Solutions: Physical Properties and Behavior

Key

Sample problems (from pages 28-29):

1. What is the mass percent of NaCl when 5.00 g of NaCl is dissolved in 95.0 g of water?

Answer: 5.00 % by mass NaCl

Set-up: \( \% \frac{m_{\text{NaCl}}}{m_{\text{solution}}} = \frac{m_{\text{NaCl}}}{m_{\text{solution}}} \times 100 = \frac{5.00\text{gNaCl}}{5.00\text{gNaCl} + 95.0\text{gwater}} \times 100 \)

2. What is the ppm of Pb\(^{2+}\) when 52 mg of Pb\(^{2+}\) is found in 1.00 L of water (density of water = 1.00 g per mL)?

Answer: 52 ppm Pb\(^{2+}\)

\[
ppm = \frac{\text{solute mass}}{\text{solution mass}} \times 10^6 = \frac{0.052\text{gPb}^{2+}}{1000\text{gwater}} \times 10^6
\]

Set-up: or

\[
ppm = \frac{\text{mg solute}}{\text{L solution}} = \frac{52\text{mgPb}^{2+}}{1.00\text{Lsolution}}
\]

3. What are the mole fractions of water and ethanol (C\(_2\)H\(_6\)O) when 180 grams of water are mixed with 230 grams of ethanol?

Answer: \( X_{\text{H}_2\text{O}} = 0.667 \) and \( X_{\text{C}_2\text{H}_6\text{O}} = 0.333 \)

Set-up:

\[
m_{\text{water}} = \frac{180\text{g}}{18.02\text{g/mole}} = 10.0\text{molewater}
\]

\[
m_{\text{ethanol}} = \frac{230\text{g}}{46.07\text{g/mole}} = 5.00\text{moleethanol}
\]

\[
\text{total moles} = 15.0
\]

\[
X_{\text{H}_2\text{O}} = \frac{\text{water moles}}{\text{total moles}} = \frac{10.0}{15.0} = 0.667
\]

\[
X_{\text{EtOH}} = \frac{\text{EtOH moles}}{\text{total moles}} = \frac{5.00}{15.0} = 0.333
\]
4. What is the molality of a solution that is prepared by mixing 9.00 g of water into 0.400 kg of ethanol?

Answer: $m = 1.25$ mole of water per kg of ethanol

\[ \text{molewater} = \frac{9.00 \text{ g}}{18.0 \text{ g/mole}} = 0.500 \text{ mole} \]

Set-up:
\[ m = \frac{\text{molesolute}}{\text{kg solvent}} = \frac{0.500 \text{ molewater}}{0.400 \text{ kgEtOH}} \]

5. What is the molarity of a solution prepared by dissolving 29.22 g of NaCl in enough water to prepare 250 mL of solution?

Answer: $2.00$ M NaCl

\[ \text{moleNaCl} = \frac{29.22 \text{ g}}{58.44 \text{ g/mole}} = 0.500 \text{ moleNaCl} \]

Set-up:
\[ M = \frac{\text{molesolute}}{\text{Lsolution}} = \frac{0.500 \text{ moleNaCl}}{0.250 \text{ L}} \]

6. How many grams of K$_2$CrO$_4$ needed to prepare 500.0 mL of 0.575 M K$_2$CrO$_4$ solution?

Answer: 55.8 grams of K$_2$CrO$_4$

\[ \text{mole} = \frac{\text{molesolute}}{\text{Lsolution}} \times \text{Lsolution} = \frac{0.575 \text{ mole}}{L} \times 0.500 \text{ L} \]

Set-up:
\[ \text{moleK}_2\text{CrO}_4 = \frac{194.2 \text{ g}}{\text{mole}} \times 0.2875 \text{ moleNaCl} \]

7. What is the molality of 1.00 g of sucrose (C$_{12}$H$_{22}$O$_{11}$, molar mass = 342.3 g/mole) in 100 grams of water?

Answer: $m = 0.0292$ mole per kg

\[ \text{molesucrose} = \frac{1.00 \text{ g}}{342.3 \text{ g/mole}} = 2.92 \times 10^{-3} \text{ mole} \]

Set-up:
\[ m = \frac{\text{molesolute}}{\text{kg solvent}} = \frac{2.92 \times 10^{-3} \text{ molesucrose}}{0.100 \text{ kgwater}} \]
8. What are the mole fractions of ethanol and water when 50.0 mL of each are combined (density of water = 1.00 g per mL and density of ethanol = 0.789 g per mL . . . ethanol is C₂H₆O

Answer: \( X_{\text{C}_2\text{H}_6\text{O}} = 0.236 \) \( X_{\text{H}_2\text{O}} = 0.764 \)

Set-up:

\[
\begin{align*}
\text{molewater} &= \frac{1.00 \text{g mL}^{-1} \times 50.0 \text{mL}}{18.02 \text{g mole}^{-1}} = 2.775 \text{ molewater} \\
\text{moleethanol} &= \frac{0.789 \text{g mL}^{-1} \times 50.0 \text{mL}}{46.07 \text{g mole}^{-1}} = 0.856 \text{mole}
\end{align*}
\]

\[
\text{totalmole} = 3.631 \text{ mole}
\]

\[
X_{\text{H}_2\text{O}} = \frac{\text{watermole}}{\text{totalmole}} = \frac{2.775}{3.631} = 0.764
\]

\[
X_{\text{EtOH}} = \frac{\text{EtOHmole}}{\text{totalmole}} = \frac{0.856}{3.631} = 0.236
\]

9. What is the percent by mass of ethanol in the solution described in question 3?

\textbf{CORRECTED} Answer: % by mass = 56.1 %

Set-up:

\[
\% \text{ EtOH} = \left( \frac{\text{solute mass}}{\text{solution mass}} \right) \times 100 = \left( \frac{230 \text{gEtOH}}{230 \text{gEtOH} + 180 \text{gwater}} \right) \times 100
\]

10. If an aqueous solution is 0.010 % by mass, how many ppm is it?

Answer: 100 ppm

Set-up:

\[
\% \text{ EtOH} = \left( \frac{\text{solute mass}}{\text{solution mass}} \right) \times 100
\]

\[
\text{ppm} = \frac{\text{solute mass}}{\text{solution mass}} \times 10^6
\]

\[
\text{thus}
\]

\[
\text{ppm} = \% \text{ EtOH} \times 10^4
\]
Sample problems (page 29 bottom):

1. How many mL of 0.500 M $\text{K}_2\text{CrO}_4$ are needed to prepare 0.750 L of 0.100 M $\text{K}_2\text{CrO}_4$?

*Answer:* 150 mL of 0.500 M $\text{K}_2\text{CrO}_4$

*Set-up:*

$$V_c C_c = V_d C_d$$

$$V_c = \frac{V_d C_d}{C_c} = \frac{(0.750 L)(0.100 M)}{0.500 M}$$

*Note: since the dilute concentration is reduced to one-fifth the starting concentration, the volume of concentrated solution needed is one-fifth the volume of the final solution*

2. How many mL of 9.00 M $\text{H}_2\text{SO}_4$ are needed to prepare 1.00 L of 0.100 M $\text{H}_2\text{SO}_4$ solution?

*Answer:* 11.1 mL of 9.00 M $\text{H}_2\text{SO}_4$

*Applying the logic in the note at the end of number one above: the dilute concentration is reduced to $1/90$th the starting concentration, the volume of concentrated solution needed is $1/90$th the volume of the final solution ($1/90$th of 1000 mL is 11.1 mL)*

Another sample - (from page 35)

**Q:** If the vapor phase in the answer above was condensed and re-vaporized one additional time at 25°C, what would be the new mole fraction of benzene in the new vapor phase?

For *ideal binary solutions of two volatile liquids* we may use **Raoult’s Law**.

$$P_{\text{total}} = P_{\text{solute}} + P_{\text{solute}} = X_{\text{solute}} P^o_{\text{solute}} + X_{\text{solute}} P^o_{\text{solute}}$$

From page 34 we can see that the vapor phase mole fractions are

$$X_{\text{benzene}} = 0.9727$$

and thus, $$X_{\text{toluene}} = 1 - X_{\text{benzene}} = 0.0273$$

When this vapor re-condenses, the new liquid phase has the same composition. This liquid would produce a vapor pressure of:

$$P_{\text{total}} = (0.9727)(95.1 \text{ mmHg}) + (0.0278)(28.4 \text{ mmHg}) =$$

$$P_{\text{total}} = 92.50 \text{ mmHg} + 0.775 \text{ mmHg} = 93.28 \text{ mmHg}$$

*A:* $X_{\text{benzene}} = 92.50/93.28 = 0.9917$ (i.e. the benzene would contain only 0.83 mole % toluene).
Sample problems (page 36):

Q: 1.921 g of nicotine (empirical formula = C_{5}H_{7}N) is dissolved in 48.92 grams of water (K_{f} = 1.86 {^\circ}C/m) creates a freezing point depression of 0.450 {^\circ}C. (a) What is the molality of the solution? (b) How many moles of solute are present? (c) What is the molar mass of the nicotine? (d) What is the molecular formula?

A: (a) 0.242 mole per kg, (b) 0.0118 mole of nicotine, (c) 162 g per mole, and (d) C_{10}H_{14}N_{2}

Set-up:

(a) \Delta T_{f} = K_{f} m, so, 0.450{^\circ}C = \left(\frac{1.86{^\circ}C}{m}\right)x
x = 0.242m
(b) \text{mole} = \left(\frac{0.242}{\text{kg}}\right)0.04892\text{kg} = 0.0118\text{mole}
(c) \text{MM} = \frac{1.921g}{0.0118\text{mole}} = \frac{162g}{\text{mole}}
(d) C_{5}H_{7}N has an emp. mass of about 81amu
\frac{162\text{amu}}{81\text{amu}} = 2, so 2 empirical units make up the molecule and 2xC_{5}H_{7}N = C_{10}H_{14}N_{2}

Note: the next problem is from your text and they have the answer wrong!
Q: When phenol (C_{6}H_{5}OH) dissolves in bromoform (CHBr_{3}) it has a tendency to form some dimmers. When 2.58 g of phenol is dissolved into 100.0 g of bromoform the freezing point is 5.726{^\circ}C. Using the same thermometer, pure bromoform is found to freeze at 8.10{^\circ}C. Given that the cryoscopic constant of bromoform is 14.1{^\circ}C/m determine what fraction of the bromoform is present as monomers and what fraction as dimers (assume these are the only two possibilities).

A: \Delta T_{f} can be used to find that the solution contained 0.01684 mole of solute “particles” and the molar mass can be used to find that 0.02741 mole of phenol was used. So now the problem is simply one of algebra. 0.02741 mole of phenol must end up as 0.01684 mole of monomers plus dimers (see “set-up” below for how we know these things).

0.01684 mole = x mole phenol + y mole dimer, but . . .
each dimer is made from two phenol molecules so . . .
x mole phenol = 0.02741 original mole phenol - 2y mole phenol
Combining these two equations we find
0.01684 mole = 0.02741 - 2y + y = 0.02741 - y
So 0.01057 mole of dimer (y) exist and 0.00627 mole of monomer (x).
Finally, the fraction of the phenol existing as monomers is 22.9% with 77.1% of the phenol tied up as dimers.

Set-up:
from the freezing pt. depression we know

\[ \Delta T_f = K_f m, \text{so, } 2.374^\circ C = \left(14.1^\circ C/m \right) x \]

\[ x = 0.168_4 m \]

\[ y_{mole} = \left( \frac{0.168_4 \text{ mole}}{kg} \right) 0.100kg = 0.0168_4 \text{ mole of solute particles} \]

\[ \text{from the mass and molar mass we know that moles of phenol} = \frac{2.58g}{94.114g/mole} = 0.0274_1 \text{ mole} \]

Questions (a short list of additional questions to test your understanding of Chapter 12)

1. A solution in which the rates of solution and crystallization are equal is called:
   a. dilute b. supersaturated c. unsaturated d. saturated e. none of the above

2. Which of the following concentration measures will change in value as the temperature of the solution changes?
   a. weight percent b. mole fraction c. molarity d. molality e. all of these

3. Which of the following FAVORS the solubility of an ionic solid in a liquid solvent?
   a. a large magnitude of the solvation energy of the ions b. a small magnitude of the lattice energy of the solute c. a large polarity of the solvent d. all of the above e. none of the above

4. A correct statement of Henry’s law is:
   a. the concentration of a gas in solution is inversely proportional to temperature b. the concentration of a gas in solution is directly proportional to the mole fraction of the solvent c. the concentration of a gas in solution is independent of pressure d. the concentration of a gas in solution is inversely proportional to pressure e. none of the above

5. A solution with stronger interactions between solute and solvent than between solvent and solvent OR between solute and solute should have an endothermic heat of solution.
   a. true b. depends on temperature c. false d. depends on pressure e. not enough information
6. The density of water is 1.00 g/cm³ and the density of CH₃OH is 0.972 g/cm³. When 20.0 mL sample of methyl alcohol (CH₃OH, MM = 32.0 g/mole) was dissolved in 30.0 mL of water.

a. What is the mole fraction of CH₃OH?

\[
\text{30.0 mL water} = 30.0 \text{ g water} = 1.667 \text{ moles water} \\
\text{20.0 mL MeOH} = 19.44 \text{ g MeOH} = 0.6075 \text{ mole MeOH} \\
X_{\text{MeOH}} = \frac{0.6075 \text{ mole MeOH}}{(0.6075 \text{ mole MeOH} + 1.667 \text{ moles water})} = 0.267
\]

b. What is the mass percent of methyl alcohol? Of water?

\[
\%m/m \text{ MeOH} = 100 \times \frac{19.44 \text{ g MeOH}}{(19.44 \text{ g MeOH} + 30.0 \text{ g water})} = 39.3\% \\
\%m/m \text{ water} = 100 \times \frac{30.0 \text{ g water}}{(19.44 \text{ g MeOH} + 30.0 \text{ g water})} = 60.7\%
\]

c. What is the volume of the solution if the solution has a density of 0.937 g/cm³?

\[
\text{volume} = \frac{1}{d}(\text{mass}) = \frac{1 \text{ mL}}{0.937 \text{ g}}(19.44 \text{ g MeOH} + 30.0 \text{ g water}) = 52.76 \text{ mL}
\]

d. What is the molarity of this solution of methyl alcohol and water?

\[
M = \frac{\text{mole MeOH}}{L \text{ soln}} = \frac{0.6075 \text{ mole MeOH}}{0.05276 \text{ L}} = 11.51 \text{ M}
\]

7. A solution needs to have a concentration of 0.100 mole fraction of ethyl alcohol dissolved in water. How many grams of ethyl alcohol (CH₃CH₂OH, molar mass = 46.0 g/mole) is required to prepare this solution if 500 g of H₂O is used?

The question can really be re-phrased as follows: given that 500 g of water is about 27.78 moles of water, what number of moles of ethanol obeys the following equation?

\[
X_{\text{EtOH}} = 0.100 = \frac{y \text{ moles EtOH}}{(y \text{ moles EtOH} + 27.78 \text{ moles of water})}
\]

This gives

\[
y = 3.087 \text{ moles EtOH}
\]

Which requires a mass of (46.0 g/mole) * (3.087 moles EtOH) = 142 g EtOH