An aqueous solution is 8.50% ammonium chloride by mass. The density of the solution is 1.024 g/mL
Find: molality and molarity.

$NH_4Cl$ : 53.491 g/mol $H_2O$: 18.016 g/mol

$$\frac{8.50\,g\ NH_4Cl}{100\,g\ solution} \longrightarrow \frac{mol\ NH_4Cl}{kg\ H_2O}$$

mass percent → molality

Assume a basis of 100g solution. This means that the solution contains 8.50 grams of ammonium chloride. We can convert the mass of ammonium chloride to moles:

$$8.50\,g\ NH_4Cl \times \frac{mol\ NH_4Cl}{53.491\,g\ NH_4Cl} = 0.158905236\,mol\ NH_4Cl$$

Now that we have moles ammonium chloride, find the mass of water:

$$100\,g\ solution - 8.50\,g\ NH_4Cl = 91.50\,g\ H_2O = 0.09150\,kg\ H_2O$$

So the molality is:

$$C_m = \frac{0.158905236\,mol\ NH_4Cl}{0.09150\,kg\ H_2O} = \boxed{1.74\,m\ NH_4Cl}$$

An aqueous solution is 8.50% ammonium chloride by mass. The density of the solution is 1.024 g/mL
Find: molality and molarity.

$NH_4Cl$ : 53.491 g/mol   $H_2O$: 18.016 g/mol

$$\frac{8.50\text{ g } NH_4Cl}{100\text{ g solution}} \longrightarrow \frac{\text{mol } NH_4Cl}{\text{L solution}}$$

mass percent                                                        molarity

As before, assume a basis of 100g solution. This means we have 8.50 grams of ammonium chloride (AND that we already know the moles because we calculated moles on the previous page!)

$$8.50\text{ g } NH_4Cl \times \frac{\text{mol } NH_4Cl}{53.491\text{ g } NH_4Cl} = 0.1589052364 \text{ mol } NH_4Cl$$

We now need to know the volume of the solution.

$$100\text{ g solution} \times \frac{\text{mL}}{1.024\text{ g}} = 97.65625\text{ mL} = 0.09765625\text{ L}$$

density (given)

$$M = \frac{0.1589052364\text{ mol } NH_4Cl}{0.09765625\text{ L}} = \boxed{1.63\text{ M } NH_4Cl}$$

# COLLIGATIVE PROPERTIES

- properties unique to solutions.

- depend only on the CONCENTRATION of a solution and not the IDENTITY of the solute**

**ionic solutes: Remember that they dissociate into MULTIPLE IONS!

(1) Freezing point depression

- The freezing temperature of a SOLUTION gets lower as the CONCENTRATION of a solution increases.

(2) Vapor pressure lowering

- The vapor pressure of a solution (pressure of sovent vapor over a liquid surface) goes DOWN as solution concentration goes UP

(3) Boiling point elevation

- The boiling temperature of a solution increases as the concentration of the solution increases.

(4) Osmotic pressure

- The pressure required to PREVENT the process of osmosis

## FREEZING POINT DEPRESSION

$$\Delta T_f = K_f \times c_m$$

- $c_m$: concentration of solute (molality)
- $K_f$: Freezing point depression constant (for SOLVENT)
- $\Delta T_f$: Freezing point depression: The amount the freezing temperature is LOWERED by the solute.

- Applications: In chemistry, this effect is often used to determine the molecular weight of an unknown molecule.

A solution of 2.500g of unknown dissolved in 100.0 g of benzene has a freezing point of 4.880 C. What is the molecular weight of the unknown?

$K_{f,\text{benzene}} = 5.065\ ^{o}C/m$, $T_{f,\text{benzene}} = 5.455^{o}C$ (see p500 9th, p509, 10th)

$\Delta T_f = K_f \times C_m$

$K_f$: $5.065\ ^{o}C/m$

$\Delta T_f$: $5.455^{o}C - 4.880^{o}C = 0.575^{o}C$

$C_m$: $\frac{\text{mol unknown}}{\text{kg benzene}}$

To find molecular weight, we need to know the MOLES of the unknown. Then , we just divide 2.500 g / ?? mol

First find cm ...

$0.575\ ^{o}C = (5.065\ ^{o}C/m) \times C_m$

$C_m = 0.1135241856\ m$

To find moles unknown, we need to multiply the molal concentration by the amount of benzene actually used in the experiment:

$0.1000\ \text{kg benzene} \times \frac{0.1135241856\ \text{mol unk}}{\text{kg benzene}} = 0.01135241856\ \text{mol unk}$

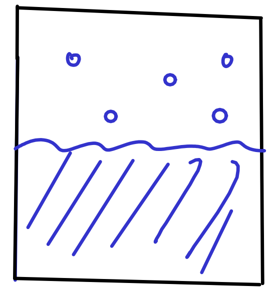
(100 g)

To find MOLECULAR WEIGHT, divide the mass of the unknown and the moles of unknown...

$MW = \frac{\text{mass unk}}{\text{mol unk}} = \frac{2.500\text{g}}{0.01135241856\ \text{mol unk}} = 22\bar{0}\ \text{g/mol}$

# VAPOR PRESSURE LOWERING

- Described by RAOULT'S LAW



$P_A$ = partial pressure of the VAPOR of solvent molecules.

$$P_A = P_A^* \times X_A$$

- $X_A$: mole fraction of component A
- $P_A^*$: vapor pressure of pure component A (depends on temperature)
- $P_A$: partial pressure of component A in a solution

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... but component "A" above is actually the SOLVENT. If we want to describe this as a colligative property, we want to express Raolt's law in terms of the SOLUTE! Assuming a two-component mixture, we get...

$$\Delta P = P_A^* \times X_B$$

- $X_B$: mole fraction of component B (the SOLUTE in a two-component mixture)
- $\Delta P$: Vapor pressure lowering. This is the DECREASE in the vapor pressure of the solvent due to the presence of solute.

# BOILING POINT ELEVATION

- Since the vapor pressure is lowered by the presence of a solute, AND since boiling occurs when the vapor pressure of a liquid equals the external pressure - solutes also cause BOILING POINT ELEVATION.

- The equation for boiling point elevation looks almost exactly like the equation for the freezing point depression, and is used in almost the same way.

$$\Delta T_b = K_b \times c_m$$

$c_m$ — concentration of solute (molality)

$K_b$ — Boiling point elevation constant (for SOLVENT) (p500, 9th p509, 10th)

$\Delta T_b$ — Boiling point elevation: The amount the boiling temperature is RAISED by the solute.

What is the boiling point of a solution that contains 2.817 g of molecular sulfur $S_8$ ) dissolved in 100.0 grams of acetic acid?

$T_b = 118.5°C$ $K_b = 3.08\ °C/m$ (see p500 for data) p509, 10th

$\Delta T_b = K_b \times C_m$ ($K_b$ = 3.08°C/m)

$C_m = \frac{\text{mol } S_8}{\text{kg AA}}$

$S_8$: $\frac{8 \times 32.07}{256.56\ g\ S_8 = \text{mol } S_8}$

To find Cm, first find moles of sulfur.

$$2.817\ g\ S_8 \times \frac{\text{mol } S_8}{256.56\ g\ S_8} = 0.010979877\ \text{mol } S_8$$

Divide mol sulfur / kg AA ...

$$\frac{0.010979877\ \text{mol } S_8}{0.1000\ kg} = 0.10979877 5\ m\ S_8$$

(100.0 g)

Find DELTA Tb ...

$$\Delta T_b = (3.08\ °C/m) \times (0.109798775\ m\ S_8) = 0.338\ °C$$

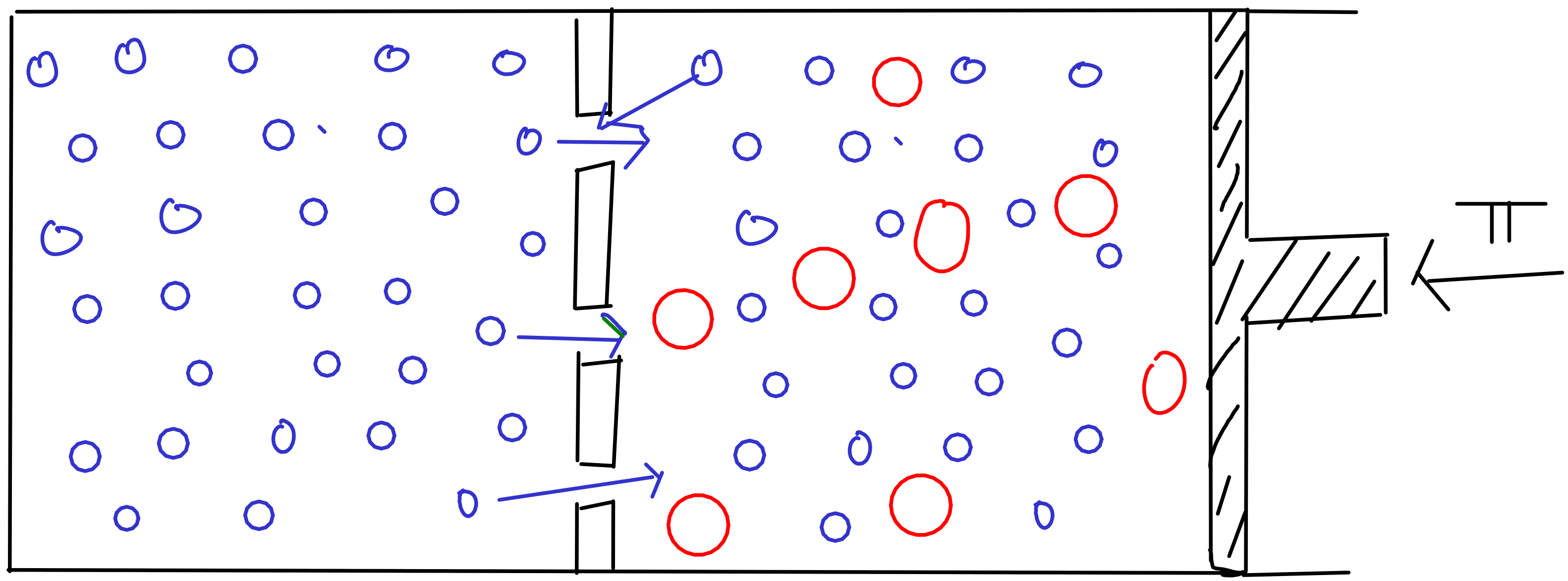
To find the BOILING POINT, add DELTA Tb to the solven't boiling point!

$$118.5°C + 0.338°C = \boxed{118.8°C}$$

## OSMOTIC PRESSURE

permits flow of solvent, but not solute particles

- OSMOSIS: the flow of solvent molecules through a SEMIPERMEABLE membrane to equalize concentration of solute on each side of the membrane.



The rate of solvent migration towards the RIGHT is greater than that towards the LEFT.

If you apply enough pressure to the piston, osmosis will not occur. This pressure is called the OSMOTIC PRESSURE

$$\pi = M \times R \times T$$

- $T$: temperature
- $R$: ideal gas constant
- $M$: molar concentration of solute

## IONIC COMPOUNDS and colligative properties

- Ionic compounds DISSOCIATE in water into their component ions. Each ion formed can act as a solute and influence the colligative properties!

$$NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$$

2 ions!

... so the concentration of IONS here is TWICE the nominal NaCl concentration.

$$CaCl_2(s) \longrightarrow Ca^{2+}(aq) + 2\,Cl^-(aq)$$

3 ions!

... so the concentration of IONS here is THREE TIMES the nominal calcium chloride concentration.

- Ions interact with each other in solution, so unless an ionic solution is DILUTE, the effective concentrations of ions in solution will be less than expected. A more advanced theory (Debye-Huckel) covers this, but we'll assume that our solutions are dilute enough so that we can use the concentration of the ions in solution to determine the colligative properties!

If you are at an altitude high enough for the boiling point of water to be 95.00 C, what amount of sodium chloride would you need to add to 1.000 kg of water to raise the boiling point to 100.00 C?

$K_b = 0.512\ ^{o}C/m$ NaCl: 58.443 g/mol

$\Delta T_b = K_b \times C_m$

$K_b$: $0.512\ ^{o}C/m$

$\Delta T_b$: $100.00^{o}C - 95.00^{o} = 5.00^{o}C$

$C_m = \frac{\text{mol ions}}{\text{kg } H_2O}$

First, find Cm ... molality of IONS in solution...

$5.00^{o}C = (0.512\ ^{o}C/m) \times C_m$ ; $C_m = 9.765625$ m ions

Find moles ions ...

$1.000 \text{ kg } H_2O \times \frac{9.765625 \text{ mol ions}}{\text{kg } H_2O} = 9.765625 \text{ mol ions}$

$NaCl \rightarrow Na^+ + Cl^-$, so mol NaCl = 2 mol ions

$9.765625 \text{ mol ions} \times \frac{\text{mol NaCl}}{2 \text{ mol ions}} = 4.8828125 \text{ mol NaCl}$

Find grams NaCL ...

$4.8828125 \text{ mol NaCl} \times \frac{58.443 \text{ g NaCl}}{\text{mol NaCl}} = \boxed{285 \text{ g NaCl}}$