Analytical Chemistry

Lec 4, 5, 6, 7, 8

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Matter is anything that has mass and takes up space.

There are five known phases, or states, of matter: solids, liquids, gases, plasma and Bose-Einstein condensates. The main difference in the structures of each state is in the densities of the particles.

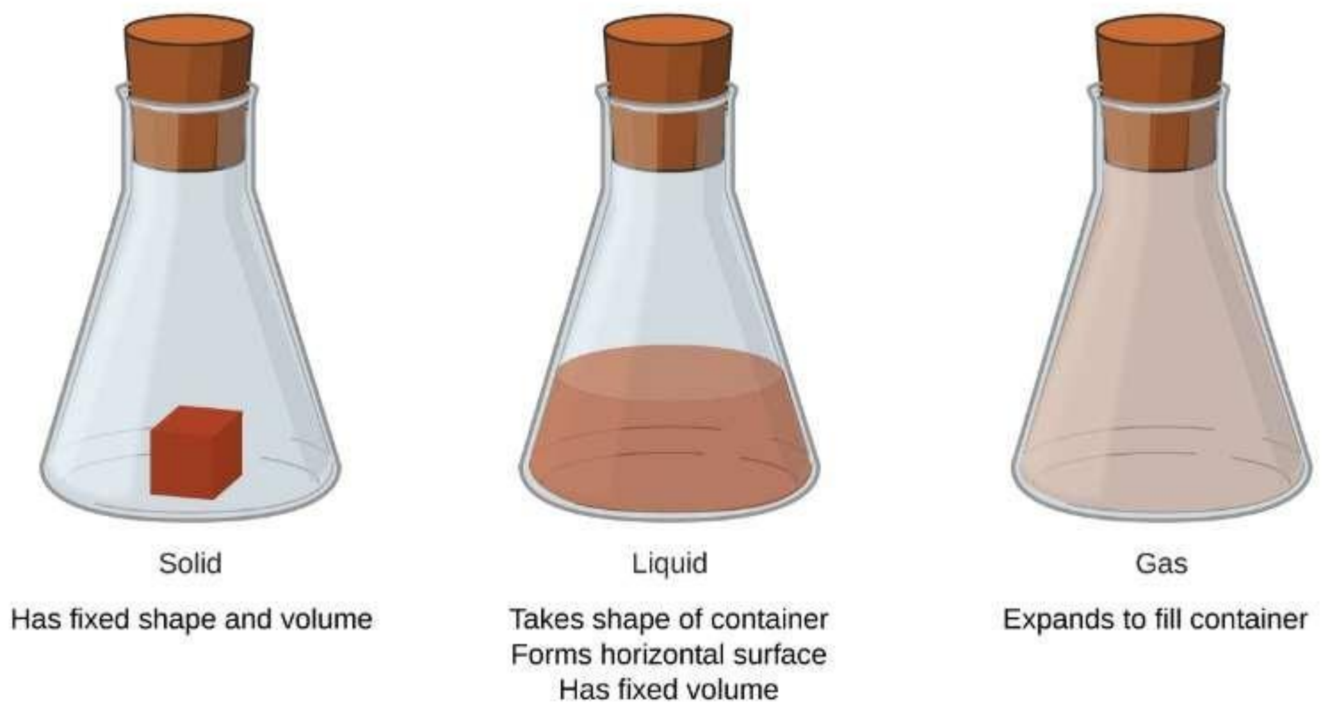


Figure 1. The three most common states or phases of matter are solid, liquid, and gas.

Solids: In a solid, particles are packed tightly together so they are unable to move about very much. Particles of a solid have very low kinetic energy.

Liquid: the particles of a substance have more kinetic energy than those in a solid. The liquid particles are not held in a regular arrangement, but are still very close to each other so liquids have a definite volume.

Gases: Gas particles have a great deal of space between them and have high kinetic energy. If unconfined, the particles of a gas will spread out indefinitely; if confined, the gas will expand to fill its container.

Plasma: Plasma is not a common state of matter here onEarth, but may be the most common state of matter in the universe. Plasma consists of highly charged particles with extremely high kinetic energy.

What is analytical chemistry??

In other word Analytical chemistry is a scientific discipline used to study the chemical composition, structure and behavior of matter.

Chemical Analysis is divided into two types:-

1- **Qualitative analysis:** - establishes the chemical identity of the species in the sample i.e. shows what elements, compounds or ions given substance contains.

2- **Quantitative analysis:** - determines the relative amounts of these species in numerical data i.e. assessments the quantity or percentage of the individual elements, compounds or ions in the sample.

Quantitative chemical analysis can be classified into the following methods:-

1- Classical Methods (conventional):

a- Volumetric methods of analysis:- determine the volume of a solution containing sufficient reagent (standard solution) to react completely with the analyte.

b- Gravimetric methods:- these methods determine the mass of the analyte or some compound chemically related to it. For example, in precipitation method, an analyte is precipitated in the form of an insoluble compound of defined stoichiometry, after collection and drying, the product is weighed on an analytical balance. From the mass and known stoichiometry the analyte is quantitatively determined.

2- Instrumental methods of analysis:- these method used special instruments to measure such physical or chemical properties of matter, which related directly or indirectly to the quantity of element, ion or compound to be tested. e.g. Density, color intensity, refractive index, emission and absorption of electromagnetic radiation, the difference in potential etc. traditionally, instrumental analysis are divided into three categories according to the property of assayed substance that is measured or used during the assay:-

a- Spectral methods

b- Electrochemical methods

c- Separation methods

Expression of analytical concentrations:-

♦ A solution is a homogeneous mixture of two or more substance.

♦ A minor species in a solution is called solute.

♦ The major species in a solution is called solvent.

♦ Concentration states how much solute is contained in a given volume or mass of solution or solvent.

♦ Mole:- is a fundamental unit describing the amount of chemical species, it is Avogadro's number ($6.02x10^{23}$)of particles (atoms, ions, molecules …etc.).

The weight of one mole of substance is its gram molecular weight (g-Mwt) or molecular weight (Mwt) and is calculated by summing the atomic weight of all elements appearing in a chemical formula.

Molecular weight = summation of (no. of mole x atomic weight)

For example:-

1- Find the molecular weight of NaCl (atomic weight of Na =23 g/mol, Cl = 35.5g/mol).

Molecular weight = 1 No. of Na x 23 g/mol (atomic weight of Na) + 1 No. of Cl x 35.5 g/mol (atomic weight of Cl)

=58.5 g/mol

Find the molecular weight of $C_6H_{12}O_6$ (atomic weight of C =12 g/mol, H = 1g/mol, O = 16 g/mol).

Molecular weight = 6 No. of C x 12 g/mol (atomic weight of C) + 12 No. of H x 1 g/mol (atomic weight of H) + 6 No. of O x 16 g/mol (atomic weight of O) = 180g/mol

Thus, 1 mole of sodium Chloride NaCl has a mass 58.5g and 1 mole of Glucose $C_6H_{12}O_6$ has a mass of 180g.

♦ **The millimole:-** sometime it is more convenient to make calculation with millimole (mmol) rather than moles, where the mmol is 1/1000 of a mol. In other word 1mole = 1000 mmol

For example:-

$$0.001 \text{mole of } NaCl = 1 \text{ mmol of } NaCl$$

$$6 \text{ mmol of } BaCl_2 = 0.006 \text{ mol of } BaCl_2$$

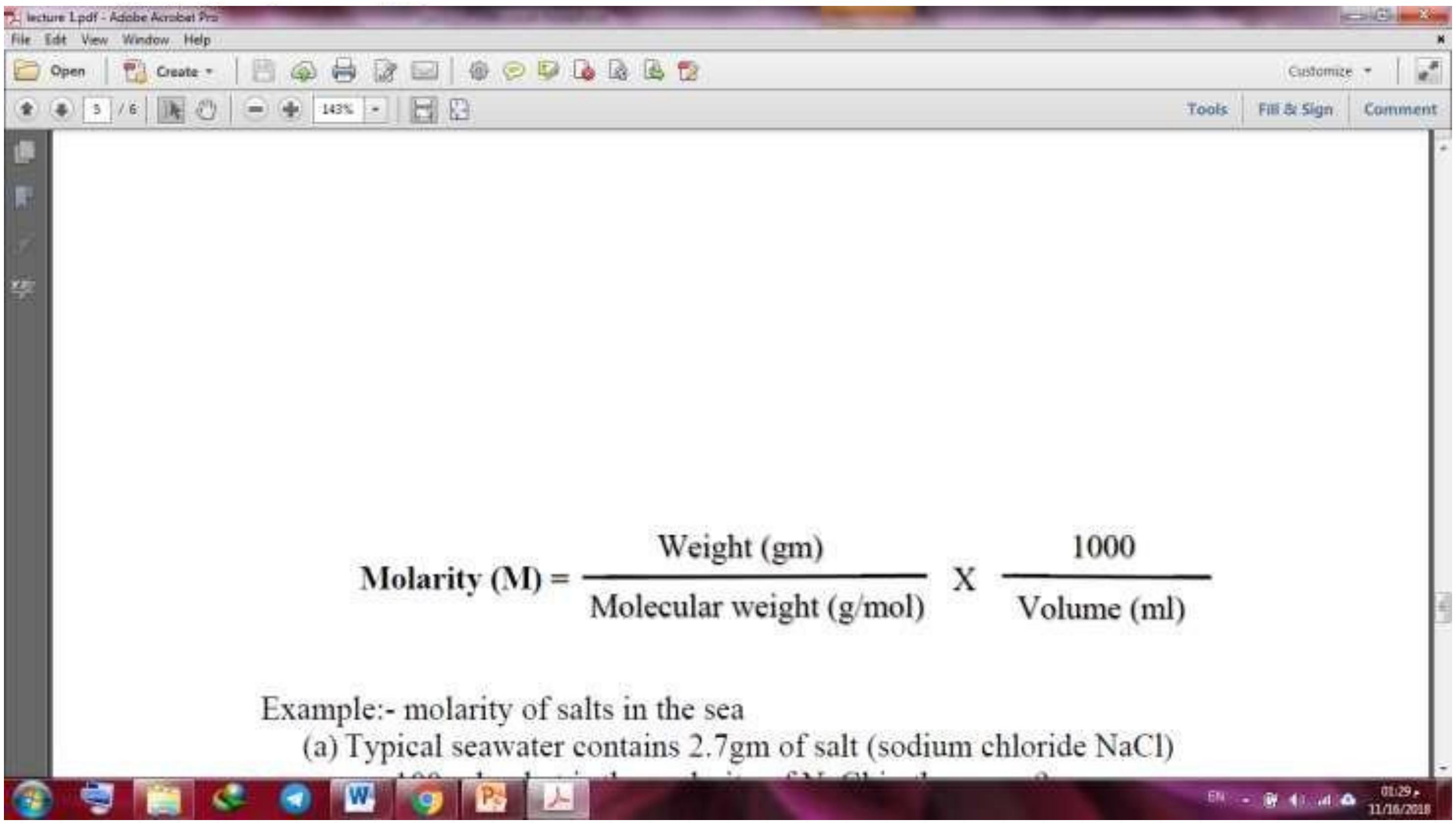
Number of moles of substance:-

$$\text{No. of moles} = \frac{\text{Weight (gm)}}{\text{Molecular weight (g/mol)}}$$

Example:- How many Moles of Barium and Chloride in 2.4gm of $BaCl_2$ (Atomic weight of Ba=137.23 g/mol, Cl=35.5g/mol).

<u>Molarity (M)</u>:- the molarity or the molar concentration of a chemical species X **is the number of moles of the solute species that is contained in one liter of the solution. M has the dimension (mol/L).**

No. of mole of solute



$$\textbf{Molarity (M)} = \frac{\text{Weight (gm)}}{\text{Molecular weight (g/mol)}} \times \frac{1000}{\text{Volume (ml)}}$$

Example:- molarity of salts in the sea

(a) Typical seawater contains 2.7gm of salt (sodium chloride NaCl)

Example:- molarity of salts in the sea

(a) Typical seawater contains 2.7gm of salt (sodium chloride NaCl) per 100 ml. what is the molarity of NaCl in the ocean?

(b) $MgCl_2$ has a concentration of 0.054M in the ocean. How many grams of $MgCl_2$ are present in 25ml of seawater?

- (a) The molecular weight of NaCl is 58.5g/mol.

  The no. of moles of salt in 2.7gm equal 0.046 mol, so the molarity is;

$$\textbf{Molarity of NaCl} = \frac{\text{No. of mole of NaCl}}{\text{Volume of seawater (L)}}$$

$$= \frac{0.046\ \text{mol}}{100\times10^{-3}\ \text{(L)}} = 0.46\ \text{M}$$

Normality

Normality of a solution is equal to the number of equivalents of material per liter of solution, the symbol is **N**.

$$N = \frac{eq}{L} = \frac{meq}{ml}$$

Where **eq** represent **equivalent** while **meq** represent **milliequivalent.**

Equivalents are based on the same concept as moles, but the number of equivalents will depend on the **number of reacting units (n)** supplied by each molecule or the number with which react. For example, if we have one mole of HCl, we have one mole of $\mathbf{H^+}$ to react as an acid. Therefore, we have one equivalent of $\mathbf{H^+}$.

On the other hand, if we have one mole of H_2SO_4, we have two moles of the reacting unit **H^+** and two equivalents of **H^+**. The number of equivalents can be calculated from the number of moles.

No.	**Reaction type**	**Reacting unit (n)**
1	Acid	Number of **H^+**
2	Base	Number of **OH^-**
3	Oxidation-redaction	Oxidation number of oxidant or reductants.
4	Salt	Number of cation atoms.

eq = mol X no. of reacting units per molecule (n)

meq = mmol X no. of reacting units per molecule (n)

Equivalent weight:-

The equivalent weight is that weight of a substance in grams that will provide one mole of the reacting unit. Thus, for HCl, the **equivalent weight is equal to the molecular weight of HCl** while for H_2SO_4, the **equivalent weight = half the molecular weight of H_2SO_4.**

$$eq.wt = \frac{M.wt}{n}$$

Example (1):-

Calculate the equivalent weights of the following substances: (a) NH_4OH $H_2C_2O_4$, (c) $KMnO_4$, (d) $KMnO_4$ [Mn (VII) is reduced to Mn^{+2}].

Atomic weight:- N=14, H=1, O=16, C=12, K= 39.0983, Mn= 54.938.

Solution:-

$$\text{(a) Eq.wt.} = \frac{\text{M.wt of } NH_4OH}{\text{No. of } OH^-}$$

M.wt of NH_4OH = (1 X 14) + (5 X1) +(1 X 16) = 35 gm/ mol

$$\text{Eq.wt.} = \frac{35 \text{ gm/mol}}{1 \text{ eq/mol}} = 35 \text{ gm/eq}$$

$$\text{(b) Eq.wt.} = \frac{\text{M.wt of } H_2C_2O_4}{\text{No. of } H^+}$$

M.wt of $H_2C_2O_4$ = (2X 1) + (2 X12) + (4X 16) = 90 gm/ mol

$$\text{Eq.wt.} = \frac{90 \text{ gm/mol}}{2 \text{ eq/mol}} = 45 \text{ gm/eq}$$

(c) $\textbf{Eq.wt.} = \dfrac{\textbf{M.wt of KMnO4}}{\textbf{Oxidation number of Mn}^{+7}}$

M.wt of $\mathbf{KMnO_4}$ = (1X 39.0983) + (1 X 54.938) + (4X 16) = 158.0363 gm/ mol

$$\text{Eq.wt.} = \frac{158.0363 \text{ gm/mol}}{7 \text{ eq/mol}} = 22.576 \text{ gm/eq}$$

(d) $\textbf{Eq.wt.} = \dfrac{\textbf{M.wt of KMnO4}}{\textbf{Oxidation number of Mn}}$

$$\textbf{Eq.wt.} = \frac{158.0363 \text{ gm/mol}}{(7\text{-}2) \text{ eq/mol}} = 31.607 \text{ gm/eq}$$

Just as we can calculate the number of moles from the number of grams by dividing by the molecular weight, we can also calculate the number of equivalents of a substance by dividing by the equivalent weight:

$$eq = \frac{\text{Weight (gm)}}{\text{Eq.wt gm/eq}} \qquad meq = \frac{\text{Weight (mg)}}{\text{Eq.wt mg/meq}}$$

- gm/eq = mg/meq

When we return to the normality equation:-

$$N = \frac{eq}{L}$$

$$N = \frac{\text{Weight (gm)}}{\text{Eq.wt gm/eq}} \times \frac{1}{\text{Volume (L)}}$$

$$N = \frac{\text{Weight (gm)}}{\text{Eq.wt gm/eq}} \times \frac{1000}{\text{Volume (ml)}}$$

Example (2):-

Calculate the normality of the solutions containing 5.3 gm/L Na_2CO_3, atomic weight Na = 23, C = 12, O = 16.

Solution:-

M.wt of $Na_2CO_3 = (2 \times 23) + (1 \times 12) + (3 \times 16) = 106$ gm/mol

$$eq.wt = \frac{M.wt}{n} = \frac{106\ gm/mol}{2\ eq/mol} = 53\ gm/eq$$

$$N = \frac{Weight\ (gm)}{Eq.wt\ gm/eq} \times \frac{1}{Volume\ (L)}$$

$$N = \frac{5.3\ gm}{53 gm/eq} \times \frac{1}{1L} \Longrightarrow N = 0.1 eq/L$$

The relationship between **Molarity** and **Normality**:-

$$N = M \times n$$

Where;

N: normality

M: molarity

n: no. of reacting units per molecule

Therefore; **M = N when n = 1**

Equivalent = no. of moles (mol) x n (eq/mol)

Therefore; **Equivalent = no. of moles when n = 1.**

Example (3):-

467.1 mg of Na_2CO_3 dissolved in 37.8 ml of pure water calculate; normality, molarity, no. of moles. Atomic weight Na = 23, C = 12, O = 16.

Solution:-

M.wt of Na_2CO_3 = (2 x23) + (1x12) + (3x16) = 106 gm/mol

$$eq.wt = \frac{M.wt}{n} = \frac{106\ gm/mol}{2\ eq/mol} = 53\ gm/eq$$

$$gm/eq = mg/meq \Longrightarrow 53\ gm/eq = 53\ mg/meq$$

$$N = \frac{meq}{ml}$$

$$meq = \frac{Weight\ (mg)}{Eq.wt\ mg/meq} = \frac{467.1\ mg}{53\ mg/meq} = 8.813\ meq$$

$$N = \frac{8.813\ meq}{37.8\ ml} = 0.233\ meq/ml$$

$N = M \times n$

$0.233 \text{ meq/ml} = M \times 2 \text{ meq/mmol}$

$$M = \frac{0.233 \text{ meq/ml}}{2 \text{ meq/mmol}} = 0.116 \text{ mmol/ml}$$

milliequivalent = no. of millimoles (mmol) x n (meq/mmol)

8.813 meq = no. of millimoles (mmol) x 2 meq/mmol

$$\text{No. of millimoles (mmol)} = \frac{8.813 \text{ meq}}{2 \text{ meq/mmol}} = 4.406 \text{ mmol}$$

1 mole = 1000 mmol

Then 4.406 mmol = 0.004406 mol

Home work:-

1- Calculate the equivalent weight of 98 gm/L of H2SO4.
2- Calculate the equivalent weight of 37.413 gm/L of HCl.
3- Calculate the normality and molarity of 500ml containing 20 gm of NaOH.
4- How many grams of $Ca(OH)_2$ to prepare 750ml of solution with 0.2N?

Atomic weight of H = 1, S = 32, O = 16, Cl = 35.5, Na = 23, Ca = 40.

Parts per million

- A part per million (ppm) is one part of solute per million parts of solution. In terms of defining equations, we can write:

$$\text{ppm (m/m)} = \frac{\text{mass solute}}{\text{mass solution}} \times 10^6$$

$$\text{ppm (v/v)} = \frac{\text{volume solute}}{\text{volume solution}} \times 10^6$$

or

$$\text{ppm (m/v)} = \frac{\text{mass solute(g)}}{\text{volume solution (mL)}} \times 10^6$$

A part per billion (ppb) is one part of solute per billion parts of solution. Here the factor is 10^9 instead of the factor of 10^6 for parts per million.

The relation between (M) and (ppm) :

ppm= M × M.M. × 1000 = mg/L

Example 3.6

Calculate the molar concentration of 2000 ppm of Pb^{2+} (A.M. = 207 g/mol)?

Solution

$$ppm = M \, x \, M.M. \, x \, 1000$$

$$M = \frac{ppm}{M.M. \, x \, 1000} = \frac{2000}{207 \, x \, 1000} = 0.009 \; mol/L$$