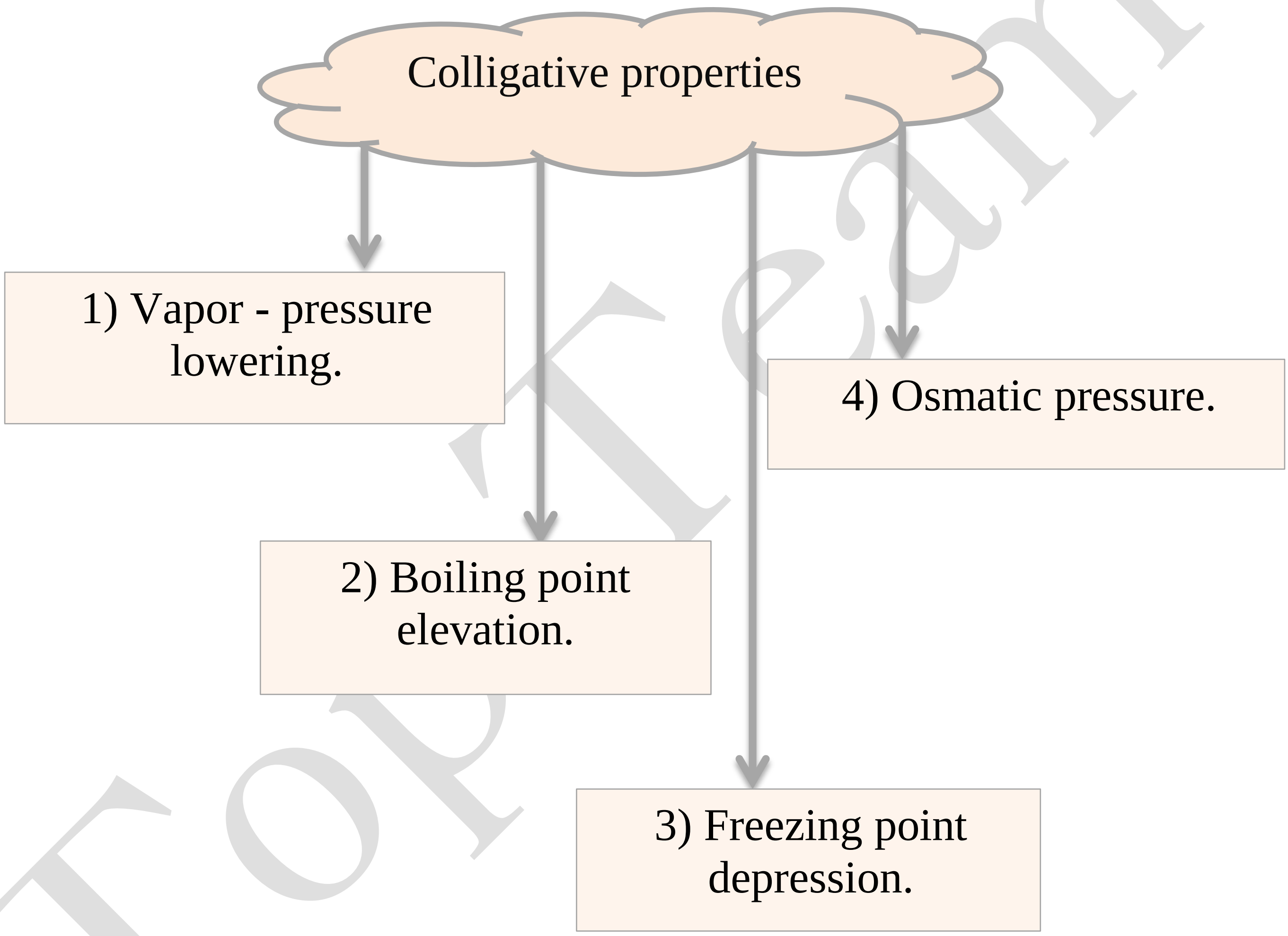
Colligative properties of non-electrolyte solutions

❖ Colligative properties :→ are properties depend only on the number of solute particles in solution and not the nature of the solute particles "atom , Ion or molecule".



☒ Colligative properties deals with relatively diluted solutions that it's concentration is $\leq 0.2M$.

Vapor pressure lowering

☒ If the solute is non-volatile:→ doesn't have measurable vapor pressure.

∴ Vapor pressure of its solution is always less than that of the pure solvent.

Raoult's law

✓ It determine the relation between solution vapor pressure and solvent vapor pressure.

$$P_1=X_1P_1°$$

P_1 →vapor pressure of solvent over a solution.

X_1→ mole fraction of the solvent.

$P_1°$→ vapor pressure of the solvent.

✓ If the solution containing only one solute

$$\therefore X_1=1-X_2$$

X_2→ mole fraction of the solute.

$P_1= (1-X_2)P_1°$

$P_1= P_1°-P_1°X_2$

$$\therefore \Delta P_1= P_1°-P_1=P_1°X_2$$

ΔP→ is directly proportional to the solute concentration " mole fraction".

Example

Calculate the vapor pressure of a solution made by dissolving 218 gm of glucose "molar mass 180 gm/mole" in 460 ml of water at 30°C , what is the vapor pressure lowering?! The vapor pressure of pure water at 30°C=31.82 mmHg

Solution

1) no. of moles of glucose $= \frac{mass}{molar\ mass} = \frac{218}{180.2} = 1.21 mole$

2) no. of moles of water $= \frac{mass}{molar\ mass} = \frac{460}{18.02} = 25.5 mole$

Note that → ml of water = gm of water

3) mole fraction of water $X_1 = \frac{25.5}{25.5+1.21} = 0.955$

$\therefore P_1 = X_1 P_1^\circ = 0.955 * 31.82 = 30.4$ mmHg

∴ Vapor pressure lowering = 31.82 – 30.4 = 1.3 mmHg.

☒ If both components of a solution are volatile → have measurable vapor pressure.

∴ The vapor pressure of a solution is the sum of the individual partial pressure.

Roult's law

$P_A = X_A . P_A°$ or $P_B = X_B . P_B°$

P_A , P_B → partial pressure for component (A,B).

$P_A°$, $P_B°$ → vapor pressure of the pure substance.

X_A , X_B → mole fraction.

Total pressure → $P_T = P_A + P_B$

$P_T = X_A P_A° + X_B P_B°$

Fractional distillation :→ procedure for separating liquid components of a solution based on their different boiling point.

Example

If we want to separate a binary system say "benzene and toluene".

- Benzene and toluene are relatively volatile.
- Their boiling point are 80.1°C and 110.6°C respectively.
- If we boil a solution containing these two substances , the vapor formed is rich with the more volatile component "benzene".
- If the vapor condense and the liquid is boiled a gain , a still higher concentration of benzene will be obtained in the vapor phase.

Choose:

1) The properties that depend only the number of solute particles in the solution is…………

A) osmatic pressure
B) colligative properties
C) freezing point depression
D) None of them

2) The properties that are not depend on the nature of the solute particles………..

A) osmatic pressure
B) freezing point depression
C) colligative properties
D) None of them

3) Colligative properties deals with relatively……..solutions.

A) concentrated
B) diluted
C) More concentrated
D) Both A and C

4) Colligative properties deals with a solution whose concentration equal or less than ……...

A) 2
B) 0.2
C) 0.02
D) 2.2

5) The solute that doesn't have measurable vapor pressure is ……..

A) non volatile
B) volatile
C) diluted
D) concentrated

6) If The solute is volatile , the vapor pressure of a solution ……that of the pure solvent.

A) equal
B) more than
C) less than
D) Both A and B

7) It determine the relation between the solution vapor pressure and solvent vapor pressure.

A) Boltzmann equation
B) Rault's equation
C) Arrhenius equation
D) Avogadro's number

8) The Rault's equation is ….. in non-volatile solution.

A) $P_1=X_1P_1^{\circ}$
B) $P_1^{\circ}=X_1P_1$
C) $P_1=\frac{X1}{P1^{\circ}}$
D) $X_1=P_1P_1^{\circ}$

9) ΔP is directly proportional to the……

A) solute nature
B) solute concentration
C) solvent concentration
D) solvent nature

10) ΔP is directly proportional to the solute conc. by…….

A) molarity
B) molality
C) mole fraction
D) normality

11) The solution that is have measurable vapor pressure is…...

A) concentrated
B) nonvolatile
C) volatile
D) diluted

12) The solution that is non-volatile , the vapor pressure of solution is …… the individual vapor pressure.

A) equal
B) greater than
C) summation
D) lower than

13) Procedure uses for separating liquid components of solutions based on their different boiling point is called ………

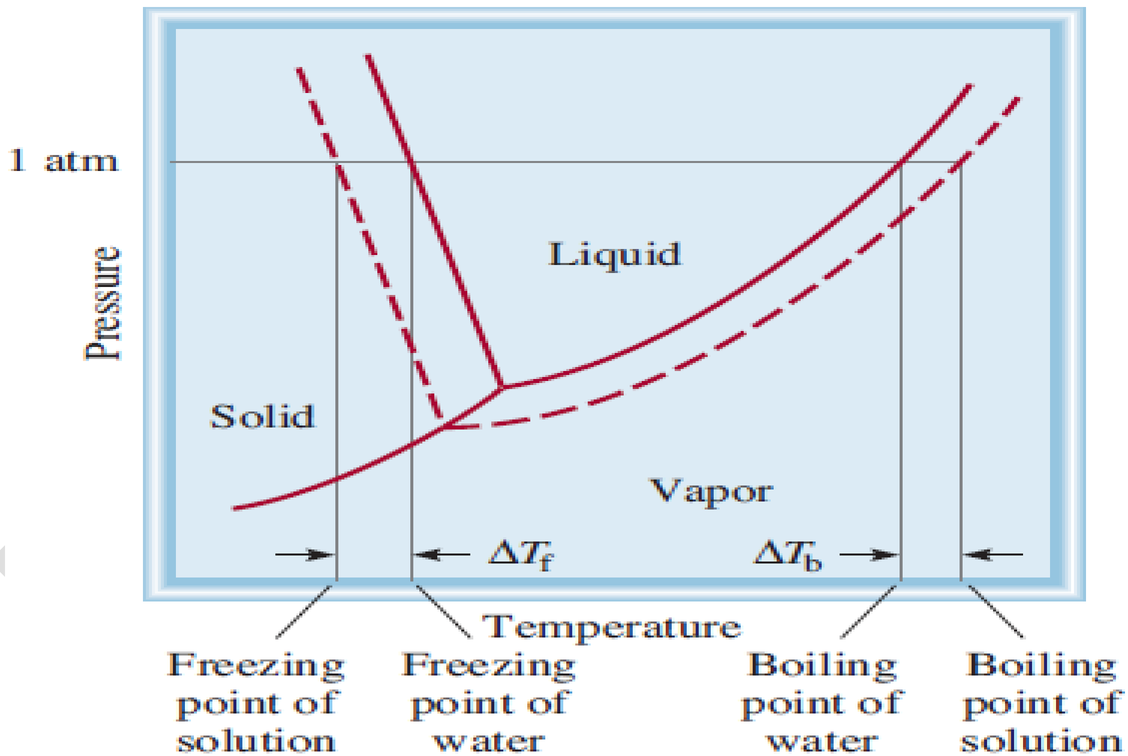
A) neutralization
B) crystallization
C) fractional distillation
D) desalination

Boiling point elevation

Boiling point of a solution: → Is the temperature at which it's vapor pressure equals to external atmospheric pressure.

- ☒ nonvolatile solute lowers vapor pressure of a solution and affect boiling point of a solution.

Phase diagram of water



This graphical analysis shows that:

☒ The boiling point of a solution is higher than that of the water.

Boiling point elevation (ΔT_P):→ is defined as the boiling point of the solution (T_b) minus the boiling point of the pure solvent($T_b°$)

$$\Delta T_b = T_b - T_b°$$

$$T_b > T_b°$$

∴ ΔT_b is positive quantity

The value of $\mathbf{\Delta T_b}$ → is proportional to the vapor pressure lowering and also proportional to the concentration "molality" of the solute.

$$\Delta T_b \; \alpha \; m$$

$$T_b = K_b \, m$$

K_b→ molal boiling point elevation constant

unit→ $°C/m$

Why we use concentration by molality?!

Because the temperature is not constant , so we can't express the concentration unit in molarity because molarity change with temperature.

Choose

1) ………… is the temperature at which the vapor pressure of a solution is equal to the atmospheric pressure.

A) boiling point
B) freezing point
C) vaporization point
D) atomization point

2) At the boiling point, the vapor pressure is ……. The atm. pressure.

A) greater than
B) equal
C) lower than
D) More than

3) Nonvolatile solute ……. Vapor pressure of a solution.

A) increase
B) decrease
C) Has no change on
D) All of the above are true

4) The equation of boiling point elevation is………

A) $\Delta Tb = Tb° - Tb$
B) $\Delta Tb = Tb - Tb°$
C) $Tb° = \Delta Tb - Tb$
D) $\Delta Tb = Tb + Tb°$

5) ………is defined as the boiling point of a solution minus the boiling point of pure solvent.

A) boiling point
B) freezing point
C) boiling point elevation
D) desalination

6) The value of boiling point elevation is proportional to……….

A) Temp. of solution
B) number of ions
C) conc. of solvent
D) conc. of solute

7) The value of boiling point elevation is proportional to……….

A) atmospheric pressure
B) conc. of solvent
C) degree of solubility
D) vapor pressure lowering

8) The value of boiling point elevation is proportional to the concentration of a solute by……….

A) molarity
B) mole fraction
C) molality
D) percentage gradient

9) The unit of K_b is…….

A) °K/m
B) °C.m
C) m/°C
D) °C/m

Freezing point depression

☒ Ice on frozen roads melts when sprinkled with salt such as NaCl.

☒ Freezing point depression (ΔT_f) :→ The freezing point of the pure solvent (**$T°_f$**) minus the freezing point of the solution (T_f).

$$\Delta T_f = T°_f - T_f$$

$$T_f° > T_f$$

ΔT_f →positive quantity.

ΔT_f → is proportional to the concentration of the solution.

$$\Delta T_f \,\alpha\, m$$

m→ conc. in molality.

$$\Delta T_f = K_f\, m$$

K_f unit→ $℃/m$

K_f → Molal freezing point depression constant.

Qualitative explanation of freezing point depression

✓ Freezing involves transition from the disorder state to order state.

So the energy must be removed from the system.

✓ Therefore, the solution has a lower freezing point than it's solvent.

Note that

- ☒ When a solution freeze , the solid that separates is the pure solvent component.
- ☒ In order for boiling point elevation to occur , the solute must be non-volatile.
- ☒ but no much restriction applied to the freezing point depression.

Example

Ethylene glycol**($OH\text{-}CH_2\text{-}CH_2\text{-}OH$)** is a common auto mobile antifreeze, it is water soluble and fairly non-volatile (B.p197°C) calculate a freezing point of a solution containing 651gm of Ethylene glycol in 2.505 L of water , the molar mass of Ethylene glycol is 62.07 gm and K_f = 1.86°C/m.

Solution

$\Delta T_f = m K_f$

$m = \frac{no.of\ moles\ of\ solute}{mass\ of\ solvent\ (Kg)}$

no. of moles of solute $= \frac{mass}{molar\ mass} = \frac{651}{62.07}$ =10.5mole

$m = \frac{10.5}{2.505Kg} = 4.19m$

$$\Delta T_f = 1.86*4.19 = 7.79°C$$

Because of pure water freeze at 0°C the solution will freeze at

0 -7.79 = -7.79°C

Choose

1) The freezing point of the pure solvent minus the freezing point of the solution is called ……..

A) freezing point depression
B) freezing point of solvent
C) salt freezing point
D) normal freezing point

2) The equation of freezing point depression is……….

A) $Tf° = \Delta Tf - Tf$
B) $\Delta Tf = Tf - Tf°$
C) $\Delta Tf = Tf° - Tf$
D) $\Delta Tf = Tf° + Tf$

3) Freezing point depression is proportional to the concentration by…………

A) molality
B) normality
C) mole fraction
D) molarity

4) ΔTf = ………

A) k_b m
B) K_f m
C) K_f /m
D) m/K_b

5) The unit of K_f is……….

A) m/°C
B) m/°K
C) °C/m
D) °K/m

6) Freezing involve transition from………… to……………

A) disorder - order
B) order - disorder
C) disorder - rondom
D) disorder to free

7) For the solution to be frozen the energy must be…………..

A) removed
B) added
C) increase
D) constant

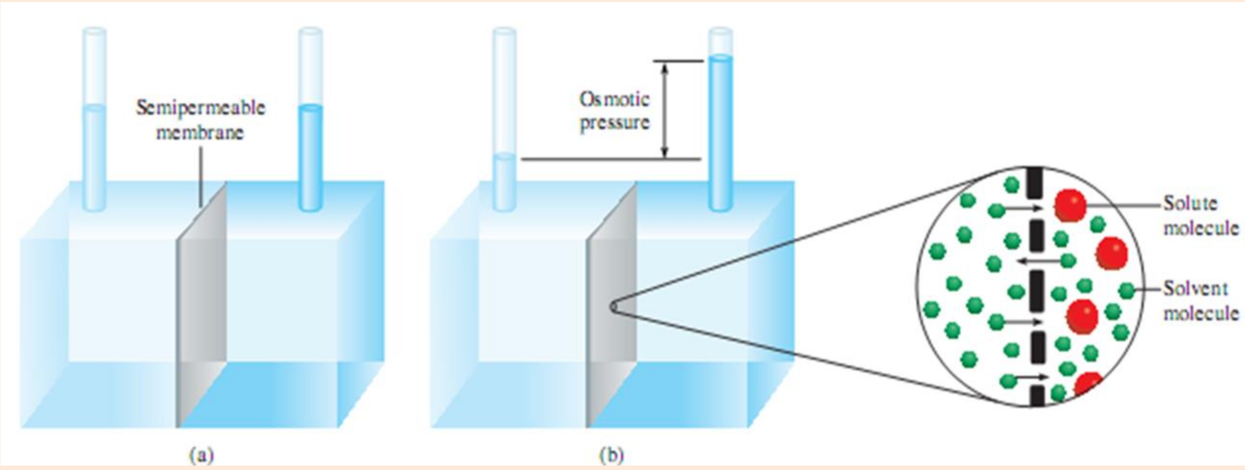
8) For boiling point elevation to occur, the solvent must be………...

A) diluted
B) concentrated
C) nonvolatile
D) volatile

Osmotic pressure

Osmosis→ is a selective passage of solvent molecules through a porous membrane from a dilute solution to a more concentrated one.

Semi permeable membrane → allows the passage of solvent molecules but blocks the passage of solute molecules.



Osmotic pressure(π)→ is the pressure required to stop osmosis.

- ❖ What cause water to move spontaneously from lower concentration to higher?!
- ✓ Because the vapor pressure of pure water is higher than the vapor pressure of the solution.

The osmotic pressure is given by:

$$\pi = MRT$$

M →concentration in molarity.
R →gas constant(0.082 L.Atm/K .mole).
T →absolute temperature "kelvin".
The unit of π → Atm.

- ❖ why we use the concentration by molarity rather than molality?!!
- ✓ because osmotic pressure carried out at constant temp.

Note that

- Osmotic pressure is directly proportional to the concentration of solution.
- Boiling point elevation is directly proportional to the conc. of solution.
- Freezing point depression is directly proportional to the conc. of solution.
- And this because all colligative properties depend only on the number of solute particles in solution.

What is the mean of isotonic , hypertonic and hypotonic?!

Hypotonic → the more diluted solution.

If the two solutions are of unequal osmotic pressure, the more concentrated solution is called→hyper- tonic

Isotonic → If the two solutions are of equal concentration, so they have the same osmotic pressure.

Semi permeable membrane may have pores small enough to let only the solvent molecules through.

Application of osmotic pressure

1) Study the content of red blood cell.

2) Home preserving of Jam and Jelly

3) Osmotic pressure also the major mechanism for transporting water up word in plant.

Example

1) The average osmotic pressure of seawater measured by the kind of apparatus is about 30 Atm. at 25°C , calculate the molar conc. of an aqueous solution of sucrose ($C_{12}H_{22}O_{11}$) that is isotonic with sea water.

Solution

$\pi = 30$ atm

$T = 25 + 273 = 298°K$

$\pi = MRT$

$M = \frac{\pi}{Rt} = \frac{30}{0.0821*298} = 1.23M$

Using colligative properties to determine molar mass

Theoretically → any of the four colligative properties is suitable for determine the molar mass.

In practice → only freezing point depression and osmotic pressure are used because they show the pronounced changes.

2) A 7.85 gm sample of a compound with the empirical formula C_5H_4 is dissolved in 301 gm of benzene the freezing point of the solution is 1.05°C below that of pure benzene . What is the molar mass and molecular formula of this compound?! (K_f=5.12°C/m)

Solution

$\Delta T_f = m\,K_f$

$$\therefore m = \frac{\Delta Tf}{Kf} = \frac{1.05}{5.12} = 0.205 \text{ molal}$$

$$\text{molality} = \frac{no.of\ moles\ of\ solute}{volume\ of\ solvent\ (Kg)}$$

$$0.205 = \frac{no.of\ moles}{0.301}$$

no. of moles of solute = 0.0617 mole

$$\text{no. of moles of solute} = \frac{mass}{molar\ mass}$$

$$0.0617 = \frac{7.85}{molar\ mass}$$

molar mass = 127 gm

$$\therefore \text{ratio} = \frac{molar\ mass}{emprical\ molar\ mass} = \frac{127}{64} \cong 2$$

Molecular formula = $(C_5H_4)_2 = C_{10}H_8$ "naphthalene"

3) A solution is prepared by dissolving 35 gm of hemoglobin (H_b) in enough water to make up 1 L in volume. If the osmotic pressure of the solution is found to be 10 mmHg at 25°C , calculate the molar mass of (H_b)

Solution

$\pi = MRT$

$M = \dfrac{\pi}{RT}$

M = 0.031/.0821*298

= $5.38*10^{-4}$

$\pi = 10mmHg$ 1atm → 760mmHg

π =0.031 atm ?atm→10mmHg

T=25+273=298°K

$$\therefore\ \pi = \frac{10}{760} = 0.013\ atm$$

R= 0.0821(L.atm/K.mole)

$$molarity = \frac{no. of\ moles\ of\ solute}{litres\ of\ solution}$$

$$5.38*10^{-4} = \frac{no.of\ moles}{1}$$

$$\therefore \text{no. of moles} = 5.38 * 10^{-4}\text{mole}$$

$$\therefore \text{no. of moles} = \frac{\text{mass}}{\text{molar mass}}$$

$$\therefore 5.38 * 10^{-4} = \frac{35}{\text{molar mass}}$$

$$\therefore molar\ mass\ of\ (Hb) = \frac{35}{5.38 * 10^{-4}} = 6.51 * 10^{-4} gm$$

Note that:

☒ The freezing point depression is more suitable for determining the molar mass of smaller and more soluble molecules , Those having molar masses of 500 gm or less , because the freezing point depression of their solutions are much greater.

Choose

1)………. is a selective passage of solvent molecules through a porous membrane from a diluted solution to a more concentrated one.

A) osmosis
B) osmotic pressure
C) vapor pressure
D) solvation

2) Osmosis is a selective passage of solvent from ……. to …….

A) concentrated-diluted
B) diluted-very dilute
C) concentrated-very concentrated
D) diluted-more concentrated

3) ………. allow the passage of solvent molecules but block the passage of solute.

A) permeable membrane
B) open membrane
C) semi permeable membrane
D) closed membrane

4) Semi permeable membrane blocks the passage of …….molecules.

A) Solvent
B) Solute
C) Solution
D) Both A and B

5) Semi permeable membrane allows the passage of…….. molecules.

A) solute
B) solution
C) solvent
D) Both A and B

6) ……… is the pressure required to stop osmosis.

A) osmotic pressure
B) partial pressure
C) total osmotic pressure
D) vapor pressure

7) The osmotic pressure is given by ………

A) $\pi = nRT$
B) $\pi = pkT$
C) $\pi = MPT$
D) $\pi = MRT$

8) The unit of osmotic pressure $\pi =$ … … … …

A) Cm Hg
B) Pascal
C) Atm.
D) Torr

9) In the following equation π=MRT , The "M" is concentration by………

A) molarity
B) molality
C) normality
D) mole fraction

10) Osmotic pressure , boiling point elevation and freezing point depression is directly proportional to………

A) number of solute
B) grams of solute
C) liters of solvent
D) conc. of solution

11) When the two solutions are of equal concentration this is called………..

A) hypertonic
B) isotonic
C) hypotonic
D) Both A and B

12) If the two solutions are of unequal osmotic pressure , the more concentrated solution is called……..

A) isotonic
B) hypertonic
C) hypotonic
D) Both A and B

13) If the two solutions are of unequal osmotic pressure , the more diluted solution is called……….

A) isotonic
B) hyper tonic
C) hypotonic
D) Both A and B

14) The average osmotic pressure of seawater measured by the kind of apparatuses is about 7 atm. at 20°C what is the molar concentration of (NaCl) that is isotonic with seawater?!

A) 1M
B) 0.35M
C) 0.3M
D) 0.52M

Solution:

$$\pi = MRT \;\; \therefore M = \frac{\pi}{RT} = \frac{7}{0.0821 * (20 + 273)} = 0.29 \text{ molar}$$