

## 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 solvent 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

$$\Delta T_f = K_f \times C_m$$

— concentration of solute (molality)

— Freezing point depression constant (for SOLVENT)

— 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?

$$K_{f, \text{benzene}} = 5.065 \text{ } ^\circ\text{C}/m, \quad T_{f, \text{benzene}} = 5.455 \text{ } ^\circ\text{C} \quad \left( \begin{array}{l} \text{see} \\ \text{p500 9th} \\ \text{p509, 10th} \end{array} \right)$$

$$\Delta T_f = K_f \times C_m \longrightarrow \frac{\text{mol unknown}}{\text{kg benzene}}$$

$$5.065 \text{ } ^\circ\text{C}/m$$

$$5.455 \text{ } ^\circ\text{C} - 4.880 \text{ } ^\circ\text{C} = 0.575 \text{ } ^\circ\text{C}$$

To find molecular weight, we need to know the moles unknown. Then, we can just divide 2.500g / moles unknown!

First, calculate the MOLAL CONCENTRATION from freezing point depression.

$$0.575 \text{ } ^\circ\text{C} = (5.065 \text{ } ^\circ\text{C}/m) (C_m)$$

$$C_m = 0.1135241856 m$$

To find the moles unknown, we need to multiply the molal concentration by the mass of benzene used!

$$0.1000 \text{ kg benzene} \times \frac{0.1135241856 \text{ mol unknown}}{\text{kg benzene}}$$

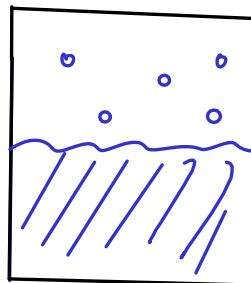
$$= 0.0113524186 \text{ mol unknown}$$

MOLECULAR WEIGHT is ...

$$MW = \frac{\text{mass unknown}}{\text{mol unknown}} = \frac{2.500 \text{ g}}{0.0113524186 \text{ mol}} = \boxed{220. \text{ g/mol}}$$

## VAPOR PRESSURE LOWERING

- Described by RAOULT'S LAW



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

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

mole fraction of component A

vapor pressure of pure component A (depends on temperature)

partial pressure of component A in a solution

... 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...

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

mole fraction of component B (the SOLUTE in a two-component mixture)

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.

$$\Delta T_b = K_b \times C_m$$

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

$K_b$  — Boiling point elevation constant (for SOLVENT)

$C_m$  — concentration of solute (molality)

(pS0C, 9th  
pS09, 10th)

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?

$$T_b = 118.5^\circ\text{C} \quad K_b = 3.08^\circ\text{C}/m \quad (\text{see p500 for data})$$

p509, 10th

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$$\Delta T_b = \frac{K_b \times C_m}{3.08^\circ\text{C}/m} \quad C_m = \frac{\text{mol } S_8}{\text{kg acetic}}$$

To find the boiling point, we'll first need to find  $C_m$  ...

$$2.817 \text{ g } S_8 \times \frac{\text{mol } S_8}{256.56 \text{ g } S_8} = 0.0109798877 \text{ mol } S_8$$

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

$$C_m = \frac{0.0109798877 \text{ mol } S_8}{0.1000 \text{ kg acetic}} = 0.1097988775 \text{ m}$$

(100.0g) ↑

Now we can find DELTA  $T_b$  ...

$$\Delta T_b = (3.08^\circ\text{C}/m)(0.1097988775 \text{ m}) = 0.338^\circ\text{C}$$

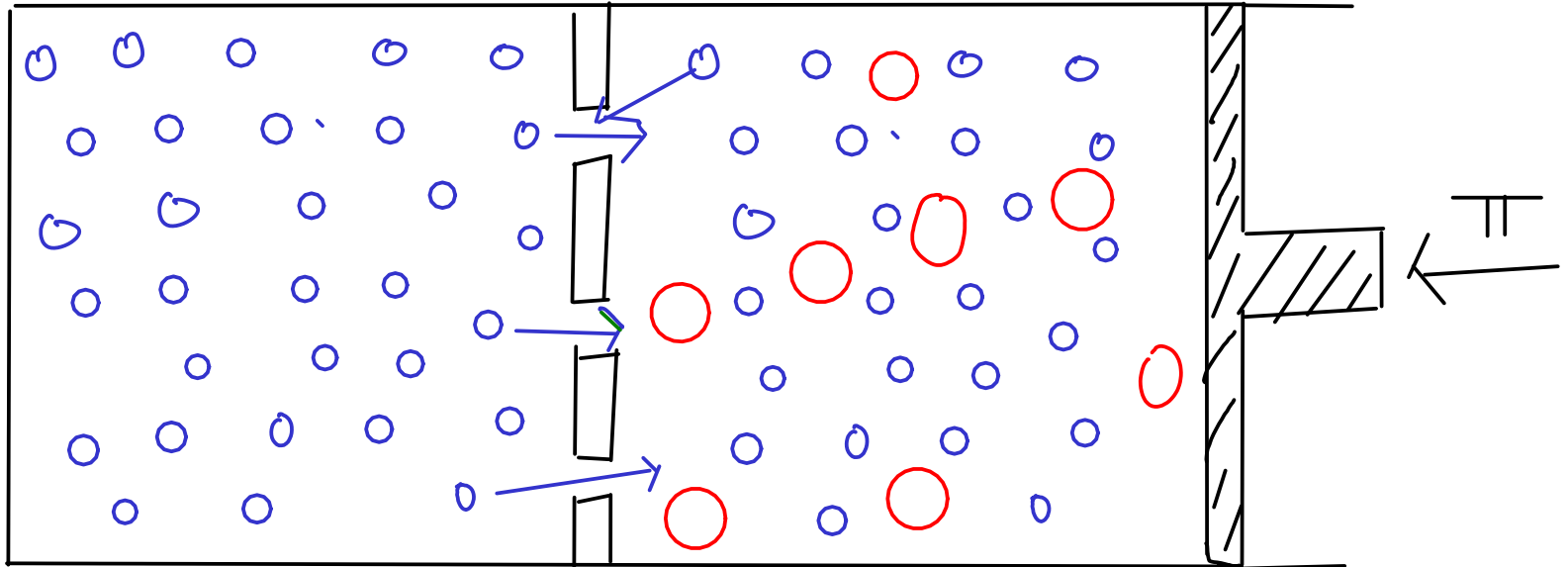
The new boiling point is ...

$$118.5^\circ\text{C} + 0.338^\circ\text{C} = \boxed{118.8^\circ\text{C}}$$

## 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

$$\Pi = M \times R \times T$$

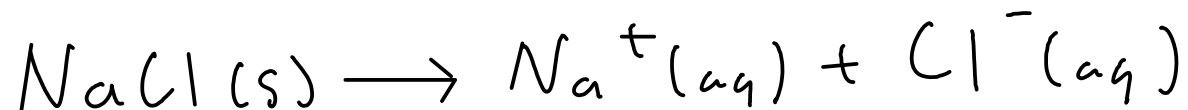
temperature

ideal gas constant

molar concentration of solute

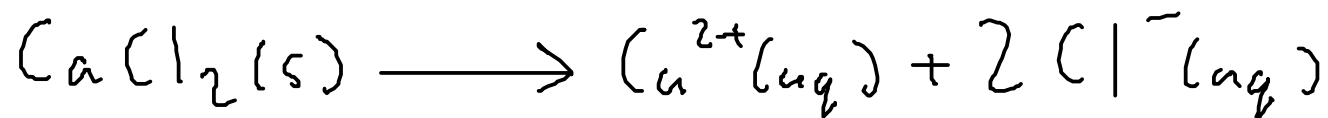
IONIC COMPOUNDS and colligative properties

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



2 ions!

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



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!