Chem 131 **Name**___________________________________
Exam 3, Ch 13, 16-17.2 **November 6, 2019**
100 Points

Please follow the instructions for each section of the exam. Show your work on all mathematical problems. Provide answers with the correct units and significant figures. Be concise in your answers to discussion questions.

Part 0: Complete all of problems 1-5

1. You have prepared a buffer solution at pH = 4.00. If you take 100 mL of this solution and dilute it to 200 mL with distilled water, what will be the pH of the new solution? (4 points)

   a. Greater than 4.00
   b. Less than 4.00
   c. 4.00
   d. Thursday

   Answer ____c_______

2. The conjugate acid of HPO_4^{2-} is ___________. (4 points)

   a. H_3PO_4
   b. $H_2PO_4^-$
   c. PO_4^{3-}
   d. H_3O^+

   Answer ____b_______

3. The effect of adding 0.001 mol KOH to 1.00 L of a solution that is 0.10 M NH_3 and 0.10 M NH_4Cl is to (4 points)
   a. Raise the pH very slightly
   b. Lower the pH very slightly
   c. Raise the pH by several units
   d. Lower the pH by several units

   Answer ____a_______

4. Write one **charge balance** and one **mass balance** expression for a solution that is 0.10 M NaOH, 0.14 M KOH, 0.10 M NaCl and 0.12 M $Ba(OH)_2$. All of the solutes are strong electrolytes. (8 points)

   Charge Balance: $[Na^+] + [K^+] + 2[Ba^{2+}] = [OH^-] + [Cl^-]$

   Mass Balance: There are several possibilities. Here are a few: $[K^+] = 0.14$ M, $[Na^+] = 0.20$ M, $[Ba^{2+}] = 0.12$ M, $[Cl^-] = 0.10$ M, $[OH^-] = 0.48$ M

5. Define **three (3)** of the following in one or two sentences each. (6 points)
   a. amphiprotic: species that can behave as both an acid and a base

   b. van't Hoff factor: a value that describes the number of particles formed when an electrolyte dissociates.

   c. molality: concentration in terms of moles solute per kilogram solvent

   d. diprotic acid: a compound capable of producing two moles of protons (or hydronium) per mole of compound.

Part I: Complete four (4) of problems 6-10. 10 points each.

6. What is the pH of a solution that contains the strong electrolytes 0.100 M NaOH, 0.140 M KOH, 0.100 M NaCl and 0.115 M $Ba(OH)_2$?

We need the total concentration of hydroxide (or hydronium). NaCl does not contribute to either of these.

From NaOH $\frac{0.100 \text{ mol NaOH}}{1 \text{ L}} \times \frac{1 \text{ mol OH}^-}{1 \text{ mol NaOH}} = \frac{0.100 \text{ mol OH}^-}{\text{L}} = 0.100 \text{ M OH}^-$

From KOH $\frac{0.140 \text{ mol KOH}}{1 \text{ L}} \times \frac{1 \text{ mol OH}^-}{1 \text{ mol KOH}} = \frac{0.140 \text{ mol OH}^-}{\text{L}} = 0.140 \text{ M OH}^-$

From $Ba(OH)_2$ $\frac{0.115 \text{ mol Ba(OH)}_2}{1 \text{ L}} \times \frac{2 \text{ mol OH}^-}{1 \text{ mol Ba(OH)}_2} = \frac{0.230 \text{ mol OH}^-}{\text{L}} = 0.230 \text{ M OH}^-$

So, the total $[OH^-]$ = 0.100M + 0.140M + 0.230M = 0.470

pOH = -log$[OH^-]$ = 0.327

pH = 14 – pOH = **13.67**

7. Vitamin B_2, riboflavin, is soluble in water. If 0.833 g of riboflavin is dissolved in 18.1 g H_2O, the resulting solution has a freezing point of -0.227°C. What is the molar mass of riboflavin?

$$\Delta t_{fp} = k_{fp}m$$

$$\text{molality} = \frac{\Delta t_{fp}}{k_{fp}} = \frac{0.227^{\circ}\text{C}}{1.86^{\circ}\text{C}m^{-1}} = \frac{0.1220 \text{ mol}}{\text{kg}}$$

From the molality, we can find moles riboflavin (B_2)

$$\text{molality} = \frac{0.1220 \text{ mol B}_2}{\text{kg water}} \times 0.0181 \text{ kg water} = 0.002209 \text{ mol B}_2$$

Using moles B_2 and the mass of B_2 used, we get the molar mass:

$$\frac{0.833 \text{ g B}_2}{0.002209 \text{ mol B}_2} = \mathbf{377 \text{ g/mol}}$$

8. 50.00 mL of 0.0188 M HCl(aq) is mixed with 75.00 mL of 0.0112 M NaOH(aq). What is the pH of the final solution?

This is a strong acid/strong base reaction. The pH will be determined by what remains when the reaction is done:

We have 50.00 mL x 0.0188 mol/L HCl, = 0.940 mmol HCl and
75.00 mL x 0.0112 mol/L NaOH = 0.840 mmol NaOH

	HCl	+	NaOH	→	NaCl	+	H_2O
Start	0.940 mmol		0.840 mmol		0		0
End	0.100 mmol		0 mmol		0.840 mmol		0.840 mmol

So, when the reaction is done, we will have 0.100 mmol of HCl in (50.00 + 75.00)mL of solution:

$$\frac{0.100 \text{ mmol HCl}}{125.00 \text{ mL}} \times \frac{1 \text{ mol H}^+}{1 \text{ mol HCl}} = \frac{8.00 \times 10^{-4} \text{ mol H}^+}{\text{L}} = 8.00 \times 10^{-4}\text{M H}^+$$

pH = -log$[H^+]$ = -log(8.00 x 10^{-4} M) = 3.10

9. In the lab you need to prepare at least 100.0 mL of the following solutions. **Select one of the solutions below** and explain how you would prepare the solution, giving amounts (masses and volumes) of material needed.
   a. 25% NaOH by mass in CH_3OH (density = 0.79 g/mL)
   b. 0.10 mole fraction of $C_6H_{12}O_6$ (molar mass 180.16 g/mol) in water.
   c. 200.0 ppm K^+ in water, using KCl as your source of K^+ (density = 1.00 g/mL)

There are several approaches to each of these. I'll show one each.

Part a: For 100 mL CH_3OH: 100 mL x 0.79 g/mL = 79 grams CH_3OH. How many grams NaOH for 25%?

$$\frac{25 \text{ g NaOH}}{100 \text{ g solution}} = \frac{x \text{ g NaOH}}{79 + x \text{ g solution}}$$

$$0.25(79+x) = x \rightarrow 19.75 + 0.25x = x \rightarrow 19.75 = 0.75x$$

x = 26.3 g NaOH needed for every 79 grams CH_3OH.

Part b: For 100 mL water:

$$100 \text{ mL } H_2O \times \frac{1 \text{ g } H_2O}{1 \text{ mL } H_2O} \times \frac{1 \text{ mol } H_2O}{18.01 \text{ g } H_2O} = 5.55 \text{ mol } H_2O$$

$$X_{C6H12O6} = 0.10 = \frac{\text{mol } C_6H_{12}O_6}{\text{mol } C_6H_{12}O_6 + \text{mol } H_2O} = \frac{x}{x + 5.55}$$

$$0.10(x + 5.55) = x \rightarrow 0.10x + 0.555 = x \rightarrow 0.555 = 0.90x$$

$$x = 0.616 \text{ mol } C_6H_{12}O_6$$

$$0.616 \text{ mol } C_6H_{12}O_6 \times \frac{180.16 \text{ g } C_6H_{12}O_6}{1 \text{ mol } C_6H_{12}O_6} = 111 \text{ g } C_6H_{12}O_6$$

So, 111 g $C_6H_{12}O_6$ for every 100 mL water

Part c

$$\frac{200.0 \text{ g } K^+}{10^6 \text{g solution}} \times \frac{1 \text{ g solution}}{1 \text{ mL solution}} \times 100 \text{ mL solution} = 0.0200 \text{ g } K^+ \text{ needed}$$

$$0.0200 \text{ g } K^+ \times \frac{1 \text{ mol } K^+}{39.098 \text{ g } K^+} \times \frac{1 \text{ mol KCl}}{1 \text{ mol } K^+} \times \frac{75.55 \text{ g KCl}}{1 \text{ mol KCl}} = 0.0386 \text{ g KCl needed}$$

So, dissolve 0.0386 g KCl in 100 mL solution.

10. A buffer solution is prepared by dissolving 0.150 moles of hydrofluoric acid ($K_a = 6.30 \times 10^{-4}$) and 0.200 moles of sodium fluoride in 0.500 L of solution.
   a. What is the pH of this buffer? (4 points)

$$pK_a = 3.20$$

$$pH = 3.20 + \log \frac{0.200 \text{ mol NaF}}{0.150 \text{ mol HF}} = 3.32$$

Answer_______3.32________________

   b. What will be the new pH after 25.00 mL of 2.087 M NaOH is added to this buffer solution? (6 points)

We have 0.02500L x 2.087 mol NaOH/L = 0.05218 mol OH^-

	HF	+	OH^-	⇄	F^-	+	H_2O
Start	0.150 mol		0.0522 mol		0.200		--
End	0.0978		0		0.2522		--

This is still a buffer solution, so we can still use Henderson-Hasselbach as in part a. You could also set up an ICE table and get the same result.

$$pH = 3.20 + \log \frac{0.2522 \text{ mol NaF}}{0.0978 \text{ mol HF}} = 3.61$$

Answer________3.61_______________

Part II. Answer three (3) of problems 9-13. Clearly mark the problems you do not want graded. 12 points each.

11. Some ethylene glycol ($C_2H_6O_2$, molar mass 62.07 g/mol) is added to your car's cooling system along with 5.0 kg of water.

a. If the freezing point of this water-glycol solution is -15.0° C, how many grams of ethylene glycol must have been added?

$$\Delta t_{fp} = k_{fp}m$$

$$\text{molality} = \frac{\Delta t_{fp}}{k_{fp}} = \frac{15.0^oC}{1.86^oC\,m^{-1}} = \frac{8.065 \text{ mol}}{\text{kg}}$$

$$\frac{8.065 \text{ mol } C_2H_6O_2}{\text{kg water}} \times \frac{5.0 \text{ kg water}}{} \times \frac{62.07 \text{ g } C_2H_6O_2}{1 \text{ mol } C_2H_6O_2} = 2503 \text{ g } C_2H_6O_2$$

Answer_______2500 g $C_2H_6O_2$___________

b. What is the boiling point of the solution?

The solution molality is the same as in part a

$$\Delta t_{bp} = k_{bp}m$$

$$\Delta t_{fp} = \frac{0.51^oC \text{ kg}}{\text{mol}} \times \frac{8.065 \text{ mol}}{\text{kg}} = \frac{15.0^oC}{1.86^oC\,m^{-1}} = 4.11^oC$$

So the boiling point is 100.0°C + 4.11°C = **104.1°C**

Answer_______104.1°C_____________

12. I've given you the task of preparing a pH 4.75 buffer. You've sought the help of a few of your classmates and have narrowed your choices down to the following list. *Each of these combinations should produce a buffer with pH=4.75.* **Which student's suggestion would provide the best choice to make the highest capacity buffer?** Justify your reasoning by identifying benefits of the "best" choice and the shortcomings of the two unfavorable choices.

Student	Buffer Composition	K_a of weak acid
Annie Yun	0.200M salicylic acid and 0.0032 M sodium salicylate	1.1×10^{-3}
Ty Trate	0.010 M acetic acid and 0.010 M sodium acetate	1.8×10^{-5}
Chris Talls	0.200 M acetic acid and 0.200 M sodium acetate	1.8×10^{-5}

For a buffer to have the best capacity, we would like the pK_a for the weak acid to be as close to the desired pH as possible, and we'd like a large concentration of both the weak acid and conjugate base to be present in the solution. The higher the concentration, the more strong acid or base can be absorbed without changing pH.

From the list above, Chris Talls recipe fits both requirements. Annie Yun suggests a combination which results in very dilute weak base because the pK_a is too far from the pH. Ty Trate has the ideal ratio of acid and conjugate base, but the dilute concentrations lead to poorer capacity that Chris' suggestion.

13. Sodium benzoate, used as a preservative in foods, is the conjugate base of benzoic acid**. Calculate the pH of a solution prepared by dissolving 8.24 grams of sodium benzoate in 500.0 mL water**. (The molar mass of sodium benzoate is 144.11 g/mol. The K_a for benzoic acid is 6.3 x 10^{-5})

In solution, sodium benzoate will dissociate to give Na^+ and A^- (benzoate anion). Therefore the solution will initially contain:

$$8.24 \text{ g NaA} \times \frac{1 \text{ mol NaA}}{144.11 \text{ g NaA}} \times \frac{1}{0.500 \text{ L}} \times \frac{1 \text{ mol } A^-}{1 \text{ ~~mol NaA~~}} = \frac{0.115 \text{ mol } A^-}{\text{L}}$$

Benzoate ion is the conjugate base of benzoic acid (HA), therefore it will behave as a base:

$$A^- + H_2O \rightleftharpoons HA + OH^-$$

To treat this system, we need K_b for A^-. $K_b = K_w/K_a = (1 \times 10^{-14})/(6.3 \times 10^{-5}) = 1.59 \times 10^{-10}$. Now we do the ICE thing:

	A^-	+ H_2O	$\rightleftharpoons$ HA	+ OH^-
I	0.115 M	--	0	0
C	-x	--	+x	+x
E	0.115-x	--	x	x

Inserting into the K_b expression, we get:

$$K_b = \frac{[HA][OH^-]}{[A]} = \frac{x^2}{0.115 - x}$$

Here you can either use the quadratic forumula or make an assumption that x<<0.115 since K_b is so small. Either approach works for this problem.

Solving for x, we get x = $[OH^-]$ = 4.28x10^{-6} M, pOH = 5.37, **pH = 14 – pOH = 8.63**

Answer_________8.63___________

14. A solution is prepared by mixing the following materials and diluting to a total volume of 2.00 liters: 15.6 grams of sodium sulfide (molar mass 78.05 g/mol), 150.0 mL of 0.500 M sodium hydroxide (molar mass 40.00 g/mol) and 20.00 g of 38.4% by mass sodium chloride (molar mass 58.44 g/mol). **What is the molarity of sodium ion in the resulting solution?** You may assume all of the solutes are strong electrolytes.

We need to find the total concentration of potassium ion, so we examine each source:

From Na_2S $$15.6\text{ g }Na_2S \times \frac{1\text{ mol }Na_2S}{78.05\text{ g }Na_2S} \times \frac{2\text{ mol }Na^+}{1\text{ mol }Na_2S} = 0.399_7\text{ mol }Na^+$$

From NaOH $$0.1500\text{ L} \times \frac{0.500\text{ mol NaOH}}{1\text{ L}} \times \frac{1\text{ mol }Na^+}{1\text{ mol NaOH}} = 0.0750\text{ mol }Na^+$$

From NaCl
$$20.00\text{ g mixture} \times \frac{38.4\text{ g NaCl}}{100\text{ g mixture}} \times \frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}} \times \frac{1\text{ mol }Na^+}{1\text{ mol NaOH}} = 0.131_4\text{ mol }Na^+$$

So, our total moles $Na^+ = 0.399_7 + 0.0750 + 0.131_4 = 0.6061$ mol Na^+

$$\frac{0.6061\text{ mol }Na^+}{2.00\text{ L}} = 0.303\text{ M }Na^+$$

Answer________0.303 M Na^+__________

Possibly Useful Information

$R = 8.31441\ J\ mol^{-1}\ K^{-1}$	$^{o}C = K - 273.15$	$R = 0.0821\ L\ atm\ mol^{-1}\ K^{-1}$
$\Delta t_{fp} = k_{fp}m$	$\Delta t_{bp} = k_{bp}m$	$\Pi = MRT = iMRT$
$\Delta G^{o} = \Delta H^{o} - T\Delta S^{o} = -RT\ln K$	$\Delta G = \Delta G^{o} - RT\ln Q$	$P_{soln} = X_{solvent}P^{o}_{solvent}$
$pH = pK_a + \log\left(\frac{[conjugate base]}{[weak acid]}\right)$	$pH + pOH = 14$	$K_aK_b = K_w = 1.00 \times 10^{-14}$
1 atm = 760 mm Hg	$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	

Selected Constants

Solvent	Normal Boiling Point (^{o}C)	k_{bp} (^{o}C kg/mol)	Normal Freezing Point (^{o}C)	k_{fp} (^{o}C kg/mol)
Water	100.0	0.51	0	1.86
Benzene	80.1	2.53	5.5	5.12
Ethyl Ether	34.5	2.02	-116.2	1.79
Chloroform	61.2	3.63	-63.5	4.70
cyclohexane	80.7	2.92	6.59	20.8
ethanol	78.4	1.22	–117.3	1.99