 8 \text{ g.}$$

**Example 12 .** Calculate the mass of  
 (i) 1 atom of magnesium.  
 (ii) 5 molecule of ethane.

(i) Relative atomic mass of magnesium = 24

$$\begin{aligned} \text{1 atom of magnesium} &= \frac{24 \times 1}{6.0 \times 10^{23}} \\ &= 4 \times 10^{-23} \text{ g} \end{aligned}$$

(ii) Molar mass of  $\text{C}_2\text{H}_6$  = (2 x 12) + (6 x 1)  
 = 30 g

$$\text{1 molecule of ethane} = \frac{30 \times 1}{6 \times 10^{23}} = 5 \times 10^{-23} \text{ g}$$

$$\therefore 5 \text{ molecules of ethane} = 25 \times 10^{-23} = 2.5 \times 10^{-22} \text{ g}$$

**Example 13.** Calculate the mole of each element present in 18.4 g of iron (III) sulphate.

$$\begin{aligned} \text{Molar mass of } \text{Fe}_2(\text{SO}_4)_3 &= 2 \times 56 + 3 \times 32 + 12 \times 16 \\ &= 112 + 96 + 192 \\ &= 400 \text{ g} \end{aligned}$$

$$\begin{aligned} \text{No. of moles of } \text{Fe}_2(\text{SO}_4)_3 &= \frac{\text{Mass given}}{\text{Mass of 1 mole}} \\ &= \frac{18.4}{400} = \mathbf{0.046} \text{ mole} \end{aligned}$$

$$\therefore \text{No. of moles of iron} = 0.046 \times 2 = 0.092 \text{ moles.}$$

$$\therefore \text{No. of moles of sulphur} = 0.046 \times 3 = 0.138 \text{ moles}$$

$$\therefore \text{No. of moles of oxygen} = 0.046 \times 12 = 0.552 \text{ moles}$$

## Exercise II

1. Using the Avogadro's constant equal to **L**, find the number of atoms in the following masses of calcium: (i) 200 g (ii) 1 kg, (iii) 4 g.

2. Taking Avogadro's constant equal to  $6 \times 10^{23}$ , find the number of molecules in

(a) 3.4 g of ammonia,  $\text{NH}_3$  (b) 7.7 g of carbon tetrachloride  $\text{CCl}_4$

(c) 16 g of sulphur dioxide,  $\text{SO}_2$  (d) 1 g of hydrogen,  $\text{H}_2$ .

3. What mass of carbon dioxide has the same number of molecule as 7 g of nitrogen,  $\text{N}_2$ ?

4. What is the mass of 0.5 mole of aluminium sulphate,  $\text{Al}_2(\text{SO}_4)_3$ ?

5. Which of these contains the same number of atoms: 16 g of sulphur, 40 g of calcium, 40.5 g of aluminium or 28 grams of iron?

(Ca = 40, N = 14, C = 12, S = 32, O = 16, Al = 27, Fe = 56)

## C. Percentage composition: Formulae

**Example 14.** Calculate the percentage composition by mass of magnesium oxide, ( $\text{Mg} = 24$ ,  $\text{O} = 16$ ).

(i) Write formula of the compound:  $\text{MgO}$

(ii) Find the formula mass of the compound:  $24 + 16 = 40$

(iii) Express each atomic mass as a percentage of the formula mass.

$$\text{Percentage of Magnesium} = \frac{24 \times 100\%}{40} = 60\%$$

$$\text{Percentage of oxygen} = \frac{16 \times 100\%}{40} = 40\%$$

**Example 15.** Calculate the percentage of water of crystallization in hydrated sodium carbonate,  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ?

$$\text{Formula mass of } \text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O} = 46 + 12 + 48 + 20 + 160 = 286$$

**Note:** The percentage of water should be calculated as a complete, separate unit i.e. ( $10 \text{H}_2\text{O} = 180$ ) in this case.

$$\begin{aligned} \text{per cent water in } \text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O} &= \frac{180 \times 100\%}{286} \\ &= 62.94\% \end{aligned}$$

## Formulae: Empirical and molecular

The **empirical formula (E.F)** of a compound is the simplest formula which expresses its composition by mass. It does not give the exact number of various atoms present in one formula unit of molecule of a compound.

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The **molecular formula (M.F)** of a compound is the one which shows the exact number of each kind of each atom present in a molecule of a compound.

The molecular formula is always a simple multiple of the empirical formula.

i.e.  $M.F = n(E.F)$  where  $n$  is a whole number e.g., E.F of glucose is  $CH_2O$ , whereas its M.F. is  $C_6H_{12}O_6$  which  $(CH_2O)_6$ .

$$\text{OR } \frac{\text{Molecular formulamass}}{\text{Emperical formulamass}} = n, \text{ a whole number.}$$

**Example 16.** Determine the formula of a lead compound, given that 4.14 g of lead combines with 0.64 g of sulphur and 1.28 g of oxygen.

We shall use the 'mole' concept to find the formula of the compound. Proceed as shown in the table below:

Element symbol	Lead, Pb	Sulphur, S	Oxygen, O
Mass in g	4.14	0.64	1.28
RAM	207	32	16
No. of moles	$\frac{4.14}{207} = 0.02$	$\frac{0.64}{32} = 0.02$	$\frac{1.28}{16} = 0.08$
Ratio of mole	$\frac{0.02}{0.02} = 1$	$\frac{0.02}{0.02} = 1$	$\frac{0.08}{0.02} = 4$
No. of atoms	1	1	4
E.F	PbSO <sub>4</sub>		

**Example 17.** The combustion of 0.92 g of copper gave 1.15 g of copper oxide.

Calculate the percentage of copper and oxygen in the sample and hence its formula.

Mass of oxygen in the oxide =  $1.15 - 0.92 = 0.23$  g

$$\text{Percentage of copper} = \frac{0.92 \times 100\%}{1.15} = 80\%$$

$$\text{Percentage of oxygen} = \frac{0.23 \times 100\%}{1.15} = 20\%$$

	Copper, Cu = 64	Oxygen, O = 16
Percentage	80	20
No. of moles	$\frac{80}{64} = 1.25$	$\frac{20}{16} = 1.25$
No. of atoms	$\frac{1.25}{1.25} = 1$	$\frac{1.25}{1.25} = 1$
Formula	CuO	

∴ The formula of copper oxide is CuO.

**Example 18** 3.22 g of hydrated sodium sulphate,  $\text{Na}_2\text{SO}_4 \cdot n\text{H}_2\text{O}$  were heated till all the water of crystallization was driven off. The anhydrous salt left had a mass of 1.42 g. Determine the formula of the hydrated salt.

Compound	$\text{Na}_2\text{SO}_4$	$\text{H}_2\text{O}$
Mass in g	1.42	1.80 (3.22 - 1.42)
R.M.M	142	180
No. of moles	$\frac{1.42}{142} = 0.01$	$\frac{1.80}{18} = 0.1$
Ratio of mole	1	10

Hydrated sodium sulphate is  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$

**Example 19.** An organic compound was found to contain 12.8% carbon, 2.1% Hydrogen and 85.1% bromine. A rough estimate gave its relative molecular mass between 150 and 200. Determine its molecular formula. Explain your answer.

Element	C (=12)	H (=1)	Br (=80)
No. of mole	$\frac{12.8}{12} = 1.06$	$\frac{2.1}{1} = 2.1$	$\frac{85.1}{80} = 1.06$
/mole ratio/No. of atoms	1	2	1

Empirical formula =  $\text{CH}_2\text{Br}$

E.F. mass = 12 + 2 + 80 = 94

Molecular formula mass = n x E.F. Mass = n x 94

i.e. M.F. mass can be 94 or 188 or 289.

In this case, it is then 188 and the M.F. of the compound is  $\text{C}_2\text{H}_4\text{Br}_2$

### Exercise III

1. What is the percentage of hydrogen and oxygen in ethanoic acid,  $\text{CH}_3\text{COOH}$ ?
2. 24.0 g of a lead oxide was completely reduced by heating it with carbon to 20.8 g of lead. What is the formula of the oxide that was reduced?
3. If 0.5 mole of a hydrated salt  $\text{X} \cdot n\text{H}_2\text{O}$  contains 63 g of water of crystallization, find the value of n.
4. 2.8 g of iron reacted with 5.3 g of chlorine to form the chloride.
  - (a) Determine the simplest formula of the chloride.
  - (b) If the molecular mass of the chloride is 325. Find the molecular formula and structural formula of the chloride.
5. When 3.6 g of magnesium was burnt in nitrogen, 5.0 g of magnesium nitride was formed. Determine the simplest

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formula of the nitride.

6. A liquid compound X has relative molecular mass of 114 and the ratio of carbon atoms to hydrogen atoms is 4:9. Determine the molecular formula of the compound. To which homologous series of organic compounds does it belong?

7. An organic compound contains by mass 60% carbon, 13.3% hydrogen and 27.7% oxygen. Determine its simplest formula? Find its possible molecular formula if its relative molecular mass is estimated to be between 50 and 80.

8. When 0.29 g of a substance X was burnt in oxygen, 0.66 g of carbon dioxide and 0.27 g of water were formed. Calculate (i) the masses of carbon, hydrogen and oxygen in X.  
(ii) Determine the empirical formula of X.

9 (a) A compound X contains carbon, 66.7% and hydrogen 11.1% the rest being oxygen. Determine the empirical formula of X.

(b) The vapor density of X is 36; determine the molecular formula of X.

10. Combustion of 5.4 g of a compound containing C, H and O only gave 7.92 g of CO<sub>2</sub> and 3.24 g of H<sub>2</sub>O. Calculate the empirical formula of the compound? The compound has a R.M.M of 180, determine its molecular formula.

1997/2

(a) A compound b contain 92.31% carbon and 6.69% hydrogen

Determine the empirical formula of B (2marks)

(b) B burns with a sooty flame and has a vapour density of 39. Determine molecular formula and write its molecular structure.

2002/2/1(a)

A compound X, vapor density 58, contain carbon 62.07%, hydrogen 10.34%, the rest being oxygen. X does not burn with sooty flame.

- (i) Calculate the empirical formula of X  
(C=12, H=1, O=16) (3marks)
- (ii) Determine the molecular formula of X

1993/1/7

(a) When 4.90 g of organic compound X, containing carbon and hydrogen only was burnt in oxygen, 15.78g of carbon dioxide and 5.38 g of water were formed. Calculate the empirical formula of X.

2003/1/7

(a) When 4.90g of organic compound X, containing carbon and hydrogen only was burnt in oxygen, 15.78g of carbon dioxide and 5.38g of water were formed. Calculate the empirical formula of X (2 ½ marks)

- (b) X was steam distilled at 80°C and 760mmHg and the distillate was found to contain 90.8% by mass of X. ( the vapor pressure of water at 80°C is 240mmHg).
  - a. Calculate the formula mass of X.
  - b. Deduce the molecular formula of X.

2005/1/16

A compound P contains 52.2% carbon, 13.0% hydrogen, the rest being oxygen

- (i) Determine the empirical formula of P.
- (ii) When vaporized, 0.1g of P occupied 78.8cm<sup>3</sup> at 157°C and pressure of 740mmHg.
  - (i) Calculate the formula mass of P
  - (ii) Determine the molecular formula of P

- (iii) Write the structural formula of all the possible isomers of P
- (iv) P does not react with sodium metal. Identify P
- (v) Write equation to show how P can be prepared from methanol.



$$0.4 \text{ mole of HCl react with } \frac{0.4}{2} = 0.2 \text{ mole of CaCO}_3.$$

$$= (0.2 \times 100)\text{g}$$

$$= 20 \text{ g of CaCO}_3$$

∴ Mass of undissolved CaCO<sub>3</sub> = (50 - 20) = **30 g**.

Volume of CO<sub>2</sub>

2 moles of HCl liberate 1 mole or 24 dm<sup>3</sup> of CO<sub>2</sub> at r.t.p.

∴ 0.4 mole of HCl will liberate  $\frac{0.4 \times 24}{2} = 4.8 \text{ dm}^3$  of CO<sub>2</sub>.

**Example 21.** According to the equation:  $2\text{C} + \text{O}_2 \rightarrow 2\text{CO}$

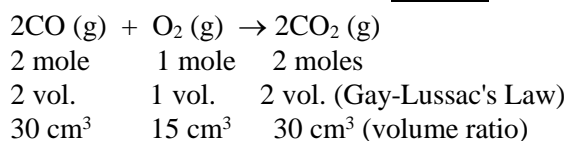
How many moles of carbon which react with 9.6 dm<sup>3</sup> of oxygen at r.t.p?

1 mole or 24 dm<sup>3</sup> (at r.t.p.) of O<sub>2</sub> react with 2 mole of carbon.

1 dm<sup>3</sup> of O<sub>2</sub> reacts with  $\frac{2}{24}$  moles of carbon

∴ 9.6 dm<sup>3</sup> react with  $\frac{2 \times 9.6}{24} = 0.8 \text{ moles}$  of carbon.

**Example 22.** 40 cm<sup>3</sup> of oxygen was added to 30 cm<sup>3</sup> of carbon monoxide and the mixture ignited. What is the volume and composition of the resulting mixture? (All volumes measured at the same temperature and pressure).



The volume of CO<sub>2</sub> produced is the same as that of CO used up, i.e. 30 cm<sup>3</sup> of CO<sub>2</sub> are produced.

15 cm<sup>3</sup> of the 40 cm<sup>3</sup> of oxygen are used up in the reaction, i.e. 25 cm<sup>3</sup> of oxygen

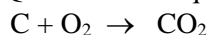
30 cm<sup>3</sup> of carbon dioxide produced and thus has a volume of 55 cm<sup>3</sup>.

## EXERCISE IV

1. Calculate the mass of magnesium oxide obtained by burning 2.4g of magnesium in excess oxygen.
2. 0.2 g of copper (II) oxide is heated in a stream of hydrogen. Calculate the mass of copper obtained if the reduction is 100 percent.
3. What mass and volume of oxygen (at r.t.p.) would be formed when 4.9 g of potassium chlorate (KClO<sub>3</sub>) are heated and completely decomposed into potassium chloride and oxygen?

4. Find the mass of sodium carbonate produced and the volume of carbon dioxide gas evolved at r.t.p. when 42 g of sodium hydrogen carbonate ( $\text{NaHCO}_3$ ) is heated and completely decomposed?
5. Write the equation of the reaction between sodium and water. 4.6 g of sodium are completely dissolved in water. Calculate the mass and volume (at r.t.p.) of hydrogen produced.
6. When 3.1 g of a carbon dioxide  $\text{MCO}_3$  are heated to constant mass, the volume of carbon dioxide evolved during the heating is  $600 \text{ cm}^3$  at r.t.p. What is the relative atomic mass of M?
7. 2.8 g of iron is reacted completely with chloride according to the reaction:  $2 \text{Fe} (\text{s}) + 3 \text{Cl}_2 (\text{g}) \rightarrow 2 \text{FeCl}_3 (\text{s})$ . Find the mass of iron (III) chloride formed and the minimum volume of chloride at r.t.p. needed for this reaction.
8. Find the mass of copper (II) sulphide that can be precipitated when hydrogen sulphide is bubbled through a solution of copper (II) sulphate containing 4.0 g of copper (II) sulphate.
9. The equation for the reduction process taking in the blast furnace is  $\text{Fe}_2\text{O}_3(\text{s}) + 3\text{CO} (\text{g}) \rightarrow 2\text{Fe}(\text{s}) + 3 \text{CO}_2 (\text{g})$   
What is the maximum mass of iron which could be extracted from 40 tones of iron (III) oxide? What is the mass and volume (at r.t.p) of carbon dioxide produced?
10. What mass of 90 percent pure ammonium chloride would be needed just to react completely with 14.8 g of slaked lime,  $\text{Ca}(\text{OH})_2$ ? What volume at s.t.p of ammonia will be produced?
11. What volume of oxygen is need for complete combustion of 20 litres of propane ( $\text{C}_3\text{H}_8$ ) to carbon dioxide and water, measured at r.t.p.?
12. Ethene reacts with oxygen according to the equation  
 $\text{C}_2\text{H}_4 (\text{g}) + 3\text{O}_2 (\text{g}) \rightarrow 2\text{CO}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{g})$   
 15  $\text{cm}^3$  of ethene were mixed with 60  $\text{cm}^3$  of oxygen and the mixture was sparked to complete the reaction. All volumes were measured at a pressure of 1 atm. and (i) at a temperature of  $120^\circ \text{C}$  (ii) at room temperature.  
 Find the volume and composition of the gas mixture left at the end of the experiment in each case.
- 13\*. 10  $\text{cm}^3$  of a gaseous hydrocarbon were mixed with 90  $\text{cm}^3$  of oxygen and sparked. The resulting volume at r.t.p. was 70  $\text{cm}^3$ , which reduced to 30  $\text{cm}^3$  on shaking with sodium hydroxide. Find the empirical formula of the hydrocarbon.
- 14 According to the equation,  
 $\text{C}_3\text{H}_8 (\text{g}) + 5\text{O}_2 (\text{g}) \rightarrow 3\text{CO}_2 (\text{g}) + 4\text{H}_2\text{O} (\text{l})$
- (a) How many moles of  $\text{CO}_2$  will be produced in the reaction of 1 Mole of  $\text{O}_2$ ?
- (b) How many grams of  $\text{CO}_2$  are produced by 1 mole  $\text{O}_2$ ?
- (c) How many grams of propane ( $\text{C}_3\text{H}_8$ ) will react with 3.2 g of  $\text{O}_2$ ?
- (d) How many moles of propane ( $\text{C}_3\text{H}_8$ ) will produce 9 g of  $\text{H}_2\text{O}$ ?
- (e) How many moles of  $\text{CO}_2$  will be produced with 36 g of water?
- \*(f) What are the maximum moles of  $\text{CO}_2$  that will be produced from a mixture of 12 g of  $\text{C}_3\text{H}_8$  and 8 g of  $\text{O}_2$ ? Assume complete reaction.

\*\*Q15 From the equation



What will be the partial pressure of  $\text{CO}_2$  in the product mixture formed from 20 g of  $\text{O}_2$  and 3 g of  $\text{CO}_2$ , assuming complete reaction.

1992/1/2

When 20 g of a mixture containing anhydrous sodium carbonate and sodium hydrogen carbonate was heated and cooled, the mass of the mixtures changed to 13.8 g.

- Write equation for the reaction that took place during the heating (1 ½ marks)
- Calculate the percentage of sodium carbonate in the mixture

1995/1/7

1.18g of compound P on evaporation occupied 300cm<sup>3</sup> at s.t.p.

- Calculate the relative molecular mass of P.
- The empirical formula of P is C<sub>2</sub>H<sub>4</sub>O. Determine its molecular formula
- Compound P reacts with sodium carbonate to produce a gas that turns lime water milky. Write the structural formula of P.

2000/1/17

When 0.55g of organic compound T was burned in oxygen 0.220g of carbon dioxide and 0.135g of water were formed.

- Determine empirical formula of T
- When 0.225g of T was vaporized at 127<sup>0</sup>C and 760mmHG it occupied a volume of 119.11cm<sup>3</sup>. (Molar volume of a gas at s.t.p is 22.4dm<sup>3</sup>). calculate the formula mass of T and determine molecular formula of T
- T reacts with acidified potassium dichromate to form ethane-1,2-dioic acid. Write the formula and the IUPAC name of T.

2001/1/8

When 142cm<sup>3</sup> of a hydrocarbon Q, of molecular mass 58 was exploded with excess oxygen and cooled to room temperature, the volume of the residual gas was 694cm<sup>3</sup>. After addition of concentrated potassium hydroxide, the volume decreased to 126cm<sup>3</sup>

- determine the molecular formula of Q
- write the names and the structural formula of all isomers of Q

2004

- When 8.8g of a hydrocarbon, Z, was burn in excess air, 14.4g of water and 13.44dm<sup>3</sup> of carbon dioxide were obtained at s.t.p. determine the empirical formula of Z.
- The vapor density of Z is 22. Write the name and molecular formula of Z.
- Write equations to show how Z can be synthesized from alcohol
- Indicate a mechanism for the first stage of the reaction in (c)(i).

2005/1/16

A compound P contains 52.2% carbon, 13.0% hydrogen, the rest being oxygen

- Determine the empirical formula of P.
- When vaporized, 0.1g of P occupied 78.8cm<sup>3</sup> at 157<sup>0</sup>C and pressure of 740mmHg.
- Calculate the formula mass of P
- Determine the molecular formula of P
- Write the structural formula of all the possible isomers of P
- P does not react with sodium metal. Identify P
- Write equation to show how P can be prepared from methanol.



## Calculations involving Concentration of Solution.

### Definitions

1. The **concentration** of a substance is the number of moles or the mass of a solute dissolved or contained in a known volume of solution. Usually the concentration of a solution is expressed in either number of grams or number of moles of solute per litre of solution.

2. A **standard substance/primary standard** is a pure substance whose mass can easily be weighed accurately and is used to standardize others.

### Properties of primary standard

- Should have high molecular mass to be weighed accurately with little errors
- Should form stable solutions
- It should be stable in air, i.e., it shouldn't be hygroscopic, deliquescent, react with air, easily lose its water of crystallization and/or it should not be volatile.

3. A **Standard solution** is a solution whose concentration is known, usually expressed in terms of molarity, mole/litre, moles/dm<sup>3</sup>, or grams/litre.

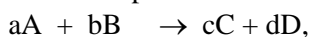
4. The **Molarity** of solution is the number of moles of the solute contained in 1 litre, 1000 ml or 1000 cm<sup>3</sup> of solution.

$$\text{Molarity} = \frac{\text{mass of solute dissolved in one litre}}{\text{molar (formula) mass}}$$

$$\text{or} = \frac{\text{concentration in g/l}}{\text{molar (formula) mass}}$$

$$\text{Hence, No. of moles} = \frac{\text{Molarity} \times \text{volume}}{1000 \text{ ml of solution}}$$

If solutions of compounds A and B react according to the equation



$$\text{then } \frac{V_A \times M_A}{V_B \times M_B} = \frac{a}{b}$$

where,  $V_A$  and  $V_B$ : volumes of solution  
and  $m_A$  and  $m_B$ : molarities of solutions

5. A **molar solution** is a solution containing 1 mole of a solute/substance per litre.



**Example 23.** Calculate the molarities of (a) 7g of potassium hydroxide KOH, in 250cm<sup>3</sup> solution (b) 9.8g of sulphuric acid in 2 dm<sup>3</sup> solution.

(a) RMM of KOH = 39 + 16 + 1 = 56 g

7g of KOH in 250cm<sup>3</sup> solution  $\equiv$  28g KOH in 1000cm<sup>3</sup>  
or 1 dm<sup>3</sup> solution

$$\text{Molarity of KOH} = \frac{g / dm^3}{RFM} = \frac{28}{56} = 0.5M$$

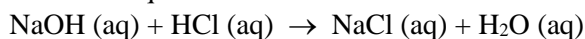
b) RMM of H<sub>2</sub>SO<sub>4</sub> = 2 + 32 + 64 = 98g

9.8g of H<sub>2</sub>SO<sub>4</sub> in 2dm<sup>3</sup> solution = 4.9g in 1 dm<sup>3</sup> solution.

$$\text{Molarity of H}_2\text{SO}_4 = \frac{g / dm^3}{RFM} = \frac{4.9}{98} = 0.05M$$

**Example 24.** 25.0 cm<sup>3</sup> of a solution of sodium hydroxide of concentration 0.1 mole dm<sup>-3</sup> were exactly neutralized by 20.0 cm<sup>3</sup> of a solution of hydrochloric acid. Calculate the concentration of the acid solution (a) as a molarity (b) in g/dm<sup>3</sup>.

Reaction equation:



Mole of NaOH

1000 m<sup>3</sup> contain 0.1 moles

$$25 \text{ cm}^3 \text{ will contain } \frac{25 \times 0.1}{1000} = 0.0025 \text{ moles}$$

Moles of HCl

From the equation

1mole of NaOH react with 1 mole of HCl

$$\Rightarrow \text{moles of HCl} = \text{moles of NaOH} \\ = 0.0025 \text{ moles}$$

Molarity of HCl

20cm<sup>3</sup> contain 0.0025mole

$$1000\text{cm}^3 \text{ will contain } \frac{0.0025 \times 1000}{20} = 0.125 \text{ moles}$$

$\Rightarrow$  molarity of HCl = 0.125M

$$\begin{aligned} \text{Concentration} &= \text{moles} \times \text{RFM} \\ &= 0.125 \times 36.5 \\ &= 4.58 \text{ g/dm}^3 \end{aligned}$$

**Example 25.** In a titration 30 cm<sup>3</sup> of 0.4M sodium hydroxide require 40cm<sup>3</sup> of 0.15 M phosphoric acid, H<sub>3</sub>PO<sub>4</sub>.

- (i) How many moles of sodium hydroxide are present in  $30\text{cm}^3$  of solution?  
 (ii) How many moles of phosphoric acid are present in  $40\text{cm}^3$  of solution?  
 (iii) Find the number of moles of sodium hydroxide required to neutralize one mole of phosphoric acid?  
 (iv) Write the formula of the sodium salt formed and the equation for the reaction between the acid and sodium hydroxide?

Answer

$$(i) \text{ moles of NaOH} = \frac{30 \times 0.4}{1000} = 0.012 \text{ moles}$$

$$(ii) \text{ moles of H}_3\text{PO}_4 = \frac{40 \times 0.15}{1000} = 0.006 \text{ moles}$$

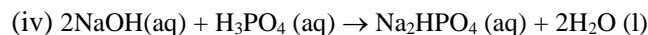
(iii) NaOH : H<sub>3</sub>PO<sub>4</sub>

$$0.012 : 0.006$$

$$0.006 \quad 0.006$$

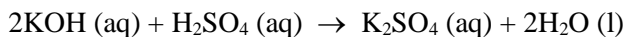
$$2 : 1$$

2 moles of NaOH required neutralizing one of phosphate acid.



The formula of sodium salt formed is Na<sub>2</sub>HPO<sub>4</sub>

**Example 26.**  $24.0\text{cm}^3$  of sodium of  $0.1\text{M}$  KOH were exactly neutralized by  $30.0\text{cm}^3$  of sodium of  $\chi\text{M}$  H<sub>2</sub>SO<sub>4</sub>. Find the concentration of the acid solution (a) as the molarity  $\chi$  (b) in  $\text{g/dm}^3$



Mole of KOH

1000 cm<sup>3</sup> contain 0.1 moles

$$24.0 \text{ cm}^3 \text{ will contain } \frac{24 \times 0.1}{1000} = 0.0024 \text{ moles}$$

Moles of H<sub>2</sub>SO<sub>4</sub>

From the equation

2mole of KOH react with 1 mole of H<sub>2</sub>SO<sub>4</sub>

⇒ moles of H<sub>2</sub>SO<sub>4</sub> = ½ moles of KOH

$$= \frac{0.0024}{2} = 0.0012 \text{ moles}$$

Molarity of  $\chi$  of H<sub>2</sub>SO<sub>4</sub>

30cm<sup>3</sup> contain 0.0012mole

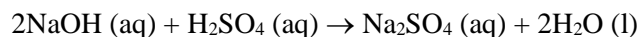
$$1000\text{cm}^3 \text{ will contains } \frac{0.0012 \times 1000}{30} = 0.04 \text{ moles}$$

$$\therefore \chi = 0.04\text{M}$$

Thus  $\text{g/dm}^3$  of H<sub>2</sub>SO<sub>4</sub> =  $0.04 \times 98 = 3.92\text{g/dm}^3$

**Example 27.** In an experiment to determine the concentration dilute sulphuric acid in moles per litre, 25 cm<sup>3</sup> of 0.2M sodium hydroxide solution required 24.6 of the acid. Calculate the molarity of the acid.

Equation.



Moles of the NaOH that reacted

1000 cm<sup>3</sup> contains 0.2 mole

1 cm<sup>3</sup> contains  $\frac{0.2}{1000}$  moles

25 cm<sup>3</sup> contain  $\frac{0.2 \times 25}{1000} = 0.005 \text{ moles}$

Moles of H<sub>2</sub>SO<sub>4</sub>

From the equation: 2 mole of NaOH reacts with 1 mole H<sub>2</sub>SO<sub>4</sub>.

0.05 mole of NaOH react with ( $\frac{1}{2} \times 0.005$ ) mole of acid

Molarity

$\therefore$  Mole of H<sub>2</sub>SO<sub>4</sub> in 24.6 cm<sup>3</sup> that reacted = 0.0025 mole

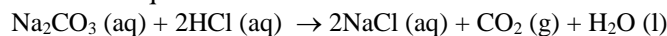
1 cm<sup>3</sup> contain  $\frac{0.0025}{24.6}$

$\Rightarrow$  1000 cm<sup>3</sup> contain  $\frac{0.0025 \times 1000}{24.6} = 0.102 \text{ mole}$

Therefore, molarity of H<sub>2</sub>SO<sub>4</sub> solution is **0.102M**

**Example 28.** Find the volume of 0.25M HCl required to exactly react with 20 cm<sup>3</sup> of 0.1M sodium carbonate solution.

Reaction equation



Moles of the Na<sub>2</sub>CO<sub>3</sub> that reacted

1000 cm<sup>3</sup> contains 0.1 moles

1 cm<sup>3</sup> contains  $\frac{0.1}{1000}$  moles

20 cm<sup>3</sup> contain  $\frac{0.1 \times 20}{1000} = 0.002 \text{ moles}$

Moles of HCl

From the equation; 1 mole of  $\text{Na}_2\text{CO}_3$  reacts with 2 mole HCl

0.02 mole of  $\text{Na}_2\text{CO}_3$  react with  $(0.02 \times 2)$  mole of HCl  
 $= 0.04$  moles

Volume of hydrochloric acid required  
 0.25 moles are contained in  $1000 \text{ cm}^3$

$$\Rightarrow 0.04 \text{ moles will be in } \frac{1000 \times 0.04}{0.25}$$

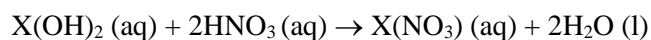
$$= 16 \text{ cm}^3$$

The volume required is  **$16 \text{ cm}^3$**

**Example 29.**  $20 \text{ cm}^3$  of  $0.1 \text{ M}$  nitric acid was completely neutralized by  $10 \text{ cm}^3$  of a hydroxide of a divalent metal  $\text{X}(\text{OH})_2$  which was made by dissolving  $5.8 \text{ g}$  of the hydroxide in 1 litre of solution. ( $\text{H}=1$ ,  $\text{O}=16$ ).

(a) Calculate the molarity of the hydroxide.

Reaction equation



No. of moles of the nitric acid that reacted

$$\begin{array}{ll} 1000 \text{ cm}^3 \text{ contains} & 0.1 \text{ moles} \\ 1 \text{ cm}^3 \text{ contains} & \frac{0.1}{1000} \text{ moles} \\ \Rightarrow 20 \text{ cm}^3 \text{ contain} & \frac{20 \times 0.1}{1000} \\ & = 0.002 \text{ moles} \end{array}$$

(b) Calculate the molar mass of  $\text{X}(\text{OH})_2$  and hence determine the atomic mass of X.

From the reaction equation 2 moles of nitric acid react with 1 mole of the hydroxide.

1 mole of nitric acid react with  $\frac{1}{2}$  moles of  $\text{X}(\text{OH})_2$

$$\Rightarrow \text{moles of the hydroxide in reacted } 0.002 \times \frac{1}{2}$$

$$= 0.001 \text{ mole}$$

Molarity of  $\text{X}(\text{OH})_2$

$$\therefore 10 \text{ cm}^3 \text{ of } \text{X}(\text{OH})_2 \text{ contain } 0.001 \text{ mole}$$

$$\begin{array}{ll} 1 \text{ cm}^3 \text{ contains} & \frac{0.001}{1000} \text{ moles} \\ \Rightarrow 1000 \text{ cm}^3 \text{ contains} & \frac{0.001 \times 1000}{10} \\ & = 0.1 \text{ moles} \end{array}$$

Therefore, molarity of the hydroxide = **0.1M.**

$$\begin{aligned} \text{(b) Molar mass of } X(\text{OH})_2 &= \frac{\text{concentration g/l}}{\text{molarity}} \\ &= \frac{5.8}{0.1} = 58\text{g} \end{aligned}$$

The atomic mass of X is obtained from using the molar mass, i.e.

$$\begin{aligned} \text{Molar mass of } X(\text{OH})_2 &= X + 2(16+1) = 58 \\ &= X + 34 = 58 \\ \Rightarrow X &= 24\text{g} \end{aligned}$$

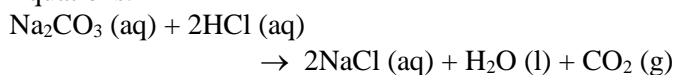
Thus, the hydroxide of compound X is magnesium hydroxide  $\text{Mg}(\text{OH})_2$ .

**Example 29.** In determination of water of crystallization of  $\text{Na}_2\text{CO}_3 \cdot n\text{H}_2\text{O}$ ,  $14 \text{ cm}^3$  of  $0.2\text{M HCl}$  was required to neutralize  $25 \text{ cm}^3$  of sodium carbonate prepared by dissolving  $4\text{g}$  of  $\text{Na}_2\text{CO}_3 \cdot n\text{H}_2\text{O}$  in  $250 \text{ cm}^3$  of solution.

(a) Calculate the molarity of sodium carbonate.

(b) Calculate the molar mass of the hydrated sodium carbonate and hence calculate the number of moles n of water of crystallization.

Equations.



Moles of the acid that reacted

$$\begin{aligned} 1000 \text{ cm}^3 &\text{ contain } 0.2 \text{ mole} \\ 1 \text{ cm}^3 &\text{ contain } \frac{0.2}{1000} \text{ moles} \\ \therefore 14 \text{ cm}^3 &\text{ contain } \frac{0.2 \times 14}{1000} = 0.0028 \text{ moles} \end{aligned}$$

From the reaction equation, 2 moles of HCl react with 1 mole of the base.

$$\begin{aligned} \text{Thus, moles } \text{Na}_2\text{CO}_3 \text{ in } 25 \text{ cm}^3 \text{ that reacted} &= \frac{0.0028}{2} \\ &= 0.0014 \text{ moles} \end{aligned}$$

$$\begin{aligned} 1 \text{ cm}^3 &\text{ contain } = \frac{0.28}{2 \times 25} \\ \Rightarrow 1000 \text{ cm}^3 &\text{ contain } \frac{0.28 \times 1000}{2 \times 25} \end{aligned}$$

22

$$= 0.056 \text{ M.}$$

thus, molarity of sodium carbonate solution is 0.056M.

(b) Molar mass of hydrated sodium carbonate

$$\text{Molar mass} = \frac{\text{Concentration g/l}}{\text{Molarity}} = \frac{2 \times 4}{0.056} = 286 \text{ g}$$

Value of n in the formula  $\text{Na}_2\text{CO}_3 \cdot n\text{H}_2\text{O}$  is calculated using the molar mass.

$$\text{thus, } (23 \times 2) + 12 + (16 \times 3) + 18n = 286$$

$$18n = 286 - 106$$

$$n = 10$$

**Example 29.** During determination of Basicity of an acid  $\text{H}_n\text{A}$ ,  $25 \text{ cm}^3$  of KOH prepared by dissolving 11.2 g in 1 litre of solution was required to neutralize  $25 \text{ cm}^3$  of 0.1M  $\text{H}_n\text{A}$ .

- (a) Calculate the molarity of the hydroxide.  
(b) Calculate the basicity of the acid.

a) Molarity of the hydroxide.

$$\text{Molarity} = \frac{\text{concentration (g/l)}}{\text{Formula mass}} \quad \text{Formula mass of KOH} = 39 + 16 + 1$$
$$= 56\text{g}$$

$$\therefore \text{Molarity} = \frac{11.2}{56} = 0.2\text{M}$$

(b) Basicity of the acid.



Reaction ratio n:1

Moles of the KOH that reacted

$$= \frac{0.2 \times 25}{1000} = 0.005 \text{ moles}$$

Moles of the acid that reacted

$$= \frac{0.1 \times 25}{1000} = 0.0025 \text{ moles}$$

Thus  $n = \frac{0.005}{0.0025} = 2$

**Example 31.** What volume of 5M  $H_2SO_4$  is required to prepare 250  $cm^3$  of 0.25M of the acid.

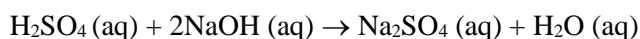
$$\text{Molarity}^1 \times \text{Volume}^1 = \text{Molarity}^2 \times \text{Volume}^2$$

$$5 \times \text{volume conc. acid} = 0.25 \times 250$$

$$\begin{aligned} \text{Volume of the conc. acid} &= \frac{0.25 \times 250}{5} \\ &= 12.5 \text{ cm}^3 \end{aligned}$$

**Example 32.** 10  $cm^3$  of concentrated sulphuric acid were diluted to 1000  $cm^3$ . 25  $cm^3$  of this diluted acid were neutralized by 30  $cm^3$  of 0.3 M sodium hydroxide. Calculate the mass of the acid in 1  $dm^3$  of the concentrated acid.

Equation.



Moles of NaOH that reacted.

1000  $cm^3$  contain 0.3 mole

$$1 \text{ cm}^3 \rightarrow \frac{0.3}{1000}$$

$$\therefore 25 \text{ cm}^3 \rightarrow \frac{0.3 \times 25}{1000}$$

$$= 0.009 \text{ moles}$$

but, 2 moles of NaOH react with 1 mole of the acid.

$\therefore$  moles of  $H_2SO_4$  in 25 ml of the dilute acid

$$= 0.009 \times \frac{1}{2}$$

$$1000 \text{ cm}^3 \text{ contain } \frac{0.009 \times 1000}{25 \times 2} = 0.18 \text{ moles}$$

$\therefore$  molarity of the dilute solution is 0.18M

Since 10  $cm^3$  of the concentrated acid was diluted to 1000  $cm^3$  to make the dilute solution, then.

$$\text{Molarity}^1 \times \text{Volume}^1 = \text{Molarity}^2 \times \text{Volume}^2$$

$$10X = 1000 \times 0.18$$

where X is the molarity of the concentrated acid.

thus,  $X = 18M$

The mass of the acid in  $1dm^3$  of concentrated acid = Molarity  $\times$  Molar mass

$$= 18 \times 98$$

$$= 1764 \text{ g.}$$

**Example 33.** In the determination of the percentage purity of  $NH_4Cl$ ; 5.0 g of an impure salt of  $NH_4Cl$  was boiled with  $100cm^3$  of  $2M$   $NaOH$  for about 10 minutes. The residual solution was made up to  $250 cm^3$  in a volumetric flask with distilled water.  $25 cm^3$  portion of the resultant solution required  $22.4 cm^3$  of  $0.5M$   $HCl$  for neutralization using methyl orange indicator.

(a) Calculate the percentage of  $NH_4Cl$  in the sample

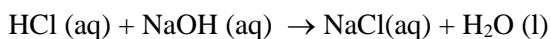
(b) Hence determine the percentage of ammonia in the pure sample.

Equations

(i) Sodium hydroxide react with  $NH_4Cl$  to release ammonium gas which is lost on heating as per the equation.



(ii) Excess sodium hydroxide reacts with  $HCl$  as per the equation.



Moles of the acid that reacted with excess base

$$\begin{aligned} 1000 \text{ cm}^3 \text{ contain } & 0.5 \text{ moles} \\ \therefore 22.4 \text{ cm}^3 \text{ contain } & \frac{0.5 \times 22.4}{1000} \\ & = 0.0112 \text{ moles} \end{aligned}$$

But, 1 mole of the acid reacts with 1 mole of the base

$\therefore$  moles of excess  $NaOH$  in  $25 cm^3$  of the solution

$$250 \text{ cm}^3 \text{ will contain } \frac{0.0112 \times 250}{25} = 0.0112 \text{ moles}$$



Moles of NaOH added to impure  $\text{NH}_4\text{Cl}$

1000  $\text{cm}^3$  contain 2 moles

$$\therefore 100 \text{ cm}^3 \text{ contain } \frac{2 \times 100}{1000} = 0.2 \text{ moles}$$

Mole of NaOH that reacted with  $\text{NH}_4\text{Cl}$  is equivalent to the difference between moles NaOH added and that found in excess.

$$= 0.2 - 0.112 = 0.088 \text{ moles}$$

Since 1 mole of NaOH reacts with 1 mole  $\text{NH}_4\text{Cl}$ , then mole of  $\text{NH}_4\text{Cl}$  that reacted  
= 0.088

$$\begin{aligned} \text{Mass of 0.088 moles of } \text{NH}_4\text{Cl} &= \text{molarity} \times \text{molar mass} \\ &= 0.088 (14+4+35.5) \\ &= 4.708 \text{ g} \end{aligned}$$

$$\text{Percentage purity} = \frac{\text{Mass of pure substance} \times 100}{\text{Total mass of impure sample}}$$

$$\therefore \text{Percentage purity of } \text{NH}_4\text{Cl} = \frac{4.708 \times 100}{5.0}$$

$$= 94.2\%$$

(b) Percentage of ammonia in the pure sample

Every 53.5 g of  $\text{NH}_4\text{Cl}$  contain 17g of  $\text{NH}_3$

$$\therefore 4.708 \text{ contain } \frac{17 \times 4.708}{53.5} = 1.496 \text{ g}$$

$$\begin{aligned} \text{Percentage of } \text{NH}_3 \text{ in pure sample} &= \frac{1.496 \times 100}{4.708} \\ &= 31.77\% \end{aligned}$$

## Exercise V

1. What is the molarity of 21.2 g of sodium carbonate dissolved in 10 litres of solution (Na=23, C=12, O=16).
2. Find the volume of 0.01M sodium hydroxide which is required to react exactly with 25  $\text{cm}^3$  of 0.02M HCl.
3. 25  $\text{cm}^3$  of 0.1M sodium carbonate was found to react with 23.3  $\text{cm}^3$  of HCl to complete neutralization. Calculate the molarity of hydrochloric acid.
4. A solution of 0.1M HCl and volume 25  $\text{cm}^3$  required 12.5  $\text{cm}^3$  of a metal hydroxide  $\text{M}(\text{OH})_2$  which was prepared by dissolving 1.45 g of the  $\text{M}(\text{OH})_2$  in 250  $\text{cm}^3$  of solution. (H=1, O=16)
  - (a) Calculate the molarity of  $\text{M}(\text{OH})_2$

- (b) Calculate the molar mass of  $M(OH)_2$   
 (c) Calculate the atomic mass of M.

5. Calculate the molarity and concentration in grams per litre of a sodium hydroxide solution, if  $12.5 \text{ cm}^3$  of  $0.2 \text{ M H}_2\text{SO}_4$  acid required  $25 \text{ cm}^3$  of NaOH for complete neutralization.

6.  $25 \text{ cm}^3$  of oxalic ( $\text{H}_2\text{C}_2\text{O}_4 \cdot n\text{H}_2\text{O}$ ) acid solution prepared by dissolving  $2.52 \text{ g}$  of the acid into  $250 \text{ cm}^3$  required  $20 \text{ cm}^3$  of sodium hydroxide solution prepared by dissolving  $8 \text{ g}$  of the hydroxide in one litre of solution.

- (a) Calculate the molarity of sodium hydroxide solution.  
 (b) Calculate the molarity of oxalic ( $\text{H}_2\text{C}_2\text{O}_4 \cdot n\text{H}_2\text{O}$ ) acid solution  
 (c) Calculate the value of n (the mole of molecules of water of crystallization ( $c=12, H=1, O=16, N=23$ ))

7. Calculate the molarities/concentrations of the following solutions.

- (a)  $20.0 \text{ g}$  of sodium hydroxide, NaOH, in  $250 \text{ cm}^3$  of solution;  
 (b)  $3.8 \text{ g}$  of iron (II) sulphate,  $\text{FeSO}_4$ , in  $100 \text{ cm}^3$  solution.

8. Calculate the number of moles of the named substance in

- (a)  $50 \text{ cm}^3$  of  $0.1 \text{ M}$  nitric acid.  
 (b)  $100 \text{ cm}^3$  of  $1.5 \text{ M}$  sodium carbonate.

9. Calculate the masses of dissolved substances contained in

- (a)  $100 \text{ cm}^3$  of  $2 \text{ M}$  sodium sulphate solution,  $\text{Na}_2\text{SO}_4$ .  
 (b)  $50 \text{ cm}^3$  of  $0.2 \text{ M}$  potassium carbonate,  $\text{K}_2\text{CO}_3$ .

10.  $8.48 \text{ g}$  of a mixture of sodium chloride and anhydrous sodium carbonate were dissolved in  $100 \text{ cm}^3$  of solution.  $5 \text{ cm}^3$  of this solution required  $40 \text{ cm}^3$  of  $0.1 \text{ M HCl}$  for complete neutralization. Calculate the percentage composition of the original mixture.

11. Concentrated hydrochloric acid containing  $36\%$  by mass of the acid has a density of  $1.18 \text{ g/cm}^3$ . Calculate the volume of this acid required to neutralize  $8.4 \text{ g}$  of sodium hydrogen carbonate.

12.  $20 \text{ cm}^3$  of  $0.9 \text{ M}$  sodium hydroxide solution were added to  $50 \text{ cm}^3$  of nitric acid. The excess acid neutralized  $20 \text{ cm}^3$  of  $1.1 \text{ M}$  alkali. Calculate the molarity of the original acid solution and the number of grams of nitric acid per  $\text{dm}^3$  of this solution.

13.  $2 \text{ g}$  of impure calcium carbonate were added to  $80 \text{ cm}^3$  of  $1.25 \text{ M}$  hydrochloric acid. The resulting solution was made up to  $100 \text{ cm}^3$  and  $10 \text{ cm}^3$  of this neutralized  $12.5 \text{ cm}^3$  of sodium hydroxide solution containing  $20 \text{ g/dm}^3$ . Determine the percentage purity of the calcium carbonate.

14.  $0.15 \text{ g}$  of an ammonium salt was heated with excess sodium hydroxide. The ammonia given off was absorbed in  $25 \text{ cm}^3$  of  $0.16 \text{ M HCl}$ . The excess acid required  $12 \text{ cm}^3$  of  $0.2 \text{ M}$  sodium hydroxide for neutralization. Calculate the percentage of ammonia in the salt.

15.  $24 \text{ cm}^3$  of solution of tribasic acid containing  $12 \text{ g}$  of the acid per  $\text{dm}^3$  of solution just neutralized  $48 \text{ cm}^3$  of  $0.09 \text{ M}$  sodium hydroxide. Calculate the molar mass of the acid.

1985/2/6

- (a) (i) Explain the term primary standard solution (3marks)  
 (ii) Why is sodium hydroxide NOT recommended as a primary standard for volumetric analysis? (2 marks)
- (b) (i) Why does the salt of sodium carbonate behaves as an alkali in acid-base titration?  
 (ii) 21.40g of hydrated sodium carbonate ( $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$ ) was dissolved in water to make a litre of solution. 25 cm<sup>3</sup> of this solution required 18.70cm<sup>3</sup> of 0.2M standard hydrochloric acid solution for complete neutralization. Calculate the value of X.

1991/1/11

A hydrated compound Q contains the following ions, iron, sulphate and ammonium.

(a) When 9.64g of Q was heated, 4.32g of water was evolved. Determine the number of moles of water of crystallization in Q. (1mark).

(b) When a solution containing 9.64g of Q was heated strongly with excess sodium hydroxide solution, 2.14g of hydroxide of iron was formed together with ammonia. The ammonia required 100cm<sup>3</sup> of 0.2M hydrochloric acid for complete neutralization.

Calculate

- (i) the number of moles of ammonium ions in Q  
 (2marks)
- (ii) the number of moles of irons in Q (2marks)
- (c) A solution containing 9.64g of Q was treated with excess barium chloride solution gave 9.32g of barium sulphate. Determine the number of moles of sulphate ions in Q (2marks)
- (d) Determine the molecular formula of Q. (2marks)

1991/1/1

Concentrated sulphuric acid is 18M. Calculate the volume, in cm<sup>3</sup> of the acid that would be required to prepare 200cm<sup>3</sup> of 2.0M sulphuric acid (3 marks)

1992/2/8

- (b) Concentrated nitric acid is 70% (w/w) and has a density of 1.42gcm<sup>-3</sup>.  
 (c) 12.68 cm<sup>3</sup> of the acid in (b) was dissolved in water and the solution made up to 250 cm<sup>3</sup> with distilled water. Calculate the volume that would react completely with 25.0cm<sup>3</sup> of 0.2M sodium carbonate (4 marks)

1994/1/15

1.55g of an acid  $\text{C}_n\text{H}_{2n}(\text{COOH})_2$  was dissolved in water and the solution made up to 250cm<sup>3</sup>. 25.0cm<sup>3</sup> of this solution required 23.5cm<sup>3</sup> of 0.1M aqueous sodium hydroxide solution for complete neutralization.

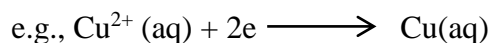
Calculate n (9 marks)

2003/2/8c

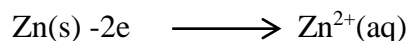
1.07g of a nitrogen containing compound was boiled with excess sodium hydroxide solution to produce ammonia. The ammonia produced neutralized 200cm<sup>3</sup> of a 0.1M monobasic acid. Calculate the percentage by mass of nitrogen in the compound (3)

## Redox titration

Redox reaction is a reaction in which both reduction and oxidation take place simultaneously. A reduction reaction is where there is addition of electrons to an ion species;



whereas, oxidation is loss of electrons from a compound.



The species which accepts electrons such as  $\text{Cu}^{2+}$  is reduced but is referred to as an oxidizing agent.

The species which donates electrons such as  $\text{Zn}^{2+}$  is oxidized but is referred to as a reducing agent

### Oxidation Number

This is a number used to express the oxidation state of an element. Atoms of elements are given oxidation number zero. Then when two elements are combined the atoms or ions of more electronegative element are regarded as being in negative oxidation state, and those of a more electropositive element in a positive state. If we arbitrarily assume that the bonds between the atoms are

all ionic, the oxidation number of an element is simply the number of electrons given up or received by an atom of an element. In sodium chloride the oxidation number of sodium is 1, while that of chlorine is -1. hydrogen in HCl has oxidation number 1 but in sodium hydride, NaH is -1. Some elements have several oxidation states. Sulphur has oxidation number -2 in H<sub>2</sub>S, 4 in SO<sub>2</sub> and VI in SO<sub>3</sub>. chlorine shows a wide variety of oxidation number, e.g. -1 in HCl, 0 in Cl<sub>2</sub>, 1 in ClO<sup>-</sup>, 3 in ClF<sub>3</sub>, 4 in ClO<sub>2</sub>, 5 in ClO<sub>3</sub><sup>-</sup>, 6 in ClO<sub>3</sub> and 7 in ClO<sub>4</sub><sup>-</sup>.

An increase in oxidation number of an element during a reaction means that an element has been oxidized. conversely, a decrease in oxidation number means that an element has been reduced.

### Calculating oxidation number of ions of an element in complex ions.

Unless otherwise stated or implied in these calculations, the oxidation number of a metal is equal to group number, e.g., Na is 1, Mg is 2 Al is 3. Oxidation number of O is -2 and that of any group 7 element is -1.

**Example 34.** calculate the oxidation number of manganese ion in KMnO<sub>4</sub>.

Here the oxidation number of K = 1 and that of oxygen is implied to be -2. if the oxidation number of Mn is X

Then,  $1 + X + -2 \times 4 = 0$  (overall charge ion the molecule)

$$X = 7$$

### Exercise VI

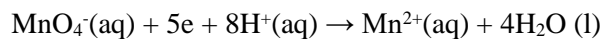
Calculate the oxidation numbers of the Bolden atoms in molecules or atoms below

1. (i) KIO<sub>3</sub>    (ii) SO<sub>4</sub><sup>2-</sup>    (iii) Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>  
 (iv) H<sub>2</sub>O<sub>2</sub>    (v) KClO<sub>4</sub>    (vi) Na<sub>2</sub>S<sub>2</sub>O<sub>6</sub>

### Half equations

These are balanced based on the number of electrons lost or accepted by a central atom.

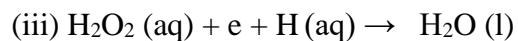
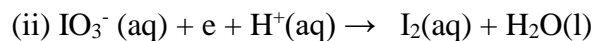
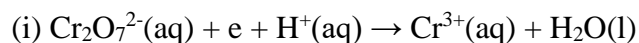
Example, equation for reduction of manganate (VII) in acidic medium is written as follows:



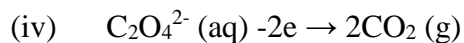
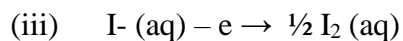
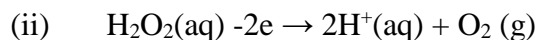
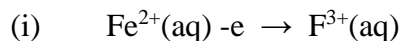
Five electrons are added because the oxidation number of Mn is reduced from 7 to 2.

### Exercise VI I

Balance the following reduction equations



The following are common oxidation half equation reactions:

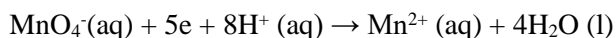


**Overall equation**

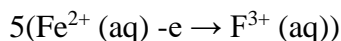
These are constructed from half equation in such a way that the number electron received by an oxidizing agent is equal to the number of electron lost from a reducing agent.

For example a reaction between  $\text{MnO}_4^-$  and  $\text{Fe}^{2+}$  in acidic medium, the half equation of  $\text{Fe}^{2+}$  is multiplied by 5 to provide the 5 electron necessary to reduce  $\text{MnO}_4^-$ .

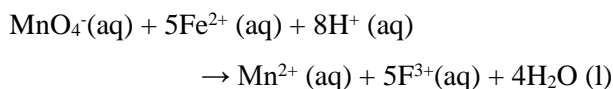
**That is,**



**Plus**



**Equals**

**Exercise VI**

1. Write overall equations between the following pairs of ions or compounds, assume acidic medium where necessary

- (a)  $\text{MnO}_4^-$  and  $\text{I}^-$     (b)  $\text{MnO}_4^-$  and  $\text{H}_2\text{O}_2$   
 (c)  $\text{KIO}_3$  and  $\text{KI}$     (d)  $\text{MnO}_4^-$  and  $\text{C}_2\text{O}_4^{2-}$   
 (e)  $\text{K}_2\text{Cr}_2\text{O}_7$  and  $\text{FeSO}_4$

2. 0.9875g of an impure potassium manganate (VII) was dissolved in water to make  $250\text{cm}^3$  of solution. When  $20.0\text{cm}^3$  of this solution was acidified with dilute sulphuric acid, warmed and titrated against sodium ethanedioate (oxalate) solution, made by dissolving 1.675g of anhydrous sodium ethanedioate to make  $250\text{cm}^3$ ,  $24.40\text{cm}^3$  of sodium ethanedioate solution was used. ( $\text{Na}_2\text{C}_2\text{O}_4 = 134$  and  $\text{KMnO}_4 = 158$ ).

Calculate percentage purity of potassium permanganate (VII)

3.  $10\text{cm}^3$  of concentrated hydrogen peroxide was diluted to  $250\text{cm}^3$ .  $20\text{cm}^3$  of the dilute solution required  $28.30\text{cm}^3$  of 0.02M potassium manganate (VII) solution for complete reaction. Find the volume strength of the concentrated hydrogen peroxide solution.

1990/1/5

Potassium permanganate is commonly used as a reagent in volumetric analysis. However it is not a primary standard.

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- (a) State two disadvantages of using potassium manganate (VII) as a reagent in volumetric analysis.
- (b) Give two reasons why potassium manganate (VII) is not used as a primary standard
- (c) Write a half equation for the reduction of manganate (VII) ions in
- acid solution
  - alkaline solution

1994/1/17

- (a) In volumetric estimation of a reducing agent, potassium dichromate (VI) is preferred to potassium manganate (VII) as an oxidant

Explain why potassium dichromate (VI) is preferred as an oxidant. (2 marks)

- (b) 3.8g of solder containing tin was dissolved in excess hydrochloric acid. The solution was made up to 250 cm<sup>3</sup>. 25.0 cm<sup>3</sup> of this solution required 23.5 cm<sup>3</sup> of a 0.01 M potassium dichromate (VI) solution for complete reaction.

Calculate the percentage, by mass, of tin in the solder.

- (d) Explain why chlorine is more soluble in dilute sodium hydroxide than in water (4 marks)

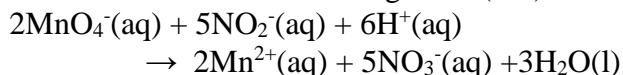
1999/1/1

- (a) Determine the oxidation number of
- Nitrogen in HNO<sub>3</sub>
  - Sulphur in S<sub>2</sub>O<sub>8</sub> (1 mark)
- (b) Write half equation for the conversion of S<sub>2</sub>O<sub>8</sub><sup>2-</sup> to SO<sub>4</sub><sup>2-</sup> ions
- (c) Complete the following and balance the equations
- S<sub>2</sub>O<sub>8</sub><sup>2-</sup> + I<sup>-</sup> →
  - Sn<sup>2+</sup>(aq) + S<sub>2</sub>O<sub>8</sub><sup>2-</sup>(aq) →

2001/1/14

Iron (II) sulphate is normally used to standardize a solution of potassium manganate (VII) acidified with sulphuric acid.

- (i) write equation for the reaction between potassium manganate (VII) and iron (II) sulphate
- (ii) State why hydrochloric acid is not used to acidify potassium manganate (VII) solution
- (b) 25 cm<sup>3</sup> of acidified solution of 0.02 M potassium manganate (VII) reacted exactly with 24.95 cm<sup>3</sup> of sodium nitrite. Potassium manganate (VII) reacts with sodium nitrite according to the following equation



Calculate the concentration of sodium nitrite in moles per litre.



**Iodometry**

Here a substance is reacted with excess potassium iodide in redox equation to liberate iodine; the amount of iodine liberated is determined by titration with sodium thiosulphate solution to determine the concentration of the substance.

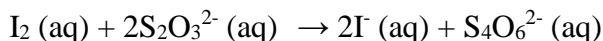
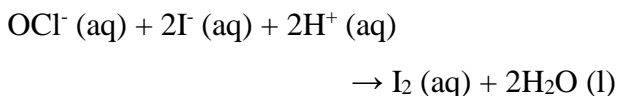
**Example 35**

Find concentration of NaOCl in gram per litre given that 20cm<sup>3</sup> of NaOCl solution was reacted with excess potassium iodide, the liberated iodine required 25 cm<sup>3</sup> of 0.1M sodium thiosulphate solution.

**Solution**

In acid medium, sodium chlorate reacts with iodide ions to liberate iodine, which oxidizes thiosulphate ions.

The reactions take place according to the following equations



Moles of sodium thiosulphate that reacted  
100cm<sup>3</sup> contain 0.1moles

$$25\text{cm}^3 \text{ contain } \frac{0.1 \times 25}{1000} = 0.0025 \text{mols}$$

Moles of iodine produced from equation 2

$$= \frac{0.0025}{2} = 0.00125 \text{moles}$$

**Moles NaOCl**

From equation 1, moles of NaOCl is equal to the moles of iodine = 0.00125 moles

**Molarity of NaOCl**

20cm<sup>3</sup> of NaOCl solution contain 0.00125 moles

$$1000\text{cm}^3 \text{ contain } \frac{0.00125 \times 1000}{20} = 0.0625\text{M}$$

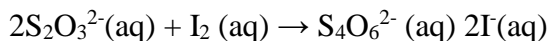
Concentration in grams per litre

$$\begin{aligned} 1 \text{ mole of NaOCl weighs} &= (40 + 16 + 35.5) \\ &= 91.5\text{g} \\ 0.0625 \text{ moles weigh} &= 91.5 \times 0.0625 \\ &= 5.7\text{g/l} \end{aligned}$$

**Exercise VII****1986/2/8e**

6.53 g of impure copper was dissolved in excess nitric acid. The solution obtained made up to 250cm<sup>3</sup> of solution with water. To 25cm<sup>3</sup> of this solution excess aqueous potassium iodide was added. The reaction that took place is given by the equation  
 $2\text{Cu}^{2+}(\text{aq}) + 4\text{I}^-(\text{aq}) \rightarrow \text{Cu}_2\text{I}_2 (\text{s}) + \text{I}_2 (\text{aq})$

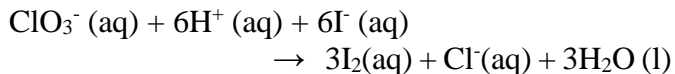
The iodine liberated reacted with 20cm<sup>3</sup> of 0.5M aqueous sodium thiosulphate according to the equation



Calculate the percentage of by mass the purity of copper in the sample (Cu =64) (6marks)

**1997/2/7c**

2.0g of a mixture of potassium chloride and potassium chlorate were dissolved in 250cm<sup>3</sup> of water. 10cm<sup>3</sup> of the solution was mixed with excess potassium iodide. The iodine liberated required 8.0cm<sup>3</sup> of a 0.2M sodium thiosulphate solution for complete reaction. Potassium chlorate and potassium chloride react according to the equation



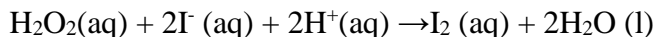
Calculate the percentage of potassium chlorate in the mixture (6marks)

**Question**

During the determination of concentration of hydrogen peroxide in g/dm<sup>3</sup> of the medical hydrogen peroxide, 12 cm<sup>3</sup> of medical hydrogen peroxide was diluted to 250cm<sup>3</sup> with distilled water. 20cm<sup>3</sup> of the

dilute solution was acidified required and excess KI added. The liberated iodine required 22cm<sup>3</sup> of sodium thiosulphate solution containing 9.3g Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>.5H<sub>2</sub>O in 250cm<sup>3</sup> of solution.

In acid medium, hydrogen peroxide reacts with iodide ions follows”



Calculate the volume strength of medical hydrogen peroxide.

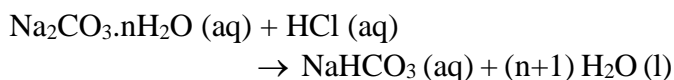
### Double indicator titration.

Titration requiring use of two indicators is employed to determine the concentrations and proportions of any two of the following base in a mixture, i.e. NaOH, Na<sub>2</sub>CO<sub>3</sub> and NaHCO<sub>3</sub>. Ideally, the two indicators referred to here are the phenolphthalein and methyl orange indicator. The basis of these titrations is that, NaOH, and Na<sub>2</sub>CO<sub>3</sub> are titrated to complete neutralization with methyl orange, whereas, NaHCO<sub>3</sub> is acidic to phenolphthalein indicator and thus Na<sub>2</sub>CO<sub>3</sub> is only half neutralized when titrated with an acid in presence of phenolphthalein indicator.

**Example 36.** 7.15 g sodium carbonate Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O was dissolved in water to make 250 ml of solution. 25.0 cm<sup>3</sup> of this solution required 12.50 cm<sup>3</sup> of 0.2 M HCl using phenolphthalein indicator. Calculate the value if n.

Equation

In presence of phenolphthalein indicator sodium carbonate is only half neutralized as per the equation



Moles of the acid that reacted:

$$1000 \text{ cm}^3 \text{ contain } 0.2 \text{ mole}$$

$$\therefore 12.5 \text{ cm}^3 \text{ contain } \frac{0.2 \times 12.5}{1000}$$

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$$= 0.0025 \text{ mole}$$

From the reaction equation, 1 mole of Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O reacts with 1 mole of HCl.

$\therefore$  0.0025 mole of the acid react with 0.0025 mole of Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O.

Molarity of Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O

$\Rightarrow$  25,0 cm<sup>3</sup> of Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O solution contain 0.0025 mole of Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O.

$$1000 \text{ cm}^3 \text{ contain } \frac{0.0025 \times 1000}{25}$$

$$= 0.1\text{M}$$

$\therefore$  Molarity of Na<sub>2</sub>CO<sub>3</sub>.nH<sub>2</sub>O solution is 0.1M

$$\text{RMM of Na}_2\text{CO}_3.n\text{H}_2\text{O} = \frac{\text{Concentration g/l}}{\text{Molarity}}$$

$$= \frac{7.15 \times 4}{0.1}$$

$$= 286$$

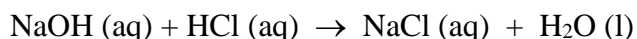
$$\text{Thus, } (23 \times 2) + 12 + (16 \times 3) + n(2+16) = 286$$

$$106 + 18n = 286$$

$$n = 10$$

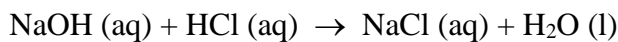
**Example 35.** 25.0 cm<sup>3</sup> of a solution containing a mixture of sodium hydroxide and sodium hydrogen carbonate require 15.0 cm<sup>3</sup> of 0.1M HCl using phenolphthalein indicator. 25.0 cm<sup>3</sup> of the same mixture required 28 cm<sup>3</sup> of the acid using methyl orange indicator. Calculate the proportion by mass of the two bases in the mixture.

Equation for the reaction that took place using phenolphthalein

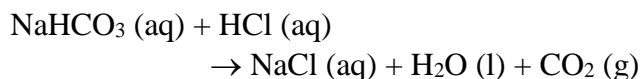


∴ 15 cm<sup>3</sup> of 0.1M HCl was required to neutralize NaOH is 25 cm<sup>3</sup> of the mixture.

*Equations using methyl orange indicator*



and



∴ The difference between the volume (28 – 15 = 13 cm<sup>3</sup>) of the acid was required to neutralize NaHCO<sub>3</sub>.

No. of moles of the acid that reacted with NaOH

1000 cm<sup>3</sup> contain 0.1 mole

∴ 15 cm<sup>3</sup> contain  $\frac{0.1 \times 15}{1000} = 0.0015$  mole

From the reaction ratio of 1:1, 1 mole of HCl reacts with 1 mole of NaOH.

⇒ moles of NaOH in 25 cm<sup>3</sup> = 0.0015 mole

1000 cm<sup>3</sup> will contain  $\frac{0.0015 \times 1000}{25}$   
= 0.06 M

Concentration of NaOH in g/L = RMM x Molarity

= 40 x 0.06

= 2.4 g/dm<sup>3</sup>

No. of moles of the acid that reacted with NaHCO<sub>3</sub>.

1000 cm<sup>3</sup> contain 0.1 mole

∴ 13 cm<sup>3</sup> contain  $\frac{0.1 \times 13}{1000} = 0.0013$  mole

From the reaction ratio of 1:1,  
1mole of HCl reacts with 1 mole of the NaHCO<sub>3</sub>.

⇒ moles of NaHCO<sub>3</sub> in 25 cm<sup>3</sup> = 0.0013 mole

1000 cm<sup>3</sup> will contain  $\frac{0.0013 \times 1000}{25}$   
= 0.052 M

Concentration of NaHCO<sub>3</sub> in g/L = RMM x Molarity

= 84 x 0.052

= 4.368 g/dm<sup>3</sup>

The ratio of masses of NaOH : NaHCO<sub>3</sub> is 2.4 : 4.368

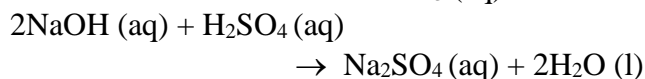
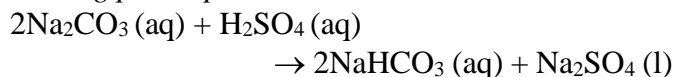
= 1 : 1.82

**Example 36. (1990/1/13)** 25.0 cm<sup>3</sup> of a solution containing a mixture of sodium carbonate and sodium hydroxide require 30.0 cm<sup>3</sup> of 0.1M H<sub>2</sub>SO<sub>4</sub> using phenolphthalein indicator. Another 25.0 cm<sup>3</sup> of the same mixture required 48.0 cm<sup>3</sup> of the acid using methyl orange indicator. Calculate the molar concentration of the mixture with respect to:

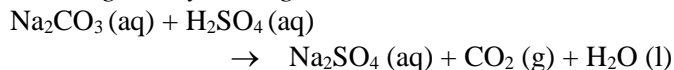
(i) Sodium carbonate (ii) sodium hydroxide. (9Marks)

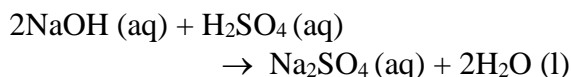
Reaction Equations.

1. Using phenolphthalein indicator.



2. Using methyl orange indicator.





From the reactions above, the extra volume (48 - 30 = 18 cm<sup>3</sup>) of acid under methyl orange indicator is used to half neutralization of Na<sub>2</sub>CO<sub>3</sub>. This also is equal to the volume of the acid that converts Na<sub>2</sub>CO<sub>3</sub> to NaHCO<sub>3</sub>.

∴ the volume of the acid that completely neutralized Na<sub>2</sub>CO<sub>3</sub> in 25 cm<sup>3</sup> of solution = 18 x 2 = 36 cm<sup>3</sup>.

And volume of the acid that reacted with NaOH = 30 - 18 = 12 cm<sup>3</sup>.

No. of moles of the acid that reacted with NaOH.

$$1000 \text{ cm}^3 \text{ contain } \frac{0.1 \text{ mole}}{1000}$$

$$\therefore 12 \text{ cm}^3 \text{ contain } \frac{0.1 \times 12}{1000} = 0.0012 \text{ mole}$$

From the reaction ratio of 1:2, 1 mole of H<sub>2</sub>SO<sub>4</sub> reacts with 2 moles of NaOH.

$$\Rightarrow \text{moles of NaOH in } 25 \text{ cm}^3 = 0.0012 \times 2 \text{ mole}$$

$$1000 \text{ cm}^3 \text{ will contain } \frac{0.0012 \times 2 \times 1000}{25}$$

$$= 0.048 \text{ M}$$

∴ Molarity of solution in respect to NaOH = 0.048M.

No. of moles of the acid that reacted with Na<sub>2</sub>CO<sub>3</sub>.

$$1000 \text{ cm}^3 \text{ contain } 0.1 \text{ mole}$$

$$\therefore 36 \text{ cm}^3 \text{ contain } \frac{0.1 \times 36}{1000} = 0.0036 \text{ mole}$$

From the reaction ratio of 1:1, 1 mole of H<sub>2</sub>SO<sub>4</sub> reacts with 1 mole of the Na<sub>2</sub>CO<sub>3</sub>.

$$\Rightarrow \text{moles of Na}_2\text{CO}_3 \text{ in } 25 \text{ cm}^3 = 0.0036 \text{ mole}$$

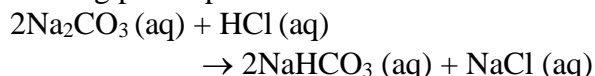
$$1000 \text{ cm}^3 \text{ will contain } \frac{0.0036 \times 1000}{25} = 0.144 \text{ M}$$

∴ the molarity of solution in respect to Na<sub>2</sub>CO<sub>3</sub> is **0.144M**

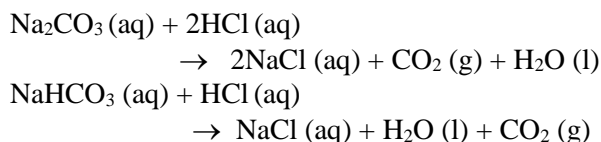
**Example 37.** 25.0 cm<sup>3</sup> of a solution containing a mixture of sodium carbonate and sodium hydrogen carbonate require 15.0 cm<sup>3</sup> of 0.5M HCl using phenolphthalein indicator. Another 25.0 cm<sup>3</sup> of the same mixture required 34.5 cm<sup>3</sup> of the acid using methyl orange indicator. Calculate the concentration of the mixture with respect to: (i) sodium carbonate (ii) sodium hydrogen carbonate per dm<sup>3</sup> of solution.

Reaction Equations.

1. Using phenolphthalein indicator.



2. Using methyl orange indicator.



From the reactions above, 15.0 cm<sup>3</sup> of the acid was required for half neutralization of Na<sub>2</sub>CO<sub>3</sub>.

∴ the volume of the acid that completely neutralized Na<sub>2</sub>CO<sub>3</sub> in 25 cm<sup>3</sup> of solution = 15 x 2 = 30 cm<sup>3</sup>.

and volume of the acid that reacted with NaHCO<sub>3</sub> initially in 25.0 cm<sup>3</sup> of the mixture = 34.5 - 30 = 4.5 cm<sup>3</sup>.

No. of moles of the acid that reacted with Na<sub>2</sub>CO<sub>3</sub>.

$$1000 \text{ cm}^3 \text{ contain } 0.5 \text{ mole}$$

$$\therefore 30 \text{ cm}^3 \text{ contain } \frac{0.5 \times 30}{1000} = 0.015 \text{ mole}$$

From the reaction ratio of 2:1, 2 mole of HCl react with 1 mole of the  $\text{Na}_2\text{CO}_3$

$$\Rightarrow \text{moles of NaOH in } 25 \text{ cm}^3 = \frac{0.015}{2} = 0.0075 \text{ moles}$$

$$1000 \text{ cm}^3 \text{ will contain } = \frac{0.0075 \times 1000}{25} = 0.3 \text{ M}$$

Concentration of  $\text{Na}_2\text{CO}_3$  in g/L = RMM x Molarity

$$= 106 \times 0.3$$

$$= 31.8 \text{ g/dm}^3$$

No. of moles of the acid that reacted with  $\text{NaHCO}_3$

$$1000 \text{ cm}^3 \text{ contain } 0.5 \text{ mole}$$

$$\therefore 4.5 \text{ cm}^3 \text{ contain } \frac{0.5 \times 4.5}{1000} = 0.00225 \text{ mole}$$

From the reaction ratio of 1:1, 1 mole of HCl reacts with 1 mole of  $\text{NaHCO}_3$ .

$$\Rightarrow \text{moles of NaHCO}_3 \text{ in } 25 \text{ cm}^3 = 0.00225 \text{ mole}$$

$$1000 \text{ cm}^3 \text{ will contain } \frac{0.00225 \times 1000}{25}$$

$$= 0.09 \text{ M}$$

Concentration of  $\text{NaHCO}_3$  in g/L

$$= \text{RMM} \times \text{Molarity}$$

$$= 84 \times 0.09$$

$$= \mathbf{7.56 \text{ g/dm}^3}$$

**Exercise IV**

1.  $25.0 \text{ cm}^3$  of a solution containing a mixture of sodium carbonate and sodium hydroxide require  $27.2 \text{ cm}^3$  of  $0.05\text{M H}_2\text{SO}_4$  using phenolphthalein indicator. Another  $25.0 \text{ cm}^3$  of the same mixture required  $37.6 \text{ cm}^3$  of the acid using methyl orange indicator. Calculate the mass of each base in  $250 \text{ cm}^3$  of the mixture.

2.  $25.0 \text{ cm}^3$  of a solution containing a mixture of sodium carbonate and sodium hydrogen carbonate require  $11.2 \text{ cm}^3$  of  $0.1\text{M HCl}$  using phenolphthalein indicator and a further  $28.6 \text{ cm}^3$  of the acid using methyl orange indicator. Calculate the percentage (w/v) of sodium carbonate in the mixture.

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$25.0\text{cm}^3$  of a solution containing a mixture of sodium carbonate and sodium hydrogen carbonate required  $15.00\text{cm}^3$  of  $0.5\text{M}$  hydrochloric acid for complete reaction using phenolphthalein indicator.

$25.0\text{cm}^3$  of solution of the mixture required  $34.50\text{cm}^3$  of the acid using methyl orange indicator. Calculate the mass of sodium carbonate and sodium hydrogen carbonate in the solution in grams per litre. (6marks)

**Answers****Exercise I**

i. (a) 132, (b) 286, (c) 90 (d) 116

ii.  $^{63}\text{Cu} = 72.5\%$ ,  $^{65}\text{Cu} = 27.5\%$

**Exercise II**

1. (i) 5L, (ii) 25L (ii) 0.1L.

2. (a)  $1.2 \times 10^{23}$  (b)  $1.2 \times 10^{22}$  (c)  $3 \times 10^{23}$  (d)  $3 \times 10^{23}$

3. 11; 4. 171; 5. 16 g of sulphur, 28 g of iron.

**Exercise III**

1. H = 6.7%, O = 53.3%; 2.  $\text{PbO}_2$ ; 3. 7; 4.  $\text{FeCl}_3$ ; 5.  $\text{Mg}_3\text{N}_2$

6.  $\text{C}_8\text{H}_{18}$ , alkane; 7.  $\text{C}_3\text{H}_8\text{O}$ ; 8. (i) H=0.03 g, C=0.18 g, O = 0.08 g (ii)  $\text{C}_3\text{H}_6\text{O}$ ; 9.  $\text{C}_4\text{H}_8\text{O}$ ,  $\text{C}_4\text{H}_8\text{O}$ ; 10.  $\text{CH}_2\text{O}$ ,  $\text{C}_6\text{H}_{12}\text{O}_6$

**Exercise IV**

1. 33.33 g; 2. 0.16 g Cu; 3.  $1.44\text{dm}^3 \text{ O}_2$ , 1.92 g oxygen  
4. 26.5 g  $\text{Na}_2\text{CO}_3$ ,  $6 \text{ dm}^3$  of  $\text{CO}_2$ ; 5. 0.2 g of  $\text{H}_2$ ,  $24 \text{ dm}^3$  of  $\text{H}_2$ .

6. 64; 7. 8.125 g  $\text{FeCl}_3$ ,  $1.8 \text{ dm}^3$  of  $\text{Cl}_2$ ; 8. 1.536 g

9. 28 tonnes of iron, 33 g of  $\text{CO}_2$ ,  $18 \text{ dm}^3$  of  $\text{CO}_2$ .

10. 23.8 g of  $\text{NH}_4\text{Cl}$ ,  $8.96 \text{ dm}^3$  of  $\text{NH}_3$  11. 100 litres of  $\text{C}_3\text{H}_8$

12. (i)  $59.3 \text{ cm}^3$ , (ii)  $45 \text{ cm}^3$  at r.t.p; 13.  $\text{C}_4\text{H}_8$  14.  $\text{C}_4\text{H}_8$

15. (a) 0.6 mole of  $\text{CO}_2$ , (b) 26.4 g of  $\text{CO}_2$  (c) 0.88 g of  $\text{C}_3\text{H}_8$ , (d) 0.125 mole of  $\text{C}_3\text{H}_8$ , (e) 66 g of  $\text{CO}_2$ , (f) 0.75;

16. 0.4

**Exercise IV**

1. 0.02M; 2.  $50 \text{ cm}^3$ ; 3. 0.2146M; 4. (a) 0.05, (b) 74, (c) 40

5. 0.2M; 6. (a) 0.2M, (b) 0.1M, (c)  $n=2$ ; 7. (a) 2M, (b) 0.25M

8. (a) 0.005 mole, (b) 0.15 mole; 9. (a) 24.4 g, (b) 1.38 g

10. 50% of each; 11.  $8.59 \text{ cm}^3$ ; 12. 0.8M,  $50.4 \text{ g/dm}^3$ , 13. 96.9%;

14. 18.1 per cent; 15. 200.

Exercise IV : 1.  $\text{Na}_2\text{CO}_3$ , 4.41;  $\text{NaOH}$ , 2.688 2. 0.445%

