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.

$$\text{Atomic mass} = \frac{\text{Average mass of an atom}}{1/12 \times \text{Mass of an atom of } C^{12}}$$

Average atomic mass: If an elements 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 *amu* = 1.66×10^{-24}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 × GAM

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

∴ Number of atoms in a given substance = No. of GAM × 6.02×10^{23}

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

(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.*)

$$= \frac{1}{\text{GAM}\ 6.02 \times 10^{23}}$$

Methods of determination of atomic mass

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

Atomic mass × Specific heat = 6.4 (*approx.*)

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

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

Atomic mass = Equivalent mass × Valency

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

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

Valency of the element = $\frac{\text{Molecular mass of chloride}}{\text{Equivalent mass of chloride}}$

$= 2 \times \frac{\text{Vapour density of chloride}}{\text{Equivalent mass of metal + 35.5}}$

Atomic mass = Equivalent mass of metal × 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 g 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 :

$$K_2SO_4, K_2CrO_4$$

and

$$K_2SeO_4$$

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

$$ZnSO_4.7H_2O, MgSO_4.7H_2O, FeSO_4.7H_2O$$

(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* $\frac{1}{12}$ *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.*

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

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

Molecular mass of a substances 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.

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

Mass of substances in *gm* = No. of *gm.* molecules × 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 = $\frac{\text{Mol. mass in gm}}{22400\text{ml}}$

Important generalizations

Number of atoms in a substance

= Number of GMM $\times 6.02 \times 10^{23} \times$ 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**.

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

(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

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

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

Where

$A_1, A_2, A_3 .....$

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

$X_1, X_2, X_3 .....$

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*.

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

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

$$= \frac{\text{Mass of metal}}{\text{Mass of } H_2 \text{ displaced}} \times 1.008$$

$$= \frac{W}{M} \times 1.008 g$$

(b) Equivalent mass of metal

$$= \frac{\text{Mass of metal}}{\text{Vol. (ml) of } H_2 \text{ displaced at STP}} \times 11200$$

$= WV \times 11200$

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

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

(b) 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).

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

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*.

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

$$\frac{W_1}{W_2} = \frac{E_1}{E_2}$$

(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.

Gram equivalent mass = 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.

$$\frac{W_1}{W_2} = \frac{E_1}{E_2}$$

(vii) **Double decomposition method**

$$AB+CD \rightarrow AD\downarrow+CB$$

$$\frac{\text{Mass of compound AB}}{\text{Mass of compound AD}}=\frac{\text{Eq. mass of A + Eq. mass of B}}{\text{Eq. mass of A + Eq. mass of D}}$$

or

$$\frac{\text{Mass of salt taken } (W_1)}{\text{Mass of ppt. obtained } (W_2)}=\frac{\text{Eq. mass of salt } (E_1)}{\text{Eq. mass of salt in ppt. } (E_2)}$$

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

$$\frac{\text{Mass of compound I } (W_1)}{\text{Mass of compound II } (W_2)}=\frac{E+\text{ Eq. mass of radical I}}{E+\text{Eq. mass of radical II}}$$

(*E* = Eq. mass of the metal)

(ix) **Volatile chloride method**

$$\text{Valency of metal} = 2\times\frac{\text{V.D. of Chloride}}{\text{Eq. mass of metal chloride}}$$

$$=2\times\frac{\text{V.D.}}{E+35.5}$$

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

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

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

Molecular mass of acid = Equivalent mass of acid ×Basicity