UNIT 6 – CHAPTER 11 STUDENT NOTES: SOLUTIONS AND IMFs

****Remember: solute – gets dissolved; solvent – does the dissolving; solution – solute + solvent****

Expressions of concentration

1.00 grams of ethanol (C_2H_5OH) is dissolved in 100 grams of water (assume the density of the solution is 1 g/mL). Express the concentration of this solution in terms of:

Molarity (*M*) = $\frac{\text{moles solute}}{\text{liters of solution}}$

$\frac{1.00\,g\,C_2H_5OH}{} \cdot \frac{1\,mol\,C_2H_5OH}{46.07\,g\,C_2H_5OH} = \frac{0.0217\,mol}{0.101\,L} = \boxed{0.215\,M}$ (100 mL + 1 g (mL))

Mass % = $\frac{\text{mass of solute}}{\text{mass of solution}}$ X 100%

$\frac{1.00\,g\,C_2H_5OH}{101\,g\,\text{SOLUTION}} = \boxed{0.990\%\,C_2H_5OH}$ (100 mL (g) + 1 g)

Mole fraction = $\frac{\text{mole A}}{\text{mole A + mole B}}$

$\frac{1.00\,g\,C_2H_5OH}{} \cdot \frac{1\,mol\,C_2H_5OH}{46.07\,g\,C_2H_5OH} = \frac{0.0217\,mol\,C_2H_5OH}{(0.0217\,mol\,C_2H_5OH) + (5.56\,mol\,H_2O)} = \boxed{0.00389\,C_2H_5OH}$

$\frac{100\,g\,H_2O}{} \cdot \frac{1\,mol\,H_2O}{18\,g\,H_2O} = 5.56\,mol\,H_2O$

Molality (*m*) = $\frac{\text{moles solute}}{\text{kg of solvent}}$

$\frac{0.0217\,mol\,C_2H_5OH}{0.100\,kg\,H_2O} = \boxed{0.217\,m\,C_2H_5OH}$

EX 1: A 1.5-liter solution of a 4.25 *M* $LiCl_2$ solution is produced. If the density of the solution is 1.126 g/mL, calculate the: a) mass %, b) molality, and c) mole fraction of the solution.

EX 2: The electrolyte in automobile lead storage batteries is a 3.75 *M* sulfuric acid solution that has a density of 1.230 g/mL. Calculate the a) mass %, b) molality, c) mole fraction of the sulfuric acid.

EX 3: Common commercial acids are sold with certain properties. For sulfuric acid they are:

H_2SO_4 density = 1.84 g/cm^3 (→ 1 cm^3 = 1 mL = .001 L)   mass % = 95 → $\frac{95g\ H_2SO_4}{(95g\ H_2SO_4 + 5g\ H_2O)}$

Calculate the a) molarity, b) molality, c) mole fraction of the solution.

a) 95% $\frac{95g\ H_2SO_4}{100g\ Solution} \cdot \frac{1\ mol\ H_2SO_4}{98.0g\ H_2SO_4} = \frac{.9694\ mol\ H_2SO_4}{100g\ Solution \cdot \frac{.001L}{1.84g}} = \frac{.9694\ mol\ H_2SO_4}{.05435\ L} = \boxed{17.8M}$

b) $5g\ H_2O = \frac{.9694\ mol\ H_2SO_4}{.005\ Kg\ H_2O} = \boxed{194\ m\ H_2SO_4}$

c) $\frac{5g\ H_2O}{} \cdot \frac{1\ mol\ H_2O}{18g\ H_2O} = .3$ $\frac{.9694\ mol\ H_2SO_4}{(.9694\ mol_{H_2SO_4}) + (.3)_{H_2O}} = \boxed{0.76\ H_2SO_4}$

Dilutions – are problems that require you to produce a certain concentration. They are of two types:

Solid dilutions - $\frac{0.2M}{1L} \cdot .750L = 0.05\ Mol\ NaCl \cdot \frac{58.5g\ NaCl}{1\ mol\ NaCl} = \boxed{8.8g\ NaCl}$

* HOW MANY GRAMS OF SALT TO MAKE 750 mL OF 0.2M SOLUTION NaCl? *

Liquid dilutions - $M_1 \cdot V_1 = M_2 \cdot V_2$

* HOW MUCH STOCK SOLUTION IS NEEDED TO MAKE 1.50L OF 0.03M SOLUTION FROM ABOVE? *

$\underbrace{(0.03M)(1.50L)}_{DILUTE} = \underbrace{(0.20M)(X\ V_2)}_{STOCK}$

V_2 = 0.225 L STOCK SOLUTION NEEDED

Raoult's Law: describes that the presence of a nonvolatile solute lowers the vapor pressure of a solute.

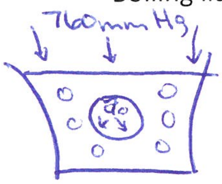
$$P_{solution} = X_{solvent} \cdot P^0_{solvent} \qquad X_{solvent} = \text{mole fraction of solvent}$$

$$P^0_{solvent} = \text{vapor pressure solvent}$$

Equilibrium vapor pressure – pressure of a liquid in equilibrium with its vapor

Liquid + energy ⟷ vapor

Boiling liquids are dependent on their equilibrium vapor pressure

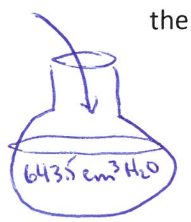


80.5°C → 355.1 mm Hg
90°C → 525.8 mm Hg
100°C → 760.0 mm Hg
105°C → 780 mm Hg
110°C → 800 mm Hg

Pascal's law – pressure on the surface of a liquid acts the same throughout the liquid

158g $C_{12}H_{22}O_{11}$

EX 4: Calculate the vapor pressure at 25⁰C for a solution prepared by dissolving 158.0 grams of table sugar ($C_{12}H_{22}O_{11}$ = 342 g/mole) in 643.5 cm³ of water. At 25⁰C the density of water is 0.9971 g/cm³ and the vapor pressure is 23.76 torr.



23.76 Torr @ 25°C
D = 0.9971g/cm³

$$P_{SOLUTION} = X_{H_2O} \cdot P^0_{H_2O}$$

$$158g\ C_{12}H_{22}O_{11} \cdot \frac{1\ mol\ C_{12}H_{22}O_{11}}{342g\ C_{12}H_{22}O_{11}} = 0.462\ mol\ C_{12}H_{22}O_{11}$$

$$643.5cm^3\ H_2O \cdot \frac{0.9971g}{1\ cm^3} = 641.6g\ H_2O \cdot \frac{1\ mol\ H_2O}{18g\ H_2O} = 35.6\ mol\ H_2O$$

$$\text{MOLE FRACTION } (X_{H_2O}) = \frac{35.6\ mol\ H_2O}{(35.6\ mol\ H_2O) + (0.462\ mol\ C_{12}H_{22}O_{11})} = 0.987$$

$$P_{SOLUTION} = (0.987) \cdot (23.76\ TORR) = \boxed{23.45\ TORR}$$

EX 5: A mixture of 10 mL of octane (C_8H_8, density = 0.75 g/mL) at a pressure of 150 torr with 15 mL butane (C_4H_{10}, density = 0.98 g/mL) at a pressure of 100 torr is mixed in a closed container. Calculate the a) vapor pressure of the solution, and b) mole fraction of the two gases in the vapor.

$$a)\ P_{SOLUTION} = P_{OCTANE} + P_{BUTANE}$$

DETERMINE X:

$$\text{OCTANE} \rightarrow 10mL \cdot \frac{0.75g}{1mL} = 7.5g\ \text{OCTANE} \cdot \frac{1\ mol\ C_8H_8}{114g\ C_8H_8} = 0.066\ mol\ C_8H_8$$

$$\text{BUTANE} \rightarrow 15mL \cdot \frac{0.98g}{1mL} = 14.7g\ \text{BUTANE} \cdot \frac{1\ mol\ C_4H_{10}}{58.0g\ C_4H_{10}} = 0.25\ mol\ C_4H_{10}$$

$$X_{OCTANE} = \frac{0.066\ mol\ C_8H_8}{(0.066)+(0.25)} = 0.209\ \text{OCTANE}$$

$$X_{BUTANE} = \frac{0.25\ mol\ C_4H_{10}}{(0.25)+(0.066)} = 0.791\ \text{BUTANE}$$

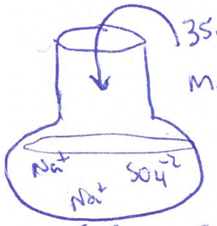
$$P_{SOLUTION} = (0.209)(150\ TORR) + (0.791)(100\ TORR) = 31.5\ TORR + 79.10\ TORR = \boxed{110.45\ TORR}$$

$$b)\ P_{GAS} = X_{SOLVENT} \cdot P^0_{TOTAL}$$

$$\text{OCTANE} \rightarrow 31.35\ TORR = X_{OCTANE} \cdot 110.45\ TORR \quad \boxed{= 0.284}$$

$$\text{BUTANE} \rightarrow 79.10\ TORR = X_{BUTANE} \cdot 110.45\ TORR \quad \boxed{= 0.716}$$

EX 6: Predict the vapor pressure of a solution prepared by mixing 35.0 grams of solid Na_2SO_4 (molar mass = 142 g/mole) with 175 grams of water at 25⁰C. (Vapor pressure of water @ 25⁰C = 23.76 torr)



35.0g Na_2SO_4
M. MASS = 142g/mol

175g SOLVENT
VP = 23.76 TORR
@ 25°C
$Na_2SO_4 \rightarrow 2Na^{+1} + 1SO_4^{-2}$
= 3 PARTICLES

$$P_{SOLUTION} = X_{H_2O} \cdot P^{\circ}_{H_2O}$$

DETERMINE X:
$H_2O \rightarrow 175g\ H_2O \cdot \frac{1\ mol\ H_2O}{18g\ H_2O} = 9.72\ mol\ H_2O$
$Na_2SO_4 \rightarrow 35.0g\ Na_2SO_4 \cdot \frac{1\ mol\ Na_2SO_4}{142g\ Na_2SO_4} = 0.246\ mol\ Na_2SO_4 \cdot \frac{3\ PARTICLES}{1\ mol} = 0.738$

$$X_{H_2O} = \frac{9.72\ mol\ H_2O}{(9.72\ mol\ H_2O) + (0.738\ mol\ Na_2SO_4)} = 0.929$$

$$P_{SOLUTION} = (0.929) \cdot 23.76\ TORR = \boxed{22.1\ TORR}$$

Colligative properties: are properties determined by the number of particles, not the type or chemistry of the solute.

Boiling point elevation - $\Delta T_b = K_b \cdot m$

K_b = boiling point constant (0.51⁰C/*m* for water)

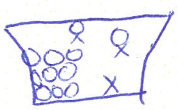
m = molality of solution

* SOLUTE RAISES BP of SOLVENT BY INCREASING PRESSURE ON BUBBLE *

Freezing point depression - $\Delta T_f = K_f \cdot m$

K_f = freezing pt constant (1.86⁰C/*m* for water)

m = molality of solution



* SOLUTE LOWERS FP OF SOLVENT BY HINDERING CRYSTAL FORMATION

TABLE 11.5 Molal Boiling-Point Elevation Constants (K_b) and Freezing-Point Depression Constants (K_f) for Several Solvents

Solvent	Boiling Point (°C)	K_b (°C · kg/mol)	Freezing Point (°C)	K_f (°C · kg/mol)
Water (H_2O)	100.0	0.51	0	1.86
Carbon tetrachloride (CCl_4)	76.5	5.03	−22.99	30.
Chloroform ($CHCl_3$)	61.2	3.63	−63.5	4.70
Benzene (C_6H_6)	80.1	2.53	5.5	5.12
Carbon disulfide (CS_2)	46.2	2.34	−111.5	3.83
Ethyl ether ($C_4H_{10}O$)	34.5	2.02	−116.2	1.79
Camphor ($C_{10}H_{16}O$)	208.0	5.95	179.8	40.

Osmotic pressure - $\pi = i \cdot M \cdot R \cdot T$

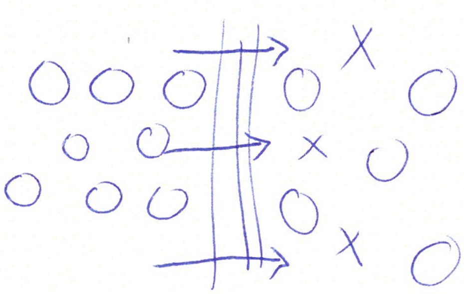
π = pressure in atmospheres

i = van't Hoff factor

M = Molarity of solution

R = 0.08206 L-atm/K·mol

T = Kelvin



EX 7: Calculate the boiling point elevation and freezing point depression of a solution that contains 2.0 grams of sucrose ($C_{12}H_{22}O_{11}$; molar mass = 343 grams) in 100 grams of solution.

The van't Hoff factor (*i*) – is the effect an ionic solute has on the colligative properties of a solution.

EX 8: Calculate the boiling point elevation and freezing point depression of a solution that contains 2.0 grams of NaCl (molar mass = 58.5 grams) in 100 grams of solution.

EX 9: A solution is prepared by dissolving 18.0 grams of a nonvolatile solute in 150.0 grams of water. The resulting solution was found to have a boiling point of 100.34°C. Calculate the molar mass of glucose.

EX 10: What mass of ethylene glycol ($C_2H_6O_2$; molar mass = 62.1 g/mol), the main component in antifreeze, must be added to 10.0 liters of water to produce a solution for use in a car radiator that freezes at -23.3°C? Assume the water density is 1 g/mL.

$C_2H_6O_2$
62.1g/mol
-23.3°C

10.0L H_2O
D=1.0g/mol

1L=1Kg H_2O
1mL=1g H_2O

* $C_2H_6O_2$ IS MOLECULAR, NON-VOLATILE (1 PARTICLE)

MOLALITY → $\Delta T_f = K_f \cdot m \cdot \#IONS$

$23.3°C = 1.86 \cdot m \cdot 1$

$m = \frac{12.5 \text{ MOLES } C_2H_6O_2 \text{ MOLES}}{1 \text{ Kg}} \Big| \frac{10 \text{ Kg } H_2O}{} = 125 \text{ MOLES } C_2H_6O_2$

$\frac{125 \text{ MOLES } C_2H_6O_2}{} \Big| \frac{62.1 \text{ g } C_2H_6O_2}{1 \text{ MOL } C_2H_6O_2} = \boxed{7{,}762.5 \text{ g } C_2H_6O_2}$

EX 11: A chemist is trying to identify a human hormone by determining its molar mass. A sample with a mass of 0.546 grams is dissolved in 15.0 g of benzene and the freezing point depression was determined to be 0.240^0C. Calculate the molar mass of the hormone.

0.546g → 15.0g BENZENE, $\Delta T_f = 0.240°C$

*M.MASS = GRAMS / MOL

MOLALITY → $\Delta T_f = K_f \cdot m \cdot \#IONS$

$0.240°C = 5.12 \cdot m \cdot 1$ (BENZENE'S K_f) → $m = \frac{0.0469\,g\ CMPD}{1\,kg\ BENZENE} \cdot 0.015\,kg\ BENZENE = 0.0007035\ MOL\ CMPD$

$\frac{15g\ CMPD}{0.0007035\ MOL\ CMPD} = 780\ g/MOL$

Osmotic pressure – is caused by passing water through a semipermeable membrane.

$$\pi = i \cdot M \cdot R \cdot T$$

EX 12: A normal human cell will burst if the pressure inside the cell exceeds 90 atm of pressure. Calculate the osmotic pressure of a cell if the contents have 0.0029 grams of NaCl dissolved in 0.0250 mL of water at 25^0C and determine if the cell can survive.

0.0029g NaCl, 0.0250 mL H_2O

CELL BURSTS @ 90 ATM

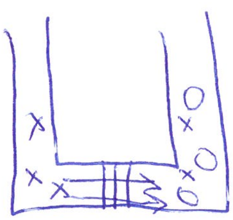
$NaCl \rightarrow Na^+ + Cl^- \rightarrow$ 2 PARTICLES

$\pi = (2)(1.98M)(0.08206)(298) \rightarrow \pi = 96.9\ ATM > 90\ ATM$ ∴ CELL WILL BURST

$M = \frac{0.0029g\ NaCl}{} \cdot \frac{1\ MOL\ NaCl}{58.5g\ NaCl} = \frac{0.0000495\,72\ MOL\ NaCl}{1\ L\ SOL'N} \cdot 0.0000250\ L\ SOL'N = 1.98M\ SOL'N$

$K = C° + 273 \rightarrow K = 25°C + 273 = 298$

EX 13: To determine the molar mass of a certain protein, 0.001 grams of it is dissolved in enough water to make 1.00 mL of solution. The osmotic pressure of this solution was found to be 1.12 torr at 25^0C. Calculate the molar mass of the protein.



0.001g PROTEIN
1.00 mL SOLUTION
1.12 TORR @ 25°C

$K = C° + 273$
$K = 298$

$\frac{1.12\ TORR}{} \cdot \frac{1\ ATM}{760\ TORR} = 0.00147\ ATM$

$\pi = i \cdot M \cdot R \cdot T$ (PROTEIN = NONVOLATILE, 1 PARTICLE)

$0.00147\ ATM = (1)(M)(0.08206)(298)$

$M = \frac{0.000060\ MOL\ PROTEIN}{1\ L\ SOL'N} \cdot 0.001L\ SOL'N = 6.01 \times 10^{-8}\ MOLES$

$\frac{0.001g\ PROTEIN}{6.01 \times 10^{-8}\ MOLES} = 16{,}639\ g/MOL$

Intermolecular and intramolecular forces

Intramolecular forces – forces that hold the atoms of compounds together, 3 types

1. Metallic bonds – metallic atoms in a "sea" of electrons

2. Ionic bonds – transfer of electrons

3. Covalent bonds – sharing of electrons

<u>Intermolecular forces (IMFs)</u> – those forces that hold molecules together.

Two important characteristics of IMFs

1) Boiling point

2) Vapor pressure

1. <u>London dispersion forces</u>

Molecule	**State @ room temp**	**Boiling Point**
F – F	Gas	-188^{0}C
Cl – Cl	Gas	-35^{0}C
Br – Br	Liquid	58^{0}C
I – I	Solid	184^{0}C

He Ar CH_4 C_8H_{18}

2. <u>Dipole-Dipole forces</u>

CO Acetone (C_2H_6O)

<u>Hydrogen bonding</u> – special dipole-dipole forces **H – F, O, N**

H – F H_2O NH_3

List the intermolecular forces present in CH_3OH, Ar, Ne, CH_3OCH_3 and then rank from lowest to highest boiling point

What determines the strength of the following forces:

Dipole-Dipole forces

Hydrogen bonding forces

London dispersion forces

Draw a picture of an ion-induced dipole:

Identify the main type of intermolecular force in the following:

Ne ____________________

NH_3 ____________________

KCl ____________________

PH_3 ____________________

BCl_2 ____________________

NaCl in water ____________________

C_2H_6 ____________________

Which of the following molecule pairs are NOT involved in hydrogen bonding?

1) HCOOH, H_2O
2) H_2O, NH_3
3) CH_3OH, CH_3COOH
4) H_2 and I_2

Which of the following molecules interact primarily through London-dispersion forces?

1) SO_2
2) CCl_4
3) CH_2Cl_2
4) H_2S

Draw diagrams showing 3 molecules of carbon dioxide in the state of matter indicated below in the box. On the diagram, show where the intermolecular and intramolecular forces are.

Liquid	Gas

In the box provided, draw a picture of a water molecule dissolving a picture of a crystal of NaCl