CHAPTER 3: CHEMICAL FORMULAE AND EQUATIONS

1. **Relative atomic mass, A_r**
   - The relative atomic mass of an element is the average mass of one atom of an element when compared with $\frac{1}{12}$ of the mass of an atom of carbon-12

$$\text{Relatove atomic mass of an element} = \frac{\text{The average mass of one atom of an element}}{\frac{1}{12} \text{ x the mass of an atom of carbon-12}}$$

   -
   - Example: The RAM of Oxygen atom is 16. This means that one atom of oxygen is 16 times heavier than $\frac{1}{12}$ of one atom of carbon

Element	Symbol	Relative Atomic Mass
Hydrogen		
Carbon		
Nitrogen		
Sodium		
Magnesium		
Aluminium		
Potassium		
Calsium		
Copper		
Bromine		

2. Relative molecular mass, M_r
   - The relative molecular mass of a molecule is the average mass of the one molecule when compared with $\frac{1}{12}$ of the mass of an atom of carbon-12

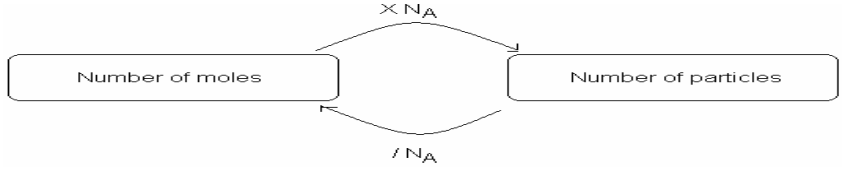
$$\text{Relative molecular mass of a molecule} = \frac{\text{The average mass of one molecule}}{\frac{1}{12} \text{ x the mass of an atom of carbon-12}}$$

   -
   - The relative molecular mass of a molecule can be calculated by adding up the relative atomic masses of all the atoms that are present in the molecule
   - Example: H_2 = 2 x A_r of H = 2 x 1 = 2
     NH_3 = A_r of N + 3(A_r of H) = 14 + 3(1) = 17

Element	Molecular Formula	Relative molecular mass
Hydrogen	H_2	
Oxygen	O_2	
Chlorine	Cl_2	
Phosphorus	P_4	
Sulphur	S_8	
Ammonia	NH_3	
Water	H_2O	
Salt	NaCl	

3. **Mole**
   - A mole is an amount of substance that contains as many particles as the number of atoms in exactly 12g of carbon-12.
   - **Symbol: mol**

4. **Avogadro constant or Avogadro number**
   - The Avogadro constant, N_A is defined as the number of particles in one mole of a substance



   - One mole of substance contains 6.02 x 10^{23} particles.
   - **6.02 x 10^{23} mol^{-1}** is known as the **Avogadro constant, N_A**
   - One mol of atom of any element or compound has the same number of particles, which is 6.02 x 10^{23} particles.
   - For ionic compounds such as sodium chloride, NaCl, 1 mol of the compound has 1 mol of Na^+ and 1 mol of Cl^-. Thus I mol of NaCl has 2 mol of ions which is 2 x 6.02 x 10^{23}.

1 mol of oxygen atom ,O	**6.02×10^{23} atoms**	1 mol of oxygen molecule, O_2	**6.02×10^{23} molecules or $2 \times 6.02 \times 10^{23}$ atoms**
1 mol of nitrogen atom, N		1 mol of nitrogen molecule, N_2	
1 mol of bromine atom, Br		1 mol of bromine molecule, Br_2	
1 mol of hydrogen atom, H		1 mol of hydrogen molecule, H_2	

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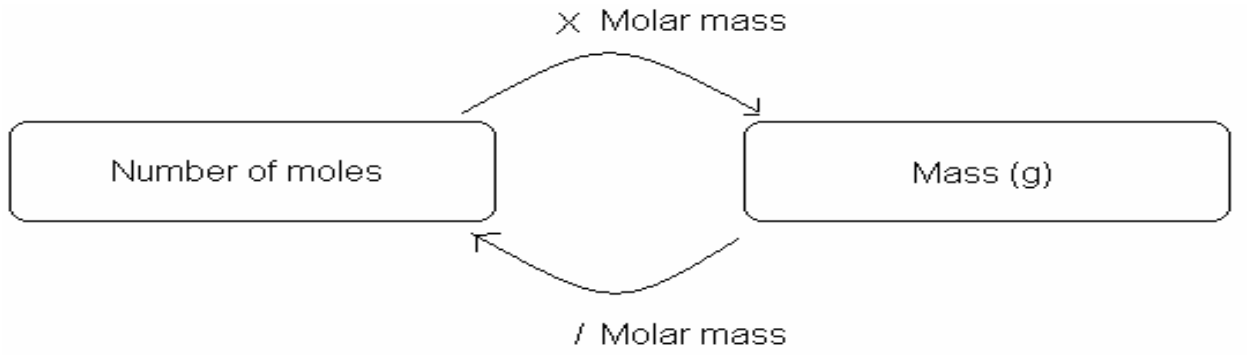
- Examples: A closed glass bottle contains 0.5 mol of oxygen gas, O_2.

a) How many oxygen molecules, O_2 are there in the bottle?	b) How many oxygen atoms are there in the bottle?
Answer: a) The number of oxygen molecules, O_2 in 0.5 mol of gas = 0.5 mol x 6.02×10^{23} mol^{-1} = 3.01×10^{23}	Answer: b) Each oxygen molecule, O_2 consists of two oxygen atoms Therefore, the number of oxygen atoms in 0.5 mol of gas = 0.5 mol x 6.02×10^{23} mol^{-1} x 2 = 3.01×10^{23} x 2 = 6.02×10^{23}

5 Molar mass

- The molar mass of a substance is the ***mass*** of ***1 mol of the substance*** with the unit grams per mol or ***g mol^{-1}***.
- The mass of one mole of atoms is numerically equal to its relative atomic mass in grams
- The mass of one mole of molecules is numerically equal to its relative molecular mass in grams



Examples:

What is the mass of

a) 0.1 mol of magnesium?

Answer:

a) The molar mass of Mg = 24 g mol^{-1}

Therefore, the mass of 0.1 mol of Mg

= 0.1 mol x 24 g mol^{-1}

= 2.4 g

b) 2.408 x 10^{23} atoms of magnesium?

b) The number of moles of Mg atoms

$= \frac{2.408 \times 10^{23}}{6.02 \times 10^{23} mol^{-1}} = 0.4 mol$

= 0.4 mol

The mass of 2.408 x 10^{23} atoms of Mg

= 0.4 mol x 24 g mol^{-1} = 9.6 g

c) How many moles of molecules are there in 16 g of sulphur dioxide gas, SO_2?

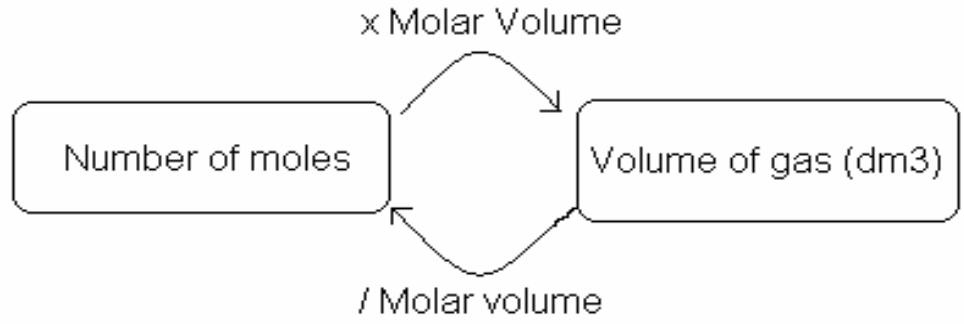
RMM of SO_2 = 32 + 2(16) = 64

The number if moles of molecules in 16g of SO_2

$= \frac{16g}{64 g mol^{-1}} = 0.25 mol$

6. Molar volume

- The molar volume of a gas is the ***volume*** occupied by ***one mole of the gas***
- One mole of any gas always has the same volume under the same temperature and pressure.
- One mole of a gas occupies a volume of **24dm^3 at room conditions** and **22.4 dm^3 at STP**



STP:
The condition 0^{0}C and 1 atm are called the standard temperature and pressure, STP

Room Condition:
The condition 25^{0}C and 1 atm are called room condition

Example:

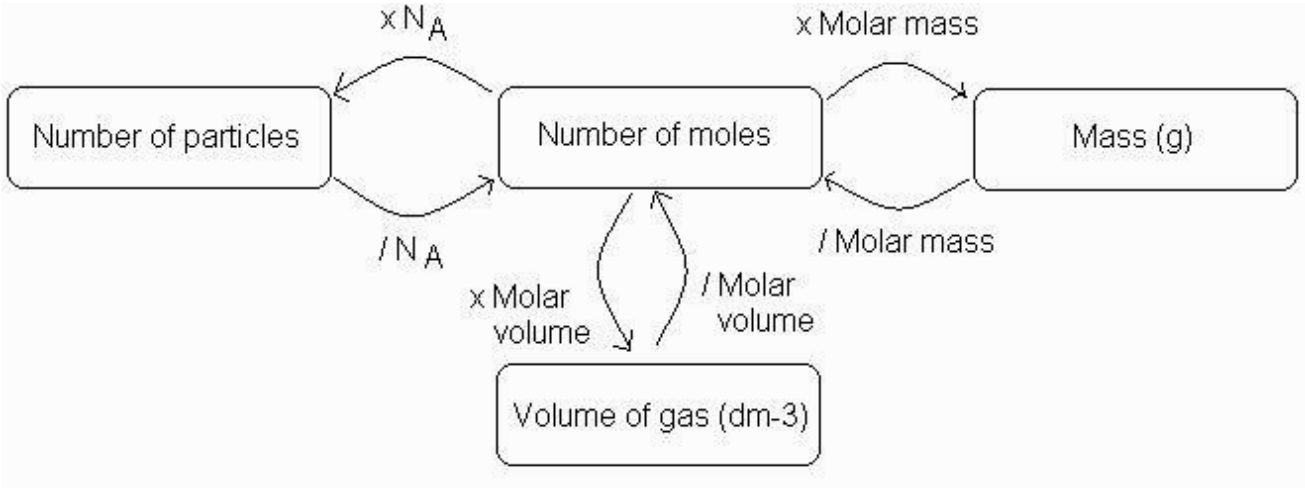
a) What is the volume of 1.2 mol of ammonia gas, NH_3 at STP?

= 1.2 mol x 22.4 dm^3 mol^{-1} = 26.88 dm^3

b) How many moles of ammonia gas, NH_3 are present in 600 cm^3 of the gas measured at room conditions?

$= \frac{0.6 dm^3}{24 dm^3 mol^{-1}} = 0.025 mol$

7. Numerical problems involving gases



Example 1:

What is the volume of 12.8 g of oxygen gas, O_2 in cm^3 at STP?

Answer:

Mass → Moles → Volume

12.8 → ? → ?

The number of moles of 12.8 g O_2

$$= \frac{12.8g}{2(16)gmol^{-1}} = 0.4mol$$

The volume of O_2 at STP

= 0.4 mol x 22.4 dm^3 mol^{-1}

= 8.96 dm^3 = 8960 cm^3

Example 2:

How many molecules of carbon dioxide, CO_2 are produced when 120 cm^3 of the gas is released during a chemical reaction between an acid and a carbonate at room condition?

Answer:

Volume → Moles → Molecules

120 cm^3 → ? → ?

Volume of CO_2 = 123 cm^3 = $\frac{120cm^3}{1000dm^3} = 0.12dm^3$

The number of moles of 0.12 dm^3 CO_2

$$= \frac{0.12dm^3}{24dm^3mol^{-1}} = 0.005mol$$

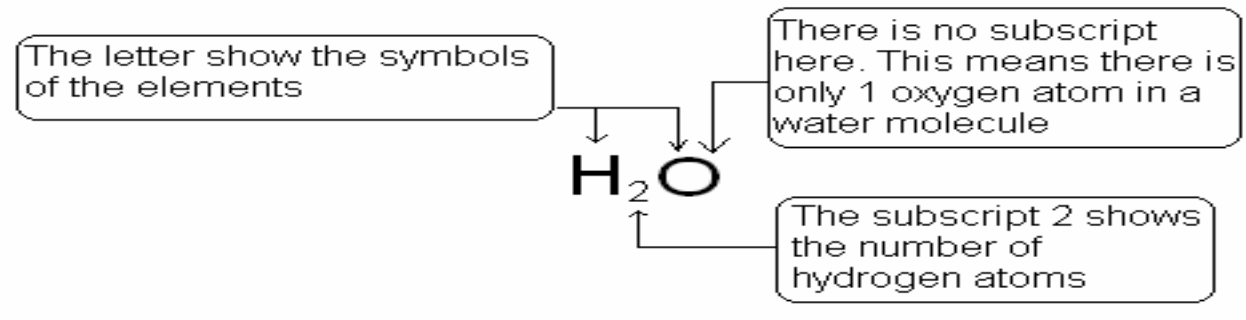
The number of molecules of CO_2

= 0.005 mol x 6.02 x 10^{23} mol^{-1}

= 3.01 x 10^{21}

8. Chemical formula

- A chemical formula is a representation of a chemical substance using letters for atoms and subscript numbers to show the numbers of each type of atoms that are present in the substance.
- Example: H_2, H_2O, NaCl, $Mg(No_3)_2$,



9. **Empirical formula**

- The empirical formula of a compound gives the simplest whole number ration of atoms of each element in the compound.
- Example: glucose $C_6H_{12}O_6$. The ration of carbon to hydrogen to oxygen atoms in the molecule is 6 : 12 : 6.
- This can be simplified as 1 : 2 : 1. Therefore, the empirical formula of glucose is CH_2O.
- A sample of aluminium oxide contains 1.08g of aluminium and 0.96g of oxygen. What is the empirical formula of this compound? [RAM: O, 16; Al, 27]

Element	**Al**	**O**	
Mass of element (g)	1.08	0.96	1. Write down the mass of each element
Number of moles	$\frac{1.08}{27} = 0.04$	$\frac{0.96}{16} = 0.06$	2. Divide each mass by its RAM
Ration of moles	$\frac{0.04}{0.04} = 1$	$\frac{0.06}{0.04} = 1.5$	3. Divide each number by the smallest number, 0.04
Simplest ration of moles	2	3	4. Multiply each answer by 2 to obtain the simplest ration in whole number

2 mol of aluminium atoms combine with 3 mol of oxygen atoms.
Therefore, **the empirical formula of the compound is Al_2O_3.**

♣ There are **two ways** to determine the empirical formula of metal oxide in laboratory

i. Combustion by using crucible lid

- **Oxide of metal which are more reactive than hydrogen**, H_2, in the reactivity series of metals
- Example: ***MgO, ZnO***

ii. Combustion by using combustion tube

- **Oxide of metal which are less reactive than hydrogen**, H_2, in the reactivity series of metals
- Example: ***CuO, PbO, FeO***

10 **Molecular Formula**

- The molecular formula of a compound gives us the actual number of atoms of each element that are present in a molecule of the compound.
- Example:

Compound	**Empirical formula**	**Molecular Formula**	***n***
Water	H_2O	$(H_2O)_1 = H_2O$	1
Ethene	CH_2	$(CH_2)_2 = C_2H_4$	2
Glucose	CH_2O	$(CH_2O)_6 = C_6H_{12}O_6$	6

11 **Ionic Formula**

- Ionic compounds are made up of positively-charged ions (cations) and negatively-charged ions (anions).

Cation	Formula	Anion	Formula
Sodium ion		Chloride ion	
Potassium ion		Bromide ion	
Zinc ion		Iodide ion	
Magnesium ion		Oxide ion	
Calcium ion		Hydroxide ion	
Iron (II) ion		Sulphate ion	
Iron (III) ion		Carbonate ion	
Copper (II) ion		Nitrate ion	
Ammonium ion		Phosphate ion	

Name of copound: **Zinc bromide**

Cation	Anion
Zinc ion, Zn^{2+}	Bromide ion, Br^-
2+	1-
1	2
Formula of compound: **$ZnBr_2$**	

Name of compound: **Aluminium oxide**

Cation	Anion
Aluminium ion, Al^{3+}	Oxide ion, O^{2-}
3+	2-
2	3
Formula of compound: **Al_2O_3**	

12 **Chemical equation**

- ✡ Chemical equation is a shorthand description of a chemical reaction.
- ✡ A chemical equation is a representation of a chemical reaction in words or using chemical formulae.
- ✡ Qualitatively, a chemical equation shows:
- types of reactants
- types of products
- the physical states of reactants and products
- ✡ Quantitatively, a chemical equation shows:
- the information on the number of moles of the reactants
- the information on the number of moles of the products

Example:

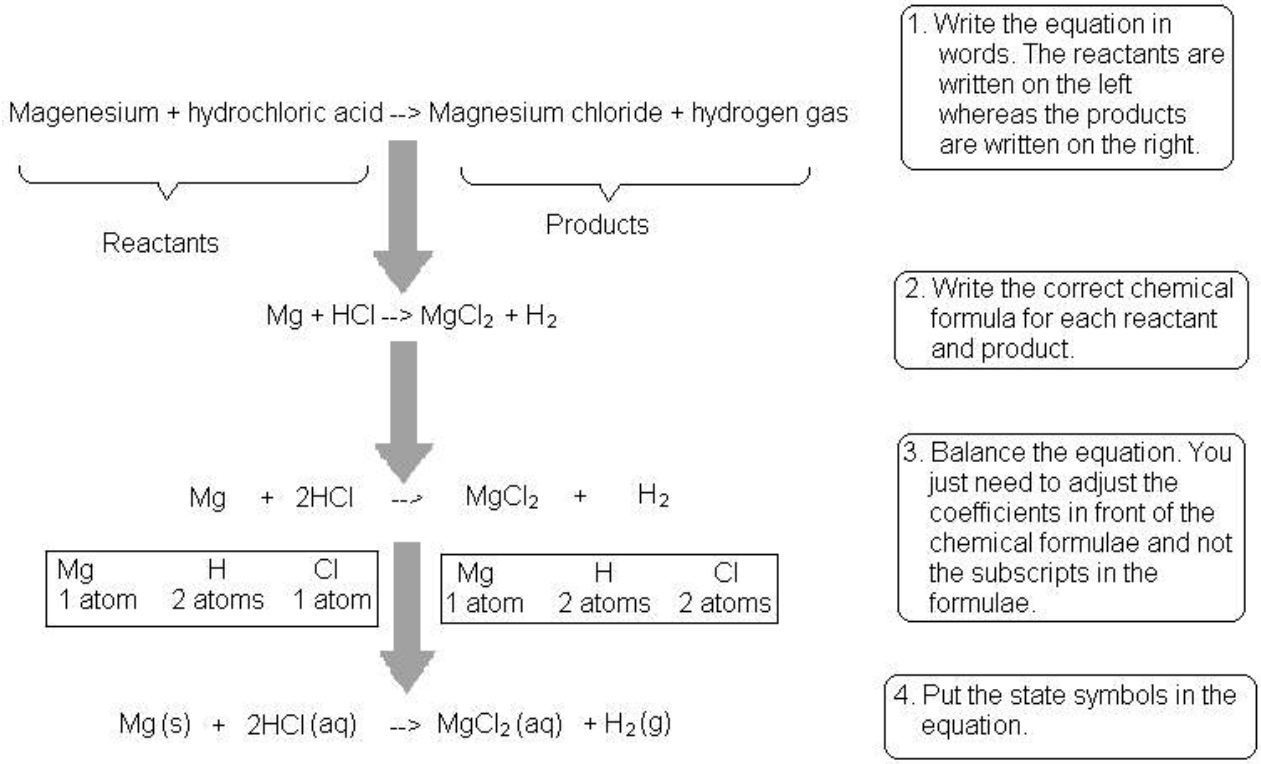
$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Symbol	***Information which can be obtained***
$CaCO_3$, HCl	Calcium carbonate and hydrochloric acid are ***reactants***
$CaCl_2$, H_2O, CO_2	Calcium chloride, water and carbon dioxide are the ***products***
→	Represents '***produces***'
(s)	Represents ***solid*** state
(aq)	Represents ***aqueous*** state
(l)	Represents ***liquid*** state
(g)	Represents ***gaseous*** state
According to the above chemical equation: 1 mol of calcium carbonate, $CaCO_3$ reacts with 2 mol of hydrochloric acid, HCl, producing 1 mol of calcium chloride, $CaCl_2$, 1 mol of water, H_2O and 1 mol of carbon dioxide, CO_2.	

Steps to write a balanced chemical equation

Magnesium reacts with dilute hydrochloric acid, HCl to produce magnesium chloride, $MgCl_2$ and hydrogen gas, H_2. write an equation to represent the reaction

Magnesium + hydrochloric acid → Magnesium chloride + hydrogen gas



Examples:

1. Hydrogen gas + oxygen gas → Water

2. Potassium iodide + Bromine gas → Iodine gas + Potassium bromide

3. Copper (II) oxide + Aluminium → Aluminium oxide + Copper

4. Calcium carbonate → Calsium monoxide + carbon dioxide

Numerical problems involving chemical equations

1. Copper (II) oxide, CuO reacts with aluminium. Calculate the mass of aluminium required to react completely with 12g of copper (II) oxide, CuO. [RAM: O, 16; Al, 27; Cu, 64]

Answer:

$3CuO(s) + 2Al(s) \rightarrow Al_2O_3(s) + 3Cu(s)$ 3 mol 2 mol 1 mol 3 mol 12 g ? The number if moles of 12 g CuO = $\frac{12g}{(60+16)gmol^{-1}} = \frac{12g}{80gmol^{-1}} = 0.15mol$	3 mol CuO react with 2 mol Al, 0.15 mol CuO react with ? mol Al The number of mol of Al = $\frac{0.15}{3} x2 = 0.1mol$ The mass of aluminium required = 0.1 mol x 27 g mol^{-1} = 2.7g

2. A student heats 20g of calsium carbonate, $CaCO_3$ strongly. It decomposes to calsium oxide and carbon dioxide.

a) If the CO_2 produced is collected at room conditions, what is the volume?

Answer:

$CaCO_3 \rightarrow CaO + CO_2$

1 mol 1 mol

20 g ? dm^3

The number of moles of 20g $CaCO_3$

$$= \frac{20g}{(40+12+3[16])gmol^{-1}} = \frac{20g}{100gmol^{-1}} = 0.2mol$$

1 mol $CaCO_3 \rightarrow$ 1 mol CO_2

0.2 mol $CacO_3 \rightarrow$ 0.2 mol CO_2

The volume of CO_2

= 0.2 mol x 25 dm^3 mol^{-1} = 4.8 dm^3

b) Calculate the mass of calcium oxide, CaO produced.

Answer:

$CaCO_3 \rightarrow CaO + CO_2$

1 mol 1 mol

20g ? g

The number of moles of 20g $CaCO_3$

$$= \frac{20g}{(40+12+3[16])gmol^{-1}} = \frac{20g}{100gmol^{-1}} = 0.2mol$$

1 mol $CaCO_3 \rightarrow$ 1 mol CaO

0.2 mol $CacO_3 \rightarrow$ 0.2 mol CaO

The mass of CaO

= 0.2 mol x [40 + 16] g mol^{-1}

= 11.2 g

Example question in Paper 2:

9 (a) Diagram 9 shows the set up of the apparatus to determine the empirical formula of oxide of metal M. M is less reactive than hydrogen.
Diagram 9 menunjukkan susunan radas untuk menentukan formula empirik oksida logam M. M kurang reaktif daripada hidrogen

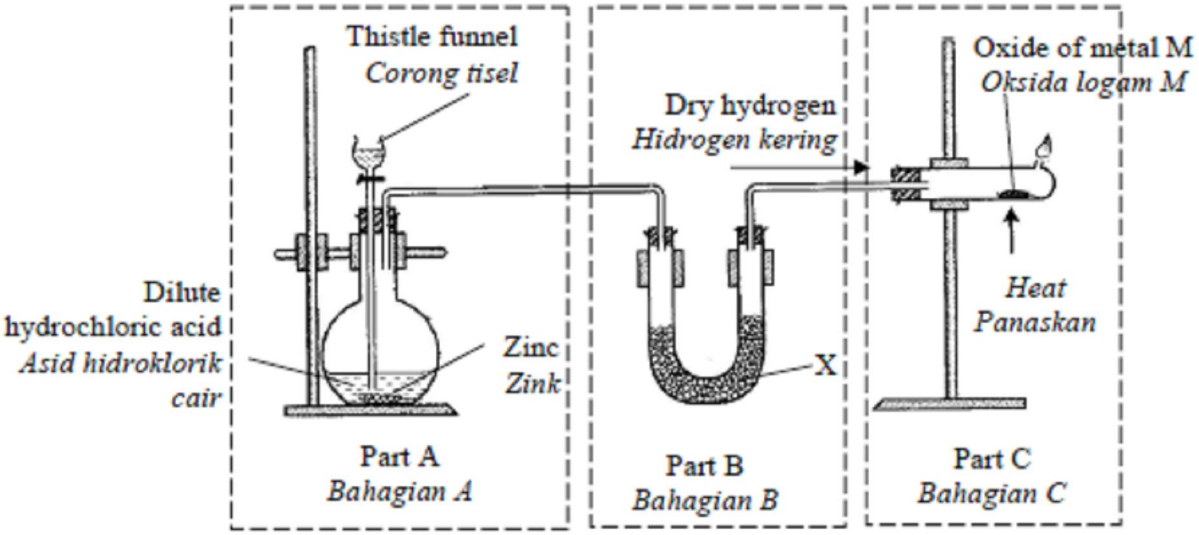


Diagram 9
Rajah 9

(i) State two precautions that must be taken in Part A while carrying out the experiment.
Nyatakan dua langkah berjaga-jaga yang perlu diambil di Bahagian A semasa menjalankan eksperimen tersebut?

[2 *marks*]

(ii) Suggest a suitable chemical substance for X in Part B and state the function of X.
Cadangkan satu bahan kimia yang sesuai bagi X di Bahagian B dan nyatakan fungsi X.

[2 *marks*]

(iii) Describe the reaction that occurs in Part C.
Huraikan tindak balas yang berlaku di Bahagian C.

[2 *marks*]

(iv) Information below shows the results of the experiment.
Maklumat di bawah menunjukkan keputusan bagi eksperimen tersebut.

Mass of combustion tube + porcelain dish *Jisim tabung pembakaran + piring porselin*	= 52.34 g
Mass of combustion tube + porcelain dish + oxide of M *Jisim tabung pembakaran + piring porselin + oksida M*	= 105.86 g
Mass of combustion tube + porcelain dish + M *Jisim tabung pembakaran + piring porselin + M*	= 102.02 g

Determine the empirical formula of the oxide of M:
Tentukan formula empirik oksida M

[Relative atomic mass of O =16 , M = 207]
[*Jisim atom relatif* O =16 , M = 207]

[4 *marks*]

(b) The information below is about hydrocarbon J
Maklumat di bawah adalah berkaitan dengan hidrokarbon J

- Empirical formula of J is CH_2
  Formula empirik J ialah CH_2
- Mass of 1 mole of J = 28 g
  Jisim 1 mol J = 28 g
- Produce by dehydration of alcohol
  Dihasilkan melalui pendehidratan alkohol

(i) Determine the molecular formula for hydrocarbon J.
[Relative atomic mass of C =12 , H = 1]
Tentukan formula molekul bagi hidrokarbon J
[*Jisim atom relatif* C =12 , H = 1]

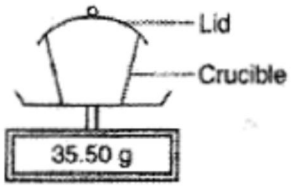
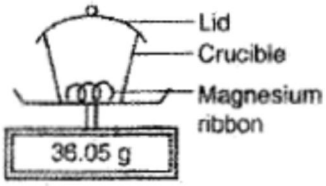
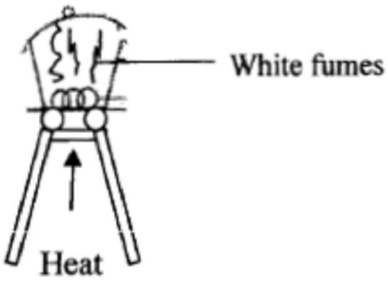
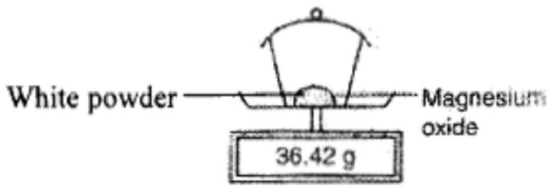
[2 *marks*]

(ii) Describe an experiment to prepare hydrocarbon J in the laboratory from its corresponding alcohol. In your answer, include the diagram of the appratus set-up, materials used, and procedure.
Huraikan satu eksperimen untuk menyediakan hidrokarbon J di makmal daripada alkohol yang sepadan. Dalam jawapan anda, hendaklah termasuk gambar rajah susunan radas, bahan dan prosedur.

[8 *marks*]

Example question in Paper 3:

1. A student had carried out an experiment to determine the empirical formula of magnesium oxide according to the following steps shown in Figure 1.
Seorang pelajar telah menjalankan satu eksperimen untuk menentukan formula empirik magnesium oksida berdasarkan langkah-langkah yang ditunjukkan dalam Rajah 1.

Step	Set-up of apparatus
A crucible and a lid are weighed. *Mangkuk pijar berserta penutupnya ditimbang.*	
The crucible, lid and a strip of clean magnesium ribbon are weighed. *Mangkuk pijar, penutup dan kepingan magnesium ditimbang.*	
Magnesium ribbon is strongly heated until the reaction is complete. *Kepingan magnesium dipanaskan dengan kuat sehingga pembakaran lengkap.*	
The crucible, lid and magnesium oxide are weighed again when cooled. *Mangkuk pijar, penutup dan magnesium oksida ditimbang semula selepas disejukkan.*	

(a) Complete the following table by stating the observations and related inferences in the experiment.
Lengkapkan jadual berikut dengan menyatakan pemerhatian dan inferens yang berkaitan dalam eksperimen itu

Observation	Inferences
1.	
2.	
3.	

[3 +3 marks]

(b) (i) Calculate the mass of magnesium that has been used.
Kirakan jisim magnesium yang telah digunakan.

(ii) Calculate the mass of oxygen that has been reacted with magnesium.
Kirakan jisim oksigen yang bertindak balas dengan magnesium.

(iii) Determine the empirical formula of magnesium oxide.
[Relative atomic mass : Mg, 24 ; O, 16]
Tentukan formula empirik bagi magnesium oksida.
[Jisim atom relatif : Mg, 24; O, 16]

[3 marks]

(c) Another experiment is carried out to determine the empirical formula of copper(II) oxide using the same method as the experiment before.
Satu lagi eksperimen dijalankan untuk menentukan formula empirik kuprum(II) oksida menggunakan kaedah yang sama seperti eksperimen sebelum ini.

(i) State whether this method can be used to determine the empirical formula for copper(II) oxide. Give the reason for your answer.
Tentukan sama ada kaedah ini boleh digunakan bagi menentukan formula empirik kuprum(II) oksida. Berikan sebab bagi jawapan anda.

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[3 marks]

(ii) Suggest the method that can be used to determine the empirical formula for copper(II) oxide.
Cadangkan kaedah yang boleh digunakan untuk menentukan formula empirik bagi kuprum(II) oksida.

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[3 marks]

(d) $CuO + H_2 \longrightarrow Cu + H_2O$

Based on the chemical equation above, determine :
Berdasarkan pada persamaan kimia di atas, tentukan :

(i) substance that is oxidised
bahan yang telah dioksidakan

.....

(ii) substance that is reduced
bahan yang diturunkan

.....

(iii) Reducing agent
Agen penurunan

.....

[3 marks]