

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 c. 4.00 Answer c
b. Less than 4.00 d. Thursday

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

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

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 Answer a
d. Lower the pH by several units

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 $\text{Ba}(\text{OH})_2$. All of the solutes are strong electrolytes. (8 points)



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

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.

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

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

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

So, the total [OH⁻] = 0.100M + 0.140M + 0.230M = 0.470

$$\text{pOH} = -\log[\text{OH}^-] = 0.327$$

$$\text{pH} = 14 - \text{pOH} = \mathbf{13.67}$$

7. Vitamin B₂, riboflavin, is soluble in water. If 0.833 g of riboflavin is dissolved in 18.1 g H₂O, the resulting solution has a freezing point of -0.227°C. What is the molar mass of riboflavin?

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

From the molality, we can find moles riboflavin (B₂)

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

Using moles B₂ and the mass of B₂ used, we get the molar mass:

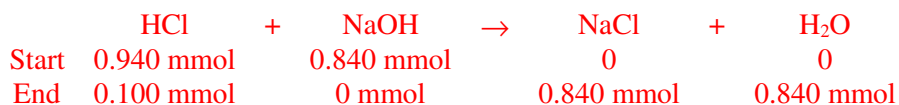
$$\frac{0.833 \text{ g B}_2}{0.002209 \text{ mol B}_2} = \mathbf{377 \text{ g/mol}}$$

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



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

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

$$\mathbf{\text{pH} = -\log[\text{H}^+] = -\log(8.00 \times 10^{-4} \text{ M}) = 3.10}$$

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.

- 25% NaOH by mass in CH₃OH (density = 0.79 g/mL)
- 0.10 mole fraction of C₆H₁₂O₆ (molar mass 180.16 g/mol) in water.
- 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 CH₃OH: 100 mL x 0.79 g/mL = 79 grams CH₃OH. How many grams NaOH for 25%?

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

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

$$x = \mathbf{26.3 \text{ g NaOH needed for every 79 grams CH}_3\text{OH.}}$$

Part b: For 100 mL water:

$$100 \text{ mL H}_2\text{O} \times \frac{1 \text{ g H}_2\text{O}}{1 \text{ mL H}_2\text{O}} \times \frac{1 \text{ mol H}_2\text{O}}{18.01 \text{ g H}_2\text{O}} = 5.55 \text{ mol H}_2\text{O}$$

$$X_{\text{C}_6\text{H}_{12}\text{O}_6} = 0.10 = \frac{\text{mol C}_6\text{H}_{12}\text{O}_6}{\text{mol C}_6\text{H}_{12}\text{O}_6 + \text{mol H}_2\text{O}} = \frac{x}{x + 5.55}$$

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

$$x = 0.616 \text{ mol C}_6\text{H}_{12}\text{O}_6$$

$$0.616 \text{ mol C}_6\text{H}_{12}\text{O}_6 \times \frac{180.16 \text{ g C}_6\text{H}_{12}\text{O}_6}{1 \text{ mol C}_6\text{H}_{12}\text{O}_6} = 111 \text{ g C}_6\text{H}_{12}\text{O}_6$$

So, 111 g C₆H₁₂O₆ 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.

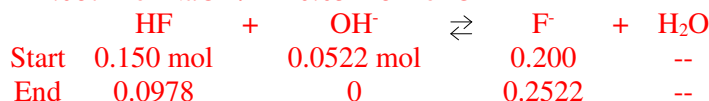
a. What is the pH of this buffer? (4 points)

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

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⁻



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.

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

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 $-15.0^\circ C$, how many grams of ethylene glycol must have been added?

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

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

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

$$\Delta t_{bp} = \frac{0.51^\circ C \text{ kg}}{\text{mol}} \times \frac{8.065 \text{ mol}}{\text{kg}} = \frac{\Delta t_{bp} = k_{bp}m}{1.86^\circ C m^{-1}} = 4.11^\circ C$$

So the boiling point is $100.0^\circ C + 4.11^\circ C = 104.1^\circ C$

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.

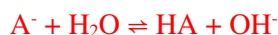
From the list above, Chris Talls recipe fits both requirements. Annie Yun suggests a combination which results in very dilute weak base because the pK_a is too far from the pH. Ty Trate has the ideal ratio of acid and conjugate base, but the dilute concentrations lead to poorer capacity than Chris' suggestion.

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 6.3×10^{-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:



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:

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

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

Solving for x, we get $x = [\text{OH}^-] = 4.28 \times 10^{-6} \text{ M}$, $\text{pOH} = 5.37$, **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:

$$\text{From Na}_2\text{S} \quad 15.6 \text{ g Na}_2\text{S} \quad \times \quad \frac{1 \text{ mol Na}_2\text{S}}{78.05 \text{ g Na}_2\text{S}} \quad \times \quad \frac{2 \text{ mol Na}^+}{1 \text{ mol Na}_2\text{S}} \quad = \quad 0.3997 \text{ mol Na}^+$$

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

$$\begin{array}{l} \text{From NaCl} \\ 20.00 \text{ g mixture} \end{array} \quad \times \quad \frac{38.4 \text{ g NaCl}}{100 \text{ g mixture}} \quad \times \quad \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} \quad \times \quad \frac{1 \text{ mol Na}^+}{1 \text{ mol NaOH}} \quad = \quad 0.1314 \text{ mol Na}^+$$

So, our total moles $\text{Na}^+ = 0.3997 + 0.0750 + 0.1314 = 0.6061 \text{ mol Na}^+$

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

Answer _____ **0.303 M Na⁺** _____

Possibly Useful Information

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

Selected Constants

Solvent	Normal Boiling Point ($^{\circ}\text{C}$)	k_{bp} ($^{\circ}\text{C kg/mol}$)	Normal Freezing Point ($^{\circ}\text{C}$)	k_{fp} ($^{\circ}\text{C kg/mol}$)
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

Periodic Table of the Elements

IA 1A																	VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 III B 3B	4 IV B 4B	5 VB 5B	6 VIB 6B	7 VII B 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 II B 2B	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]
		57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967	
		89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]	