KSQUARE CAREER INSTITUTE

SOLUTIONS

Class 12 Chemistry • Concentration • Vapour Pressure • Raoult's Law • NEET / JEE Notes

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Chapter at a Glance

1. Binary solutions — solute & solvent
2. Concentration terms — temperature-dependent vs independent; formulas & interconversions
3. Solved numericals on concentration
4. Vapour pressure — definition, factors, volatile & non-volatile substances
5. Raoult's law — non-volatile solute & two volatile components; vapour-phase composition
6. Ideal & non-ideal solutions — +ve and –ve deviation, boiling point, azeotropes
7. Added: Henry's law, colligative properties & van't Hoff factor, practice MCQs

BINARY SOLUTION

Definition

Binary solution = 1 solute + 1 solvent (2 components)

- **Solute** → present in **less** quantity; **Solvent** → present in **more** quantity.
- e.g. salt in water → salt = solute, water = solvent.
- e.g. aqueous sugar solution → solvent = H_2O, solute = sugar.

CONCENTRATION TERMS

Group A — Temperature dependent (volume related)	Group B — Temperature independent (mass related)
% V/V	% W/W
% W/V	Molality (m)
Molarity (M)	Mole fraction (χ)
Normality (N)	ppm & ppb

NEET Point / PYQ Alert

Volume changes with temperature, mass does not — so any term with **volume** in it is **temperature dependent**.

Percentage Formulas

Percentages

$$\% \text{ V/V} = (\text{Volume of solute in mL} \div \text{Volume of solution in mL}) \times 100$$

$$\% \text{ W/V} = (\text{Weight of solute} \div \text{Volume of solution in mL}) \times 100$$

$$\% \text{ W/W} = (\text{Weight of solute} \div \text{Weight of solution}) \times 100$$

Always (mass conservation)

$W_{solute} + W_{solvent} = W_{solution}$ → e.g. 10 g sugar + 40 g H_2O = 50 g solution

$V_{solute} + V_{solvent} = V_{solution}$ only for an **ideal solution** (volume conserved) → e.g. 30 mL C_2H_5OH + 60 mL H_2O = 90 mL (ideally)

Molarity (M) — temperature dependent

Molarity

$$M = n_{solute} \div \text{Volume of solution (L)}$$

$$M = [n_{solute} \times 1000] \div \text{Volume of solution (mL)}$$

$$n = \text{given mass} \div \text{molar mass}$$

Mole Fraction (χ) — temperature independent

Mole fraction

$$\chi = \text{moles of the component} \div \text{total moles}$$

$$\chi_A = n_A / (n_A + n_B) \; ; \quad \chi_B = n_B / (n_A + n_B)$$

$$\chi_A + \chi_B = 1 \quad (\text{for 100 components: } \chi_1 + \chi_2 + \ldots + \chi_{100} = 1)$$

Molality (m) — temperature independent

Molality

$$m = n_{solute} \div \text{Weight of solvent (kg)}$$

$$m = [n_{solute} \times 1000] \div \text{Weight of solvent (g)}$$

Molarity & Molality Units

Term	Molarity	Term	Molality
Molar	1 M	Molal	1 m
Semi-molar	1/2 M	Semi-molal	1/2 m

Term	Molarity	Term	Molality
Deci-molar	1/10 M	Deci-molal	1/10 m
Centi-molar	1/100 M	Centi-molal	1/100 m
Milli-molar	1/1000 M	Milli-molal	1/1000 m

▸ Important Interconversion Formulas

Shortcuts

$$1)\ \%\ W/V = \%\ W/W \times d$$

$$2)\ M = (10 \times \%\ W/W \times d) \div MM_{solute}$$

$$3)\ m = 1000\ M \div (1000\ d - M \times MM_{solute})$$

$$4)\ m = (\chi_{solute} \times 1000) \div (\chi_{solvent} \times MM_{solvent})$$

$$d = \text{density of solution (g/mL)};\ MM = \text{molar mass}$$

Other terms (Added)

Normality N = gram equivalents of solute / volume of solution (L); N = M × n-factor.

ppm = (mass of solute / mass of solution) × 10^6; **ppb** = × 10^9 (used for very dilute solutions, e.g. pollutants).

SOLVED NUMERICALS — CONCENTRATION

Q1. Find the mole fraction of H_2O in a 19.6% w/w H_2SO_4 solution.

- 19.6% w/w ⇒ 19.6 g H_2SO_4 in 100 g solution ⇒ water = 100 – 19.6 = **80.4 g**.
- $n(H_2SO_4)$ = 19.6 / 98 = **0.2 mol**; $n(H_2O)$ = 80.4 / 18 ≈ **4.4 mol**.
- Total moles = 4.4 + 0.2 = 4.6 ⇒ **$\chi(H_2O)$ = 4.4 / 4.6 ≈ 0.957**.

Q2. 37 g of $Ca(OH)_2$ is dissolved in 1500 mL water. Find $[Ca^{2+}]$ and $[OH^-]$.

- n = 37 / 74 = 1/2 mol; $[Ca(OH)_2]$ = (1/2 × 1000) / 1500 = **1/3 M**.
- $Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$ ⇒ **$[Ca^{2+}]$ = 1/3 M, $[OH^-]$ = 2/3 M**.

Q3. Find the molarity of 4.9% w/w H_2SO_4, density 1.86 g/mL (MM = 98).

- M = (10 × 4.9 × 1.86) / 98 = **0.93 M**.

VAPOUR PRESSURE

- In a closed vessel, **evaporation ⇌ condensation**; at **equilibrium** the vapours exert a constant pressure.

Vapour pressure (VP)

Pressure exerted by the **vapours on the surface of a liquid**, established at the **equilibrium point**.

Factors affecting VP	VP does NOT depend on
Temperature — VP ∝ temperature	Amount of liquid
Nature of liquid — VP ∝ 1 / intermolecular force	Surface area
	Volume of vessel

Type	Feature	Examples
Volatile	Can be converted into vapours; VP ≠ 0	H_2O, I_2, benzene
Non-volatile	Cannot be converted into vapour; VP = 0	Urea, glucose, sucrose

VAPOUR PRESSURE OF SOLUTIONS & RAOULT'S LAW

Case 1 — Non-volatile Solute

- Solvent (A) → volatile ($p°_A \neq 0$); solute (B) → non-volatile ($p°_B = 0$).
- A non-volatile solute **blocks part of the surface** → fewer solvent molecules escape → **VP decreases**.

Lowering of vapour pressure

$$\text{On adding a non-volatile solute: } p°_A > p_A$$

$$\text{Lowering of VP} = p°_A - p_A$$

Raoult's law

The **vapour pressure of any volatile component** in a solution is **directly proportional to its mole fraction** in the solution.

$p_A \propto \chi_A \Rightarrow p_A = p°_A \chi_A$ (= $P_{solution}$ when the solute is non-volatile); $p_B = 0$

Case 2 — Volatile Solute (both components volatile)

- Both components contribute vapours: $\mathbf{P_{solution} = p_A + p_B}$ (Dalton's law of partial pressures).

Raoult's law — 3 forms of P~{total}

$$p_A = p°_A \chi_A ; \quad p_B = p°_B \chi_B$$

$$1)\ P_{sol} = p°_A \chi_A + p°_B \chi_B$$

$$2)\ P_{sol} = p°_B + (p°_A - p°_B)\chi_A$$

$$3)\ P_{sol} = p°_A + (p°_B - p°_A)\chi_B$$

Trick for forms 2 & 3

Start with the p° of the component **opposite** to the χ used, then add (p° of that component – p° of the other) × χ.

Q4. $p°_A$ = 300 mm Hg, n_A = 2; $p°_B$ = 200 mm Hg, n_B = 3. Find the VP of the solution.

- χ_A = 2/5, χ_B = 3/5. P = 300 × 2/5 + 200 × 3/5 = 120 + 120 = **240 mm Hg** (lies between 200 and 300 ✔).

Q5. $P_{solution}$ = 4.7 – 1.2 χ_B. Find $p°_A$ and $p°_B$.

- Compare with P = $p°_A$ + ($p°_B$ – $p°_A$) χ_B: **$p°_A$ = 4.7**; $p°_B$ – $p°_A$ = –1.2 ⇒ **$p°_B$ = 3.5**.

▸ Mole Fraction in the Vapour Phase

- χ_A, χ_B → mole fractions in the **solution** (liquid); y_A, y_B → mole fractions in the **vapour**. $\chi_A + \chi_B = 1$; $y_A + y_B = 1$.

Vapour composition

$$y_A = p_A / P_{sol} = p°_A \chi_A / (p°_A \chi_A + p°_B \chi_B)$$

$$y_B = p_B / P_{sol} = p°_B \chi_B / (p°_A \chi_A + p°_B \chi_B)$$

$$\text{Useful ratio: } y_A / y_B = (p°_A \times n_A) / (p°_B \times n_B)$$

Q6. n_A = 3, $p°_A$ = 400; n_B = 5, $p°_B$ = 500. Find y_A/y_B.

- y_A/y_B = (400 × 3)/(500 × 5) = 1200/2500 = **12/25** ⇒ y_A = 12/37, y_B = 25/37.

NEET Point / PYQ Alert

The vapour is always **richer in the more volatile component** (higher p°).

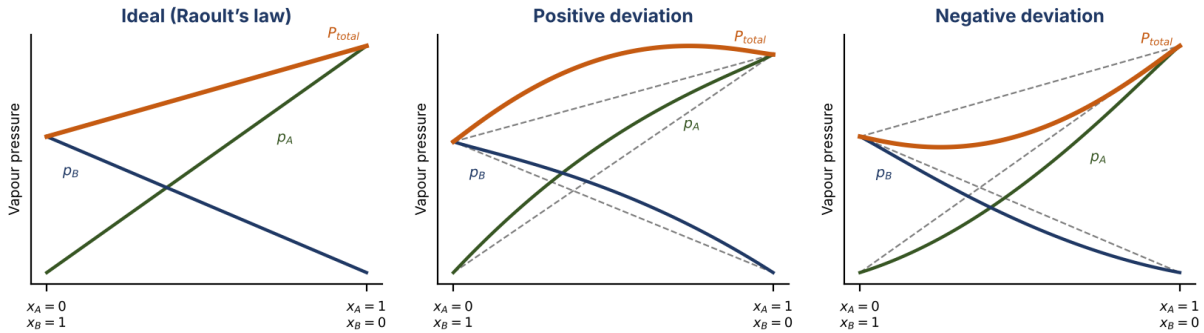
IDEAL & NON-IDEAL SOLUTIONS

In a solution there are A–A (solvent), B–B (solute) and A–B interactions. Thermodynamic quantities of mixing: ΔV_{mix}, ΔH_{mix}, ΔS_{mix}, ΔG_{mix}.

Always (for any solution formed spontaneously)

$\Delta S_{mix} > 0$ (number of particles / disorder increases)

$\Delta G_{mix} < 0$ (spontaneous process)



▸ Ideal Solution

- Follows **Raoult's law at all temperatures and pressures**: $p_A = p°_A\chi_A$, $p_B = p°_B\chi_B$, $P_T = p°_A\chi_A + p°_B\chi_B$.
- P(calculated) = P(observed) — theoretical = experimental.
- **A–B interaction = A–A = B–B interaction ⇒ $\Delta V_{mix} = 0$, $\Delta H_{mix} = 0$.**

- **Examples:** benzene + toluene, n-hexane + n-heptane, methanol + ethanol, $C_2H_5Cl + C_2H_5Br$, chlorobenzene + bromobenzene.

> **Remember**
> Similar structure / same functional group → all interactions alike ("bhai–bhai"): A–A ≈ B–B ≈ A–B.

▸ Non-Ideal Solutions

Do **not** obey Raoult's law: P(calculated) ≠ P(observed).

Property	Positive deviation	Negative deviation
Vapour pressure	$p_{obs} > p_{cal}$ (VP ↑)	$p_{obs} < p_{cal}$ (VP ↓)
Interactions	**A–B < A–A or B–B**	**A–B > A–A or B–B**
ΔV_{mix}	> 0 (expansion)	< 0 (contraction)
ΔH_{mix}	> 0 (endothermic)	< 0 (exothermic)
ΔS_{mix} , ΔG_{mix}	> 0 , < 0	> 0 , < 0
Boiling point	**BP ↓**	**BP ↑**
Azeotrope	**Minimum-boiling** azeotrope	**Maximum-boiling** azeotrope
Examples	Ethanol + acetone, ethanol + water, CS_2 + acetone, acetone + benzene, CCl_4 + $CHCl_3$	Chloroform + acetone, phenol + aniline, HNO_3 + water, HCl + water

*Note: the PDF slide on +ve deviation writes "$\Delta U_{mix} < 0$ (Always)" — this should read **$\Delta G_{mix} < 0$**.*

> **NEET Point / PYQ Alert**
> Chloroform + acetone: H-bond forms between $CHCl_3$ (H) and acetone (C=O) → stronger A–B → **–ve deviation**.
>
> Ethanol + water/acetone: added component **breaks H-bonds** of ethanol → weaker A–B → **+ve deviation**.
>
> Azeotrope examples: ~95% ethanol + water (min-boiling, 351 K); 68% HNO_3 + water (max-boiling, 393.5 K).

BOILING POINT & AZEOTROPES

- **Boiling point** — temperature at which **VP = atmospheric pressure** (1 atm).
- **VP ∝ 1 / boiling point**: liquid A with VP 0.2 atm needs more heating to reach 1 atm ⇒ **higher BP**; liquid B with VP 0.6 atm ⇒ **lower BP**.
- **Azeotropes** — solutions that **boil at a constant temperature** with the same composition in liquid and vapour; they **cannot be separated by simple/fractional distillation**.

HENRY'S LAW (ADDITIONAL TOPIC)

Henry's law

The **partial pressure of a gas in the vapour phase** is proportional to its **mole fraction in the solution**: $p = K_H \chi$

Higher $K_H \Rightarrow$ **lower solubility** of the gas. Solubility of gases **decreases with temperature** (K_H increases).

- Applications: soda bottles sealed under high CO_2 pressure; **bends** in scuba divers (N_2 dissolves at high pressure); **anoxia** at high altitude (low O_2 pressure).
- Raoult's law is a special case of Henry's law when $K_H = p°$.

COLLIGATIVE PROPERTIES (ADDITIONAL TOPIC)

Properties that depend only on the **number of solute particles**, not on their nature (for dilute solutions of non-volatile solutes).

Property	Formula	Notes
Relative lowering of VP	$(p° - p)/p° = \chi_B = n_B/(n_A+n_B)$	For dilute: $\approx n_B/n_A$
Elevation of boiling point	$\Delta T_b = K_b \cdot m$	K_b = ebullioscopic constant (K kg mol^{-1})
Depression of freezing point	$\Delta T_f = K_f \cdot m$	K_f = cryoscopic constant (water 1.86)
Osmotic pressure	$\pi = CRT = (n/V)RT$	Best for macromolecules (proteins, polymers)

van't Hoff Factor (i)

van't Hoff factor

$$i = \text{observed colligative property / calculated colligative property}$$

$$= \text{moles of particles after association/dissociation / moles before}$$

$$\text{Modified: } \Delta T_b = i\, K_b\, m\ ;\quad \Delta T_f = i\, K_f\, m\ ;\quad \pi = i\, CRT$$

- **Dissociation** (e.g. NaCl, $i \approx 2$; K_2SO_4, $i \approx 3$) → $i > 1$ → abnormally **low** molar mass.
- **Association** (e.g. ethanoic acid dimerises in benzene, $i \approx 0.5$) → $i < 1$ → abnormally **high** molar mass.
- Isotonic solutions have the same osmotic pressure (0.9% NaCl ≈ blood); **hypertonic** → cell shrinks (plasmolysis); **hypotonic** → cell swells.

PRACTICE MCQS

Q1. Which of the following concentration terms is temperature dependent?

(a) Molality
(b) Mole fraction
(c) Molarity

(d) % W/W

Answer: (c) — Contains volume.

Q2. The vapour pressure of a liquid depends on

(a) Amount of liquid
(b) Surface area
(c) Temperature
(d) Volume of vessel

Answer: (c)

Q3. A solution of chloroform and acetone shows

(a) Positive deviation
(b) Negative deviation
(c) Ideal behaviour
(d) No deviation

Answer: (b) — H-bonding between them.

Q4. For an ideal solution, which is correct?

(a) $\Delta H_{mix} > 0$
(b) $\Delta V_{mix} < 0$
(c) $\Delta H_{mix} = 0$, $\Delta V_{mix} = 0$
(d) $\Delta S_{mix} = 0$

Answer: (c)

Q5. A solution showing positive deviation from Raoult's law forms

(a) Maximum-boiling azeotrope
(b) Minimum-boiling azeotrope
(c) No azeotrope
(d) Ideal solution

Answer: (b)

Q6. Two liquids A and B have $p°_A = 300$ and $p°_B = 200$ mm Hg. For $\chi_A = 0.4$, the total vapour pressure is

(a) 240 mm Hg
(b) 260 mm Hg
(c) 280 mm Hg
(d) 220 mm Hg

Answer: (a) — 300(0.4) + 200(0.6) = 240.

Q7. Molarity of 4.9% w/w H_2SO_4 (d = 1.86 g/mL) is

(a) 0.5 M
(b) 0.93 M
(c) 1.86 M
(d) 9.3 M

Answer: (b)

Q8. Which mixture forms an ideal solution?

(a) Ethanol + water
(b) Benzene + toluene
(c) Phenol + aniline
(d) Acetone + chloroform

Answer: (b)

Q9. The van't Hoff factor for K_2SO_4 (complete dissociation) is

(a) 1
(b) 2
(c) 3
(d) 4

Answer: (c) — $2K^+ + SO_4^{2-}$.

Q10. Which is a colligative property?

(a) Vapour pressure
(b) Osmotic pressure
(c) Boiling point
(d) Density

Answer: (b) — Relative lowering of VP is colligative, not VP itself.

QUICK REVISION

- Temp dependent: %V/V, %W/V, M, N. Temp independent: %W/W, m, χ, ppm.
- $M = n \times 1000 / V(mL)$; $m = n \times 1000 / W_{solvent}(g)$; $\chi_A + \chi_B = 1$.
- $M = 10 \times \%W/W \times d / MM$; $m = 1000M / (1000d - M \cdot MM)$.
- VP ∝ T, ∝ 1/intermolecular force; independent of amount, area, vessel volume.
- Raoult: $p_A = p^\circ_A \chi_A$; $P = p^\circ_A \chi_A + p^\circ_B \chi_B$; $y_A = p_A/P$.
- Ideal: ΔH = 0, ΔV = 0, A–B = A–A = B–B (benzene + toluene).
- +ve deviation: A–B weaker, ΔH, ΔV > 0, VP ↑, BP ↓, min-boiling azeotrope (ethanol + water).
- –ve deviation: A–B stronger, ΔH, ΔV < 0, VP ↓, BP ↑, max-boiling azeotrope ($CHCl_3$ + acetone).
- Always $\Delta S_{mix} > 0$, $\Delta G_{mix} < 0$.
- Colligative: RLVP = χ_B; $\Delta T_b = iK_bm$; $\Delta T_f = iK_fm$; $\pi = iCRT$.

Practice numericals daily — chemistry rewards consistency.