Colligative Properties – Supplemental Worksheet
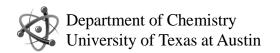
PROBLEM #1: Give the molecular formula, the van't hoff factor for the following Ionic Compounds as well as guess the solubility of the compounds. If you cannot write the molecular formulas of these compounds, review your polyatomic ions at http://ch301.cm.utexas.edu/?post_type=module&p=504. Remember that the rule of thumb for solubility is if the salt has a Group I metal or a nitrate group it will be soluble.

Ionic Compound	Molecular Formula	Van't Hoff Factor	Solubility Guess
Manganese (IV) Phosphate	$Mn_3(PO_4)_4$	7	"insoluble"
Chromium (III) Carbonate	$Cr_2(CO_3)_3$	5	"insoluble"
Chromium (III) Hydroxide	$Cr(OH)_3$	4	"insoluble"
Chromium (II) Chlorate	$Cr(ClO_3)_2$	3	Soluble
Copper (II) Sulfate	$CuSO_4$	2	Soluble
Copper (II) Hydroxide	$Cu(OH)_2$	3	"insoluble"
Aluminium Sulfate	$Al_2(SO_4)_3$	5	Soluble
Aluminium Phosphate	$AlPO_4$	2	"insoluble"
Strontium Chlorate	$Sr(ClO_3)_2$	3	Soluble
Barium Nitrate	$Be(NO_3)_2$	3	Soluble
Ammonium Hydroxide	NH_4OH	2	Soluble
Lithium Nitrate	$LiNO_3$	2	Soluble
Lithium Chlorate	$Li(ClO_3)$	2	soluble

**We expect you to know the solubility of Lithium Chlorate, Lithium Nitrate, and Barium Nitrate. However, the others you most likely had to look up.

**We put "insoluble" in quotations since at the macroscopic level these compounds look like they are "insoluble," but at the microscopic level we know even the most "insoluble" compound has a K_{sp} and is in equilibrium with at least a very small amount of its ions.

PROBLEM #2: At a lake in the Rocky Mountains, the partial pressure of oxygen is 0.19 atm. What is the molar concentration of oxygen in the lake at 25 °C? The value of Henry's Law constant for O_2 dissolved in water at 298 K is $4.34*10^4$ atm. Assume the density of the lake is 1 g/ml.

STEP-BY-STEP QUESTIONS

1. What equation did we learn in class that has to do with the material in this problem?
   Henry's Law!
$$P_{solute} = K_{solvent}X_{solute}$$

2. Is what we are looking for found in this equation?
   No

3. What can we find using this equation and what we have been given? Calculate that value.
   Since we have P_{solute} and $K_{solvent}$ from here we can solve for X_{solute}
$$X_{solute} \frac{P_{solute}}{K_{solvent}} = \frac{0.19\ atm}{4.34 \times 10^4\ atm} = 4.378 \times 10^{-6}$$

4. This value is going to help us find the molar concentration of oxygen. Assume a sample that contains 4.378E-6 moles of oxygen. How many moles of water are in the sample?
   The sum of all mole fractions of a mixture is 1.
$$1 = X_{solute} + X_{solvent}$$

$$X_{solvent} = 1 - X_{solute}$$
$$X_{solvent} = 1 - 4.378 \times 10^{-6} = 0.999996$$
   So, for this sample we have 0.999996 moles of H_2O.

5. What is the mass of this sample?
   The moles of O_2 compared to the moles of H_2O is so small that its contribution to the mass of the sample is negligible.
$$m_{sample} \sim m_{H2O} = n_{H2O} \times M_{H2O}$$
$$m_{H2O} = 0.999996\ mole\ H_2O \times \frac{18\ g}{1\ mol\ H_2O} \cong 18\ g$$

6. What is the volume of this sample?
   Since we have the mass of solution and the density of solution, we can solve for the volume of solution.
$$V_{sample} = \frac{m_{sample}}{density_{sample}} = \frac{18\ g}{1\frac{g}{ml}} = 18\ mL = 0.018\ L$$

7. What then is the molar concentration of this sample? Remember the molar concentration is the moles of solute in 1 liter of solution.

We will calculate the concentration of this sample since we know the moles of O_2 and the volume of the sample.

$$C_{Lake} = C_{sample} \times \frac{n_{solute}}{V_{solution}} = \frac{4.378 \times 10^{-6} \ moles}{0.018 \ L} = 2.4322 \times 10^{-4} \frac{mol}{L}$$

PROBLEM #3: Calculate the equilibrium vapor pressure of the 100 mL of 0.1 M lithium sulfate. The density of the solution is 1.15 g/mL) and the vapor pressure of pure water is 25 Torr at room temperature.

STEP-BY-STEP QUESTIONS

1. What equation did we learn in class that has to do with the material in this problem?

   Raout's Law
   $$P_{solution} = X_{solvent} \times P^0_{solvent \ pure}$$

2. Is what we are looking for found in this equation?
   Yes!

3. Do we have everything we need to solve for the vapor pressure of the solution? If not, what are we missing?
   No, we have P^0
   But, we are not given $X_{solvent}$

4. What do we need to find the information we are missing?
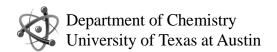 $$X_{solvent} = \frac{n_{solvent}}{n_{solvent} + n_{solute}}$$

   We need:
   - moles of solvent
   - moles of solute

5. How many moles of lithium sulfate do we have in the solution? What is the equation for lithium sulfate? How much mass does lithium sulfate contribute to the mass of the solution?
   Formula for Lithium Sulfate = Li_2SO_4

   $$n_{Li2SO4} = M_{Li2SO4} \times V_{Li2SO4} = 0.1 \frac{mol}{L} \ Li_2SO_4 \times 0.100 \ L \ Li_2SO_4 = 0.01 \ mol \ Li_2SO_4$$
   $$m_{Li2SO4} = n_{Li2SO4} \times M_{Li2SO4}$$
   $$m_{Li2SO4} = 0.01 \ mol \ Li_2SO_4 \times \frac{[(7 \times 2) + 32 + (16 \times 4)]g}{mol} \ of \ Li_2SO_4 = 1.1 \ g \ Li_2SO_4$$

6. What is the total weight of the solution?
We can find this using the density of the solution.

$$m_{total} = V \times density = 100 \ mL \times 1.15 \frac{g}{mL} = 150 \ g$$

7. How much of the mass of the solution is due to the water molecules?

$$m_{total} = m_{Li2SO4} + m_{H2O}$$
$$m_{H2O} = m_{total} - m_{Li2SO4} = 150 \ g - 1.1 \ g = 148.9 \ g \ H_2O$$

8. How many moles of water molecules are in the solution?

$$n_{H2O} = \frac{m_{H2O}}{M_{H2O}} = \frac{148.9 \ g}{18 \frac{g}{mol}} = 8.27 \ mol$$

9. What is the solvent molar fraction?
Now, since we have the number of moles of solute and solvent, we can calculate the molar fraction.

$$X_{solvent} = \frac{n_{H2O}}{n_{H2O} + n_{Li2SO4}} = \frac{8.27 \ mol}{8.27 \ mol + 0.01 \ mol} = 0.9988$$

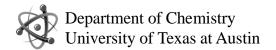10. Calculate the vapor pressure of the solution.
Since we have calculated the molar fraction we can now calculate the vapor pressure.

$$P_{solution} = X_{solvent} \times P^o_{solvent \ pure} = 0.9988 \times 25 \ torr = 24.970 \ torr$$

Compare and Contrast Moment

What aspects were the same about problem #3 and problem #2?
Both discussed pressures and solutions.

What aspects were different about problem #3 and problem #2?
Problem #2 is dealing with a gas solute dissolving in water and is asking for the molar fraction of the SOLUTE. The pressure needed to get the molar fraction is the partial pressure of the gas solute. Due to this situation we use Henry's Law.

Problem #3 is dealing with a solid solute dissolving in water and is asking the vapor pressure of the solution. The mole fraction needed to get the vapor pressure is the molar fraction of the SOLVENT. Due to this situation we use Raoult's Law.

PROBLEM #4: The addition of 125 mg of caffeine to 100 g of cyclohexane lowered the freezing point by 0.13 k. Calculate the molar mass of caffeine. The K(f) for cyclohexane is 20.1 K*kg*mol^{-1}.

STEP-BY-STEP QUESTIONS

1. What equation did we learn in class that has to do with the material in this problem?

$$\Delta T = -k_f m_{solute}$$

2. Is what we are looking for found in this equation?
   No

3. What can we find using this equation? Calculate that value.
   We are given ΔT and k$_f$. We can now solve for m$_{solute}$.

$$m_{solute} = \frac{\Delta T}{-k_f} = \frac{\Delta T}{k_f} = \frac{0.13\ K}{20.1\ K \cdot \frac{kg}{mol}} = 0.00646\ \frac{mol\ of\ solute}{kg\ of\ solvent} \times \frac{1\ kg}{1000\ g}$$

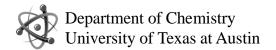$$= 6.46 \times 10^{-6}\ \frac{mol\ caffeine}{1\ gram\ cyclohexane}$$

4. Can that value help us find the molar mass of caffeine? How?
   We can use the molality (which gives us the moles of caffeine per grams of solvent) and the mass of caffeine and cyclohexane used to make the solution to find the moles of caffeine and then molar mass of caffeine.

5. How many moles of caffeine are in the solution?

$$n_{caffeine} = molality_{caffeine} \times mass_{solvent}$$

$$= 6.46 \times 10^{-6}\ \frac{mol\ caffeine}{1\ gram\ cyclohexane} \times 100\ g\ cyclohexane$$

$$= 6.46 \times 10^{-4}$$

6. What is the molar mass of caffeine? Remember that the molar mass of a compound is the mass of 1 mole of the compound.
   With n$_{caffeine}$ in the sample and the mass of caffeine used to make the solution we have all the elements to find the molar mass of caffeine.

$$M_{caffeine} = \frac{m_{caffeine}}{n_{caffeine}} = \frac{0.125\ g}{6.46 \times 10^{-4}\ mol} = 193.50\ \frac{g}{mol}$$

PROBLEM#5: A mysterious ionic compound is soluble in water and dissociates into one anion and one cation in solution. The aqueous solution of this mysterious compound containing 25 g/L develops an osmotic pressure of 0.54 torr at 25°C. Find the approximate molecular weight of this compound.

STEP-BY-STEP QUESTIONS

1. What equation did we learn in class that has to do with the material in this problem?

$$\Pi = MRT$$

2. Is what we are looking for found in this equation?
No

3. What can we find using this equation? Calculate that value.
We are given Π and T and R is a constant. From these values we can calculate M.
T = 25°C = (273 + 25) K = 298 K
Π=0.54 torr
R= 63.36 $^{L\,torr}/_{mol\,K}$

$$M = \frac{\Pi}{RT} = \frac{0.54\ torr}{62.36\frac{L \cdot torr}{mol \cdot K} \times 298K} = 2.906 \times 10^{-5}\frac{mol}{L}$$

4. Is the above value the molarity of the compound or molarity of ions in solution?
The M we calculated above is the molarity of ions in solution. This is because the colligative properties are affected by the number of particles in solution.
So

$$M_{mysterious\ ionic\ compound} = \frac{M_{ions}}{2}$$

$$= \frac{2.906 \times 10^{-5}\frac{mol\ of\ ions}{L}}{2}\ 1.453 \times 10^{-5}\frac{mol\ of\ compound}{L}$$
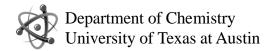
5. Can that value help us find the molecular weight of the compound? How?

Yes, now we have the moles of compound per liter AND the grams of compound per liter. So we can assume 1 liter of solution and use the moles and grams of compound to find the molar mass of the compound.

6. Calculate the molecular weight of the mysterious compound.
1 liter of solution has 25 grams of compound and 1.453•10⁻⁵ moles of compound. So,

$$M_{compound} = \frac{25\ g\ compound}{1.453 \times 10^{-5}\ mol\ of\ compound} = 1,720,578\frac{g}{mol}$$

Compare and Contrast Moment

What aspects were the same about problem #4 and problem #5?

Both problems are asking for the molar weight (molar mass) of the solute.

What aspects were different about problem #4 and problem #5?

In problem #4, the solute does not dissociate into ions when in solution and freezing point data is given. So, the freezing point depression equation is used.

In problem #5, the solute dissociates into 2 ions when in solution and osmotic pressure data is given. So, the osmotic pressure equation is used.