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Cambridge
International
AS & A Level
As notes
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CHEMISTRY
0300-4815012
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Physical chemistry

1 Atoms, molecules and stoichiometry

This topic illustrates how quantitative relationships can be established when different substances react. (The term *relative formula mass* or M_r will be used for all compounds including ionic compounds.)

	Learning outcomes Candidates should be able to:
1.1 Relative masses of atoms and molecules	a) define and use the terms *relative atomic, isotopic, molecular* and *formula masses*, based on the ^{12}C scale
1.2 The mole and the Avogadro constant	a) define and use the term *mole* in terms of the Avogadro constant
1.3 The determination of relative atomic masses, A_r	a) analyse mass spectra in terms of isotopic abundances (knowledge of the working of the mass spectrometer is not required) b) calculate the relative atomic mass of an element given the relative abundances of its isotopes, or its mass spectrum
1.4 The calculation of empirical and molecular formulae	a) define and use the terms *empirical* and *molecular formula* b) calculate empirical and molecular formulae, using combustion data or composition by mass
1.5 Reacting masses and volumes (of solutions and gases)	a) write and construct balanced equations b) perform calculations, including use of the mole concept, involving: (i) reacting masses (from formulae and equations) (ii) volumes of gases (e.g. in the burning of hydrocarbons) (iii) volumes and concentrations of solutions When performing calculations, candidates' answers should reflect the number of significant figures given or asked for in the question. When rounding up or down, candidates should ensure that significant figures are neither lost unnecessarily nor used beyond what is justified (see also Practical Assessment, Paper 3, Display of calculation and reasoning on page 51). c) deduce stoichiometric relationships from calculations such as those in 1.5(b)

Chapter 1 Atoms, molecules and Stoichiometry

Relative atomic mass (A_r) :-

It is the average mass of an atom of an element as compared to $\frac{1}{12}$ of the mass of an atom of carbon which is taken as 12.

e.g; Bromine has two isotopes ^{79}Br and ^{81}Br, both has equal abundance

$$A_r \text{ of Bromine} = \frac{79 \times 50 + 81 \times 50}{100}$$

$$80$$

Similary A_r of Chlorine ~~by~~ can be calculated by calculating the average ~~mo~~ of the masses of its isotopes

^{35}Cl relative abundance 75%
^{37}Cl relative abundance 25%

$$A_r = \frac{35 \times 75 + 37 \times 25}{100}$$

$$= 35.5$$

Relative molecular mass (M_r):

It is the mass of one molecule of an element or compound as compared to $\frac{1}{12}$ of the mass of an atom which is taken as 12.

e.g; M_r of O_2 is 32
M_r of H_2 is 2
M_r of CO_2 is 44

Relative formula mass: This term is used for ionic compounds, it is the sum of the relative atomic masses of elements present in one formula unit of ionic compounds

e.g; relative formula mass of MgO is 24+16 = 40.
Relative formula mass can be defined as the mass of one formula unit of an ionic compound as compared to $\frac{1}{12}$ of the mass of an atom of C-12.

Relative isotopic mass:- The mass of an isotope of an element as compared to $\frac{1}{12}$ of the mass of an atom of C-12.

Relative ionic mass:- The mass of an ion of an element or a compound as compared to $\frac{1}{12}$ of the mass of an atom of C-12.

Mole (Definition):- Mole is that amount of a substance which contains 6.02×10^{23} particles of that substance

OR

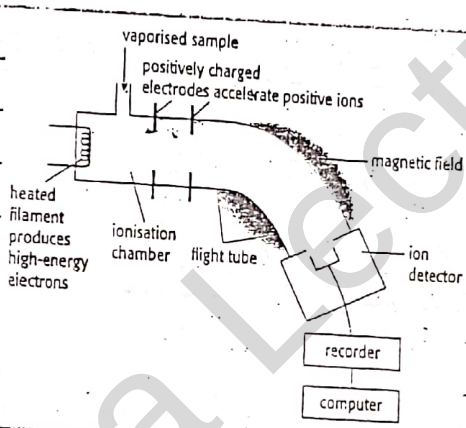
the amount of a substance containing as many particles as there are atoms in 12g of Carbon-12.

Isotopes:- Atoms of the same element which have same proton number but different mass number.
Isotopes have same chemical but different physical properties.

Spectrometry and Ar
Mass spectrometer is used to measure the mass and relative abundance of each isotope.

Working of mass spectrometer
⇒ Atoms of the element become monopositive ion when a gaseous sample of an element is introduced in spectrometer.
⇒ The stream of positive ions is brought to a detector after being deflected by a magnetic field.

Lighter ions (isotopes) are deflected more than heavier ions.
Deflected ions are brought to the detector, the detector is connected to a computer which displays the mass spectrum.
The mass spectrum produced shows the relative abundance on the vertical axis and the mass to charge ratio (m/e) on the horizontal axis.

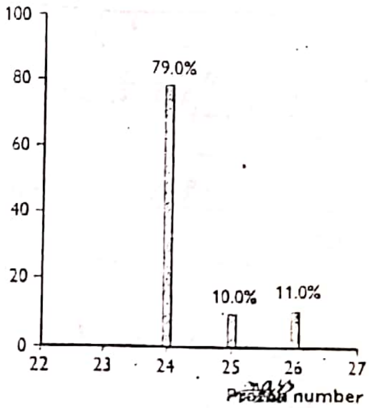


Determination of Ar from mass spectra

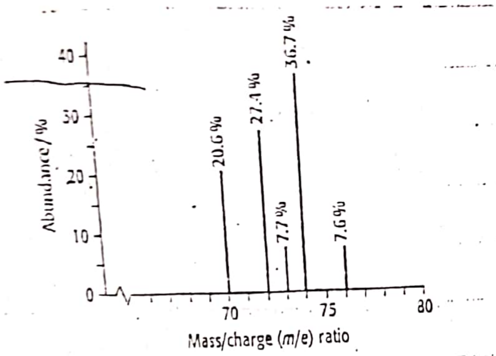
Calculate the Ar of Magnesium using mass spectra

$$Ar = \frac{24 \times 79 + 25 \times 10 + 26 \times 11}{100}$$

$= 24.32$



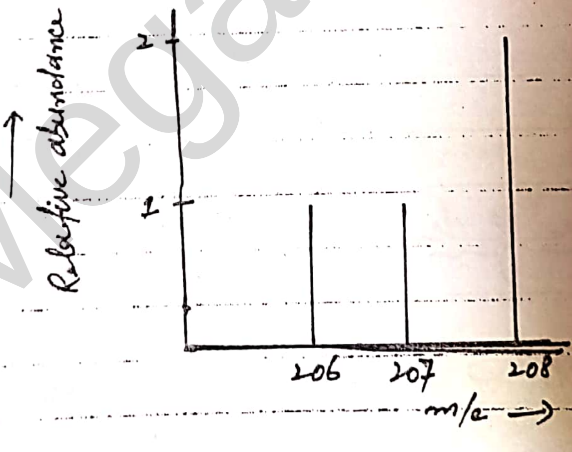
Mass spectrum of germanium



$$A_r = \frac{70\times 20.6 + 72\times 27.4 + 73\times 7.7 + 74\times 36.7 + 77\times 7.6}{100}$$

$$= 72.7$$

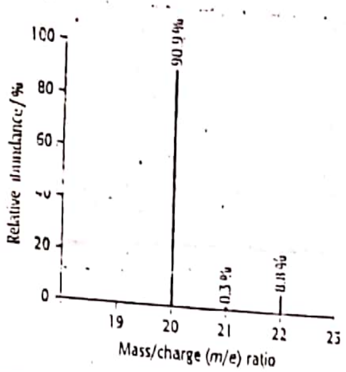
Mass spectrum of Lead



$$A_r = \frac{206\times 1 + 207\times 1 + 208\times 2}{4}$$

$$= 207.25$$

Mass spectrum of Neon



$$A_r = \frac{20 \times 90.9 + 21 \times 0.3 + 22 \times 8.8}{100}$$

$$= 20.2$$

Determination of relative abundance of an isotope

The relative atomic mass of Boron, which consists of the isotopes $^{10}_{5}B$ and $^{11}_{5}B$ is 10.8. Calculate the relative abundance of each isotope of Boron.

Solution

$A_r = 10.8$

relative abundance of $^{11}_{5}B = x$

relative abundance of $^{10}_{5}B = 100 - x$

$$A_r = \frac{11 \times x + 10(100-x)}{100}$$

$$10.8 = \frac{11x + 1000 - 10x}{100}$$

$$x = 80$$

So $^{11}_{5}B = 80\%$

and $^{10}_{5}B = 20\%$

Note: Relative abundance will be x for that isotope which mass is closer to A_r

Determination of relative isotopic abundance of the isotopes of Potassium

The relative atomic mass of Potassium is 39.1. The two main isotopes of Potassium are ^{39}K and ^{41}K.
Calculate the relative isotopic abundance of each isotope.

Solution

$A_r = 39.1$

relative abundance of $^{39}K = x$

relative abundance of $^{41}K = 100 - x$

$$39.1 = \frac{39 \times x + 41(100-x)}{100}$$

$$x = 95\%$$

$^{39}K = 95\%$

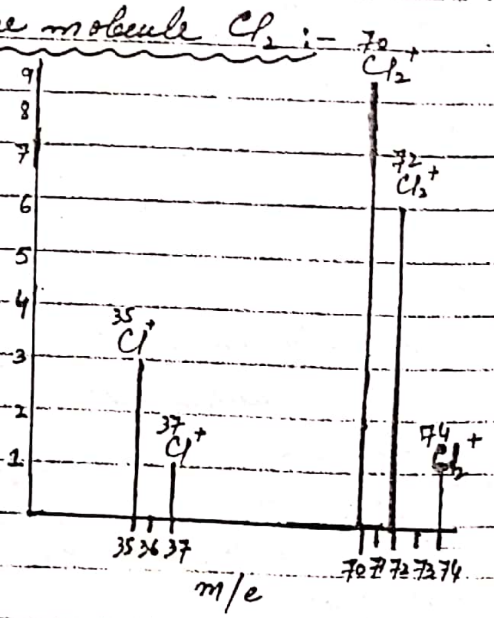
$^{41}K = 5\%$

Mass spectrum of diatomic molecules

Mass spectrum of Chlorine molecule Cl_2:-

When Chlorine gas is introduced in a mass spectrometer, a fraction of Chlorine molecules undergo fragmentation and produce 5 peaks due to following ions.

$^{35}Cl^+$, $^{37}Cl^+$, $^{70}Cl_2^+$ ($^{35}Cl\,^{35}Cl$)
$^{72}Cl_2$ ($^{35}Cl\,^{37}Cl$), $^{74}Cl_2$ ($^{37}Cl\,^{37}Cl$).



$^{70}Cl_2^+ \longrightarrow {}^{35}Cl^+ + {}^{35}Cl^\bullet$

$^{74}Cl_2^+ \longrightarrow {}^{37}Cl^+ + {}^{37}Cl^\bullet$

Stoichiometric calculations

The typical daily food requirement of a person can be considered to be 1.2 kg of carbohydrate. The person obtains energy by the oxidation of carbohydrate which can be represented by the formula $(CH_2O)_n$.

(a) Construct an equation for the complete combustion of carbohydrate.

(b) The empirical formula mass of the carbohydrate is 30, calculate the number of moles of oxygen required by the person each day.

Solution

$$(CH_2O)_n + nO_2 \longrightarrow nCO_2 + nH_2O$$

mass = 1.2 kg = 1200 g

$M_r = 30 \times n$

$\text{mole} = \frac{\text{Mass}}{M_r}$

$n = \frac{1200}{30n}$

$\text{moles} = \frac{40}{n}$

Number of oxygen

$(CH_2O)_n$	nO_2
1 mole	n moles
$\frac{40}{n}$	x

$x = \frac{40}{n} \times n$

40 moles of O_2 are required each day

0.144g of an aluminium compound X reacts with an excess of water, to produce a gas. This gas burns completely in O_2 to form H_2O and 72 cm^3 of CO_2 only. The volume of CO_2 was measured at s.t.p.
What could be the formula of X?

(A) Al_2C_3 (B) Al_3C_4 (C) Al_4C_3 (D) Al_5C_3

Solution

Mass of CO_2

24000 cm^3 — 44g
72 cm^3 — x

0.132g of CO_2

Mass of C from CO_2

12g — 44g
x — 0.132g

x = 0.036g of C

moles of C

$\frac{0.036}{12}$ = 0.003 mol of C

Mass of Al from unknown compound

0.144 − 0.036 = $\frac{0.108 g}{27}$

= 0.004 mole of Al

Mole ratio of C & Al

0.003   0.004

3 : 4

Al_4C_3

When a sports medal with a total surface area of 150 cm^2 was evenly coated with silver, using electrolysis, its mass increased by 0.216 g.
How many atoms of Ag were deposited per cm^2 of the surface of medal?

Solution 0.00144g ← 150 cm^2 — 0.216g
1 cm^2 — x

108g × 6 × 10^{23}
0.00144g — x

8×10^{18} atm