Resonance®

CHEMISTRY

Target : JEE (Main)

SOLUTION & COLLIGATIVE PROPERTIES

SOLUTION & COLLIGATIVE PROPERTIES

Contents

JEE(MAIN) SYLLABUS

Different methods for expressing concentration of solution- molality, molarity, mole fraction, percentage (by volume and mass both), vapour pressure of solutions and Raoult's Law-Ideal and non-ideal solutions, vapour pressure-composition, plots for ideal and non-ideal solutions; Colligative properties of dilute solutions-relative lowering of vapour pressure, depression of freezing point, elevation of boiling point and osmotic pressure; Determination of molecular mass using colligative properties; Abnormal value of molar mass, van.t Hoff factor and its significance.

JEE(ADVANCED) SYLLABUS

Concentration in terms of mole fraction, molarity, molality and normality.
Raoult's law; Molecular weight determination from lowering of vapour pressure, elevation of boiling point and depression of freezing point.

Solutions And Colligative Properties

1. **Introduction :** A solution is a homogeneous mixture of two or more substances which are chemically non-reacting. We come across many types of solutions in our daily life. e.g., solid-liquid, liquid-liquid, gas-gas. In this chapter we will learn several properties of solutions and their applications.

Solution : *A homogeneous mixture of two or more substances is known as solution*

Solute : *The substance present in smaller amount in a solution is called solute.*

Solvent : *The substance present in larger amount in a solution is called solvent.*

2. **Types of Solutions :**

S.No.	Solute	Solvent	Types of Solutions	Examples
Solid Solutions				
1	Solid	Solid	Solid in solid	All alloys like brass, bronze, an alloy of copper and gold, et
2	Liquid	Solid	Liquid in solid	Amalgam of mercury with Na, $CuSO_4.5H_2O$. $FeSO_4.7H_2O$
3	Gas	Solid	Gas in solid	Solution of H_2 in Pd, dissolved gases in minerals.
Liquid Solutions				
4	Solid	Liquid	Solid in liquid	Sugar solution, salt solution, I_2 in CCl_4
5	Liquid	Liquid	Liquid in liquid	Benzene in toluene, alcohol in water.
6	Gas	Liquid	Gas in liquid	CO_2 in water, NH_3 in water etc.
Gaseous Solutions				
7	Solid	Gas	Solid in gas	Iodine vapours in air, camphor vapours in N_2.
8	Liquid	Gas	Liquid in gas	Water vapours in air, $CHCl_3$ vapours in N_2.
9	Gas	Gas	Gas in gas	Air (O_2 + N_2)

The concentration of a solution can be expressed by different concentration terms which are described as follows.

3. **Concentration Terms :**

% Concentration

Mass percentage : *It is the amount of solute in grams dissolved per 100 g of solution.* e.g., 10% solution of sodium chloride means 10 g of solid sodium chloride present in 100 g of solution.

$$\% \text{ w/w} = \frac{\text{weight of solute (g)}}{\text{weight of solution (g)}} \times 100$$

Ex. 10% w/w urea solution = 10 g of urea is present in 100 g of solution.
= 10 g of urea is present in 90 g of water.

Mass by volume percentage (% w/v) : *It is defined as mass of solute dissolved per 100 ml of solution.* is commonly used in medicine and pharmacy.

% wt/vol. (w/v)

% w/v = wt. of solute/100 mL of solution

$$\% \text{ w/v} = \frac{\text{gram of solutes}}{\text{volume of solution in mL}} \times 100$$

Ex. 10% (w/v) urea solution. = 10 g of urea is present in 100 mL of solution.
But not 10 g of urea present in 90 ml of water
for dilute solution : volume solution = volume solvent.

Volume percentage (% v/v) : *It is defined as volume of a solute dissolved per 100 ml of solution.*

$$\% \text{ v/v} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100$$

Strength of solution in g/L : Weight of solute (in gram) per litre (1000 mL) of solution.

Ex. 10% (w/v) sucrose solution, then specify its concentration in g/L
100 mL .... 10 g

$\therefore$ 1000 mL .... $\frac{10}{100} \times 1000 = 100$ g/L

Solved Examples

Example-1 If we have 6% w/w urea solution with density 1.060 g/mL, then calculate its strength in g/L ?

Sol. 6 g urea is present in 100 g solution.

6 g in $\frac{100}{1.060}$ mL

$\frac{100}{1.060}$ mL $\longrightarrow$ 6 g.

$\therefore$ 1000 mL $= \frac{6}{100} \times 1.060 \times 1000 = 10.6 \times 6 = 63.6$

Molarity (M) : *It is expressed as the number of moles of solute per litre of solution.*
Molarity = No. of moles of solute per litre of solution.
Let n = No. of moles of solute ; N = No. of moles of solvent ; V = volume of solution

$$M = \frac{n}{V(\text{in L})} = \left(\frac{W}{M}\right) \times \frac{1000}{V(\text{in mL})}$$

no. of moles of solute = molarity x volume (in L)
no. of m. moles of solute = molarity x volume (in mL)

If V_1 mL of C_1 molarity solution is mixed with V_2 mL of C_2 molarity solution (same substance or solute)

$\therefore C_f(V_1+V_2) = C_1V_1 + C_2V_2$

$$C_f = \left[\frac{C_1V_1 + C_2V_2}{V_1+V_2}\right] = \frac{\text{Total moles}}{\text{Total volume}}$$ where C_f = molarity of final solution

Molality (m) : *It is defined as number of moles of solute per 1000 g or 1 kg of solvent.*
Molality = No. of moles of solute per kg(1000 g) of solvent.
Let w gram of solute (Molar mass = Mg/mole) is dissolved in 'W' gram of solvent.

$$\text{molality} = \left(\frac{w}{M}\right) \times \frac{1000}{W(g)} ; \qquad \text{molality} = \frac{\text{moles} \times 1000}{W(g)\text{of solvent}}$$

Molality not depends on temperature.

Solved Examples

Example-2 If 20 ml of 0.5 M Na_2SO_4 is mixed with 50 ml of 0.2 M H_2SO_4 & 30 ml of 0.4 M $Al_2(SO_4)_3$ solution. Calculate $[Na^+]$, $[H^+]$, $[SO_4^{2-}]$, $[Al^{3+}]$. [Assuming 100% dissociation]

Sol. Molarity = $\frac{\text{moles}}{\text{volume}}$ ⇒ 10 m. moles of Na_2SO_4 ⇒ 20 m. moles of Na^+

(i) $\therefore [Na^+] = \frac{20}{100} = 0.2$ M

(ii) $[H^+] = ?$
10 m. moles H_2SO_4
20 m. moles H^+
$[H^+] = \frac{20}{100} = 0.2$ M

(iii) $[SO_4^{2-}] = \frac{10+10+36}{100} = \frac{56}{100} = 0.56$ M

(iv) $[Al^{3+}] = \frac{24}{100} = 0.24$ M

Example-3 **(a)** Derive a relationship between molality & molarity of a solution in which w g of solute of molar mass M g/mol is dissolved in W g solvent & density of resulting solution = 'd' g/ml.
(b) Calculate molality of 1.2 M H_2SO_4 solution ? If its $\rho = 1.4$ g/mL

Sol. **(a)** Say 1 L solution taken,
mass of 1 lit solution = (1000 d) g
moles of solute = (molarity)
mass of solute = (molarity) × m
mass of solvent = W = 1000 d − (molarity) × m

$$\therefore \text{molality} = \frac{(\text{molarity}) \times 1000}{1000\,d - \text{molarity} \times \text{M.Wt}}$$ [Where no.of moles of solute = molarity]

(b) Molality = $\frac{1.2 \times 1000}{1000 \times 1.4 - 1.2 \times 98}$ **= 0.936**

Normality : *It is defined as number of gram equivalents of solute dissolved per litre of solution.*

$$\text{No. of equivalents per litre of solution} = \frac{\text{no. of equivalents of solute}}{\text{volume of solution (in L)}} = \text{n-factor} \times \text{molarity}$$

No. of equivalents = normality × volume (in L)

$$\text{Equivalent mass} = \frac{\text{Molar mass}}{\text{n} - \text{factor}}$$

$$\text{No. of equivalent} = \frac{\text{Mass of the species}}{\text{equivalent mass}} = \frac{\text{Mass of the species}}{\frac{\text{Molar mass}}{\text{n} - \text{factor}}}$$

'n' - factor

(i) For oxidizing/reducing agents : no. of e^- involved in oxidation/reduction half reaction per mole of oxidising agent /reducing agent.

e.g. : $5e^- + 8H^+ + MnO_4^- \rightarrow Mn^{2+} + H_2O$ n-factor = 5

(ii) For acid/ base reactions : no. of H^+ ions displaced/ OH^- ions displaced per mole of acid/ base.

e.g. : NaOH n - factor = 1 H_2SO_4 n-factor = 2

(iii) For salt : n = Total charge on cations.
or
total charge on anions
} Simple salts

e.g. : $Al_2(SO_4)_3$ n - factor = charge on the cation = 2 x 3 = 6

Mole-fraction (x) : *It is the ratio of number of moles of a particular component to the total number of moles of all the components.* e.g., mole-fraction of component A, $x_A = \frac{n_A}{n_A + n_B}$, where n_A is the number of moles of component 'A' and n_B is the number of moles of component 'B'.

For binary mixture.

$$X_{solute} = \frac{\text{moles of solute}}{\text{total moles in solutions}} = \frac{n}{n+N} \quad ; \quad X_{Solvent} = \frac{\text{moles of solvent}}{\text{Total moles in solutions}} = \frac{N}{n+N}$$

$X_{solute} + X_{Solvent} = 1$

Parts per million (ppm) : *The number of parts of solute present in 1 million parts of solution are called its ppm.* When a solute is present in small quantities (very minute amounts), it is easier to express the concentration in parts per million.

(a) $$\text{ppm (w/w)} = \frac{\text{wt. of solute (in g)}}{\text{wt. of solution (in g)}} \times 10^6$$

(b) $$\text{ppm (w/v)} = \frac{\text{wt. of solute (in g)}}{\text{vol. of solution (in mL)}} \times 10^6$$

(c) $$\text{ppm (moles/moles)} = \frac{\text{moles of solute}}{\text{moles of solution}} \times 10^6$$

Table : 1

Name	Units	Advantage	Disadvantages
Molarity (M)	$\frac{\text{mol solute}}{\text{L solution}}$	Useful in stoichiometry; measure by volume	Temperature-dependent; must know density to find solvent mass
Mole fraction (x)	None	Temperature-independent; useful in special applications	Measure by mass ; must know density to convert to molarity
Mass %	%	Temperature-independent; useful for small amounts	Measure by mass ; must know density to convert to molarity
Molality (m)	$\frac{\text{mol solute}}{\text{kg solvent}}$	Temperature-independent useful in special applications	Measure by mass ; must know density to convert to molarity

Note : All volume related concentration terms are temperature dependent.

Solved Examples

Example-4 If we have 10 molal urea solution, Calculate mole fraction of urea in this solution & also calculate % w/w of urea (MW = 60).

Sol. 10 moles urea in 1000 g of water

$$X_{urea} = \frac{10}{10 + \frac{1000}{18}} = \frac{10}{65.55} = 0.1526$$

$$\text{\% w/w weight of urea} = \frac{10 \times 60}{10 \times 60 + 1000} \times 100 = 37.5\%$$

*** Note :** For dil. aq. solution molality ≈ molarity, as d ≈ 1 g/mL

$$\text{molality} = \frac{\text{molarity} \times 1000}{1000 \times d - \text{molarity} \times m}$$

Example-5 Calculate molarity of $CaCO_3(aq.)$ solution which has concentration of $CaCO_3$ = 200 ppm.

Sol. 200 g of $CaCO_3$ in 10^6 g of water.

$\frac{200}{100} = 2$ moles of $CaCO_3$ in 10^3 liters of water. (density =1g/mL)

So molarity = $\frac{2}{10^3} = 2 \times 10^{-3}$ M.

4. Colligative properties & constitutional properties :

- **Constitutional Properties :** Properties which are dependent on nature of particles are constitutional properties like electrical conductance.
- **Colligative properties :** The properties of the solution which are dependent only on the total no. of particles relative to solvent/solution or total concentration of particles in the solution and are not dependent on the nature of particle i.e. shape, size, neutral /charge etc. of the particles.

There are 4 colligative properties of soution :

- Osmotic pressure
- Elevation in b.p. (ΔT_b)
- Relative lowering in vapour pressure $\left(\frac{\Delta P}{P}\right)$
- Depression in freezing pt. (ΔT_f)

(i) Osmosis & Osmotic pressure :

Diffusion : Spontaneous flow of particles from high concentration region to lower concentration region is known as diffusion.

Ex.

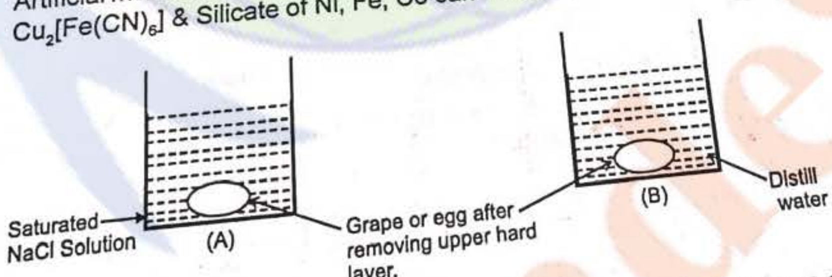
Osmosis: The spontaneous flow of solvent particles from solvent side to solution side or from solution of low concentration side to solution of high concentration side through a semipermeable membrane (SPM) is known as osmosis.

Semipermeable Membrane(SPM): A membrane which allows only solvent particles to move across it.

(a) Natural : Semi permeable membrane
Animal/plant cell membrane formed just below the outer skins.

(b) Artificial membranes also : A copper ferrocyanide.
$Cu_2[Fe(CN)_6]$ & Silicate of Ni, Fe, Co can act as SPM.

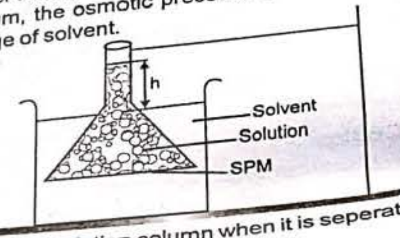
Ex.



Conclusion : After some time in (A) grape or egg will shrink and in (B) grape or egg will swell.

e.g. (i) A raw mango placed in concentrated salt solution loses water & shrivel into pickle.
(ii) People taking lot of salt, experience water retention in tissue cells. This results in puffiness or swelling called edema.

The phenomenon of osmosis : A solution inside the bulb is separated from pure solvent in the beaker by a semipermeable membrane. Net passage of solvent from the beaker through the memberane occurs, and the liquid in the tube rises untill equilibrium is reached. At equilibrium, the osmotic pressure exerted by the column liquid in the tube is sufficient to prevent further net passage of solvent.



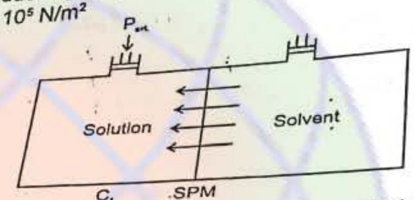
Although the passage of solvent through the membrane takes place in both direction, passage from the pure solvent side to the solution side is more favoured and occurs faster. As a result, the amount of liquid on the pure solvent side decreases, the amount of liquid on the solution side increases, and the concentration of the solution decreases.

Osmotic Pressure : The equilibrium hydrostatic pressure developed by solution column when it is seperated from solvent by semipermeable membrane is called O.P. of the solution.

$\pi = \rho g h$; ρ = density of soln.

g = acceleration due to gravity ; h = eq. height

1 atm = 1.013×10^5 N/m^2



Definition : The external pressure which must be applied on solution side to stop the process of osmosis is called osmotic pressure of the solution.

If two solutions of concentration C_1 and C_2 are kept separated by SPM, and $C_1 > C_2$ then particle movement take place from lower to higher concentration. So, extra pressure is applied on higher concentration side to stop osmosis. And $P_{ext.} = (\pi_1 - \pi_2)$

Reverse Osmosis : If the pressure applied on the solution side is more than osmotic pressure of the solution then the solvent particles will move from solution to solvent side. This process is known as reverse osmosis.

Berkely : Hartely device/method uses the above pressure to measure osmotic pressure.

e.g. used in desalination of sea-water.

Vant – Hoff Formula (For calculation of osmotic pressure)

- $\pi \propto$ concentration (molarity)
  $\propto T$
  $\pi = CST$
  S = ideal solution constant
  = 8.314 J mol^{-1} K^{-1} (exp value)
  = R (ideal gas) constant

π = atm. { C – mol/lit. ; R – 0.082 lit.atm. mol^{-1} K^{-1} ; T – kelvin }

$$\pi = CRT = \frac{n}{V} RT \text{ (just like ideal gas equation)}$$

- In ideal solution solute particles can be assumed to be moving randomly without any interactions.

$\therefore$ C = total concentration of all types of particles.

$= C_1 + C_2 + C_3 + s$.................

$$= \frac{(n_1 + n_2 + n_3 + ...)}{V}$$

Solved Examples

Example-6 If V_1 mL of C_1 solution + V_2 mL of C_2 solution are mixed together then calculate final concentration of solution and final osmotic pressure. If initial osmotic pressure of two solutions are π_1 and π_2 respectively?

Sol. $C_f = \dfrac{C_1V_1 + C_2V_2}{V_1 + V_2}$

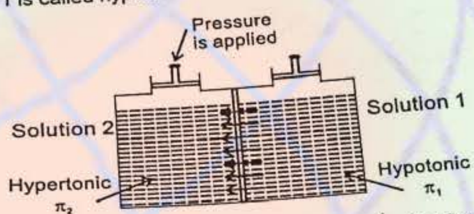
$\pi_1 = C_1RT,\ C_1 = \left(\dfrac{\pi_1}{RT}\right)$; $\pi_2 = C_2RT,\ C_2 = \left(\dfrac{\pi_2}{RT}\right)$

$\pi = \left(\dfrac{C_1V_1 + C_2V_2}{V_1 + V_2}\right)RT$; $\pi = \left(\dfrac{\pi_1V_1 + \pi_2V_2}{V_1 + V_2}\right)$

Type of solutions :

(a) Isotonic soution : Two solutions having same osmotic pressure are consider as isotonic solution.
$\pi_1 = \pi_2$ (at same temperature)

(b) Hypotonic & Hypertonic solutions : If two solutions 1 and 2 are such that $\pi_2 > \pi_1$, then 2 is called hypertonic solution and 1 is called hypotonic solution.



Conclusion : Pressure is applied on the hypertonic solution to stop the flow of solvent partices, this pressure become equal to $(\pi_2 - \pi_1)$ and if hypotonic solution is replaced by pure solvent then pressure becomes equal to π_2.

Note : Osmotic pressure of very dilute solutions is also quite significant. So, its measurement in lab is very easy.

Plasmolysis : *When the cell is placed in solution having osmotic pressure greater than that of the cell sap, water passes out of the cell due to osmosis. Consequently, cell material shrinks gradually. The gradual shrinking of the cell material is called plasmolysis.*

- **Abnormal Colligative Properties : [Vant–Hoff correction :]**
  - For electrolytic solutes the number of particles would be different from the number of particles actually added, due to dissociation or association of solute.
  - The actual extent of dissociation/association can be expressed with a correction factor known as vant Haff factor (i).

Vant–Hoff factor : $i = \dfrac{\text{moles of particles in solution after dissociation / association}}{\text{moles of solute dissolved}}$

- If solute gets associated or dissociated in solution then experimental / observed / actual value of colligative property will be different from theoretically predicted value so it is also known as **abnormal colligative property.**
- This abnormality can be calculated in terms of Vant-Hoff factor.

$$i = \frac{\text{exp/ observed / actual / abnormal value of colligative property}}{\text{Theoretical value of colligative property}}$$

$$= \frac{\text{exp./observed no. of particles or concentration}}{\text{Theoretical no. of particles or concentration}} = \frac{\text{(Theoretical molar mass of substance)}}{\text{(Experimental molar mass of the substance)}}$$

$i > 1$ dissociation

$i < 1$ association

$$i = \frac{\pi_{exp.}}{\pi_{theor.}}$$

RESONANCE STUDY CENTRES (Self Owned)

KOTA (Head Office):
Pre-Engineering Division: JEE (Advanced)
Pre-Engineering Division: JEE (Main)
Pre-Medical Division: AIIMS/ AIPMT
Tel.: 0744-3012222, 3192222, 6635555
e-mail: contact@resonance.ac.in

Commerce & Law Program Division (CLPD)
Tel.: 0744-3192229, 6060663
e-mail: clpd@resonance.ac.in

PCCP/PSPD/MEx
Tel.: 0744-2434727, 8824078330, 3192223, 2440488
e-mail: pccp@resonance.ac.in

DLPD
Tel.: 0744-6635556, 3012222
e-mail: dlpd@resonance.ac.in

eLPD
Tel.: 0744-3058242
e-mail: elpd@resonance.ac.in

JAIPUR
Tel.: 0141-6060661/ 64, 3103666, 6060662/63
e-mail: jaipurc@resonance.ac.in

BHOPAL
Tel.: 0755-3206353, 3192222, 3256353
e-mail: bhopal@resonance.ac.in

NEW DELHI
Tel.: 011-60606601/ 2/ 3/ 4/ 5/ 6/ 7
e-mail: delhi@resonance.ac.in

LUCKNOW
Tel.: 0522-3192222, 3192223/ 4, 6060660/ 61/ 62
e-mail: lko@resonance.ac.in

KOLKATA
Tel.: 033-31922222, 60606600/ 01/ 02
email: kolkata@resonance.ac.in

NAGPUR
Tel: 0712-3017222, 3192222, 6060660
e-mail: nagpur@resonance.ac.in

NANDED
Tel.: 02462-250220, 606066
e-mail: nanded@resonance.ac.in

MUMBAI
Tel.: 022-31922222, 60606600
e-mail: andheri@resonance.ac.in

UDAIPUR
Tel.: 0294-6060660, 5107510, 3192222
e-mail: udaipur@resonance.ac.in

BHUBANESWAR
Tel.: 0674-3192222, 3274919, 6060660/ 61
e-mail: bbsr@resonance.ac.in

AHMEDABAD
Tel.: 079-31922222/ 3/ 4 & 079-60606600/ 1/ 2
e-mail: abad@resonance.ac.in

PATNA
Tel.: 0612-3192222, 3192222/ 3
e-mail: patna@resonance.ac.in

JODHPUR
Tel.: 0291- 6060660
e-mail: jodhpur@resonance.ac.in

AJMER
Tel.: 0145-3192222, 6060660/ 65
e-mail: ajmer@resonance.ac.in

INDORE
Tel: 0731-3192222, 4274200
e-mail: indore@resonance.ac.in

SIKAR
Tel: 01572-319222, 606066
e-mail: sikar@resonance.ac.in

AGRA
Tel: 0562-3192222, 6060660
e-mail: agra@resonance.ac.in

RANCHI
Tel.: 0651-6060660
e-mail: ranchi@resonance.ac.in

ALLAHABAD.
Tel.: 0532-6060660
e-mail: allahabad@resonance.ac.in

NASHIK
Tel.: 0253-6090028
e-mail: nashik@resonance.ac.in

RAIPUR
Tel.: 0771- 6060660
e-mail: raipur@resonance.ac.in

AURANGABAD
Tel.: 0240-6060660
e-mail: aurangabad@resonance.ac.in

JABALPUR
Tel.: 0761- 6060660
e-mail: jabalpur@resonance.ac.in

GWALIOR
Tel.: 0751-6060660
e-mail: gwalior@resonance.ac.in

CHANDRAPUR
Tel.: 07172-606066
e-mail: chandrapur@resonance.ac.in

SURAT
Tel.: 0261-6060660
e-mail: surat@resonance.ac.in

RAJKOT
Tel.: 0281-6002011
e-mail: rajkot@resonance.ac.in

VADODARA
Tel.: 0265-6060660
e-mail: vadodara@resonance.ac.in

BASE STUDY CENTRES

Base Education Service Pvt. Ltd.
Bengaluru (Main Branch):
Reg. Office : No.27, Next to Indian Oil Petrol Bunk, Bull Temple Road, Basavanagudi, Bengaluru- 560004
Tel. No.: 42604600/ 95381 41504
E-Mail : info@base-edu.in
Website: www.base-edu.in

BANASANKARI II STAGE
Tel : 26710835/26710836

BELAGAVI
Tel : 0831- 4208687 | Mobile : 9845228000

CHITRADURGA
Mobile : 9886464755, 9972413844

HUBLI
Tel : 0836- 2252685 | Mobile : 9844118615

INDIRANAGAR
Tel : 41179342/25201306

KALYAN NAGAR
Tel : 080-25443363/25443364

KORAMANGALA
Tel : 40925512/40925534

MALLESHWARAM
Tel : 41400008

MYSURU
Tel : 0821-4242100 /4258100/4243100

RAJAJINAGAR
Tel: 08023327588/41162135

SHIVAMOGGA
Tel : 08182-223980, 8884849590

TUMAKURU
Tel :0816-2252387

UDUPI
Tel : 0820-2522449, 2522994, 9986663074

VIJAYANAGAR
Tel : 23111333/23111334

YELAHANKA
Tel: 08028463922/42289643

CHIKKAMAGALURU
Mobile : 7411329369, 9448396890

HASSAN
Mobile : 9481392014, 9972038283

J P NAGAR
Tel : 26595151/26595153.

KALABURGI
Tel : 08472-230914
Mobile : 9845905200/9844510914

Resonance®
Educating for better tomorrow

Corporate Office: CG Tower, A-46 & 52, IPIA, Near City Mall, Jhalawar Road, Kota (Rajasthan)- 324005
Reg. Office: J-2, Jawahar Nagar Main Road, Kota (Raj.)- 05 | **Tel. No.:** 0744-3192222, 3012222, 6635555 | **CIN:** U80302RJ2007PLC024029
To Know more: sms **RESO** at **56677** | **E-mail:** contact@resonance.ac.in | **Website:** www.resonance.ac.in

Toll Free : 1800 258 5555 | 08003 444 888 | facebook.com/ResonanceEdu | twitter.com/ResonanceEdu | www.youtube.com/resowatch | blog.resonance.ac.in