Chemistry

07

Quantification of Elements and Compounds

7.1 Relative Atomic Mass (Ar)

Assignment – 7.1

Discuss with the teacher and the students in your class about the units suitable to measure the mass of the following.

- A motor car
- A loaf of bread
- A molecule of carbondioxide
- A brick
- A tablet of medicine
- A helium atom

To measure the mass of items like a motor car, a brick, a loaf bread, a tea spoonful of sugar and a tablet of medicine, units like kilogram, gram and milligram can be used. But if the mass of very small particles such as a carbon dioxide molecule, or a helium atom is given in units like kilogram or gram, the value obtained is extremely small. Even the attogram (ag), the smallest units of mass is too large to indicate the mass of atoms or ions.

$$1 \text{ ag} = 10^{-18} \text{ g}$$

For example, the mass of an atom of the lightest element, hydrogen (H) is 1.674×10^{-24} g. That is 0.000000000000000000000001674 g. Masses of some other atoms are given below.

Mass of a carbon (C) atom	$= 1.993 \times 10^{-23}$ g
Mass of a sodium (Na) atom	$= 3.819 \times 10^{-23}$ g
Mass of a chlorine (Cl) atom	$= 5.903 \times 10^{-23}$ g
Mass of a potassium (K) atom	$= 6.476 \times 10^{-23}$ g

It is cumbersome to use this type of small figures in calculations.

For this reason, the mass of a selected atom was taken as a unit and the masses of the other atoms were given relative to it. The mass so expressed is known as the relative atomic mass. The relative atomic mass is not the true mass of an atom of an element. In the past, the mass of an atom of hydrogen, the lightest element was used as the atomic mass unit.

• Atomic Mass Unit

The mass of the unit relative to which the masses of other atoms are expressed is called the atomic mass unit.

At present $\frac{1}{12}^{th}$ the mass of $^{12}_{6}C$ isotope is used as the atomic mass unit.

$$\text{Atomic mass unit} = \frac{\text{Mass of the } ^{12}_{6}C \text{ isotope}}{12}$$

$$= \frac{1.99 \times 10^{-23}\ g}{12}$$

$$= 1.67 \times 10^{-24}\ g$$

How many times an atom of a given element weighs as much as 1/12 the mass of C - 12 isotope is the relative atomic mass of that element.

$$\text{Relative atomic mass } (A_r) = \frac{\text{Mass of an atom of the element}}{\frac{1}{12} \times \text{mass of a } ^{12}_{6}C \text{ atom}}$$

For example, the true mass of an oxygen atom (O) is 2.66×10^{-23} g.

The true mass of a $^{12}_{6}C$ atom is 1.99×10^{-23} g. Therefore, the relative atomic mass of oxygen can be found as follows.

$$\text{Relative atomic mass of oxygen (O)} = \frac{\text{Mass of an oxygen atom}}{\frac{1}{12} \times \text{mass of a } ^{12}_{6}C \text{ atom}}$$

$$= \frac{2.66 \times 10^{-23} g}{\frac{1}{12} \times 1.99 \times 10^{-23}\ g}$$

$$= 16.02$$

According to foregoing calculations, you may understand that the relative atomic mass has no units.

• Relative Atomic Masses of Some Elements

Atomic number	Element	Symbol	Relative atomic mass
1	Hydrogen	H	1
2	Helium	He	4
3	Lithium	Li	7
4	Beryllium	Be	9
5	Boron	B	11
6	Carbon	C	12
7	Nitrogen	N	14
8	Oxygen	O	16
9	Fluorine	F	19
10	Neon	Ne	20
11	Sodium	Na	23
12	Magnesium	Mg	24
13	Aluminium	Al	27
14	Silicon	Si	28
15	Phosphorus	P	31
16	Sulphur	S	32
17	Chlorine	Cl	35.5
18	Argon	Ar	40
19	Potassium	K	39
20	Calcium	Ca	40

Worked Examples

01. The mass of a potassium (K) atom is 6.476×10^{-23} g. The mass of a ${}^{12}_{6}C$ atom is 1.99×10^{-23} g. Find the relative atomic mass of potassium.

Relative atomic mass of potassium $= \dfrac{\text{Mass of potasium atom}}{\frac{1}{12} \times \text{Mass of a } {}^{12}_{6}C \text{ atom}}$

$$= \frac{6.476 \times 10^{-23}\,g}{\frac{1}{12} \times 1.99 \times 10^{-23}\,g}$$

$$= 39$$

02. The mass of an atom of element A is eight times the mass of ${}^{12}_{6}C$ isotope. Find the relative atomic mass of A.

Relative atomic mass of A $= \dfrac{\text{Mass of an atom of a}}{\frac{1}{12} \times \text{mass of a } {}^{12}_{6}C \text{ atom}}$

Mass of an atom of A $= \text{Mass of a } {}^{12}_{6}C \text{ atom x } 8$

Relative atomic mass of A $= \left(\dfrac{8 \times \text{ Mass of } {}^{12}_{6}C \text{ atom}}{\frac{1}{12} \times \text{mass of a } {}^{12}_{6}C \text{ atom}} \right)$

$= 8 \times 12$

$= 96$

03. Mass of a sodium atom is 3.819 x 10^{-23} g. The value of the atomic mass unit is 1.67 x 10^{-24} g. Find the relative atomic mass of sodium.

Relative atomic mass of sodium $= \dfrac{\text{Mass of a sodium atom}}{\text{Value of the atomic mass unit}}$

$= \dfrac{3.819 \times 10^{-23} g}{1.67 \times 10^{-24} g}$

$= 23.00$

7.2 Relative Molecular Mass (M_r)

Since many elements are reactive, their atoms do not exist as free atoms. They exist naturally as molecules formed by joining two or more atoms of them. Compounds are composed of molecules formed by the combination of atoms belonging to different elements.

How many times a given molecule of an element or a compound weighs as much as 1/12 the mass of C - 12 isotope is the relative molecular mass of that element or compound.

$$\text{Relative molecular mass } (M_r) = \frac{\text{Mass of a molecule of an element or a compound}}{\frac{1}{12} \times \text{Mass of a } {}^{12}_{6}\text{C atom}}$$

For instance, the true mass of a carbon dioxide (CO_2) molecule is 7.31×10^{-23} g. Mass of a carbon atom is 1.99×10^{-23} g.

$$\text{Relative molecular mass of } CO_2 = \frac{\text{Mass of a molecule of a Carbon dioxide}}{\frac{1}{12} \times \text{mass of a } {}^{12}_{6}\text{C atom}}$$

$$= \frac{7.31 \times 10^{-23}\,\text{g}}{\frac{1}{12} \times 1.99 \times 10^{-23}\,\text{g}}$$

$$= 44$$

As the relative atomic mass, relative molecular mass too does not have a unit.

The mass of a water molecule is (H_2O) 2.99×10^{-23} g. Atomic mass unit is 1.67×10^{-24} g. Find the relative molecular mass of water.

$$\text{Relative molecular mass of } H_2O = \frac{\text{Mass of a } H_2O \text{ molecule}}{\text{Atomic mass unit}}$$

$$= \frac{2.99 \times 10^{-23}\,\text{g}}{1.67 \times 10^{-24}\,\text{g}}$$

$$= 18$$

If the molecular formula of an element or a compound is known, its relative molecular mass can be calculated. This is because the relative molecular mass is equal to the sum of relative atomic masses of the atoms in a molecule.

For example a water molecule has two hydrogen atoms (H) and one oxygen atom (O) bound together. Therefore, the relative molecular mass of water (H_2O) is the sum of the relative atomic masses of two hydrogen atoms and an oxygen atom.

Since the relative atomic mass of hydrogen is 1 and oxygen is 16, the relative molecular mass of water can be calculated as follows.

$$H_2O = 2 \times 1 + 16 = 18$$

Relative molecular masses of some elements and compounds are tabulated in Table 7.1.

Table 7.1

Species	Molecular formula	Relative molecular mass
1. Hydrogen	H_2	$2 \times 1 = 2$
2. Nitrogen	N_2	$2 \times 14 = 28$
3. Oxygen	O_2	$2 \times 16 = 32$
4. Carbon dioxide	CO_2	$12 + (2\times 16) = 44$
5. Glucose	$C_6H_{12}O_6$	$(6\times12) + (12\times1) + (6\times16) = 180$

Exercise 01

Calculate the relative molecular mass of the following compounds.

01. Ammonia (NH_3)
Relative atomic masses H - 1 ; N - 14

02. Sulphuric acid (H_2SO_4)
Relative atomic masses H - 1 ; O - 16 ; S - 32

03. Sucrose ($C_{12}H_{22}O_{11}$)
Relative atomic masses H - 1 ; C - 12 ; O -16

The ionic compounds such as sodium chloride (NaCl) exist as lattices but not molecules. Its formula is written to indicate the simplest ratio in which Na^+ and Cl^- ions are present in the ionic lattice. In such compounds what is calculated as the relative molecular mass is the mass relevant to their empirical formula. It is known as the relative formula mass or formula mass.

Relative atomic mass Na - 23 ; Cl - 35.5

Relative formula mass of sodium chloride (NaCl) = 23 + 35.5
= 58.5

Exercise 02

Calculate the relative formula mass of the following compounds.

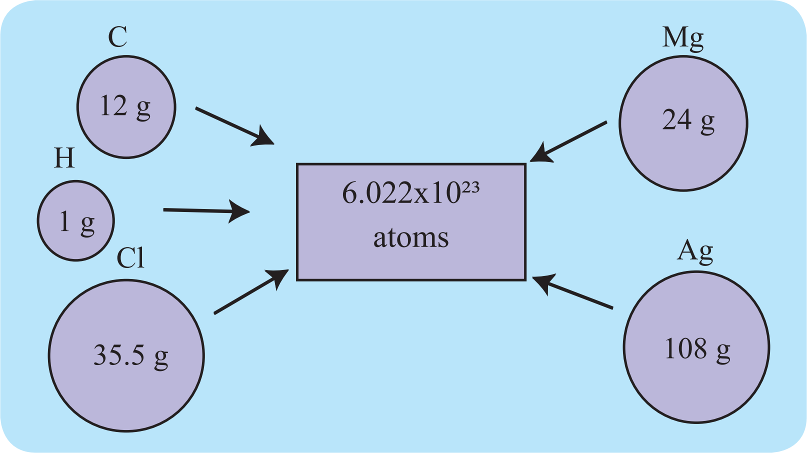
01. Magnesium oxide (MgO)
Relative atomic masses O - 16 ; Mg - 24

02. Calcium carbonate ($CaCO_3$)
Relative atomic masses C - 12 ; O - 16 ; Ca - 40

03. Potassium sulphate (K_2SO_4)
Relative atomic masses O - 16 ; S - 32 ; K - 39

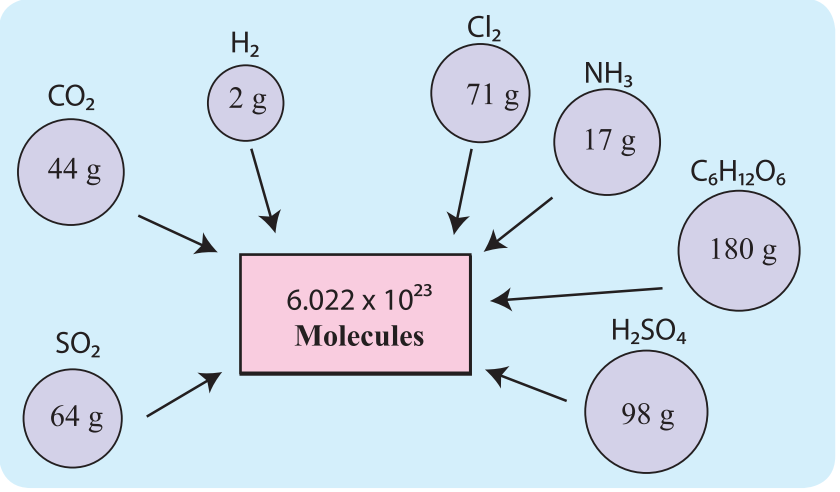
7.3 Avogadro constant

When a mass of any element equal to its relative atomic mass is taken in grams, it is seen that it contains the same number of atoms irrespective of the element.



Similarly, it can also be shown that when a mass of any substance equal to its relative molecular mass is taken in grams, it contains the same number of molecules.

After the great scientist Amedeo Avogadro, this constant number is called **Avogadro Constant**.



The presently accepted value of this constant is 6.022×10^{23} **and it is symbolised as L .**

7.4 Mole

In various tasks, measurement of the amount of a substance is a requirement. A dozen of books means 12 books. Similarly 'ream' is used to measure the amount of papers.

In the SI unit system, the unit used to measure the amount of a substance is the mole.

The mole is the amount of a substance that contains as many basic building units (atoms, molecules, ions) as there are atoms in exactly 12.00 g of C – 12 isotope.

The number of basic units contained in a mole of any substance is a constant and it is equal to the Avogadro constant or 6.022×10^{23}.

Thus, the relative atomic mass of any element taken in grams contains one mole of atoms or 6.022×10^{23} atoms. The relative molecular mass of any substance taken in grams contains one mole of molecules or 6.022×10^{23} molecules.

A mole of an element or a compound that exists as molecules means a mole of molecules of them.

Since mole is a unit that indicates a very large amount, it is not suitable to measure the amount of substances that we come across in day to day life. Therefore, the unit mole is practically used to measure the amounts of things such as atoms, molecules and ions which exist in very large numbers.

The following example illustrates the magnitude of the number representing a mole.

Suppose there are 1000 million children in the world. This in powers of ten is,

$$1000 \text{ million} = 1000 \times 10^6 = 10^9$$

If a mole of lozenges is equally distributed among these children,

$$\begin{aligned}\text{The number of lozenges each child gets} &= \frac{6.022\times10^{23}}{10^9}\\ &= 6.022\times10^{14}\\ &= 602200000000000\end{aligned}$$

As the number of units belonging to a mole is very large, counting is impossible. Therefore, other methods are used to measure the mole. One method to have a mole of atoms of an element is weighing out its relative atomic mass in grams. For example, the relative atomic mass of sodium is 23.

1 mol of sodium atoms = 23 g of sodium

In order to have a mole of molecules of a given compound, its relative molecular mass has to be weighed out in grams. For instance, the relative molecular mass of glucose ($C_6H_{12}O_6$) is 180.

1 mol of glucose molecules = 180 g of glucose

- ## Molar Mass

Molar mass is the mass of a mole of any substance.

Though relative atomic mass and relative molecular mass have no units, grams per mole (g mol^{-1}) or kilograms per mole (kg mol^{-1}) is the unit of the molar mass.

1.	Relative atomic mass of sodium (Na)	=	23
	Molar mass of sodium	=	23g mol^{-1}

2.	Relative molecular mass of carbon dioxide (CO_2)	=	44
	Molar mass of carbon dioxide	=	44 g mol^{-1}
3.	Relative formula mass of sodium chloride (NaCl)	=	58.5
	Molar mass of sodium chloride	=	58.5 g mol^{-1}
4.	Relative formula mass of calcium carbonate ($CaCO_3$)	=	100
	Molar mass of calcium carbonate	=	100 g mol^{-1}

The following relationship can also be used to find the amount of any given substance (number of moles).

$$\text{Amount of substance (number of moles)} = \frac{\text{Mass of the substance}}{\text{Molar mass of the substance}}$$

$$n = \frac{m}{M}$$

Worked Examples

01. Find the number of atoms in 4 mol of carbon.

Number of atoms in 1 mol of carbon $= 6.022 \times 10^{23}$

Number of atoms in 4 mol of carbon $= 6.022 \times 10^{23} \times 4$

$= 2.409 \times 10^{24}$

02. Find,

i. the number of molecules;

ii. total number of atoms; and

iii. the number of oxygen atoms

in 5 mol of carbon dioxide.

i. Number of CO_2 molecules in 1 mol of carbon dioxide molecules $= 6.022 \times 10^{23}$

Number of CO_2 molecules in 5 mol of carbon dioxide molecules $= 6.022 \times 10^{23} \times 5$

$= 30.11 \times 10^{23}$

$= 3.011 \times 10^{24}$

ii. Total number of atoms in a carbon dioxide molecule $= 3$

Total number of atoms in 5 mol of carbon dioxide $= 3.011 \times 10^{24} \times 3$

$= 9.033 \times 10^{24}$

iii. Number of oxygen atoms in a carbon dioxide molecule $= 2$

Number of oxygen atoms in 5 mol of carbon dioxide $= 3.011 \times 10^{24} \times 2$

$= 6.022 \times 10^{24}$

03. Molar mass of carbon is 12 g mol^{-1}. Find the amount of carbon in 10 g of carbon.

Amount of carbon in 12 g of carbon = 1 mol

Amount of carbon in 10 g of carbon $= \frac{1\ mol}{12\ g} \times 10\ g$

$= 0.83\ mol$

04. Find the number of molecules in 0.1 mol of carbon dioxide.

Number of molecules in 1 mol of carbon dioxide $= 6.022 \times 10^{23}$

Number of molecules in 0.1 mol $= \frac{6.022 \times 10^{23} \times 0.1\ mol}{1\ mol}$

$= 6.022 \times 10^{22}$

05. Relative molecular mass of oxygen (O_2) is 32. Find the number of oxygen molecules (O_2) in 10 g of oxygen.

Number of molecules in 32 g of oxygen $= 6.022 \times 10^{23}$

Number of molecules in 10 g oxygen $= 6.022 \times 10^{23} \times 10g/ 32g$

$= 1.88 \times 10^{23}$

06. Molar mass of water is 18 g mol^{-1}. Find the amount of water in 20 g of water.

Amount of water in 18 g of water = 1 mol

Amount of water in 20 g of water $= \frac{1\ mol}{18\ g} \times 20\ g$

$= 1.11\ mol$

07. Calculate the amount of carbon dioxide in 22 g of carbon dioxide (Molar mass of carbon dioxide is 44 g mol^{-1}).

Amount of carbon dioxide in 44 g of carbon dioxide = 1 mol

Amount of carbon dioxide in 22g of carbon dioxide $= \frac{1\ mol}{44\ g} \times 22\ g$

$= 0.5\ mol$

This can also be solved using the formula as follows.

$$n = \frac{m}{M}$$

$$= \frac{22\ g}{44\ g\ mol^{-1}}$$

$$= 0.5\ mol$$

08. Calculate the amount of carbon in 24 g of carbon. Molar mass of carbon is 12 g mol^{-1}.

Amount of carbon in 12 g of carbon $= 1\ mol$

Amount of carbon in 24 g of carbon $= \frac{1\ mol}{12\ g} \times 24\ g$

This can also be solved using the formula as follows. $= 2\ mol$

$$n = \frac{m}{M}$$

$$= \frac{24\ g}{12\ g\ mol^{-1}}$$

$$= 2\ mol$$

Summary

- Atoms are very small. Therefore their masses are given relative to the mass of a selected atom instead of expressing them in units like grams and kilograms.
- The atomic mass unit is $1/12^{th}$ the mass of C – 12 isotope.
- The relative atomic mass of an element is the mass of an atom of that element relative to $1/12^{th}$ the mass of C – 12 isotope.
- When the relative molecular mass of an element or a compound is taken in grams it contains 6.022×10^{23} molecules.
- The international unit (SI Unit) of measuring the quantity of a substance is the mole.
- The mole is the amount of substance which contains as many atoms or molecules as there are atoms in exactly 12 g of C – 12 isotope.
- The number of basic units in a mole of a given substance is a constant. It is equal to the Avogadro Constant (6.022×10^{23}).
- Molar mass is the mass of a mole of a given substance. The substance may be composed of atoms or molecules. The unit of molar mass is g mol^{-1}
- $$\text{Amount of moles of a substance (n)} = \frac{\text{Mass of that substance (m)}}{\text{Molar mass of that substance (M)}}$$

Exercises

01. Find the relative molecular mass of the following substances.

i.	CH_3OH	(Methyl alcohol / Methanol)
ii.	CS_2	(Carbon disulphide)
iii.	C_8H_{18}	(Octane)
iv.	CH_3COOH	(Acetic acid)
v.	$C_{12}H_{22}O_{11}$	(Sucrose)
vi.	$CO(NH_2)_2$	(Urea)
vii.	$C_9H_8O_4$	(Aspirin)
viii.	HNO_3	(Nitric acid)
ix.	CCl_4	(Carbon tetrachloride)
x.	$C_8H_9NO_2$	((Paracetamol)

(R.A.M : H - 1, C - 12, N - 14, O - 16, S - 32, Cl - 35.5)

02. Find the molar mass of the following compounds.

i.	CO_2	(Carbon dioxide)
ii.	NaCl	(Sodium chloride)
iii.	$CaCO_3$	(Calcium carbonate)
iv.	NH_4Cl	(Ammonium chloride)
v.	Mg_3N_2	((Magnesium nitride)
vi.	H_2S	(Hydrogen sulphide)
vii.	$AlCl_3$	(Aluminium chloride)
viii.	$(NH_4)_2CO_3$	(Ammonium carbonate)
ix.	$CuSO_4$	(Copper sulphate)
x.	$Na_2C_2O_4$	(Sodium oxalate)

R.A.M : H - 1, C - 12, N - 14, O - 16, Na - 23, Mg - 24, Al - 27, S - 32, Cl - 35.5,Ca - 40, Cu - 63.5)

03.

i. What is the amount of substance in moles in 12 g of magnesium (Mg) ?

ii. What is the amount of substance in moles in 10 g of calcium carbonate ($CaCO_3$) ?

iii. How many molecules are there in 5 mol of carbon dioxide (CO_2) ?

iv. How many water molecules are present in 4 mol of water (H_2O) ?

v. What is the mass of 2 mol of urea ($CO(NH_2)_2$) ?

04. How many moles of oxygen atoms (O) does one mole of each of the following compounds contain ?

i. Al_2O_3 ii. CO_2 iii. Cl_2O_7
iv. CH_3COOH v. $Ba_3(PO_4)_2$

Technical terms

Atomic mass unit	-	පරමාණුක ස්කන්ධ ඒකකය	-	அணுத்திணிவு அலகு
Relative atomic mass	-	සාපේක්ෂ පරමාණුක ස්කන්ධය	-	சார் அணுத்திணிவு
Relative molecular mass	-	සාපේක්ෂ අණුක ස්කන්ධය	-	சார் மூலக்கூற்றுத் திணிவு
Avogadro constant	-	ඇවගාඩ්රෝ නියතය	-	அவகாதரோ மாறிலி
Mole	-	මවුලය	-	மூல்
Molar mass	-	මවුලික ස්කන්ධය	-	மூலர்த்திணிவு