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}Cl and ^{37}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 $^{35}\mathbf{Cl}$ and 25 atoms of ^{37}Cl

Total mass of 100 atoms of chlorine = 75 x 35 + 25 x 37
= 3550

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}Ne, ^{21}Ne and ^{22}Ne in percentage ^{20}Ne = 90.22%, ^{21}Ne = 0.26% and ^{22}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}Cl and ^{37}Cl. (3 marks)

5. 2001/2/1,
   a. Define the term relative atomic mass (2mark)
   b. Explain how the relative atomic mass can be dertermined 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 X 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 X 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

= 6 x 12)+(12 x 2)+(6 x 16)
= 72+12+96
= 180

Exercise Ib

(1) Calculate the formula mass of
(a) Ammonium sulphate, $(NH_4)_2SO_4$
(b) Sodium carbonate decahydrate, $Na_2CO_3.10H_2O$.
(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 ($^{12}_{6}C$). A mole of any substance contains 6.02 X 10^{23} particles.
The number of particles in any mole of a substance (6.02 x 10^{23}) is called **AVOGADRO'S NUMBER, L.**

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 6.0×10^{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 6.0×10^{23} atoms.

$\therefore$ 8 g of carbon has $\frac{8x6.6x10^{23}}{12}$ atoms

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

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

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

$\therefore$ 4.5×10^{23} atoms are in $\frac{4.5x10^{23}x64}{6.0x10^{23}}$

= 48 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 6.0×10^{23} molecules.

$\therefore$ 35.5 g of chlorine contains $\frac{35.5x6.0x10^{23}}{71}$

$= 3.0 \times 10^{23}$ 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 = 6.0×10^{23} atoms.

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

Mass of 1 mole of $CuCl_2$ = 64 + (2 x 35.5)

= 135 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.

4

$\therefore$ 13.5 g of $CuCl_2$ contain $\frac{13.5 x 36.0 x 10^{23}}{135}$

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

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

The 'mole' concept in calculations

To convert Mass of a substance into moles

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

To convert moles of a substance in grams

Mass in grams = No. of moles **x** mass of 1 mole.

Example 9. *How many moles of carbon dioxide molecules are present in 11 g of carbon dioxide, CO_2?*

Mass of 1 mole of $CO_2 = 12 + (2 \times 16) = 44$ g

No. moles of $CO_2 = \frac{Mass in\ grams}{Mass of\ 1 mole}$

$= \frac{11}{44} moles = 0.25$ moles

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

The Molar mass of CO = (12 + 16) = 28 g

Mass in grams = No. of moles **x** mass of 1 mole.

= 3 x 28

= 84 g

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

No. of moles of carbon = $\frac{Mass in\ grams}{Mass of\ 1 mole} = \frac{4}{12} moles$

= 0.333 mol

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.

Mass of 0.333 moles magnesium =

No. of moles x Mass of 1 mole

= 0.333 X 24

5
= 8 g.

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

(i) Relative atomic mass of magnesium = 24

1 atom of magnesium $= \frac{24x1}{6.0x10^{23}}$

$= 4 X 10^{-23}$ g

(ii) Molar mass of C_2H_6 = (2 x 12) + (6 x 1)
= 30 g

1 molecule of ethane $= \frac{30x1}{6x10^{23}} = 5x10^{23} g$

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

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

Molar mass of $Fe_2(SO_4)_3$ = 2 x 56 + 3 x 32 + 12 x 16

= 112 + 96 + 192

= 400 g

No. of moles of $Fe_2(SO_4)_3$ = $\frac{Mass\,given}{Mass\,of\,1\,mole}$

$= \frac{18.4}{400}$ = **0.046** mole

$\therefore$ No. of moles of iron = 0.046 x 2 = 0.092 moles.
$\therefore$ No. of moles of sulphur = 0.046 x 3 = 0.138 moles
$\therefore$ No. of moles of oxygen = 0.046 x 12 = 0.552 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 x 10^{23}, find the number of molecules in

(a) 3.4 g of ammonia, NH_3 (b) 7.7 g of carbon tetrachloride CCl_4

(c)16 g of sulphur dioxide, SO_2 (d) 1 g of hydrogen, H_2.

3. What mass of carbon dioxide has the same number of molecule as 7 g of nitrogen, N_2?

4.What is the mass of 0.5 mole of aluminium sulphate, $Al_2(SO_4)$?

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, (Mg = 24, O = 16).*

(i) Write formula of the compound: MgO

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

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

Percentage of Magnesium $= \frac{24x100\%}{40} = 60\%$

Percentage of oxygen $= \frac{16x100\%}{40} = 40\%$

Example 15. *Calculate the percentage of water of crystallization in hydrated sodium carbonate, $Na_2CO_3.10H_2O$?*

Formula mass of $Na_2CO_3.10H_2O$ = 46 +12 +48 +20 +160 = 286

Note: The percentage of water should be calculated as a complete, separate unit i.e. ($10\ H_2O$ = 180) in this case.

per cent water in $Na_2CO_3.10H_2O = \frac{180x100\%}{286}$

= 62.94%

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.

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 $(CH_2O)_6$.

OR $\frac{Molecular\ formulamass}{Emperical\ formulamass}$ = n, 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	$PbSO_4$		

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

Percentage of copper = $\frac{0.92x100\%}{1.15} = 80\%$

Percentage of oxygen = $\frac{0.23x100\%}{1.15} = 20\%$

	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	

$\therefore$ The formula of copper oxide is CuO.

Example 18 *3.22 g of hydrated sodium sulphate, $Na_2SO_4.nH_2O$ 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	Na_2SO_4	H_2O
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 $Na_2SO_4.10H_2O$

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 = CH_2Br
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 $C_2H_4Br_2$

Exercise III

1. What is the percentage of hydrogen and oxygen in ethanoic acid, CH_3COOH?

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 $X.nH_2O$ 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 is325. 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

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_2 and 3.24 g of H_2O. 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 80^0C and 760mmHg and the distillate was found to contain 90.8% by mass of X. (the vapor pressure of water at 80^0C 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^3 at 157^0C 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.

D. Calculation involving Equations, Masses and Volumes

Chemical changes can be described by use of chemical equations, e.g., carbon dioxide reacts with oxygen to form carbon dioxide. This reaction is written as:

$C + O_2 \rightarrow CO_2$ .... (1)

The plus sign (+) indicates addition of carbon to oxygen (vice versa) OR a mixture of the two. The arrow ($\rightarrow$) is often read 'yields'. Substances on the left of the arrow are **reactants, or starting materials.** Those on the right are the **products** of the reaction. Chemical equations have meaning on the atomic and molecular level. The equation (1) means that one atom of carbon (C) reacts with one molecule of oxygen (O_2) to produce one molecule of carbon dioxide, CO_2. One carbon atom weighs 12 grams. One oxygen molecule weighs 32 grams, (2 x 16 grams per oxygen atom).
Similarly, in the above equation 12 grams of carbon react with 32 grams of oxygen. i.e., 12 mass units of carbon react with 32 mass units of oxygen. The ratio of the masses of the individual reactants is 12:32.

It is not convenient to weigh gases. They are normally measure by volumes. The volume occupied at s.t.p. by one mole of oxygen or carbon dioxide is 22.4 dm^3 or 22400 cm^3. This volume is called the molar volume.

Equal volumes of all gases, under the same conditions of temperature and pressure, contain the same number of molecules (Avogadro's Law)

It follows that 1 mole of any gas occupies a volume of 22.4 dm^3 at s.t.p. and a volume of 24.0 dm3 at r.t.p. (room temperature and pressure).

These are the values we will be using in all calculations.

Gay-Lussac's Law

When gases react together, they do so in volumes which are related to each other in simple ratio and to the product if gaseous, provided all measurements are made at the same temperature and pressure.

Example 20 *How much marble ($CaCO_3$) remains undissolved and what volume of carbon dioxide (at r.t.p.) formed when all 14.6 g of hydrochloric acid are allowed to react with 50g marble?*

The equation is as follows:

$CaCO_3 (s) + 2HCl (aq) \rightarrow CaCl_2 (aq) + CO_2 (g) + H_2O (l)$

1 mole 2 moles 1 mole

The question can be solved using mole concept.

Molar mass mole of HCl =36.5 g.

Moles of HCl used = $\frac{14.6}{36.5}$ = 0.4 mole

Mass of $CaCO_3$ that reacted (thus dissolved)
From the equation,
2 moles of HCl react with 1 mole of $CaCO_3$ (=100)

0.4 mole of HCl react with $\frac{0.4}{2}$ = 0.2 mole of $CaCO_3$.
= (0.2 x 100)g
= 20 g of $CaCO_3$

$\therefore$ Mass of undissolved $CaCO_3$ = (50 - 20) = **30 g**.

Volume of CO_2
2 moles of HCl liberate 1 mole or 24 dm^3 of CO_2 at r.t.p.

$\therefore$ 0.4 mole of HCl will liberate $\frac{0.4x24}{2} = 4.8\ dm^3$ of CO_2.

Example 21. According to the equation: $2C + O_2 \rightarrow 2CO$

How many moles of carbon which react with 9.6 dm^3 of oxygen at r.t.p?

1 mole or 24 dm^3 (at r.t.p.) of O_2 react with 2 mole of carbon.
1 dm^3 of O_2 reacts with $\frac{2}{24}$ moles of carbon

$\therefore$ 9.6 dm^3 react with $\frac{2x9.6}{24} = 0.8\,moles$ of carbon.

Example 22. *40 cm^3 of oxygen was added to 30 cm^3 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).*

$2CO\ (g)$ +	$O_2\ (g)$ $\rightarrow$	$2CO_2\ (g)$
2 mole	1 mole	2 moles
2 vol.	1 vol.	2 vol. (Gay-Lussac's Law)
30 cm^3	15 cm^3	30 cm^3 (volume ratio)

The volume of CO_2 produced is the same as that of CO used up, i.e. 30 cm^3 of CO_2 are produced.
15 cm^3 of the 40 cm^3 of oxygen are used up in the reaction, i.e. 25 cm^3 of oxygen
30 cm^3 of carbon dioxide produced and thus has a volume of 55 cm^3.

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 ($KClO_3$) 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 ($NaHCO_3$) 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 MCO_3 are heated to constant mass, the volume of carbon dioxide evolved during the heating is 600 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: $2\,Fe\,(s) + 3\,Cl_2\,(g) \rightarrow 2\,FeCl_3\,(s)$. 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 $Fe_2O_3(s) + 3CO\,(g) \rightarrow 2Fe(s) + 3\,CO_2\,(g)$
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, $Ca(OH)_2$? 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 (C_3H_8) to carbon dioxide and water, measured at r.t.p.?

12. Ethene reacts with oxygen according to the equation

$C_2H_4\,(g) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 2H_2O\,(g)$

15 cm^3 of ethene were mixed with 60 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 120^0 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 cm^3 of a gaseous hydrocarbon were mixed with 90 cm^3 of oxygen and sparked. The resulting volume at r.t.p. was 70 cm^3, which reduced to 30 cm^3 on shaking with sodium hydroxide. Find the empirical formula of the hydrocarbon.

14 According to the equation,

$C_3H_8\,(g) + 5O_2\,(g) \rightarrow 3CO_2\,(g) + 4H_2O\,(l)$

(a) How many moles of CO_2 will be produced in the reaction of 1 Mole of O_2?
(b) How many grams of CO_2 are produced by 1 mole O_2?
(c) How many grams of propane (C_3H_8) will react with 3.2 g of O_2?
(d) How many moles of propane (C_3H_8) will produce 9 g of H_2O?
(e) How many moles of CO_2 will be produced with 36 g of water?
*(f) What are the maximum moles of CO_2 that will be produced from a mixture of 12 g of C_3H_8 and 8 g of O_2? Assume complete reaction.

**Q15 From the equation

$C + O_2 \rightarrow CO_2$

What will be the partial pressure of CO_2 in the product mixture formed from 20 g of O_2 and 3 g of 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.

(a) Write equation for the reaction that took place during the heating (1 ½ marks)

(b) Calculate the percentage of sodium carbonate in the mixture

1995/1/7

1.18g of compound P on evaporation occupied 300cm3 at s.t.p.

(a) Calculate the relative molecular mass of P.

(b) The empirical formula of P is C_2H_4O. Determine its molecular formula

(c) 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.

(i) Determine empirical formula of T

(ii) When 0.225g of T was vaporized at 127^0C and 760mmHG it occupied a volume of 119.11cm^3. (Molar volume of a gas at s.t.p is 22.4dm^3). calculate the formula mass of T and determine molecular formula of T

(iii) 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^3 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^3. After addition of concentrated potassium hydroxide, the volume decreased to 126cm^3

(a) determine the molecular formula of Q

(b) write the names and the structural formula of all isomers of Q

2004

(a) When 8.8g of a hydrocarbon, Z, was burn in excess air, 14.4g of water and 13.44dm^3 of carbon dioxide were obtained at s.t.p. determine the empirical formula of Z.

(b) The vapor density of Z is 22. Write the name and molecular formula of Z.

(c) Write equations to show how Z can be synthesized from alcohol

(d) 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

(i) Determine the empirical formula of P.

(ii) When vaporized, 0.1g of P occupied 78.8cm^3 at 157^0C and pressure of 740mmHg.

(vi) Calculate the formula mass of P

(vii) Determine the molecular formula of P

(viii) Write the structural formula of all the possible isomers of P

(ix) P does not react with sodium metal. Identify P

(x) 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^3, 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^3 of solution.

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

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

$$\text{Hence, No. of moles} = \frac{Molarity\ x\ volume}{100ml\ of\ solution}$$

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

$$aA + bB \rightarrow cC + dD,$$

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

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 250cm³ solution (b) 9.8g of sulphuric acid in 2 dm³ solution.*

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

7g of KOH in $250cm^3$ solution ≡ 28g KOH in $1000cm^3$ or 1 dm^3 solution

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

b) RMM of H_2SO_4 = 2 + 32 + 64 = 98g

9.8g of H_2SO_4 in $2dm^3$ solution = 4.9g in 1 dm^3 solution.

Molarity of H_2SO_4 = $\frac{g/dm}{RFM} = \frac{4.9}{98} = 0.05M$

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

Reaction equation:

NaOH (aq) + HCl (aq) → NaCl (aq) + H_2O (aq)

Mole of NaOH

1000 m^3 contain 0.1 moles

25 cm^3 will contain $\frac{25x0.1}{1000} = 0.0025\ moles$

Moles of HCl

From the equation

1mole of NaOH react with 1 mole of HCl

⇨ moles of HCl = moles of NaOH

= 0.0025moles

Molarity of HCl

$20cm^3$ contain 0.0025mole

$1000cm^3$ will contains $\frac{0.0025x1000}{20} = 0.125moles$

=> molarity of HCl = 0.125M

Concentration = moles x RFM

= 0.125 x 36.5

= 4.58 g/dm^3

Example 25. *In a titration 30 cm^3 of 0.4M sodium hydroxide require $40cm^3$ of 0.15 M phosphoric acid, H_3PO_4.*

(i) How many moles of sodium hydroxide are present in 30cm^3 of solution?
(ii) How many moles of phosphoric acid are present in 40cm^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) moles of NaOH = $\frac{30x0.4}{1000} = 0.012\ moles$

(ii) moles of H_3PO4 = $\frac{40x0.15}{1000} = 0.006\ moles$

(iii) NaOH : H_3PO4
0.012 : 0.006
0.006 0.006
2 : 1
2 moles of NaOH required neutralizing one of phosphate acid.

(iv) $2NaOH(aq) + H_3PO_4(aq) \rightarrow Na_2HPO_4(aq) + 2H_2O(l)$
The formula of sodium salt formed is Na_2HPO_4

Example 26. *24.0cm^3 of sodium of 0.1M KOH were exactly neutralized by 30.0cm^3 of sodium of χ M H_2SO_4. Find the concentration of the acid solution (a) as the molarity χ (b) in g/dm^3*

$2KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$
Mole of KOH
1000 cm^3 contain 0.1 moles

24.0 cm^3 will contain $\frac{24x0.1}{1000} = 0.0024\ moles$
Moles of H_2SO_4
From the equation
2mole of KOH react with 1 mole of H_2SO_4
⇨ moles of H_2SO_4 = ½ moles of KOH
$= \frac{0.0024}{2} = 0.0012 moles$
Molarity of χ of H_2SO_4

30cm^3 contain 0.0012mole
1000cm^3 will contains $\frac{0.0012x1000}{30} = 0.04\ moles$

$\therefore \chi = 0.04M$

Thus g/dm^3 of H_2SO_4 = 0.04 X 98 = 3.92g/dm^3

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

Equation.

$2NaOH (aq) + H_2SO_4 (aq) \rightarrow Na_2SO_4 (aq) + 2H_2O (l)$

Moles of the NaOH that reacted
1000 cm^3 contains 0.2 mole

1cm^3 contains $\frac{0.2}{1000}$ moles

25 cm^3 contain $\frac{0.2x25}{1000} = 0.005moles$

Moles of H_2SO_4
From the equation: 2 mole of NaOH reacts with 1 mole H_2SO_4.

0.05 mole of NaOH react with (½ x 0.005) mole of acid
Molarity
$\therefore$ Mole of H_2SO_4 in 24.6cm^3 that reacted = 0.0025mole

1 cm^3 contain $\frac{0.0025}{24.6}$

$\Rightarrow$ 1000 cm^3 contain $\frac{0.0025x1000}{24.6} = 0.102\ mole$

Therefore, molarity of H_2SO_4 solution is **0.102M**

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

Reaction equation
$Na_2CO_3 (aq) + 2HCl (aq) \rightarrow 2NaCl (aq) + CO_2 (g) + H_2O (l)$

Moles of the Na_2CO_3 that reacted
1000 cm^3 contains 0.1 moles

1cm^3 contains $\frac{0.1}{1000}$ moles

20 cm^3 contain $\frac{0.1x20}{1000} = 0.002moles$

Moles of HCl

$$\frac{}{20}$$

From the equation; 1 mole of Na_2CO_3 reacts with 2 mole HCl

0.02 mole of Na_2CO_3 react with (0.002x2) mole of HCl
= 0.004 moles

Volume of hydrochloric acid required
0.25moles are contained in $1000cm^3$

$\Rightarrow$ 0.004 moles will be in $\frac{1000x0.004}{0.25}$
= 16 cm^3

The volume required is **16 cm^3**

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

(a) Calculate the molarity of the hydroxide.

Reaction equation

$X(OH)_2$ (aq) + $2HNO_3$ (aq) $\rightarrow$ $X(NO_3)$ (aq) + $2H_2O$ (l)

No. of moles of the nitric acid that reacted

1000 cm^3 contains 0.1 moles

1 cm^3 contains $\frac{0.1}{1000}$ moles

=> 20 cm^3 contain $\frac{20x0.1}{1000}$
= 0.002 moles

(b) Calculate the molar mass of $X(OH)_2$ 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 ½ moles of $X(OH)_2$

$\Rightarrow$ moles of the hydroxide in reacted 0.002 x ½
= 0.001 mole

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

1 cm^3 contains $\frac{0.001}{1000}$ moles

$\Rightarrow$ 1000 cm^3 contains $\frac{0.001x1000}{10}$
= 0.1 moles

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

(b) Molar mass of $X(OH)_2$ = $\frac{concentration\, g/l}{morality}$

$= \frac{5.8}{0.1} = 58g$

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

Molar mass of $X(OH)_2$ = X + 2(16+1) = 58

= X + 34 = 58

$\Rightarrow$ X = 24g

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

Example 29. *In determination of water of crystallization of $Na_2CO_3.nH_2O$, 14 cm^3 of 0.2M HCl was required to neutralize 25cm^3 of sodium carbonate prepared by dissolving 4g of $Na_2CO_3.nH_2O$ in 250 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.
Na_2CO_3 (aq) + 2HCl (aq)
$\rightarrow$ 2NaCl (aq) + H_2O (l) + CO_2 (g)

Moles of the acid that reacted

1000 cm^3 contain 0.2 mole

1 cm^3 contain $\frac{0.2}{1000} moles$

$\therefore$ 14 cm^3 contain $\frac{0.2x14}{1000}$ = 0.0028 moles

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

Thus, moles Na_2CO_3 in 25 cm^3 that reacted = $\frac{0.0028}{2}$

= 0.0014moles

1 cm^3 contain = $\frac{0.28}{2x25}$

$\Rightarrow$ 1000 cm^3 contain $\frac{0.28\, x1000}{2x25}$

$$22$$

= 0.056 M.

thus, molarity of sodium carbonate solution is 0.056M.

(b) Molar mass of hydrated sodium carbonate

$$Molar\,mass = \frac{Concentration\,g/l}{Molarity} = \frac{2x4}{0.056} = 286\text{ g}$$

Value of n in the formula $Na_2CO_3.nH_2O$ is calculated using the molar mass.

thus, (23 x 2) + 12 + (16 x 3) + 18n = 286

18n = 286 - 106

n = 10

Example 29. *During determination of Basicity of an acid H_nA, 25 cm^3 of KOH prepared by dissolving 11.2 g in 1 litre of solution was required to neutralize 25 cm^3 of 0.1M H_nA.*

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

a) Molarity of the hydroxide.

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

= 56g

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

(b) Basicity of the acid.

Equation., $nKOH\,(aq) + H_nA\,(aq) \rightarrow K_nA\,(aq) + nH_2O\,(l)$

Reaction ratio n:1

Moles of the KOH that reacted

$$= \frac{0.2x25}{1000} = 0.005 moles$$

Moles of the acid that reacted

$$= \frac{0.1x25}{1000} = 0.0025moles$$

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.*

Molarity^1 x Volume^1 = Molarity^2 x Volume^2

5 x volume conc. acid = 0.25 x 250

Volume of the conc. acid = $\frac{0.25x250}{5}$

= 12.5 cm^3

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.

H_2SO_4 (aq) + 2NaOH (aq) $\rightarrow$ Na_2SO_4 (aq) + H_2O (aq)

Moles of NaOH that reacted.

1000 cm^3 contain 0.3 mole

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

$\therefore$ 25 cm^3 $\rightarrow$ $\frac{0.3x30}{1000}$

= 0.009 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 x ½

1000cm^3 contain $\frac{0.009x1000}{25x2} = 0.18moles$ $\therefore$ 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.

Molarity^1 x Volume^1 = Molarity^2 x 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 x Molar mass

= 18 x 98

= 1764 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.

$NH_4Cl\ (aq) + NaOH\ (aq) \rightarrow NH_3\ (g) + NaCl\ (aq) + H_2O\ (aq)$

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

$HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl(aq) + H_2O\ (l)$

Moles of the acid that reacted with excess base

1000 cm^3 contain 0.5 moles

$\therefore$ 22.4 cm^3 contain $\frac{0.5 x 22.4}{1000}$

= 0.0112 moles

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

Moles of NaOH added to impure NH_4Cl

1000 cm^3 contain 2 moles

$\therefore$ 100 cm^3 contain $\frac{2x100}{1000} = 0.2moles$

Mole of NaOH that reacted with NH_4Cl is equivalent to the difference between moles NaOH added and that found in excess.

= 0.2 - 0.112 = 0.088 moles

Since 1 mole of NaOH reacts with 1 mole NH_4Cl, then mole of NH_4Cl that reacted

= 0.088

Mass of 0.088 moles of NH_4Cl = molarity x molar mass

= 0.088 (14+4+35.5)

= 4.708g

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

$\therefore$ Percentage purity of NH4Cl = $\frac{4.708x100}{5.0}$

= 94.2%

(b) Percentage of ammonia in the pure sample

Every 53.5 g of NH_4Cl contain 17g of NH_3

$\therefore$ 4.708 contain $\frac{17x4.708}{53.5} = 1.496g$

Percentage of NH_3 in pure sample $\frac{1.496x100}{4.708}$

$=31.77\%$

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 cm^3 of 0.02M HCl.

3. 25 cm^3 of 0.1M sodium carbonate was found to react with 23.3 cm^3 of HCl to complete neutralization. Calculate the molarity of hydrochloric acid.

4. A solution of 0.1M HCl and volume 25 cm^3 required 12.5 cm^3 of a metal hydroxide $M(OH)_2$ which was prepared by dissolving 1.45 g of the $M(OH)_2$ in 250cm^3 of solution. (H=1, O=16)

(a) Calculate the molarity of $M(OH)_2$

(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 cm^3 of 0.2M H_2SO_4 acid required 25 cm^3 of NaOH for complete neutralization.

6. 25 cm^3 of oxalic ($H_2C_2O_4.nH_2O$) acid solution prepared by dissolving 2.52 g of the acid into 250 cm^3 required 20 cm^3 of sodium hydroxide solution prepared by dissolving 8 g of the hydroxide in one litre of solution.

(a) Calculate the molarity of sodium hydroxide solution.
(b) Calculate the molarity of oxalic ($H_2C_2O_4.nH_2O$) 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) 20.0g of sodium hydroxide, NaOH, in 250cm^3 of solution;
(b) 3.8g of iron (II) sulphate, $FeSO_4$, in 100cm^3 solution.

8. Calculate the number of moles of the named substance in
(a) 50cm^3 of 0.1 M nitric acid.
(b) 100cm^3 of 1.5 M sodium carbonate.

9. Calculate the masses of dissolved substances contained in
(a) 100cm^3 of 2 M sodium sulphate solution, Na_2SO_4.
(b) 50cm^3 of 0.2 M potassium carbonate, K_2CO_3.

10. 8.48 grams of a mixture of sodium chloride and anhydrous sodium carbonate were dissolved in 100 cm^3 of solution. 5 cm^3 of this solution required 40 cm^3 of 0.1M 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 g/cm^3. Calculate the volume of this acid required to neutralize 8.4 grams of sodium hydrogen carbonate.

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

13. 2 grams of impure calcium carbonate were added to 80 cm^3 of 1.25M hydrochloric acid. The resulting solution was made up to 100 cm^3 and 10 cm^3 of this neutralized 12.5 cm^3 of sodium hydroxide solution containing 20 g/dm^3. Determine the percentage purity of the calcium carbonate.
14. 0.15 gram of an ammonium salt was heated with excess sodium hydroxide. The ammonia given off was absorbed in 25 cm^3 of 0.16M HCl. The excess acid required 12 cm^3 of 0.2M sodium hydroxide for neutralization. Calculate the percentage of ammonia in the salt.

15. 24 cm^3 of solution of tribasic acid containing 12 grams of the acid per dm^3 of solution just neutralized 48 cm^3 of 0.09M 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 ($Na_2CO_3.xH_2O$) was dissolved in water to make a litre of solution. 25 cm^3 of this solution required 18.70cm^3 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^3 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 containing9.64g 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^3 of the acid that would be required to prepare 200cm^3 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^{-3}.

(c) 12.68 cm^3 of the acid in (b) was dissolved in water and the solution made up to 250 cm^3 with distilled water. Calculate the volume that would react completely with 25.0cm^3 of 0.2M sodium carbonate (4 marks)

1994/1/15

1.55g of an acid $C_nH_{2n}(COOH)_2$ was dissolved in water and the solution made up to 250cm^3. 25.0cm^3 of this solution required 23.5cm^3 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^3 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 elections to an ion species;

e.g., Cu^{2+} (aq) + 2e $\longrightarrow$ Cu(aq)

whereas, oxidation is loss of electrons from a compound.

Zn(s) -2e $\longrightarrow$ Zn^{2+}(aq)

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

The species which donates electrons such as 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 arbitrary 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_2S, 4 in SO_2 and VI inSO_3. chlorine shows a wide variety of oxidation number, e.g. -1 in HCl, 0 in Cl_2, 1 in ClO^-, 3 in ClF_3, 4 in ClO_2, 5 in ClO_3^-, 6 in ClO_3 and 7 in ClO_4^-.

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 $KMnO_4$.

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 x 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) K**I**O_3 (ii) **S**O_4^{2-} (iii) **Cr**$_2O_7^{2-}$

(iv) H_2**O**$_2$ (v) K**Cl**O4 (vi) Na_2**S**$_2O_6$

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:

$MnO_4^-(aq) + 5e + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 4H_2O\ (l)$

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

Exercise VI I

Balance the following reduction equations

(i) $Cr_2O_7^{2-}(aq) + e + H^+(aq) \rightarrow Cr^{3+}(aq) + H_2O(l)$

(ii) $IO_3^-\ (aq) + e + H^+(aq) \rightarrow\ I_2(aq) + H_2O(l)$

(iii) $H_2O_2\ (aq) + e + H\ (aq) \rightarrow\ H_2O\ (l)$

The following are common oxidation half equation reactions:

(i) $Fe^{2+}(aq)\ -e \rightarrow F^{3+}(aq)$

(ii) $H_2O_2(aq)\ -2e \rightarrow 2H^+(aq) + O_2\ (g)$

(iii) $I-\ (aq) - e \rightarrow \frac{1}{2} I_2\ (aq)$

(iv) $C_2O_4^{2-}\ (aq)\ -2e \rightarrow 2CO_2\ (g)$

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 MnO_4^- and Fe^{2+} in acidic medium, the half equation of Fe^{2+} is multiplied by 5 to provide the 5 electron necessary to reduce MnO_4^-.

That is,

$MnO_4^-(aq) + 5e + 8H^+ (aq) \rightarrow Mn^{2+} (aq) + 4H_2O (l)$

Plus

$5(Fe^{2+} (aq) -e \rightarrow F^{3+} (aq))$

Equals

$MnO_4^-(aq) + 5Fe^{2+} (aq) + 8H^+ (aq)$

$\rightarrow Mn^{2+} (aq) + 5F^{3+}(aq) + 4H_2O (l)$

Exercise VI

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

(a) MnO_4^- and I- (b) MnO_4^- and H_2O_2

(c) KIO_3 and KI (d) MnO_4^- and $C_2O_4^{2-}$

(e) $K_2Cr_2O_7$ and $FeSO_4$

2. 0.9875g of an impure potassium manganate (VII) was dissolved in water to make 250cm^3 of solution. When 20.0cm^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 cm^3, 24.40cm^3 of sodium ethanedioate solution was used. ($Na_2C_2O_4$ =134 and KMnO4 = 158).

   Calculate percentage purity of potassium permanganate (VII)

3. 10cm^3 of concentrated hydrogen peroxide was diluted to 250cm^3. 20cm^3 of the dilute solution required 28.30cm^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.

(a) State two disadvantage 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
(i) acid solution
(ii) alkaline solution

1994/1/17
(a)In volumetric estimation of 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 250cm^3. 25.0cm^3 of this solution required 23.5cm^3 of a 0.01M 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
i. Nitrogen in HNO_3
ii. Sulphur in S_2O_8 (1marks)
(b) Write half equation for the conversion of $S_2O_8^{2-}$ to SO_4^{2-} ions
(c) Complete the following and balance the equations
i. $S_2O_8^{2-} + I^- \rightarrow$
ii. Sn2+(aq) + $S_2O_8^{2-}$(aq) $\rightarrow$

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^3 of acidified solution of 0.02M potassium manganate (II) reacted exactly with 24.95 cm^3 of sodium nitrite. Potassium manganate (VII) reacts with sodium nitrite according to the following equation

$$2MnO_4^-(aq) + 5NO_2^-(aq) + 6H^+(aq) \rightarrow 2Mn^{2+}(aq) + 5NO_3^-(aq) + 3H_2O(l)$$

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^3 of NaOCl solution was reacted with excess potassium iodide, the liberated iodine required 25 cm^3 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

OCl^- (aq) + $2I^-$ (aq) + $2H^+$ (aq)

$\rightarrow I_2$ (aq) + $2H_2O$ (l)

I_2 (aq) + $2S_2O_3^{2-}$ (aq) $\rightarrow 2I^-$ (aq) + $S_4O_6^{2-}$ (aq)

Moles of sodium thiosulphate that reacted

100cm^3 contain 0.1moles

25cm^3 contain $\frac{0.1x25}{1000}$ = $0.0025mols$

Moles of iodine produced from equation 2

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

Moles NaOCl

From equation 1, moles of NaOCl is equal to the moles of iodine = 0.0015 moles

Molarity of NaOCl

20cm^3 of NaOCl solution contain 0.00125 moles

1000cm^3 contain $\frac{0.00125x1000}{20}$

= 0.0625M

Concentration in grams per litre

1 mole of NaOCl weighs (40 + 16+ 35.5)

= 91.5g

0.0625 moles weigh = 91.5 x 0.0625

= 5.7g/l

Exercise VII

1986/2/8e

6.53 g of impure copper was dissolved in excess nitric acid. The solution obtained mad up to 250cm^3 of solution with water. To 25cm3 of this solution excess aqueous potassium iodide was added. The reaction that took place is given by the equation

$2Cu^{2+}$(aq) + $4I^-$(aq) $\rightarrow Cu_2I_2$ (s) + I_2 (aq)

The iodine liberated reacted with 20cm3 of 0.5M aqueous sodium thiosulphate according to the equation

$2S_2O_3^{2-}$(aq) + I_2 (aq) $\rightarrow S_4O_6^{2-}$ (aq) $2I^-$(aq)

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^3 of water. 10cm^3 of the solution was mixed with excess potassium iodide. The iodine liberated required 8.0cm^3 of a 0.2M sodium thiosulphate solution for complete reaction. Potassium chlorate and potassium chloride react according to the equation

ClO_3^- (aq) + $6H^+$ (aq) + $6I^-$ (aq)

$\rightarrow$ $3I_2$(aq) + Cl^-(aq) + $3H_2O$ (l)

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

Question

During the determination of concentration of hydrogen peroxide in g/dm^3 of the medical hydrogen peroxide, 12 cm^3 of medical hydrogen peroxide was diluted to 250cm^3 with distilled water. 20cm^3 of the dilute solution was acidified required and excess KI added. The liberated iodine required $22cm^3$ of sodium thiosulphate solution containing 9.3g $Na_2S_2O_3.5H_2O$ in $250cm^3$ of solution.

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

$$H_2O_2(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow I_2(aq) + 2H_2O(l)$$

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_2CO_3 and $NaHCO_3$. Ideally, the two indicators referred to here are the phenolphthalein and methyl orange indicator. The basis of these titrations is that, NaOH, and Na_2CO_3 are titrated to complete neutralization with methyl orange, whereas, $NaHCO_3$ is acidic to phenolphthalein indicator and thus Na2CO3 is only half neutralized when titrated with an acid in presence of phenolphthalein indicator.

Example 36. *7.15 g sodium carbonate $Na_2CO_3.nH_2O$ was dissolved in water to make 250 ml of solution. 25.0 cm^3 of this solution required 12.50 cm^3 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

$$Na_2CO_3.nH_2O(aq) + HCl(aq) \rightarrow NaHCO_3(aq) + (n+1)H_2O(l)$$

Moles of the acid that reacted:
1000 cm^3 contain 0.2 mole

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

= 0.0025 mole

From the reaction equation, 1 mole of $Na_2CO_3.nH_2O$ reacts with 1 mole of HCl.

$\therefore$ 0.0025 mole of the acid react with 0.0025 mole of $Na_2CO_3.nH_2O$.

Morality of $Na_2CO_3.nH_2O$
$\Rightarrow$ 25,0 cm^3 of $Na_2CO_3.nH_2O$ solution contain 0.0025 mole of $Na_2CO_3.nH_2O$.

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

= 0.1M

$\therefore$ Molarity of $Na_2CO_3.nH_2O$ solution is 0.1M

RMM of $Na_2CO_3.nH_2O$ = $\frac{\text{Concentration g/l}}{\text{Molarity}}$

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

= 286

Thus, (23 x 2) + 12 + (16 x 3) + n (2+16) = 286

106 + 18n = 286

n = 10

Example 35. *25.0 cm^3 of a solution containing a mixture of sodium hydroxide and sodium hydrogen carbonate require 15.0 cm^3 of 0.1M HCl using phenolphthalein indicator. 25.0 cm^3 of the same mixture required 28 cm^3 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

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

$\therefore$ 15 cm^3 of 0.1M HCl was required to neutralize NaOH is 25 cm^3 of the mixture.

Equations using methyl orange indicator

$NaOH (aq) + HCl (aq) \rightarrow NaCl (aq) + H_2O (l)$
and
$NaHCO_3 (aq) + HCl (aq)$
$\rightarrow NaCl (aq) + H_2O (l) + CO_2 (g)$

$\therefore$ The difference between the volume (28 – 15 =13 cm^3) of the acid was required to neutralize $NaHCO_3$.

No. of moles of the acid that reacted with NaOH

1000 cm^3 contain 0.1 mole

$\therefore$ 15 cm^3 contain $\frac{0.1x15}{1000}$ = 0.0015 mole

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

$\Rightarrow$ moles of NaOH in 25 cm^3 = 0.0015 mole

1000 cm^3 will contain $\frac{0.0015x1000}{25}$

= 0.06 M

Concentration of NaOH in g/L = RMM x Molarity

= 40 x 0.06

= 2.4 g/dm^3

No. of moles of the acid that reacted with $NaHCO_3$.

1000 cm^3 contain 0.1 mole

$\therefore$ 13 cm^3 contain $\frac{0.1x13}{1000}$ = 0.0013 mole

From the reaction ratio of 1:1,
1mole of HCl reacts with 1 mole of the $NaHCO_3$.

$\Rightarrow$ moles of $NaHCO_3$ in 25 cm^3 = 0.0013 mole

1000 cm^3 will contain $\frac{0.0013x1000}{25}$

= 0.052 M

Concentration of $NaHCO_3$ in g/L = RMM x Molarity

= 84 x 0.052

= 4.368 g/dm^3

The ratio of masses of NaOH : $NaHCO_3$ is 2.4 : 4.368

= 1 : 1.82

Example 36. (1990/1/13) *25.0 cm^3 of a solution containing a mixture of sodium carbonate and sodium hydroxide require 30.0 cm^3 of 0.1M H_2SO_4 using phenolphthalein indicator. Another 25.0 cm^3 of the same mixture required 48.0 cm^3 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.
$2Na_2CO_3 (aq) + H_2SO_4 (aq)$
$\rightarrow 2NaHCO_3 (aq) + Na_2SO_4 (l)$
$2NaOH (aq) + H_2SO_4 (aq)$
$\rightarrow Na_2SO_4 (aq) + 2H_2O (l)$

2. *Using methyl orange indicator.*
$Na_2CO_3 (aq) + H_2SO_4 (aq)$
$\rightarrow Na_2SO_4 (aq) + CO_2 (g) + H_2O (l)$

$2NaOH (aq) + H_2SO_4 (aq) \rightarrow Na_2SO_4 (aq) + 2H_2O (l)$

From the reactions above, the extra volume (48 - 30 = 18 cm^3) of acid under methyl orange indicator is used to half neutralization ~~of Na_2CO_3~~. This also is equal to the volume of the acid that converts Na_2CO_3 to $NaHCO_3$.

∴ the volume of the acid that completely neutralized Na_2CO_3 in 25 cm^3 of solution = 18 x 2 = 36 cm^3.

And volume of the acid that reacted with NaOH = 30 - 18 = 12 cm^3.

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

1000 cm^3 contain 0.1 mole

$$\therefore 12 \text{ cm}^3 \text{ contain } \frac{0.1x12}{1000} = 0.0012 \text{ mole}$$

From the reaction ratio of 1:2, 1 mole of H_2SO_4 reacts with 2 moles of NaOH.

⇒ moles of NaOH in 25 cm^3 = 0.0012 x 2 mole

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

= 0.048 M

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

No. of moles of the acid that reacted with Na_2CO_3.

1000 cm^3 contain 0.1 mole

$$\therefore 36 \text{ cm}^3 \text{ contain } \frac{0.1x36}{1000} = 0.0036 \text{ mole}$$

From the reaction ratio of 1:1, 1 mole of H_2SO_4 reacts with 1 mole of the Na_2CO_3.

⇒ moles of Na_2CO_3 in 25 cm^3 = 0.0036 mole

$$1000 \text{ cm}^3 \text{ will contain } \frac{0.0036x1000}{25} = 0.144 \text{ M}$$

∴ the molarity of solution in respect to Na_2CO_3 is **0.144M**

Example 37. *25.0 cm^3 of a solution containing a mixture of sodium carbonate and sodium hydrogen carbonate require 15.0 cm^3 of 0.5M HCl using phenolphthalein indicator. Another 25.0 cm^3 of the same mixture required 34.5 cm^3 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^3 of solution.

Reaction Equations.

1.Using phenolphthalein indicator.

$2Na_2CO_3 (aq) + HCl (aq) \rightarrow 2NaHCO_3 (aq) + NaCl (aq)$

2. Using methyl orange indicator.

$Na_2CO_3 (aq) + 2HCl (aq) \rightarrow 2NaCl (aq) + CO_2 (g) + H_2O (l)$

$NaHCO_3 (aq) + HCl (aq) \rightarrow NaCl (aq) + H_2O (l) + CO_2 (g)$

From the reactions above, 15.0 cm^3 of the acid was required for half neutralization of Na_2CO_3.

∴ the volume of the acid that completely neutralized Na_2CO_3 in 25 cm^3 of solution = 15 x 2 = 30 cm^3.

and volume of the acid that reacted with $NaHCO_3$ initially in 25.0 cm^3 of the mixture = 34.5 - 30 = 4.5 cm^3.

No. of moles of the acid that reacted with Na_2CO_3.

1000 cm^3 contain 0.5 mole

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

From the reaction ratio of 2:1, 2 mole of HCl react with 1 mole of the Na_2CO_3

$\Rightarrow$ moles of NaOH in 25 cm^3

$$= \frac{0.015}{2} = 0.0075\, moles$$

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

Concentration of Na_2CO_3 in g/L = RMM x Molarity

= 106 x 0.3

= 31.8 g/dm^3

No. of moles of the acid that reacted with $NaHCO_3$

1000 cm^3 contain 0.5 mole

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

From the reaction ratio of 1:1, 1 mole of HCl reacts with 1 mole of $NaHCO_3$.

$\Rightarrow$ moles of $NaHCO_3$ in 25 cm^3 = 0.00225 mole

1000 cm^3 will contain $\frac{0.00225x1000}{25}$

= 0.09 M

Concentration of $NaHCO_3$ in g/L

= RMM x Molarity

= 84 x 0.09

= 7.56 g/dm^3

Exercise IV

1. *25.0 cm^3 of a solution containing a mixture of sodium carbonate and sodium hydroxide require 27.2 cm^3 of 0.05M H_2SO_4 using phenolphthalein indicator. Another 25.0 cm^3 of the same mixture required 37.6 cm^3 of the acid using methyl orange indicator. Calculate the mass of each base in 250 cm^3 of the mixture.*

2. *25.0 cm^3 of a solution containing a mixture of sodium carbonate and sodium hydrogen carbonate require 11.2 cm^3 of 0.1M HCl using phenolphthalein indicator and a further 28.6 cm3 of the acid using methyl orrange indicator.* Calculate the per centage (w/v) of sodium carbonate in the mixture.

1993/2/7c

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

25.0cm^3 of solution of the mixture required 34.50cm^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}Cu =72.5%, ^{65}Cu = 27.5%

Exercise II
1. (i) 5L, (ii) 25L (ii) 0.1L.
2. (a) 1.2 x 10^{23} (b) 1.2 x 10^{22} (c) 3 x 10^{23} (d) 3 x 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. PbO_2; 3. 7; 4. $FeCl_3$; 5. Mg_3N_2
6. C_8H_{18}, alkane; 7. C_3H_8O; 8. (i) H=0.03 g, C=0.18 g, O = 0.08 g (ii) C_3H_6O; 9. C_4H_8O, C_4H_8O; 10. CH_2O, $C_6H_{12}O_6$

Exercise IV
1. 33.33 g; 2. 0.16 g Cu; 3. 1.44dm^3 O_2, 1.92 g oxygen
4.26.5 g Na_2CO_3, 6 dm^3 of CO_2; 5. 0.2 g of H_2, 24 dm^3 of H_2.
6. 64; 7. 8.125 g $FeCl_3$, 1.8 dm^3 of Cl_2; 8. 1.536 g
9. 28 tonnes of iron, 33 g of CO_2, 18 dm^3 of CO_2.
10. 23.8 g of NH_4Cl, 8.96 dm^3 of NH_3 11. 100 litres of C_3H_8
12. (i) 59.3 cm3, (ii) 45 cm3 at r.t.p; 13. C_4H_8 14. C_4H_8
15. (a) 0.6 mole of CO_2, (b) 26.4 g of CO_2 (c) 0.88 g of C_3H_8, (d) 0.125 mole of C_3H_8, (e) 66 g of CO_2, (f) 0.75; 16. 0.4

Exercise IV

1. 0.02M; 2. 50 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 cm^3; 12. 0.8M, 50.4 g/dm^3, 13. 96.9%;
14. 18.1 per cent; 15. 200.

Exercise IV : 1. Na_2CO_3 , 4.41; NaOH,2.688 2. 0.445%