Colligative Properties: Freezing Point Depression, Vapor Pressure Lowering,Boiling Point Elevation Additional Problems

1. Adding a nonvolatile ionic solute to water has what effect on the boiling point of the solvent?

   - ☐ Does not affect the b.p.
   - ☐ Lower the b.p.
   - ■ Raises the b.p.
   - ☐ Cannot tell without more information, such as concentration

2. What is the van't Hoff factor?

   Used in calculations involving the colligative properties. It represents the quantity (in moles) of particles (ions or molecules) in solution per mole of solute dissolved.

3. What is a *colligative property* (a definition; not "it's freezing point depression", etc.)

   A colligative property is one which depends upon the number of particles in solution without regard to their identity.

4. Give an example of a colligative property other than freezing point depression.

   Vapor pressure lowering
   Boiling point elevation
   Osmotic pressure

5. What is the equation that relates the freezing point depression and concentration? Define each variable.

$$\Delta T_{fp} = -iK_f c$$

ΔT_{fp} is the freezing point depression, i is the van't Hoff factor, K_f is the molal freezing point depression constant, and c is the molal concentration of the solute

6. Calculate the molal concentration of a sucrose ($C_{12}H_{22}O_{11}$) solution that is prepared by dissolving 10.0 g of the solid in 150.0 g of water.

$$C_{12}H_{22}O_{11}, \ 342.30 \text{ g mol}^{-1}$$

$$n_{\text{sucrose}} = {}^{10.0 \text{ g}}\!\big/_{342.30 \text{ g mol}^{-1}} = 0.02921 \text{ mol}$$

$$c = \frac{0.02921 \text{ mol}}{0.1500 \text{ kg}} = 0.195\ m$$

7. What is the freezing point of the solution prepared in question 6? The molal freezing point depression constant for water is 1.86 °C/*m*.

$$\Delta T_{\mathrm{fp}} = -K_{\mathrm{f}} c = -1.86\,{}^{\circ\mathrm{C}}\!/\!_{m} \times 0.1948\ m = -0.362^{\circ}\mathrm{C}$$

$$\mathrm{T}_{\mathrm{fp}} = -0.362^{\circ}\mathrm{C} - 0.00^{\circ}\mathrm{C} = -0.362^{\circ}\mathrm{C}$$

8. A certain pheromone from the gypsy moth has a percentage composition of 79.12%C, 9.79%H and 11.09%O. A solution containing 0.363 g of the compound in 5.00 g of benzene freezes at 4.27°C. What is the molar mass of the pheromone and what is its molecular formula? $K_{f,benzene}$ = 5.12°C/*m*.

Since the percentages add up to about 100%, there are no other atoms other than C, H, and O.

First, determine the empirical formula:

$$\left\{\begin{array}{l} n_{\mathrm{C}} = {}^{79.12\mathrm{g}}\!/\!_{12.01\frac{\mathrm{g}}{\mathrm{mol}}} = 6.5878\ \text{mol C} \\ n_{\mathrm{H}} = {}^{9.79\mathrm{g}}\!/\!_{1.008\frac{\mathrm{g}}{\mathrm{mol}}} = 9.7123\ \text{mol H} \\ n_{\mathrm{C}} = {}^{11.09\mathrm{g}}\!/\!_{16.00\frac{\mathrm{g}}{\mathrm{mol}}} = 0.6931\ \text{mol O} \end{array}\right\} \text{normalize by } 0.6931 \left\{\begin{array}{l} n_{\mathrm{C}} = {}^{6.5878\ \text{mol C}}\!/\!_{0.6931\ \text{mol}} = 9.5\ \mathrm{C} \\ n_{\mathrm{H}} = {}^{9.7123\ \text{mol H}}\!/\!_{0.6931\ \text{mol}} = 14\ \mathrm{H} \\ n_{\mathrm{C}} = {}^{0.6931\ \text{mol O}}\!/\!_{0.6931\ \text{mol}} = 1\ \mathrm{O} \end{array}\right\}$$

$$\boxed{\text{Empirical Formula: } C_{19}H_{28}O_2 \quad \text{Empirical molar mass: } 288.4\,\tfrac{\mathrm{g}}{\mathrm{mol}}}$$

Now determine the molar mass from the freezing point depression:

It is necessary to look up the normal freezing point of benzene; $fp = m.p. = 5.5^{\circ}\mathrm{C}$

$$\Delta T = -iK_f c \qquad c = \frac{n_{\text{pheromone}}}{m_{\text{benzene}}} = \frac{{}^{m_{\text{pheromone}}}\!/\!_{M_{\text{pheromone}}}}{m_{\text{benzene}}}$$

$$\Delta T = 4.27^{\circ}\mathrm{C} - 5.5^{\circ}\mathrm{C} = -1.23^{\circ}\mathrm{C} \qquad i = 1$$

$$M_{\text{pheromone}} = \frac{iK_f m_{\text{pheromone}}}{\Delta T m_{\text{benzene}}} = -\frac{1\left(5.12\,\frac{^{\circ}\mathrm{C}}{\mathrm{m}}\right)\left(0.363\ \mathrm{g}\right)}{\left(-1.23^{\circ}\mathrm{C}\right)\left(0.00500\ \mathrm{kg}\right)} = 302.2\,\frac{\mathrm{g}}{\mathrm{mol}}$$

The empirical molar mass and actual molar mass are very close to each other so the molecular formula is the empirical formula.

9. Assuming complete dissociation of the solid, what is the predicted melting point of a 1.5 *m* solution of sodium chloride?

$$\Delta T = -iK_f c = 2\left(1.86\,\frac{^{\circ}\mathrm{C}}{\mathrm{m}}\right)\left(1.5\ \mathrm{m}\right) = -5.58^{\circ}\mathrm{C}$$

$$\Delta T = T_f - T_f^{\circ}$$

$$T_f = -5.58^{\circ}\mathrm{C}$$

10. Draw a typical cooling curve for a *pure* solvent. Draw the cooling curve for a 1-*m* solution of the same solvent which has a molal freezing point depression constant of 2.0 °C/*m*. Identify each region of the curve.

11. The vapor pressure of water at 25.0°C is 23.8 torr. What is the vapor pressure of a solution of 10.0 g of glucose ($C_6H_{12}O_6$, 180.2 g mol^{-1}) dissolved in 100.0 g of water?

$$n_{\text{glucose}} = {}^{10.0\text{ g}}\!\big/_{180.2\,\frac{\text{g}}{\text{mol}}} = 0.05549\text{ mol glucose}$$

$$n_{\text{H}_2\text{O}} = {}^{100\text{ g}}\!\big/_{18.015\,\frac{\text{g}}{\text{mol}}} = 5.551\text{ mol H}_2\text{O}$$

$$P = X_{\text{H}_2\text{O}}P_0 = \frac{5.551\text{ mol}}{5.551\text{ mol} + 0.05549}\left(23.8\text{ torr}\right) = 23.6\text{ torr}$$

12. Assume no deviation from ideal behavior, what is the vapor pressure at 25°C of the solution prepared by mixing 50.0 mL of benzene with 50.0 mL of hexane? Some important information is given in the table. Not all information may be necessary.

Property	**Hexane**	**Benzene**
Formula	C_6H_{14}	C_6H_6
Vapor Pressure at 25°C (mm Hg)	151.6	95.1
Density (g/mL)	0.659	0.874
Normal boiling point (°C)	68.7	80.1

The vapor pressure of a mixture of volatile substances is the sum of the calculated vapor pressures of each solvent as if the other is a non-volatile solute.

$$n_{\text{hexane}} = \frac{50.0\text{ mL} \times 0.659\,\frac{\text{g}}{\text{mL}}}{86.172\,\frac{\text{g}}{\text{mol}}} = 0.3824\text{ mol hexane}$$

$$n_{\text{benzene}} = \frac{50.0\text{ mL} \times 0.874\,\frac{\text{g}}{\text{mL}}}{78.108\,\frac{\text{g}}{\text{mol}}} = 0.5595\text{ mol benzene}$$

$$P_{\text{total}} = P_{\text{hexane}} + P_{\text{benzene}} = X_{\text{hexane}}P^0_{\text{hexane}} + X_{\text{benzene}}P^0_{\text{benzene}}$$

$$P_{\text{total}} = \left(\frac{0.3824}{0.9419}\right)\left(151.6\text{ mmHg}\right) + \left(\frac{0.5595}{0.9419}\right)\left(95.1\text{ mmHg}\right) = 118.0\text{ mmHg}$$