÷ Solution ÷

Topic to be covered ÷

(1.) Molality.

(2.) Mole fraction.

(3.) Normality

(4.) Titration : (only simple acid-base titration):

Molality:

It is defined as the number of moles of solute present in 1kg of the solvent. It is denoted by 'm'.

$$\text{Molality} = \left(\frac{W_B / M_B}{W_A / 1000} \right) \text{mol/kg}$$

Where,
W_B = weight of solute (in g)
M_B = Molecular wt. of solute. (in g/mole)
W_A = weight of solvent (in g).

$$\text{Molality} = \frac{\text{solubility} \times 10}{\text{Molecular mass of solute.}}$$

where, 'solubility = $\frac{\text{mass of solute in (gram)}}{\text{Mass of solvent in (g)}} \times 100$.

Relation between Molarity & Molality:

$$\frac{1}{m} = \frac{\rho}{M} - \frac{m_B}{1000}$$

where, ρ = density of solution.
m = molality
M = Molarity
m_B = molecular mass of solute

Mole fraction:

It is defined as the ratio of number of moles of one component to total no. of moles of the solution.

Mole fraction of component (X_i)

$$X_1 = \frac{n_i}{\sum n_i} = \frac{n_1}{n_1 + n_2 + n_3 \cdots n_n}.$$

Also, $$x_i = \frac{w_i / M_i}{\sum_{i=1} w_i / M_i}$$ where, w_i = mass of each component (i)
M_i = Molecular wt. of component i]

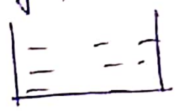
$$x_1 = \left(\frac{w_1 / M_1}{\frac{w_1}{M_1} + \frac{w_2}{M_2} + \frac{w_3}{M_3} --- \frac{w_n}{M_n}} \right)$$

Also, sum of Mole fraction of each component = 1.

$$\sum_{i=1}^{n} x_i = 1$$

$$x_1 + x_2 + x_3 --- x_n = 1.$$

Relation between Mole fraction & Molarity:



$$M = \frac{x_B \times 1000 \times d}{x_A M_A + x_B M_B}$$

where, x_B = mole fraction of solute
x_A = mole fraction of solvent.
d = density.
M_A = molecular wt. of solvent A.
M_B = molecular wt. of solute B.

Relation between Mole fraction & Molality:

$$\frac{x_B \times 1000}{(1 - x_B)\, m_A} = m.$$

Where, x_B = Mole fraction of solute B.
M_A = Molecular weight of solvent A.

Q.1 Example 1: The density of a 3M sodium thiosulphate solution ($Na_2S_2O_3$) is 1.25 g/mL. Calculate (i) the percentage by mass of sodium thiosulphate, (ii) the mole fraction of sodium thiosulphate (iii) The molalities of $Na^{\oplus}$ & $S_2O_3^{2-}$ ion?

Soln. (i) Molarity = $\dfrac{x \times \text{density} \times 10}{m_A}$ where x = % mass of solute, m_A = molecular wt.

$$3 = \frac{x \times 1.25 \times 10}{158}$$

$$x = 37.92\ \%$$

(ii) No. of moles of $Na_2S_2O_3 = \dfrac{474}{158} = 3$

Mass of water = $(1250 - 474) = 776g$

No. of moles of water = $\dfrac{776g}{18\ g/mol} = 43.1$

Mole fraction of $Na_2S_2O_3 = \dfrac{3}{43.1+3} = 0.065$

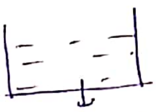
(iii) No. of moles of $Na^{\oplus}$ ion $= 2 \times 3 = 6$ mole

Molality of $Na^{\oplus}$ ions $= \dfrac{\text{No. of moles of } Na^{\oplus} \text{ ions}}{\text{Mass of water in (kg)}}$

$$= \frac{6}{776} \times 1000 = 7.73\,m.$$

Example : 2 : What would be molality of a solution made by mixing equal volume of 30% by mass of H_2SO_4 ($\rho = 1.218\ g/cm^3$) & 70% by mass of H_2SO_4 (density = $1.610\ g/cm^3$).

Soln :

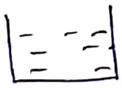


100mL solution 1

Mass of solution = 121.8g

Mass of H_2SO_4 = 36.54g

Mass of water = 85.26g



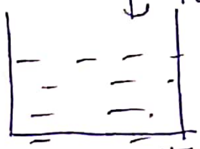
100mL solution 2.

Mass of solution = 161g.

Mass of H_2SO_4 = 112.7g

mass of water = 48.30g

↓ Total H_2SO_4 = 149.24g



Total water = 133.56g

$$\text{Molality} = \frac{(149.24g / 98\ g/mole)}{133.56\ g / 1000\ g/kg} = 11.4\,m.$$

Example 3: The mole fraction of CH_3OH in an aqueous solution is 0.02 & its density is 0.994 g/cm³. Determine its molarity & Molality?

Soln: let x mole of CH_3OH & y mole of water be present in solution.

Mole fraction of CH_3OH $= \left(\frac{x}{x+y}\right) = 0.02$.

$$\frac{y}{x} = 49$$

$$\text{Molality} = \frac{x}{18 \times y} \times 1000 = \frac{1000}{18 \times 49} = 1.13\ m.$$

$$\text{volume of solution} = \frac{\text{Total mass}}{\text{density}} = \frac{32x + 18y}{0.994}\ mL$$

$$= \frac{32x + 18y}{994}\ L.$$

$$\text{Molarity} = \frac{x}{32x + 18y} \times 994.$$

$$= \frac{994}{32 + 18\left(\frac{y}{x}\right)} = 1.0875\ M.$$

Normality: It is defined as no. of equivalent of solute present in one litre of solution is known as Normality (N).

$$\text{Normality (N)} = \frac{\text{No. of equivalent of solute}}{\text{Volume of solution in (Litre)}}$$

$$= \frac{\text{wt of solute / Equivalent weight of solute}}{\text{volume of solution in litre}}$$

No. of equivalent of solute = (Volume of solution (in litre) × Normality of solution)

No. of milli equivalent of solute = (Normality of solution × vol. of solution in millilitre)

$$\text{Equivalent weight} = \left(\frac{\text{Atomic weight}}{\text{n- factor}}\right)$$

Relation between Normality & Molarity:

Normality = Molarity × n-factor

Calculation of n-factor:

For calculating n-factor of any reactant in any reaction. The reaction may be classified into the following three types:

1. Acid-Base Reaction / Neutralization Reactions.
2. Redox Reactions
3. Precipitation Reactions / Double decomposition Reactions

Acid-Base Reaction:

The number of $H^{\oplus}$ ions furnished per molecule of the acid is its n-factor. also called basicity. Similarly the number of $OH^{\ominus}$ ions furnished by the base per molecule is its n-factor also called acidity.

Example: $HCl \longrightarrow H^{\oplus} + Cl^{\ominus}$: $n=1$

$H_2SO_4 \longrightarrow 2H^{\oplus} + SO_4^{2\ominus}$: $n=2$.

$H_3PO_4 \longrightarrow H^{\oplus} + H_2PO_4^{\ominus}$: $n=1$.

$H_3PO_4 \longrightarrow 3H^{\oplus} + PO_4^{3\ominus}$: $n=3$

$NaOH \longrightarrow Na^{\oplus} + OH^{\ominus}$: $n=1$

$Ba(OH)_2 \longrightarrow Ba^{2\oplus} + 2OH^{\ominus}$: $n=2$.

Redox Reaction:

(i) When one atom undergoing either reduction or oxidation

$MnO_4^{\ominus} \longrightarrow Mn^{2\oplus}$: n-factor $= |(+2)\times 1 - (+7)\times 1| = 5$.

$Fe^{2+} \longrightarrow Fe^{3+}$: n-factor $= |(3\times 1) - (+2)\times 1| = 1$.

$C_2O_4^{2-} \longrightarrow 2CO_2$. n-factor $= |(+4)\times 2 - (+3)\times 2| = 2$

$Cr_2O_7^{2-} \longrightarrow 2Cr^{3+}$: n-factor $= |(+3)\times 2 - (+6)\times 2| = 6$

(ii) Salt which reacts in such a way that only one atom undergoes change in oxidation state but appears in two product with the same oxidation state.

$$Cr_2O_7^{2-} \longrightarrow Cr^{3+} + Cr^{3+}.$$

$$n\text{-factor} = |(+6)\times 2 - (+3)\times 2| = 6$$

(iii) Salt which react in such a way that only one atom undergoes change in oxidation state but goes in two product with different oxidation state as a result of either only oxidation or reduction

$$3\overset{(+7)}{MnO_4^{\ominus}} \longrightarrow 2Mn^{2\oplus} + Mn^{+6}$$

$$n\text{-factor} = |[2\times(+2) - 2\times(+7)]| + |[1\times(+6) - 1\times(+7)]|$$

$$= |4-14| + |6-7| = 11$$

$$n\text{-factor} = 11/3$$

(iv) Salt which react in such a way that only one atom undergoes change in oxidation state in two product; in one product with changed oxidation state & in other product with same oxidation state as that of reactant.

$$K_2Cr_2O_7 + 14HCl \longrightarrow 2KCl + 2CrCl_3 + 3Cl_2 + 7H_2O$$

$$n\text{-factor} = |(14\times -1) - [(2\times -1) + (6\times(-1)) + 6\times 0]$$

$$= 6.$$

$$n\text{-factor of } HCl = 6/14 = 3/7$$

(v) Salt which react in such a way that two or more atom in the salt undergoes change in oxidation states as a result of either oxidation or reduction.

$$FeC_2O_4 \longrightarrow Fe^{3+} + 2CO_2.$$

$$\text{Total change in oxidation state} = |1\times(+2) - 1\times(+3)| + |2\times(+3) - 2\times(+4)|$$

$$= 1 + 1 = 2.$$

Scanned with CamScanner

vi) Salt which react in such a way that the two atoms undergoing change in oxidation state but one undergoing oxidation & other reduction reaction. In such a case one has to calculate the change in oxidation state of either the atom being oxidized or the atom being reduced.

$$\overset{-3}{(NH_4)_2}\overset{+6}{Cr_2O_7} \longrightarrow \overset{0}{N_2} + \overset{+3}{Cr_2O_3} + 4H_2O$$

$$n\text{-factor} = |(-3)\times 2 - 0\times 2| = 6$$

(vii) species which undergoes disproportionation reaction: Those reaction in which oxidant & reductant are the same species or the same element from the species is getting oxidized as well as reduced.

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

$$n\text{-factor}: |2\times 0 - (-1)\times 2| = 2.$$

Precipitation / Double Decomposition Reaction: In such reactions, there is no change in the oxidation state of any atom. The n-factor of the salt can be calculated by multiplying the oxidation state of the cation / anion by total no. of atoms per molecule of the salt.

$$BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4\downarrow + 2NaCl.$$

n-factor = (oxidation state of Ba atom in $BaCl_2$) × number of Ba atoms in 1 molecule of $BaCl_2$

$$= (+2)\times 1 = +2.$$

Calculate the n-factor of the reactant in following:

1. $IO_3^{\ominus} \longrightarrow I_2$.
2. $Zn \longrightarrow ZnO_2^{2-}$
3. $NO_3^{\ominus} \longrightarrow NH_3$
4. $NH_4^{\oplus} \longrightarrow NH_2OH$
5. $3MnO_4^{\ominus} \longrightarrow 2Mn^{2+} + Mn^{4+}$
6. $2MnO_4^{\ominus} \longrightarrow Mn^{2\oplus} + Mn^{+6}$
7. $2MnO_4^{\ominus} \longrightarrow MnO_4^{\ominus} + MnO_2$.
8. $3MnO_4^{\ominus} \longrightarrow 2MnO_4^{\ominus} + Mn^{2+}$

(9.) $FeS_2 \rightarrow Fe_2O_3 + SO_2$

(10.) $[Fe(CN)_6]^{4-} \rightarrow Fe^{3+} + CO_2 + NO_3^{\ominus}$

(11.) $Cu_2S \rightarrow Cu^{2+} + SO_2$

(12.) $Fe_2(SO_4)_3 \rightarrow Fe^{2+} + SO_2$.

(13.) $KClO_3 \rightarrow KCl + O_2$.

(14.) $P_4 \rightarrow PH_3$

(15.) $Br_2 + OH^{\ominus} \rightarrow BrO^{\ominus}$.

Titration :
The process of determination of concentration of solution with the help of a solution of known concentration (standard solution) is called titration.
Titration is ~~division~~ divided into following four catogories:

(1.) simple titration.
(2.) Double titration
(3) Back titration
(4.) Iodimetric & Iodometric titration.

Simple titration: At the end point (equivalence point) the equivalent or milliequivalents of the two reacting substance are equal.
At equivalence point: $N_AV_A = N_BV_B$.

Q.) 40 ml of N/10 HCl & 60 ml of N/20 KOH are mixed together calculate the normality of the acid or base left. What is the normality of the salt formed in the solution.

Soln: Milliequivalent of HCl $= 40 \times 1/10 = 4$.
Meq of KOH $= 60 \times 1/20 = 3$
Meq of Acid left $= 4 - 3 = 1$
Normality of HCl left $= N \times V = N \times 100 = 1 \therefore N = 0.01$.

CONCENTRATION TERMS

Q.1 Calculate the molarity of the following solutions :

(a) 4g of caustic soda is dissolved in 200 mL of the solution.

(b) 5.3 g of anhydrous sodium carbonate is dissolved in 100 mL of solution.

(c) 0.365 g of pure HCl gas is dissolved in 50 mL of solution.

Q.2 The density of a solution containing 13% by mass of sulphuric acid is 1.09 g/mL. Calculate the molarity of the solution.

Q.3 The mole fraction of CH_3OH in an aqueous solution is 0.02 and its density is 0.994 g cm^{-3}. Determine its molarity and molality.

Q.4 The density of a solution containing 40% by mass of HCl is 1.2 g/mL. Calculate the molarity of the solution.

Q.5 A mixture of ethanol and water contains 54% water by mass. Calculate the mole fraction of alcohol in this solution.

Q.6 15 g of methyl alcohol is present in 100 mL of solution. If density of solution is 0.90 g mL^{-1}. Calculate the mass percentage of methyl alcohol in solution.

Q.7 Units of parts per million (ppm) or per billion (ppb) are often used to describe the concentrations of solutes in very dilute solutions. The units are defined as the number of grams of solute per million or per billion grams of solvent. Bay of Bengal has 1.9 ppm of lithium ions. What is the molality of Li^+ in this water ?

Q.8 A 6.90 M solution of KOH in water contains 30% by mass of KOH. Calculate the density of the solution.

Q.9 Fill in the blanks in the following table.

Compound	Grams Compd	Grams Water	Molality of Compd	Mole Fraction of Compd
Na_2CO_3	______	250	0.0125	______
CH_3OH	13.5	150	_____	______
KNO_3	_____	555	_____	0.0934

Q.10 A solution of specific gravity 1.6 is 67% by weight. What will be the % by weight of the solution of same acid if it is diluted to specific gravity 1.2 ?

Q.11 Find out the volume of 98% w/w H_2SO_4 (density = 1.8 gm/ ml) must be diluted to prepare 12.5 litres of 2.5 M sulphuric acid solution.

Q.12 Determine the volume of diluted nitric acid (d = 1.11 g mL^{-1}, 19% w/v HNO_3) That can be prepared by diluting with water 50 mL of conc. HNO_3 (d =1.42 g mL^{-1}, 69.8% w /v).

Q.13 A mixture of Xe and F_2 was heated. A sample of white solid thus formed reacted with H_2, to give 112 ml of Xe at STP and HF formed required 30 ml of 1 M NaOH for complete neutralization. Determine empirical formula.

Q.14 A certain oxide of iron contains 2.5 grams of oxygen for every 7.0 grams of iron. If it is regarded as a mixture of FeO and Fe_2O_3 in the weight ratio x : y, what is x : y, (atomic weight of iron = 56).

Q.15 In what ratio shoudl you mix 0.2M $NaNO_3$ and 0.1M $Ca(NO_3)_2$ solution so that in resulting solution, the concentration of negative ion is 50% greater than conc. of positive ion.

Answer Key

Q.1 (a) 0.5 M, (b) 0.5 M, (c) 0.2 M

Q.2	1.445 M	Q.3	1.088 M, 1.13 m			Q.4	13.15 M
Q.5	0.25	Q.6	16.67%	Q.7	2.7×10^{-4} m	Q.8	1.288 gm/ml
Q.9	0.331, 2.25×10^{-4}, 2.81, 0.0482, 321, 5.72			Q.10	29.77%	Q.11	1736.1 ml
Q.12	183.68 ml	Q.13	XeF_6	Q.14	9 : 10	Q.15	1 : 2

Acid Base Titration

Q1. A small amount of $CaCO_3$ completely neutralized 52.5 mL of N/10 HCl and no acid is left at the end. After converting all calcium chloride to $CaSO_4$, how much plaster of paris can be obtained?

Q2. How many ml of 0.1 N HCl are required to react completely with 1 g mixture of Na_2CO_3 and $NaHCO_3$ containing equimolar amounts of two?

Q3. 10 g $CaCO_3$ were dissolved in 250 ml of M HCl and the solution was boiled. What volume of 2 M KOH would be required to equivalence point after boiling? Assume no change in volume during boiling.

Q4. 125 mL of a solution of tribasic acid (molecular weight = 210) was neutralized by 118mL of decinormal NaOH solution and the trisodium salt was formed. Calculate the concentration of the acid in grams per litre.

Q5. Upon heating one litre of N/2 HCl solution, 2.675g of hydrogen chloride is lost and the volume of solution shrinks to 750 ml. Calculate (i) the normality of the resultant solution (ii) the number of milli-equivalents of HCl in 100 mL of the original solution.

Q6. For the standardization of a $Ba(OH)_2$ solution, 0.2g of potassium acid phthalate (m.wt. 204.2g) weighed which was then titrated with $Ba(OH)_2$ solution. The titration requires 27.80mL $Ba(OH)_2$ solution. What is the molarity of base? The reaction products include $BaC_8H_4O_4$ as only Ba containing species.

Q7. A definite amount of NH_4Cl was boiled with 100mL of 0.8N NaOH for complete reaction. After the reaction, the reactant mixture containing excess of NaOH was neutralized with 12.5mL of 0.75N H_2SO_4. Calculate the amount of NH_4Cl taken.

Q8. H_3PO_4 is a tri basic acid and one of its salt is NaH_2PO_4. What volume of 1 M NaOH solution should be added to 12 g of NaH_2PO_4 to convert it into Na_3PO_4?

Q9. Calculate the number of gm. of borax, $Na_2B_4O_7.10H_2O$, per litre of a solution of which 25cc required 15.6 cc of N/10 hydrochloric acid for naturalization, methyl orange being used as indicator. In aqueous solution, borax hydrolyses according to the equation:

$$Na_2B_4O_7 + 7H_2O = 2NaOH + 4H_3BO_3$$

The liberated boric acid is a weak acid and is without effect on methyl orange.

Q10. 25mL of a solution of Na_2CO_3 having a specific gravity of 1.25g ml^{-1} required 32.9 mL of a solution of HCl containing 109.5g of the acid per litre for complete neutralization. Calculate the volume of 0.84N H_2SO_4 that will be completely neutralized by 125g of Na_2CO_3 solution.

Q11. A solution containing 4.2 g of KOH and $Ca(OH)_2$ is neutralized by an acid. It consumes 0.1 equivalent of acid, calculate the percentage composition of the sample.

Q12. 5gm of a double sulphate of iron and ammonia was boiled with an excess of sodium hydroxide solution and the liberated ammonia was passed into 50cc of normal sulphuric acid. The excess of acid was found to require 24.5cc of normal sodium hydroxide for naturalization. Calculate the percentage of ammonia (expressed as NH_3) in the double salt.

Q13. 0.5 g of fuming H_2SO_4 (oleum) is diluted with water. The solution requires 26.7 ml of 0.4 N NaOH for complete neutralization. Find the % of free SO_3 in the sample of oleum.

Q14. 1.64 g of a mixture of $CaCO_3$ and $MgCO_3$ was dissolved in 50 mL of 0.8 M HCl. The excess of acid required 16 mL of 0.25 M NaOH for neutralization. Calculate the percentage of $CaCO_3$ and $MgCO_3$ in the sample.

Q15. 1.5 g of chalk were treated with 10 ml of 4N – HCl. The chalk was dissolved and the solution made to 100 ml 25 ml of this solution required 18.75 ml of 0.2 N – NaOH solution for complete neutralisation. Calculate the percentage of pure $CaCO_3$ in the sample of chalk?

Q16. 2.013g of a commercial sample of NaOH containing Na_2CO_3 as an impurity was dissolved to give 250ml solution. A 10ml portion of this solution required 20ml of 0.1N H_2SO_4 for complete neutralization. Calculate % by weight of Na_2CO_3.

Q17. Exactly 50 ml of Na_2CO_3 solution is equivalent to 56.3 ml of 0.102 N HCl in an acid-base neutralisation. How many gram $CaCO_3$ would be precipitated if an excess of $CaCl_2$ solution were added to 100 ml of this Na_2CO_3 solution.

Q18. 6g mixture of NH_4Cl and NaCl is treated with 110mL of a solution of caustic soda of 0.63N. The solution was then boiled to remove NH_3. The resulting solution required 48.1mL of a solution of 0.1N HCl. What is % composition of mixture?

Q19. Calculate the number of gm(a) of hydrochloric acid, (b) of potassium chloride in 1 litre of a solution, 25cc of which required 21.9cc of N/10 sodium hydroxide for naturalization and another 25cc after the addition of an excess of powdered chalk, required 45.3cc of N/10 silver nitrate for the complete precipitation of the chloride ion.

Q20. 2.5 gm of a mixture containing $NaHCO_3$, Na_2CO_3 and NaCl is dissolved in 100 ml water and its 50 ml portion required 13.33 ml 1.0 N HCl solution to reach the equivalence point. On the other hand its other 50 ml portion required 19 ml 0.25 M NaOH solution to reach the equivalence point. Determine mass % of each component? (Na_2CO_3 = 36.38%, $NaHCO_3$ = 31.92%, NaCl = 31.7%)

ANSWER KEY

Acid Base Titration

Q1. 0.381 g Q2. V = 157.8 ml Q3. V = 25 mL Q4. 6.608 g/litre Q5. (i) 0.569N, (ii) 50
Q6. 0.0176M Q7. 3.78g Q8.200 mL Q9. 11.92 g/litre Q10. 470 mL
Q11. KOH = 35%, $Ca(OH)_2$ = 65% Q12. 8.67 Q13. 20.72 %
Q14. $MgCO_3$ = 52.02%, $CaCO_3$ = 47.98 % Q15. 83.33 Q16. 2.63% Q17. 0.575 gm
Q18. % of NH_4Cl = 57.5%, % of NaCl = 42.5%
Q19. 3.198 g HCl/litre, 6.974 g KCl/litre
Q20. 0.06gm; 0.0265gm