

Atomic, Molecular and Equivalent masses

(1) **Atomic mass:** It is the average relative mass of atom of element as compared with an atom of carbon-12 isotope taken as 12.

$$\text{Atomic mass} = \frac{\text{Average mass of an atom}}{12} \times \text{Mass of an atom of } C_{12}$$

Average atomic mass: If an element exists in two isotopes having atomic masses 'a' and 'b' in the ratio $m : n$, then average atomic mass = $\frac{(m \times a) + (n \times b)}{m + n}$.

Since the atomic mass is a ratio, it has no units and is expressed in *amu*, $1 \text{ amu} = 1.66 \times 10^{-24} \text{ g}$. One atomic mass unit (amu) is equal to $\frac{1}{12}$ th of the mass of an atom of carbon-12 isotope.

Gram atomic mass (GAM): Atomic mass of an element expressed in grams is called *Gram atomic mass or gram atom or mole atom*.

(i) Number of gram atoms = $\frac{\text{Mass of an element}}{\text{GAM}}$

(ii) Mass of an element in *gm.* = No. of *gm. atom* \times GAM

(iii) Number of atoms in 1 GAM = 6.02×10^{23}

$$\begin{aligned} \therefore \text{Number of atoms in a given substance} &= \text{No. of GAM} \times 6.02 \times 10^{23} \\ &= \frac{\text{Mass}}{\text{GAM}} \times 6.02 \times 10^{23} \end{aligned}$$

(iv) Number of atoms in 1 *gm* of element = $\frac{6.02 \times 10^{23}}{\text{Atomic mass}}$

(v) Mass of one atom of the element (in *gm.*)

$$= \frac{\text{GAM}}{6.02 \times 10^{23}}$$

Methods of determination of atomic mass

(i) **Dulong and Pettit's method :** According to Dulong and Pettit's law

$$\text{Atomic mass} \times \text{Specific heat} = 6.4 \text{ (approx.)}$$

$$\text{Atomic mass (approx.)} = \frac{6.4}{\text{Specific heat (in cal.)}}$$

This law is applicable to solid elements only except Be, B, C and Si because their specific heat is variable with temperature.

$$\text{Atomic mass} = \text{Equivalent mass} \times \text{Valency}$$

$$\text{Valency} = \frac{\text{Approximate atomic mass}}{\text{Equivalent mass}}$$

(ii) **Vapour density method :** It is suitable for elements whose chlorides are volatile.

$$\begin{aligned} \text{Valency of the element} &= \frac{\text{Molecular mass of chloride}}{\text{Equivalent mass of chloride}} \\ &= \frac{2 \times \text{Vapour density of chloride}}{\text{Equivalent mass of metal} + 35.5} \end{aligned}$$

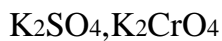
$$\text{Atomic mass} = \text{Equivalent mass of metal} \times \text{Valency}$$

(iii) **Specific heat method** : It is suitable only for gases. The two types of specific heats of gases are C_p (at constant pressure) and C_v (at constant volume). *Their ratio is known as γ whose value is constant (1.66 for monoatomic, 1.40 for diatomic and 1.33 for triatomic gases).*

$$\text{Atomic mass of a gaseous element} = \frac{\text{Molecular mass}}{\text{Atomicity}}$$

(iv) **Isomorphism method** : It is based on law of isomorphism which states that compounds having identical crystal structure have similar constitution and chemical formulae.

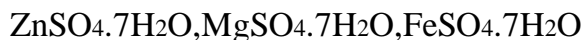
Example :



and



(valency of S, Cr, Se = 6),



(valency of Zn, Mg, Fe = 2).

(2) **Molecular mass** : Molecular mass of a molecule, of an element or a compound may be defined as a *number which indicates how many times heavier is a molecule of that element or compound as compared with 1/12 of the mass of an atom of carbon-12*. Molecular mass is a ratio and hence has no units. It is expressed in *a.m.u.*

$$\text{Molecular mass} = \frac{\text{Mass of one molecule of the substance}}{1/12 \times \text{Mass of one atom of C-12}}$$

$$\text{Actual mass of one molecule} = \text{Mol. mass} \times 1.66 \times 10^{-24} \text{ gm.}$$

Molecular mass of a substance is the additive property and can be calculated by adding the atomic masses present in one molecule.

Gram molecular mass (GMM) and Gram molar volume : Molecular mass of an element or compound when expressed in *gm.* is called its gram molecular mass, gram molecule or mole molecule.

$$\text{Number of gm molecules} = \frac{\text{Mass of substance}}{\text{GMM}}$$

$$\text{Mass of substance in gm} = \text{No. of gm. molecules} \times \text{GMM}$$

Volume occupied by one mole of any gas at STP is called **Gram molar volume**. The value of gram molar volume is 22.4 litres. *Volume of 1 mole of any gas at STP = 22.4 litres*

Expression for mass and density

Mass of 11.2L of any gas at STP = V.D. of that gas in gm.

Density of a gas at NTP = Mol. mass in gm. / 22400ml

Important generalizations

Number of atoms in a substance

$$= \text{Number of GMM} \times 6.02 \times 10^{23} \times \text{Atomicity}$$

Number of electrons in given substance = Number of GMM $\times 6.02 \times 10^{23} \times$ Number of electrons

Methods of determination of molecular mass

Following methods are used to determine molecular mass,

(i) **Diffusion method** (For gases) : The ratio of rates of diffusion of two gases is inversely proportional to the square root of their molecular masses.

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

(ii) **Vapour density method** (For gases only) : Mass of a fixed volume of the vapour is compared with the mass of the same volume of hydrogen under same conditions. The ratio of these masses is called **Vapour density** or **Relative density**.

$$\text{Molecular mass} = 2 \times \text{Vapour density}$$

(iii) **Victor Meyer method** (For volatile liquids or solids)

It is based on Dalton's law of partial pressure and Avogadro's hypothesis (gram molar volume).

22400 ml of vapours of a substance = Molecular mass of that substance

(iv) **Colligative property method** (For non-volatile solids)

Discussed in colligative properties of solutions.

Average atomic mass and molecular mass

$$\bar{A} \text{ (Average atomic mass)} = \sum A_i X_i / \sum X_{\text{total}}$$

$$\bar{M} \text{ (Average molecular mass)} = \sum M_i X_i / \sum X_{\text{total}}$$

Where

A_1, A_2, A_3, \dots

are atomic mass of species 1, 2, 3, ... etc. with % ratio as

X_1, X_2, X_3, \dots

etc. Similar terms are for molecular masses.

(3) **Equivalent mass** : The number of parts by mass of a substance that combines with or displaces 1.008 parts by mass of hydrogen or 8.0 parts of oxygen or 35.5 parts of chlorine is called its *equivalent mass* (EM). On the other hand *quantity of a substance in grams numerically equal to its equivalent mass is called its gram equivalent mass (GEM) or gram equivalent.*

Number of GEM = $\frac{\text{Mass of the substance in grams}}{\text{GEM of the substance}}$

Expressions for equivalent mass (EM)

(i) EM of an element = $\frac{\text{Atomic mass}}{\text{Valency}}$

(ii) EM of an acid = $\frac{\text{Molecular mass}}{\text{Basicity}}$

- (*Basicity of acid is the number of replaceable hydrogen atoms in one molecule of the acid*).

(iii) EM of a base = $\frac{\text{Molecular mass}}{\text{Acidity}}$

(*Acidity of a base is the number of replaceable—*

OH

groups in one molecule of the base).

(iv) EM of a salt = $\frac{\text{Formula mass}}{\text{Total positive or negative charge}}$

(v) EM of an oxidising agent

= $\frac{\text{Formula mass}}{\text{Number of electrons gained per molecule or Total change in O.N.}}$

Equivalent mass of common oxidising agent changes with the medium of the reaction.

Methods of determination of equivalent mass

(i) **Hydrogen displacement method** : The mass of metal which displaces 11200 ml of hydrogen at NTP from an acid, alkali or alcohol is the equivalent mass of the metal.

(a) Equivalent mass of metal

= $\frac{\text{Mass of metal}}{\text{Mass of H}_2\text{displaced}} \times 1.008$

= $W \times 1.008 \text{g}$

(b) Equivalent mass of metal

= $\frac{\text{Mass of metal}}{\text{Vol. (ml) of H}_2\text{displaced at STP}} \times 11200$

$$= \frac{W}{V} \times 11200$$

This method is useful for metals which can displace hydrogen from acids or can combine with hydrogen

(Mg, Zn, Na, Ca etc.)

(ii) **Oxide formation method** : The mass of the element which combines with 8 grams of oxygen is the equivalent mass of the element.

$$(a) \text{ Equivalent mass of metal} = \frac{\text{Mass of metal}}{\text{Mass of oxygen}} \times 8$$

$$(b) \text{ Equivalent mass of metal} = \frac{\text{Mass of metal}}{\text{Vol. of O}_2 \text{ at S.T.P. in ml}} \times 5600$$

(iii) **Chloride formation method** : The mass of an element which reacts with 35.5 gm. of chlorine is the equivalent mass of that element.

$$(a) \text{ Equivalent mass of metal} = \frac{\text{Mass of metal}}{\text{Mass of chlorine}} \times 35.5$$

$$(b) \text{ Equivalent mass of metal} = \frac{\text{Mass of metal}}{\text{Vol. of Cl}_2 \text{ (in ml.) at STP}} \times 11200$$

(iv) **Neutralisation method** : (For acids and bases).

$$\text{Equivalent mass of acid (or base)} = \frac{W}{V} \times N$$

Where ,

W = Mass of acid or base in gm.,

V = Vol. of base or acid in litre required for neutralisation

N is Normality of base or acid

(v) **Metal displacement method** : *It is based on the fact that one gm. equivalent of a more electropositive metal displaces one gm equivalent of a less electropositive metal from its salt solution.*

$$\frac{\text{Mass of metal added}}{\text{Mass of metal displaced}} = \frac{\text{Eq. mass of metal added}}{\text{Eq. mass of metal displaced}}$$

$$W_1 W_2 = E_1 E_2$$

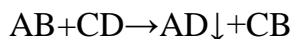
(vi) **Electrolytic method** : The quantity of substance that reacts at electrode when 1 faraday of electricity is passed is equal to its gram equivalent mass.

$$\text{Gram equivalent mass} = \text{Electrochemical equivalent} \times 96500$$

The ratio of masses of two metals deposited by the same quantity of electricity will be in the ratio of their equivalent masses.

$$W_1 W_2 = E_1 E_2$$

(vii) **Double decomposition method**



Mass of compound AB = Mass of compound AD = Eq. mass of A + Eq. mass of B
Eq. mass of A + Eq. mass of D

or

Mass of salt taken (W_1) = Mass of ppt. obtained (W_2) = Eq. mass of salt (E_1)
Eq. mass of salt in ppt. (E_2)

(viii) **Conversion method** : When one compound of a metal is converted to another compound of the same metal, then

Mass of compound I (W_1) = Mass of compound II (W_2) = $E +$ Eq. mass of radical I
 $E +$ Eq. mass of radical II

(E = Eq. mass of the metal)

(ix) **Volatile chloride method**

Valency of metal = $2 \times$ V.D. of Chloride / Eq. mass of metal chloride
 $= 2 \times$ V.D. / $E + 35.5$

$\therefore E = \frac{2 \times \text{V.D. of Chloride}}{\text{Valency}} - 35.5$

(x) **Silver salt method** (For organic acids)

Equivalent Mass of acid = $\frac{108 \times \text{Mass of silver salt}}{\text{Mass of Ag metal}} - 107$

Molecular mass of acid = Equivalent mass of acid \times Basicity