Colligative Properties

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	Mn3(PO4)4	7	"insoluble"
Chromium (III) Carbonate	Cr2(CO3)3	5	"insoluble"
Chromium (III) Hydroxide	Cr(OH)3	4	"insoluble"
Chromium (II) Chlorate	Cr(ClO3)2	3	soluble
Copper (II) Sulfate	CuSO4	2	soluble
Copper (II) Hydroxide	Cu(OH)2	3	"insoluble"
Aluminium Sulfate	Al2(SO4)3	5	soluble
Aluminium Phosphate	AlPO4	2	"insoluble"
Strontium Chlorate	Sr(ClO3)2	3	soluble
Barium Nitrate	Ba(NO3)2	3	soluble
Ammonium Hydroxide	NH4OH	2	soluble
Lithium Nitrate	LiNO3	2	soluble
Lithium Chlorate	Li(ClO3)	2	soluble

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

** We put "insoluble" in quotations since at a microscopic level these compounds look like they are "insoluble," but at a 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.

   We have P_{solute} + $K_{solvent}$. We can solve for X_{solute}

   $$X_{solute} = \frac{P_{solute}}{K_{solvent}} = \frac{0.19\,atm}{4.34\times10^4\,atm} = 4.378\times10^{-6}$$

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.

   $1 = X_{solute} + X_{solvent}$

   $\Rightarrow X_{solvent} = 1 - X_{solute} = 1 - 4.378\times10^{-6} = 0.999996$

   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 negligable

   $$m_{sample} \sim m_{H_2O} = n_{H_2O} \times M_{H_2O} = 0.999996\,mol_{H_2O} \times \frac{18g}{1\,mol\,H_2O} \sim 18g$$

6. What is the volume of this sample?

   We have m_{soln} + d_{soln}, so we can find V_{soln}.

   $$V_{sample} = \frac{m}{d} = \frac{18g}{1g/mL} = 18mL = 0.018L$$

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. This is equal to the concentration of the Lake.

   $$C_{Lake} = C_{sample} = \frac{n_{solute}}{V_{soln}} = \frac{4.378\times10^{-6}\,mols}{0.018L} = 2.4322\times10^{-4}\,mol/L$$

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?

   Raoult's Law $P_{soln} = X_{solvent} P^{o}_{solvent\ pure}$

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^o
   But, we are NOT given $X_{solvent}$

4. What do we need to find the information we are missing?

   $X_{solvent} = \frac{n_{solvent}}{n_{solvent} + n_{solute}}$ So 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? Lithium Sulfate = Li_2SO_4

   $n_{Li_2SO_4} = C \times V = 0.1 \frac{mol}{L} Li_2SO_4 \times 0.100 L\ Li_2SO_4 = 0.01 mol\ Li_2SO_4$

   $m_{Li_2SO_4} = n \times M = 0.01 mol \times (7 \times 2 + 32 + 16 \times 4) \frac{g}{mol} = 1.1 g$

6. What is the total weight of the solution?

   We can find this using the density of the soln

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

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

   $m_{total} = m_{Li_2SO_4} + m_{H_2O}$

   $\Rightarrow m_{H_2O} = m_{total} - m_{Li_2SO_4} = 150 g - 1.1 g = 148.9 g$

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

$$n_{H_2O} = \frac{m}{M} = \frac{148.9\,g}{18\,g/mol} = 8.27\ mol$$

9. What is the solvent molar fraction?

We now have all the elements we were missing

$$X_{solvent} = \frac{n_{H_2O}}{n_{H_2O} + n_{Li_2SO_4}} = \frac{8.27\ mol}{(8.27 + 0.01)\ mol} = 0.9988$$

10. Calculate the vapor pressure of the solution.

We now have everything to calculate P_{soln}

$$P_{soln} = X_{solvent} \times P^{o}_{solvent\ pure} = 0.9988 \times 25\ torr = 24.970\ torr$$

Compare and Contrast Moment

What aspects were the same about problem #3 and problem #2?

Both talked about 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 the 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 the 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 + K_f. We can solve for m_{solute}.

$$m_{solute} = \frac{\Delta T}{-K_f} = \frac{\Delta T}{K_f} = \frac{0.13 K}{20.1 \frac{K \cdot kg}{mol}} = 0.00646 \frac{mol\ of\ solute}{kg\ of\ solvent} \cdot \frac{1 kg}{1000 g} = 6.46 \times 10^{-6} \frac{mol\ caffeine}{1 g\ cyclohexane}$$

b/c we are given the magnitude of the change

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 soln to find the moles of caffeine and then molar mass of caffeine.

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

$$n_{caffeine} = \text{molality of caffeine} \times \text{mass solvent} = \frac{6.46 \times 10^{-6} \text{ mol Caf}}{1 g \text{ cyclo}} \times 100 g \text{ cyclo} = 6.46 \times 10^{-4} \text{ mol caffeine}$$

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 $m_{caffeine}$ (mass) used to make the soln we have all the elements to find the molar mass of caffeine ($M_{caffeine}$)

$$M_{caffeine} = \frac{m_{caffeine}}{n_{caffeine}} = \frac{.125 g}{6.46 \times 10^{-4} mol} = 193.50 \text{ g/mol}$$

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. So we can calculate M.

   $T = 25°C = (273+25)K = 298K$. $\Pi = 0.54$ torr

   We want to use $R = 62.36 \frac{L \cdot torr}{mol \cdot K}$ b/c it fits the units in the pb.

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

4. Is the above value the molarity of the compound or molarity of ions in solution?

   M above is molarity of ions in soln b/c colligative properties are effected by the number of particles in soln.

   So $M_{\text{mysterious ionic compound}} = \frac{M_{ions}}{2} = \frac{2.906 \times 10^{-5} \text{ mol of ions}/L}{2} = 1.453 \times 10^{-5} \frac{\text{mol of compound}}{L}$

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 assume 1 liter of soln and use the moles + grams of compound to find the molar mass of the compound

6. Calculate the molar weigh of the mysterious compound.

   molecular weight

   1 liter of soln has
   - 1.453×10^{-5} mol of compound
   - 25 g of compound

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

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 into2 ions when in solution and osmotic pressure data is given. So, the osmotic pressure equation is used.