Solutions II: Colligative Properties

1. What is the boiling point of the solution prepared to be 10.0 g of $C_2H_6O_2$ (62.07 g mol^{-1}) dissolved in 100.0 g of water?

$$K_\text{b} = 0.512\,\tfrac{\text{J}}{m}$$
$$c = \frac{10.0\text{ g} / 62.07\text{g mol}^{-1}}{0.1000\text{ kg}} = 1.611\ m$$
$$\Delta T_\text{bp} = K_\text{b}c = 0.512\,\tfrac{\text{J}}{m} \times 1.611\ m = 0.825°\text{C}$$
$$T_\text{bp} = T° + \Delta T_\text{bp} = 100°\text{C} + 0.825°\text{C} = 100.8°\text{C}$$

2. What is the predicted freezing point of the solution from (1)?

$$K_\text{f} = 1.86\,\tfrac{\text{J}}{m}$$
$$c = \frac{10.0\text{ g} / 62.07\text{g mol}^{-1}}{0.1000\text{ kg}} = 1.611\ m$$
$$\Delta T_\text{fp} = -K_\text{f}c = 1.86\,\tfrac{\text{J}}{m} \times 1.611\ m = -3.00°\text{C}$$
$$T_\text{fp} = T° + \Delta T_\text{fp} = 0.0°\text{C} + (-3.00°\text{C}) = -3.00°\text{C}$$

3. How many gallons of antifreeze (ethylene glycol) must be added to 4.0 gallons of water to lower the freezing point of the solution to –10.0°F (a fairly bad winter day on the east coast)? (Hint: You will probably need to use the CRC *Handbook of Chemistry and Physics*, *Merck Index*, or other resource to get some of the information you need.)

Conversions and constants:

ethylene glycol: $C_2H_6O_2$, 62.07 g mol^{-1}

$1\text{ gal} = 3.785\text{ L} \qquad K_\text{f} = 1.86\,\tfrac{°\text{C}}{m}$

$T = (-10°\text{F} - 32) \times \tfrac{5}{9} = -23.3°\text{C}\ (= \Delta T_\text{fp})$

$m_{\text{H}_2\text{O}} = 4.0\text{ gal} \times \tfrac{3.785\text{ L}}{\text{gal}} \times \tfrac{1\text{ kg}}{\text{L}} = 15.14\text{ kg}$

$\Delta T_\text{fp} = -K_\text{f}c \qquad \text{so...} \qquad c = \dfrac{-23.3°\text{C}}{-1.86\,\tfrac{°\text{C}}{m}} = 12.53\ m$

$n_\text{ethylene glycol} = 12.53\ m \times 15.14\text{ kg} = 189.7\text{ mol ethylene glycol}$

$m_\text{ethylene glycol} = 189.7\text{ mol} \times 62.07\text{ g mol}^{-1} = 11{,}800\text{ g}$

Just for fun:

$$V_\text{ethylene glycol} = \frac{11{,}800\text{ g}}{1.11\,\tfrac{\text{g}}{\text{mL}}} \times \frac{1\text{ L}}{1000\text{ mL}} = 10.6\text{ L} \quad \text{(or 2.8 gal)}$$

4. A solution of the male hormone, testosterone, containing 0.363 g of the hormone in 5.00 g of benzene has a freezing point of 4.27°C. What is the molar mass of testosterone? The freezing point of pure benzene is 5.50°C. Additional data: A solution of 1.13 g of naphthalene ($C_{10}H_8$) in 10.00 g of benzene had a freezing point of 0.99°C.)

1. Get $K_{\text{b, benzene}}$

$$c_{\text{naphthalene}} = \frac{1.13\text{ g} \big/ 128.17\text{ g mol}^{-1}}{0.01000\text{ kg}} = 0.8816\, m$$

$$K_{\text{b}} = -\frac{\Delta T}{c} = -\frac{(0.99°\text{C} - 5.50°\text{C})}{0.8816\, m} = 5.116\,\tfrac{°\text{C}}{m}$$

2. Get $M_{\text{testosterone}}$

$$c_{\text{testosterone}} = -\frac{\Delta T}{K_{\text{b}}} = -\frac{(4.27°\text{C} - 5.50°\text{C})}{5.116\,\frac{°\text{C}}{m}} = 0.2404\; m$$

$$n_{\text{testosterone}} = 0.2404\; m \times 0.00500\text{ kg} = 0.001202\text{ mol testosterone}$$

$$M = \frac{0.363\text{ g}}{0.001202\text{ mol}} = 302\text{ g mol}^{-1}$$

5. Testosterone contains only carbon, hydrogen, and oxygen. The percentage composition of the molecule is 79.12%C and 9.79%H. What is the molecular formula and accurate molar mass?

Use the algorithm to get molecular formula:

$$n_{\text{C}} = 79.12\text{ g C} \big/ 12.011\text{ g mol}^{-1} = 6.587\text{ mol C}$$

$$n_{\text{O}} = 9.79\text{ g H} \big/ 1.008\text{ g mol}^{-1} = 9.712\text{ mol H}$$

$$n_{\text{H}} = 11.09\text{ g O} \big/ 16.00\text{ g mol}^{-1} = 0.6931\text{ mol O}$$

normalize to one O by dividing by 0.6931 mol

$C_{9.5}H_{14}O$ Empirical molar mass: 144 g mol^{-1}

$$\text{stoichiometric factor} = \frac{302\text{ g mol}^{-1}}{144\text{ g mol}^{-1}} = 2$$

Molecular Formula:

$C_{19}H_{28}O_2$ Molecular molar mass: 288.4 g mol^{-1}