

2019-2020 ABRHS Science Olympiad Chemistry Lab SSSS

Acids/Bases and Aqueous Solutions



Name: Key Score: 200/200

Instructions:

- This test consists of two sections, acids & bases and aqueous solutions, each with 100 points. The tiebreakers are bonus points which do NOT contribute to the final score except in the case of a tie.
- You have **50 minutes** to complete this test. Do NOT open the test until instructed.
- You are allowed **one 8.5" x 11" double-sided cheat sheet** and **one stand-alone non-programmable, non-graphing calculator**.
- For calculations, a correct answer earns full credit, regardless of work shown. However, work is encouraged for potential partial credit if the answer is incorrect.
- All answers should be given with the correct units and significant digits (deviations of ± 1 are allowed). 0.5 points will be deducted for further deviations.
- A periodic table is attached at the end of this test. You may remove any pages from the test packet for your convenience.

Section 1: Acids and Bases (100 Points) - by Yuying Fan

Part I: Multiple Choice (2 pts each, 28 pts total)

___1) Which of the following ionic salts is a weak base?

- A. $\text{Mg}(\text{OH})_2$
- B. LiOH
- C. NaOH
- D. None of the above

___2) Of the following species, which can only act as a base?

- A. H_2O
- B. HCO_3^-
- C. S^{2-}
- D. $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$

___3) Consider the reaction $\text{HPO}_4^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{PO}_4^- + \text{OH}^-$:

- A. H_2O is the acid, OH^- is its conjugate base
- B. H_2O is the acid, HPO_4^{2-} is its conjugate base
- C. HPO_4^{2-} is the acid, OH^- is its conjugate base
- D. HPO_4^{2-} is the acid, H_2PO_4^- is its conjugate base

___4) Which of the following is NOT a conjugate acid-base pair?

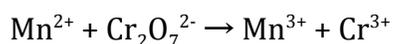
- A. NH_3 and NH_2^-
- B. NaOH and Na^+
- C. HS^- and S^{2-}
- D. H_2O and OH^-

___5) According to the Brønsted-Lowry Theory, which of the following consists of species that can all act as bases?

- A. HAc , H_3PO_4 , H_2O
- B. Ac^- , PO_4^{3-} , H_2O
- C. HAc , H_2PO_4^- , OH^-
- D. Ac^- , PO_4^{3-} , NH_4^+

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___6) The unbalanced redox reaction displayed below occurs in what type of condition?



- A. Acidic condition
- B. Basic condition
- C. Neutral
- D. Indeterminable

___7) Aqueous solutions of bases F^- , CN^- and HCOO^- are prepared with the same concentration. Which of the following correctly orders the solutions in terms of alkalinity?

(pK_a for $\text{HF} = 3.18$, pK_a for $\text{HCN} = 9.21$, and pK_a for $\text{HCOOH} = 3.74$.)

- A. $\text{F}^- > \text{CN}^- > \text{HCOO}^-$
- B. $\text{CN}^- > \text{HCOO}^- > \text{F}^-$
- C. $\text{CN}^- > \text{F}^- > \text{HCOO}^-$
- D. $\text{F}^- > \text{HCOO}^- > \text{CN}^-$

___8) Which of the following indicates that CH_3COOH must be a weak acid?

- A. It dissolves in water.
- B. Under room temperature, a 0.1 mol/L CH_3COOH solution contains 1.32×10^{-3} mol/L of H^+ ions.
- C. It can turn litmus paper red.
- D. It can be neutralized with an ammonia solution, which is a weak base.

___9) At 100 °C, the ionic product of water is 1×10^{-12} . If the concentration of H^+ ions in a specific solution is 1×10^{-7} M at this temperature, then this solution is...

- A. acidic
- B. neutral
- C. basic
- D. none of the above

___10) Refer to the solution in question 10. Which of the following statements about the concentrations of H^+ and OH^- ions in this solution is correct?

- A. $[\text{H}^+] = 100[\text{OH}^-]$
- B. $[\text{H}^+] = 10[\text{OH}^-]$
- C. $[\text{H}^+] = [\text{OH}^-]$
- D. $[\text{OH}^-] = 100[\text{H}^+]$

___11) Which of the following solution(s) has/have a pH lower than 7?

- I. Human blood
- II. Orange juice
- III. Sucrose solution
- IV. Gastric juice

- A. II only
- B. II and IV
- C. I, II and IV
- D. II, III and IV

___12) A solution of a strong base with pH = 13 is mixed together with a solution of a strong acid with pH = 2. The resulting solution has a pH of 11. What is the ratio of the volumes of strong base solution and strong acid solution added?

- A. 11 : 1
- B. 9 : 1
- C. 1 : 11
- D. 1 : 9

___13) At room temperature, which of the following solution pairs must have a pH greater than 7 after mixing an equal volume of each together?

- I. 0.1M hydrochloric acid and 0.1M sodium hydroxide solution
- II. 0.1M hydrochloric acid and 0.1M barium hydroxide solution
- III. Acetic acid with pH = 4 and sodium hydroxide solution with pH = 10
- IV. Hydrochloric acid with pH = 4 and ammonia water with pH = 10

- A. I and III
- B. I and IV
- C. II and III
- D. II and IV

___14) When titrating ammonia water with sulfuric acid, which indicator should be used?

- A. Methyl orange
- B. Litmus
- C. Phenolphthalein
- D. Any of the above

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Part II: Open Response (72 pts)

1. Complete the table. (8 pts total, 1 pt each)

Acid	H_2O	H_3O^+	H_2PO_4^-	HCO_3^-
Conjugate Base	OH^-	H_2O	HPO_4^{2-}	CO_3^{2-}
Acid	NH_4^+	$\text{NH}_3^+\text{CH}_2\text{COO}^-$	$[\text{Al}(\text{H}_2\text{O})_6]^{3+}$	HS^-
Conjugate Base	NH_3	$\text{NH}_2\text{CH}_2\text{COO}^-$	$[\text{Al}(\text{H}_2\text{O})_5\text{OH}]^{2+}$	S^{2-}

2. Determine which of the following are Lewis acids and which are Lewis bases:

H^+ , F^- , OH^- , Cu^{2+} , $\text{C}_2\text{O}_4^{2-}$, BF_3 , H_2O , SO_3 (8 pts)

a) Lewis acids: (4 pts total, 0.5 for correctly including or NOT including a species)

H^+ , Cu^{2+} , BF_3 , H_2O , SO_3

b) Lewis bases: (4 pts total, 0.5 for correctly including or NOT including a species)

F^- , OH^- , $\text{C}_2\text{O}_4^{2-}$, H_2O

3. Draw the Lewis dot structure of each of the following anions, then order them in terms of relative basic strength. Explain your reasoning using the Lewis dot structures you draw. (7 pts)

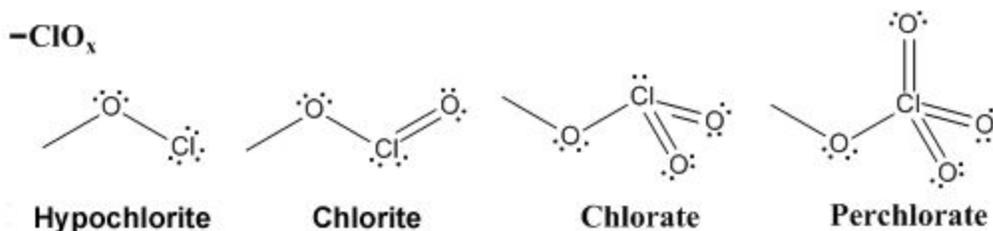
① ClO^-

② ClO_2^-

③ ClO_3^-

④ ClO_4^-

Lewis Structure: (1 pt each, 4 pts total)



Order: (1 pt) ① ClO^- > ② ClO_2^- > ③ ClO_3^- > ④ ClO_4^-

Explanation: (2 pts)

The more oxygen atoms present, the higher the electron delocalization there is in the anion. (1 pt)

The more delocalized the electrons are, the more stable the anion is and the less likely it will donate electrons, lowering its basicity.

OR

The more delocalized the electrons are, the weaker the pull on H^+ its conjugate acid has, increasing the acidity of the conjugate acid. The stronger the conjugate acid, the weaker the base. (1 pt)

4. At 25 °C, an HCl solution has $pH = x$, and a NaOH solution has $pH = y$. Use V_x L HCl to neutralize V_y L NaOH. (5 pts)

HCl with $pH = x$: $[HCl] = [H^+] = 10^{-x} M$

NaOH with $pH = y$: $[H^+] = 10^{-y} M$, $[NaOH] = [OH^-] = 10^{y-14} M$

Neutralization: $V_x \times 10^{-x} = V_y \times 10^{y-14}$, so $\frac{V_x}{V_y} = 10^{x+y-14}$

a) If $x + y = 13$, then $\frac{V_x}{V_y} = \underline{\hspace{2cm}0.1\hspace{2cm}}$ (a number);

b) If $x + y = 14$, then $\frac{V_x}{V_y} = \underline{\hspace{2cm}1\hspace{2cm}}$ (a number);

c) If $x + y = 15$, then $\frac{V_x}{V_y} = \underline{\hspace{2cm}10\hspace{2cm}}$ (a number);

d) If $x + y > 14$, then $\frac{V_x}{V_y} = \underline{\hspace{2cm}10^{x+y-14}\hspace{2cm}}$ (an expression containing x and y), and $V_x \underline{\hspace{2cm}} > \underline{\hspace{2cm}} V_y$ (" $>$," " $<$ " or " $=$ ").

5. The nitrogen content of nitrogen fertilizers or soil can be determined by acid-base titration. Weigh 0.2000 g of the nitrogen fertilizer ammonium chloride and place it in a flask. Add distilled water to dissolve the ammonium chloride, then add excess concentrated NaOH. Heat the solution and guide the ammonia gas produced into 40.00 mL of 0.1004M sulfuric acid solution to be absorbed. Titrate the remaining sulfuric acid with 0.1600M standardized NaOH. The standardized NaOH solution consumed is 20.11 mL. (7 pts)

a) Write out the equation for the titration reaction. (1 pt)



b) How many mmol of NaOH is consumed in the titration? (2 pts)

$$20.11 \text{ mL} \times 0.1600 \text{ mol/L} = \mathbf{3.218 \text{ mmol}}$$

c) How many mmol of H_2SO_4 is consumed to absorb ammonia gas? (2 pts)

$$(40.00 \text{ mL} \times 0.1004 \text{ mol/L}) - (3.218 \text{ mmol} / 2) = \mathbf{2.407 \text{ mmol}}$$

d) What is the mass fraction of nitrogen in the nitrogen fertilizer sample? (2 pts)

$$2.407 \text{ mmol} \times \frac{1 \text{ mol}}{1000 \text{ mmol}} \times 14.00 \text{ g/mol} = 0.03370 \text{ g}$$

$$\frac{0.03370 \text{ g}}{0.2000 \text{ g}} \times 100\% = \mathbf{16.85\%}$$

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6. Lactic acid $\text{HC}_3\text{H}_5\text{O}_3$, the end product of glycolysis, can cause muscle fatigue and acidosis when accumulated in the human body. Given that $K_a = 1.4 \times 10^{-4}$ for lactic acid, calculate the pH of a 1.0×10^{-3} M lactic acid solution. (3 pts)

Note: Since K_a is big, the assumption does not hold and the shortcut formulas cannot be used.

R	HA	+	H_2O	\rightleftharpoons	A^-	+	H_3O^+
I	1.0×10^{-3}		-		0		0
C	-x		-		+x		+x
E	$1.0 \times 10^{-3} - x$		-		x		x

(1 pt)

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

$$1.4 \times 10^{-4} = \frac{x^2}{1.0 \times 10^{-3} - x}, \quad x = 3.1 \times 10^{-4} \quad (1 \text{ pt})$$

$$\text{pH} = -\log(x) = \mathbf{3.51} \quad (1 \text{ pt})$$

7. Mix 50.00 mL of 0.10M HA solution with 20.00 mL of 0.10M KOH solution and dilute the resulting solution to 100.0 mL with water. The pH of the final solution is 5.25. What is the dissociation constant of the weak acid HA? (4 pts)



Because of the existence of excess HA, a HA-KA buffer solution is formed.

$$[\text{HA}] = \frac{0.10\text{M} \times 50.00 \text{ mL} - 0.10\text{M} \times 20.00 \text{ mL}}{100.0 \text{ mL}} = 0.030\text{M} \quad (1 \text{ pt})$$

$$[\text{A}^-] = \frac{0.10\text{M} \times 20.00 \text{ mL}}{100.0 \text{ mL}} = 0.020\text{M} \quad (1 \text{ pt})$$

$$[\text{H}_3\text{O}^+] = 10^{-5.25} = 5.6 \times 10^{-6} \text{ M} \quad (1 \text{ pt})$$

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} = \frac{5.6 \times 10^{-6} \times 0.020}{0.030} = 3.7 \times 10^{-6} \quad (1 \text{ pt})$$

8. A group of students plans to determine the acid content (g/100 mL) of vinegar (CH_3COOH) using acid-base titration. (12 pts)

Materials

500 mL white vinegar sample

0.1000M standardized NaOH solution

Distilled water

0.1% methyl orange solution

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0.1% methyl red solution

0.1% bromothymol blue solution

0.1% phenolphthalein solution

...

Procedure

- I. Take 10 mL of white vinegar sample and place it in a 100 mL beaker. Add distilled water (boil to remove CO₂ and cool quickly) to the 100 mL mark and stir to get the diluted vinegar solution to be tested.
- II. Place 20.00 mL of vinegar solution in a B (letter) to be titrated. (1 pt)
 - A. Beaker
 - B. Erlenmeyer flask
 - C. Volumetric flask
 - D. Graduated cylinder
- III. Add 3 drops of the indicator solution to the vinegar solution.
- IV. Rinse the buret thoroughly with distilled water and 0.1000M NaOH.
- V. Fill the buret to the 0.00 mL mark with the 0.1000M NaOH. Record the initial volume of standardized NaOH solution.
- VI. Titrate the vinegar solution with NaOH, and record the volume of NaOH at the end point. Repeat the titration for 2-3 times.

Data

Titration of vinegar with 0.1000M NaOH

	Trial 1	Trial 2	Trial 3
V _{sample} (mL)	20.00	20.00	20.00
V _i of NaOH (mL)	0.00	0.20	0.10
V _f of NaOH (mL)	14.98	15.20	15.12

Analysis

a) What is the molarity of CH₃COOH in the white vinegar sample? (3 pts)



$$\text{Trial 1: } \frac{(14.98 \text{ mL} - 0.00 \text{ mL}) \times 0.1000\text{M}}{20.00 \text{ mL}} = 0.07490\text{M} \quad (1 \text{ pt for getting one trial})$$

$$\text{Trial 2: } \frac{(15.20 \text{ mL} - 0.20 \text{ mL}) \times 0.1000\text{M}}{20.00 \text{ mL}} = 0.07500\text{M}$$

$$\text{Trial 3: } \frac{(15.12 \text{ mL} - 0.10 \text{ mL}) \times 0.1000\text{M}}{20.00 \text{ mL}} = 0.07510\text{M}$$

$$[\text{CH}_3\text{COOH}]_{\text{solution}} = (0.07490\text{M} + 0.07500\text{M} + 0.07510\text{M}) / 3 = 0.07500\text{M} \quad (1 \text{ pt})$$

$$M_1V_1 = M_2V_2$$

$$[\text{CH}_3\text{COOH}]_{\text{sample}} = \frac{0.07500\text{M} \times 100 \text{ mL}}{10 \text{ mL}} = 0.7500\text{M} \quad (1 \text{ pt})$$

b) What is the acid content (g/100 mL) of the white vinegar sample? (1 pt)

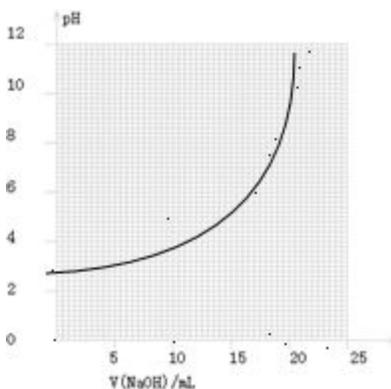
$$\frac{0.7500 \text{ mol}}{1 \text{ L}} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{60.05 \text{ g}}{1 \text{ mol}} \times 100 \text{ mL} = 4.538 \text{ g/100 mL}$$

c) When a student titrated a different sample of white vinegar with 0.1000M NaOH, he recorded the change in pH of the solution in the following table using a pH probe.

Volume of NaOH added and pH

V_{NaOH} (mL)	0.00	10.00	18.00	19.80	19.98	20.00	20.02	20.20	22.00
pH	2.88	4.70	5.70	6.74	7.74	8.72	9.70	10.70	11.70

i) Sketch a titration curve for this titration by plotting the data. (2 pts)



Axes - labels + V_{NaOH} on the x-axis and pH on the y-axis (1 pt)

Plot all data points correctly and sketch the curve (1 pt)

ii) From the table and the graph, the pH range for the equivalence point is 7.74-9.70. (1 pt)

iii) Referring to the table below, if an indicator is to be used, the student should choose phenolphthalein. The color pink will signify the end point. (2 pts)

Indicators

Indicator	Colors		pK _a	pH Range
	In acidic solution	In basic solution		
Methyl Orange	Red	Yellow	3.7	3.2-4.4
Methyl Red	Red	Yellow	5.1	4.8-6.0
Bromothymol Blue	Yellow	Blue	7.0	6.0-7.6
Phenolphthalein	Colorless	Pink	9.4	8.2-10.0

Error analysis

While rinsing the buret with distilled water and NaOH, if a student did not run the 0.1000M NaOH through the tip, and some distilled water was left in the tip, how would his calculated concentration of vinegar solution deviate from the actual concentration? Explain. (2 pts)

The student's calculated concentration will be higher than the actual concentration. (1 pt)

The distilled water left in the tip dilutes the standardized NaOH solution in the buret. Thus, a larger volume of NaOH would be needed to reach the end point, and the calculated concentration of vinegar would be higher. (1 pt)

9. For systems with non-aqueous solvents, it is meaningless to use pH. However, for some protic solvents similar to water, we can define "pH" similarly using the solvent's acid-base reactions. For instance, in liquid ammonia, we define $pA = p[NH_4^+]$, $pB = p[NH_2^-]$. (18 pts)

It has been discovered that at 223K, the autoionization of liquid ammonia has the equilibrium constant $K_s = 1.9 \times 10^{-30}$.

a) In a liquid ammonia solution at 223K, if the system is "neutral," write out the value of pA. (2 pts)

$$[NH_4^+] \times [NH_2^-] = K_s;$$

When the solution is "neutral," $[NH_4^+] = [NH_2^-]$;

$$\text{So } [NH_4^+] = \sqrt{K_s} = \sqrt{1.9 \times 10^{-30}} = 1.4 \times 10^{-15}; \text{ (1 pt)}$$

$$pA = -\log[NH_4^+] = \mathbf{14.86}. \text{ (1 pt)}$$

b) Many weak acids in water, such as CH_3COOH and HCN , have pK_a's differing by several orders of magnitude. However, in liquid ammonia they become strong acids of equivalent strength. Explain this phenomenon. (2 pts)

Since both CH_3COOH and HCN are stronger acids than NH_4^+ , when the acid

concentration is not too high they both completely dissociate in liquid ammonia.
(1 pt)

All acids that completely dissociate are levelled to the strength of NH_4^+ ion which is left in solution and is common to all such solutions. (Leveling effect) (1 pt)

c) Urea (H_2NCONH_2) is a weak acid in liquid ammonia.

i) Write out the K_a expression for urea in liquid ammonia. (1 pt)

$$K_a = \frac{[\text{H}_2\text{NCONH}^-][\text{NH}_4^+]}{[\text{H}_2\text{NCONH}_2]}$$

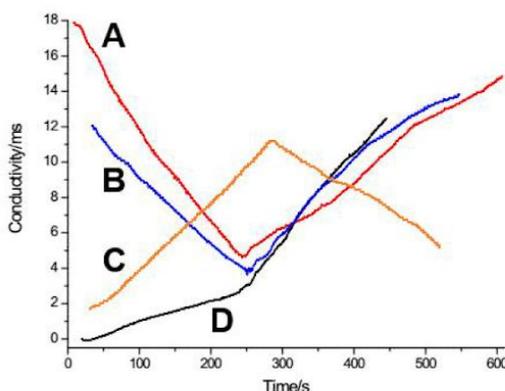
*Including $[\text{NH}_3]$ in the expression or writing $[\text{NH}_4^+]$ as $[\text{H}^+]$ will not earn points.

ii) Given that $K_a = 2.39 \times 10^{-15}$ for urea in 223 K liquid ammonia, what is the pA of 0.100M urea-liquid ammonia solution? (2 pts)

$$[\text{NH}_4^+] = \sqrt{cK_a} = 1.55 \times 10^{-8} \text{ M (1 pt)}$$

$$\text{pA} = -\log[\text{NH}_4^+] = \mathbf{7.810} \text{ (1 pt)}$$

d) Take 20.00 mL of urea-liquid ammonia solution with unknown concentration at 223K and conduct a conductometric titration with 0.02179M NaNH_2 liquid ammonia solution at constant temperature. The conductivity of the solution over time is recorded in the graph below.



i) Identify which of the four conductometric titration curve (A, B, C, D) belongs to the titration of urea with NaNH_2 . (1 pt) **D**

Explanation (NOT required for credit): since urea is a weak acid in liquid ammonia, the initial conductivity should be relatively low due to the low $[\text{NH}_4^+]$ obtained during dissociation of urea. Upon adding the strong base NaNH_2 , the conductivity first decreases slightly with consumption of NH_4^+ but soon increases slowly as NaNH_2 neutralizes the undissociated H_2NCONH_2 to NaNHCONH_2 , which is a strong

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electrolyte. After the equivalence point is reached, the conductivity increases rapidly due to the excess of highly conducting NH_2^- ions.

* This is comparable to a weak acid-strong base conductometric titration in water, such as the titration of acetic acid with NaOH.

ii) When the rate of change in conductivity suddenly changes, the volume of the standardized solution added is 18.75 mL. Calculate the pA at this moment and the concentration of the urea-liquid ammonia solution tested. (5 pts)

Neutralization: $\text{H}_2\text{NCONH}_2 + \text{NaNH}_2 \rightarrow \text{NaHNCONH}_2 + \text{NH}_3$ (1 pt)

When the rate of change in conductivity suddenly changes, the equivalence point is reached.

$$\text{Concentration of urea} = \frac{(0.02179\text{M} \times 18.75\text{ mL})}{20.00\text{ mL}} = \mathbf{0.02043\text{M}} \quad (1\text{ pt})$$

(mol H_2NCONH_2 = mol NaNH_2 .)

At the equivalence point, all H_2NCONH_2 has been converted to NaHNCONH_2 .

mol NaHNCONH_2 = mol H_2NCONH_2 = mol NaNH_2 .

$$[\text{NaHNCONH}_2] = \frac{(0.02179\text{M} \times 18.75\text{ mL})}{(20.00\text{ mL} + 18.75\text{ mL})} = 0.01054\text{M} \quad (1\text{ pt})$$

$\text{NaHNCONH}_2 \rightarrow \text{Na}^+ + \text{H}_2\text{NCONH}^-$

$c = [\text{H}_2\text{NCONH}^-] = [\text{NaHNCONH}_2] = 0.01054\text{M}$

$$\text{pA} = \text{pK}_s - \text{pB} = -\log K_s + \log \sqrt{cK_b} = -\log K_s + \frac{1}{2} \log(c \frac{K_s}{K_a}) = \mathbf{21.18} \quad (2\text{ pts})$$

iii) Calculate the volume of standardized solutions added when the solution is titrated to the "neutral" state. (5 pts)

From part f) we know that the solution is "basic" at the equivalence point.

Therefore, the solution reaches the state of being "neutral" before the equivalence point is reached. At this moment, there is excess acid and inadequate base in the solution. The solution is hence a buffer system with liquid ammonia as solvent.

$$\text{pA} = \text{pK}_a + \log \frac{[\text{H}_2\text{NCONH}^-]}{[\text{H}_2\text{NCONH}_2]} \quad (1\text{ pt})$$

Since the two species share the same volume, their ratio in concentration is equal to their ratio in moles.

$$\text{Hence pA} = \text{pK}_a + \log \frac{c_1 V_1}{C_0 V_0 - c_1 V_1} \quad (2\text{ pts}),$$

where c_0 = initial concentration of urea, V_0 = initial volume of urea,

c_1 = concentration of NaNH_2 , V_1 = volume of NaNH_2 added

(mol H_2NCONH^- = mol NaHNCONH_2 = mol NaNH_2 = $c_1 V_1$)

Given: $pK_a = -\log(2.39 \times 10^{-15}) = 14.622$; $V_0 = 20.00 \text{ mL}$; $c_1 = 0.02179 \text{ M}$

From part a): the "neutral" $pA = 14.86$

From part f): $c_0 = 0.02043 \text{ M}$

Solve the equation: $V_1 = \frac{c_0 V_0}{c_1} \times \frac{10^{pA - pK_a}}{1 + 10^{pA - pK_a}} = \mathbf{12 \text{ mL}}$ (2 pts)

e) Nonaqueous titrations such as that with liquid ammonia have important uses in testing some organic compounds. However, choosing the appropriate solvent and technique has decisive impact on the feasibility and accuracy of such tests.

i) **(Tiebreaker #2, +2 pts)** To determine the content of pyridine in a substance, should perchloric acid-glacial acetic acid solution or ethylenediamine (EDA) be chosen as the solvent? Explain your reasoning.

Perchloric acid-glacial acetic acid solution (1 pt)

Pyridine is a weak base and should be titrated with an acidic substance. Therefore, a basic solvent (EDA) is not suitable for the titration. (1 pt)

ii) **(Tiebreaker #4, +1 pt)** Conductometric methods are usually not suitable to be used in redox titrations with nonaqueous solvents. Why?

Redox titrations often require the introduction of many other substances into the reacting system to complete, causing the system's change in conductivity to be not as

obvious and thus making it difficult to determine the endpoint if conductometric methods are used.

Section 2: Aqueous Solutions (100 Points) - by Mukundh Murthy

Part I: Multiple Choice (2 pts each, 28 pts total)

___ 1) Which of the following salts are soluble?

- a) Hg_2Cl_2
- b) HgCl_2
- c) PbCl_2
- d) None of the above

___ 2) A substance is soluble if its...

- a) Heat of solution > Lattice Energy
- b) $|\text{Enthalpy of hydration}| > \text{Heat of solution}$
- c) $|\text{Enthalpy of hydration}| > \text{Lattice Energy}$
- d) Lattice Energy > Heat of solution

___ 3) A solution of which of the following ions has a green color?

- a) Cr^{3+}
- b) Mn^{2+}
- c) Ni^{2+}
- d) Ag^+

___ 4) Adding a solution of HCl to a solution of $\text{Co}(\text{H}_2\text{O})_6$ will turn it...

- a) Blue
- b) Pink
- c) Purple
- d) Green

___ 5) A solution containing an unknown solute has an absorbance of 0.224. 10.11 milligrams of the substance are dissolved to form 64 mL of solution. If the molar absorptivity constant of the substance is $2240. \text{ L} \cdot \text{ mol}^{-1}\text{cm}^{-1}$, which of the following substances is most likely the unknown solute?

- a) KMnO_4
- b) ZnSO_4
- c) $[\text{Fe}(\text{SCN})_2]\text{Cl}_2$
- d) Tetraammonium copper (II) sulfate

Questions 6-7 are both related to the insoluble compound silver chloride.

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___6) Which of the following changes in conditions will increase the solubility of AgCl at room temperature?

- I. Bubbling gaseous ammonia into the solution
- II. Adding concentrated HNO₃

- a) I
- b) II
- c) I and II
- d) Neither I nor II

___7) Which of the following equilibrium constants provides an explanation to the correct answer for the question above?

- a) K_c
- b) K_a
- c) K_{sp}
- d) K_f

___8) The main difference between colloids, suspensions, and solutions is...

- a) Particle size
- b) Particle composition
- c) Particle polarity
- d) Density of the added particles

___9) Henry's Law states that...

The van't Hoff factor of a weak acid can be between two integers, since a weak acid only partially dissociates.

- a) Positive deviations from Raoult's law result in a higher than normal vapor pressure.
- b) Like dissolves like (Polar dissolves polar and nonpolar dissolves nonpolar)
- c) The amount of gas dissolved is directly proportional to its partial pressure above the solution.

___10) Which of the following pairs of compounds are miscible?

- a) *cis*-dichloroethene and *trans*-dichloroethene
- b) Lithium sulfate and Carbon tetrachloride
- c) *trans*-dichloroethene and Carbon tetrachloride
- d) *cis*-dichloroethene and lithium sulfate

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___11) Which of the following solutions will have the highest boiling point at STP?

- a) 0.03m CaCl_2
- b) 0.10m NaCl
- c) 0.03m $\text{Ca}_3(\text{PO}_4)_2$
- d) 0.06m PCl_5

___12) Of the following units, which unit is not interconvertible with all of the others?

- a) %w/w (percent weight/mass)
- b) Molality
- c) Molarity
- d) Mole fraction (Assume there are only two components to the solution)

___13) In order for selective precipitation to be most efficient, one must precipitate different metal ions in which of the following orders?

- I. Insoluble Phosphates
- II. Insoluble chlorides
- III. Base-insoluble sulfides
- IV. Acid-insoluble sulfides

- a) I, II, III, IV
- b) II, IV, III, I
- c) II, III, IV, I
- d) I, III, II, IV

___14) Which of the following ions are hydrated to the largest extent?

- a) Li^+
- b) Mg^{2+}
- c) Al^{3+}
- d) Na^+

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Part II: Open Response (72 pts)

1) You're extremely bored in lab, and so you obtain a solution of sulfuric acid to see if you can boil it down and get it in a solid, crystalline form. There are 0.500 mol of H_2SO_4 dissolved in a beaker. (15 points)

a) (1 pt) What laboratory technique are you about to try and use to obtain the solid form of sulfuric acid? **No partial credit: Distillation/(Fractional Distillation)**

b) (3 pts) The weight of the solution with the flask is 153.47 g. If the flask weighs 46.23 g, find χ_{H_2O} (M).

- **Find the weight of the solution (0.25 pt):** $153.47\text{g} - 46.23\text{g} = 107.24\text{g}$
- **Subtract the mass of sulfuric acid from the mass of the solution (0.5 pt):** $107.24\text{g} - (0.500\text{ mol} * 98.076 \frac{\text{g}}{\text{mol}}) = 58.2\text{g}$
- **Find the number of moles of water (0.5 pt):** $\frac{58.2\text{g}}{18.016 \frac{\text{g}}{\text{mol}}} = 3.23\text{ mol}$
- **Use the formula for mole fraction to find χ_{H_2O} (1.75 pts):**
 - $\chi_{H_2O} = \frac{\text{mol } H_2O}{(\text{mol } H_2O + \text{mol } H_2SO_4)}$
 - $\frac{3.23\text{ mol}}{(3.23\text{ mol} + 0.500\text{ mol})}$
 - 0.866

c) You keep boiling the solution down using the technique from part (a). After standing for a few hours, you realize that the solution has completely boiled off and there is nothing left in the flask! Fortunately, using a micropipette, you are able to salvage 7.8 μL of concentrated H_2SO_4 that have collected on the bottom of the flask! You skillfully perform a titration and determine that 280.8 μL of 1.0M NaOH are required to reach an endpoint. What is the final density of the concentrated H_2SO_4 solution in g/ml? (5 pts)

- $2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$
- **This is a strong acid-strong base titration with a 2:1 titrant to analyte ratio. Use the given information to find the grams of sulfuric acid.**

- $0.2808 \text{ mL} * 1.0\text{M} = 0.28 \text{ mmol}$ (1.25 pt)
- $\frac{0.28 \text{ mmol NaOH}}{2} = 0.14 \text{ mmol H}_2\text{SO}_4$ (1.25 pt)
- $1.4 * 10^{-4} \text{ mol H}_2\text{SO}_4 * 98.076 \frac{\text{g}}{\text{mol}} = 0.014 \text{ g H}_2\text{SO}_4$ (1.25 pt)
- $\frac{0.014 \text{ g H}_2\text{SO}_4}{7.8 * 10^{-3} \text{ ml}} = \frac{1.8\text{g}}{\text{ml}}$ (1.25 pt)

d) Use part of the information you calculated in part c to find the density of your original solution. (Assume the solution obtained in part c has reached its maximum concentration). (6 pts)

- **The trick in this problem is to use the density that you calculated for sulfuric acid (1.8 g/ml) to find the volume of the solution part a. (Volume of the solution = Volume sulfuric acid + volume water)**

- $\text{Volume water} = \frac{\text{mass}}{\text{density}} = \frac{1\text{ml}}{1.0\text{g}} * 58.2 \text{ g} = 58.2 \text{ ml}$ (1.0 pt)
- $\text{Volume sulfuric acid} = \frac{\text{mass}}{\text{density}} = \frac{1\text{ml}}{1.8\text{g}} * (0.500 \text{ mol} * 98.076 \frac{\text{g}}{\text{mol}}) = 27\text{ml}$
(3.0 pts)
- $58.2 \text{ ml} + 27 \text{ ml} = 85 \text{ ml}$ (1.0 pt)
- $\frac{107.24\text{g}}{85\text{ml}} = \frac{1.3\text{g}}{\text{ml}}$ (1.0 pt)

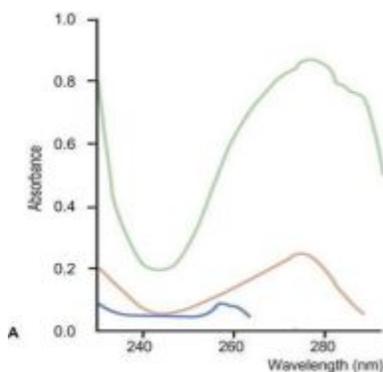
- **This answer makes sense as the original density is lower than the density of the sulfuric acid solution at its maximum concentration. (1.3 g/ml vs 1.8 g/ml)**

e) Also known as a “constant boiling point mixture,” what type of solution explains the experimental results obtained in part d? How do the properties of this type of solution show that acids can never be obtained as a solid, but only as highly concentrated liquids? (Tiebreaker #1, 5 Pts).

- **An Azeotrope is a mixture of two or more liquids (0.5 pt). The composition/concentration of an azeotrope throughout distillation remains the same, since the vapor released by the solution has the same composition as the**

solution itself (1.5 pts); therefore, the proportions of various components within the solution will not be altered (1.5 pts). Thus, since a solution of sulfuric acid at its maximum concentration behaves as an azeotrope (0.75 pts), it cannot be concentrated any further, and can be regarded as "pure." (0.75 pts)

2) Color and Spectrophotometry: Tyrosine, Tryptophan, and Phenylalanine are three amino acids out of the twenty with special optical properties that majorly contribute to the absorbance of specific wavelengths by proteins. You are analyzing two solutions. One of the solutions contains tryptophan and the other contains tyrosine. Unfortunately, you forget to label the two solutions! Fortunately, using a mass spectrophotometer, you obtain a graph of Absorbance vs. wavelength online, and you use this, in conjunction with other data that you collected, to figure out which solution is which. **For all the problems below, assume the length of the cuvette is 1.00 cm.** (10 points)



a) Circle the wavelength at which Tryptophan and Tyrosine transmit the most light. This wavelength falls in the range of what type of light? **240 nm (0.5 pt) (UV light) (0.5 pt)**

b) A 0.678mM solution of tryptophan has an absorbance of 3.729. What is its molar extinction coefficient in $M^{-1}cm^{-1}$. **$5.50 * 10^3 M^{-1} cm^{-1}$**

- **Absorbance = molar extinction coefficient * concentration (in M) * length of cuvette (1 pt)**
- **$3.729 = \epsilon * 0.000678M * 1.00cm$ (0.5 pt)**
- **$\epsilon = 5.50 * 10^3 M^{-1} cm^{-1}$ (0.5 pt)**

c) If a solution consisting of 2.038 mg of tyrosine (MM = 181.19g/mol) dissolved in 50.00 ml of water has a transmittance of 46.2%, what is the intensity (I) of light passing through a 0.368mM solution of tyrosine if the initial light intensity is 25 W/m². 14 $\frac{W}{m^2}$

- **First, you must find the absorbance of the first solution (1 pt)**
 - $A = 2 - \log (\%T)$
 - $A = 2 - \log (46.2)$
 - $A = 0.335$
- **Now, find the molar extinction coefficient. (2pt)**
 - $A = \epsilon cl$
 - **Find the concentration:**
 - $2.028 * 10^{-3}g * (\frac{1mol}{181.19g}) = 1.119 * 10^{-5} mol$
 - $1.119 * 10^{-5} mol / 0.05000 L = \frac{1.119 * 10^{-5}mol}{0.05000L} = 2.239 * 10^{-4} M$
 - $0.335 = \epsilon * 2.239 * 10^{-4}M * 1.00cm$
 - $\epsilon = 1.50 * 10^3 M^{-1}cm^{-1}$
- **Find the absorbance of the new solution (1pt)**
 - $A = 1.50 * 10^3 M^{-1}cm^{-1} * 3.68 * 10^{-4}M * 1.00cm$
 - 0.552
- **Use the relationship $A = (I/I_0)$ (1pt)**
 - $0.552 = \frac{I}{25W/m^2}$
 - $\frac{14W}{m^2}$

d) Based on molar extinction coefficients that you calculated in parts b and c, which line (Blue, green, or orange) represents tryptophan and which one represents tyrosine? Be sure to **explain** your answer.

- **The green line represents tryptophan (1.0 pts) and the orange line represents tyrosine (1.0 pts).** Since tryptophan has a higher molar absorptivity constant, it absorbs more light than tyrosine at the same wavelength, as evidenced by the graph. (Neither amino acid is represented by the blue line because the blue line does not absorb a significant amount of light).

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3) How many milligrams of magnesium phosphate can be dissolved in 15L of solution if the pH of the solution is 13.00. $K_{sp}(\text{Mg}_3(\text{PO}_4)_2) = 1.0 * 10^{-25}$. For H_3PO_4 , $K_{a1} = 7.1 * 10^{-3}$, $K_{a2} = 6.3 * 10^{-8}$, $K_{a3} = 4.5 * 10^{-13}$. (7 pts)

$$\circ K_{sp} = [\text{Mg}^{2+}]^3[\text{PO}_4^{3-}]^2 = 1.0 * 10^{-25}$$

$$\circ K_{sp} = [3s]^3[2s]^2 = 1.0 * 10^{-25} \text{ (1 pt)}$$

- **But**, we must take into account this equilibrium, since PO_4^{3-} is a relatively strong base with a high K_b .

$$\bullet [3s]^3[2s-x]^2 = 1.0 * 10^{-25}$$

- Let's find the K_b ,

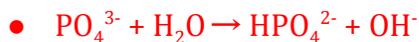


$$K_b = \frac{K_w}{K_{a3}}$$

$$K_b = \frac{1.0 * 10^{-14}}{4.5 * 10^{-13}}$$

$$K_b = 0.021$$

- Let's make an ICE table.



Initial	2s	N/A	0	0.10
Change	- x	N/A	+x	+x
Equilibrium	2s - x	N/A	+x	0.10+x

$$\bullet K_b = \frac{x(0.10+x)}{2s-x} = 0.021$$

- $0.022 = \frac{(0.10)x}{2s}$
- $x = 0.44s$ (3 pts)
- Now, let's use this value of x and plug it back into our original equation.
 - $[3s]^3[2s-0.44s]^2 = 1.0 * 10^{-25}$
 - $65.7s^5 = 1.0 * 10^{-25}$
 - $s = 4.3 * 10^{-6} \text{ M}$ (2 pts)
- Now, we have to find the # of milligrams that will dissolve in 15 Liters given the concentration that we just found. (1 pt)
 - $4.3 * 10^{-6} \text{ M} * 15\text{L} = 6.5 * 10^{-5} \text{ mol}$
 - $6.5 * 10^{-5} \text{ mol} * 262.86 \frac{\text{g}}{\text{mol}} = 0.017 \text{ g}$
 - $0.017 \text{ g} * 1000 = 17 \text{ mg}$

4) Based on the following clues, write the chemical name of compound X, which is formed by adding 0.3993 grams of $\text{Cr}(\text{NO}_3)_3$ to a 100. mL solution HCl. (10 pts)

a) In complex ions, the coordination number of the transition metal is often twice its oxidation number, as it is in compound X. What is the coordination number of chromium in compound X? (1 pt). 6

b) All ligands are monodentate. What are two possible ligands that are attached to chromium in compound X?

- Ligand 1: Water, H_2O
- Ligand 2: Chloride, Cl^-

c) When 0.0541 grams of Compound X are heated in excess O_2 , 0.0203 g of CrO_3 are formed. What is the molar mass of compound X?

- This is a redox reaction where O_2 is reduced to O^{2-} and Chromium is oxidized to Cr^{3+} .

- $\text{Cr}^{3+} + \text{O}_2 \rightarrow \text{CrO}_3$ (If you balance this redox reaction, which I am too lazy to do here : -), you will see that the molar stoichiometric ratio of Cr^{3+} to CrO_3 is still 1:1.
- **Find the # of moles of CrO_3**
- $$\frac{0.0203\text{g}}{\frac{100.00\text{g}}{\text{mol}}} = 0.000203 \text{ mol}$$
- $$\frac{0.0541\text{g}}{0.000203\text{mol}} = 266.50 \frac{\text{g}}{\text{mol}}$$

d) The percent mass of water in Compound X is 40.57% and the percent mass of chlorine is 39.91%. What is the empirical formula of Compound X? **(1.5 points) (no partial credit)**

- **Standard Empirical formula calculations**
 - Assume 100 grams of compound X
 - 40.57 grams H_2O = 2.252 mol H_2O
 - 39.91 grams Cl = 1.126 mol Cl
 - $100 - (40.57 + 39.91) \text{ g} = 19.52 \text{ g Cr} = 0.3754 \text{ mol Cr}$
 - $\text{CrCl}_3 * 6\text{H}_2\text{O}$

e) The boiling point of a 0.33m solution of Compound X is 100.52°C . What is the van't Hoff factor for Compound X? **(1.5 points) (Assume that the volume added to the solution by HCl is negligible). (no partial credit)**

- $\Delta T = iK_b m$
 - $0.52^\circ\text{C} = i * \frac{0.52^\circ\text{C}}{m} * 0.33m$
 - $i = 3$

f) Write out the name and chemical formula of compound X based on your answers to parts a-e above. **(2 points) (no partial credit)**

Formula: $[\text{Cr}(\text{H}_2\text{O})_5\text{Cl}]\text{Cl}_2 * \text{H}_2\text{O}$, Name: Pentaquachlorochromium(III) chloride monohydrate

- From part a - six ligands
- From part b - Cl^- and H_2O are possible ligands
- From part c - molar mass = 266.50 g/mol
- From part d - empirical formula = $\text{CrCl}_3 * 6\text{H}_2\text{O}$
- From part e - $i = 3$

- Based part e and the empirical formula you need to decide how many out of the three Cl⁻ ions in the molecular formula can be used as counterions. If two are used as counterions, then $i=3$.

5) Unit Conversions :) (5 questions, 1 points each) Convert each quantity from one unit to the other. If the conversion is not possible without additional information, draw an X next to the question.

a) 12 ppm Na₂SO₄ to Millimolarity (mM)

■ ppm converts to $\frac{\mu\text{g}}{\text{L}}$

- $12 \frac{\mu\text{g}}{\text{L}} * \frac{\text{g}}{10^6 \mu\text{g}} * \frac{\text{mol}}{142.04\text{g}} * \frac{1000 \text{ mmol}}{\text{mol}} = 8.4 * 10^{-5} \text{ mM}$
- -0.25 if M given instead of mM
- Quarter point for each conversion factor

b) 5.0 molar NaCl to Molality (m)

- X (not possible since you would need to know the density of NaCl)

c) Mole fraction of water = 0.896; Molality (m) = ...

■ $\chi_{\text{solute}} = 1 - \chi_{\text{solvent}} = 1 - 0.896 = 0.104$ (0.25 point)

■ $\chi_{\text{solute}} = \frac{0.104 \text{ mol solute}}{0.896 \text{ mol H}_2\text{O} + 0.104 \text{ mol solute}}$ (0.25 point)

■ Kg of solvent = $0.896 \text{ mol H}_2\text{O} * 18.016 \frac{\text{g}}{\text{mol}} * \frac{1\text{kg}}{1000\text{g}} = 0.0161 \text{ kg H}_2\text{O}$ (0.25 point)

■ Molality = $\frac{0.104 \text{ mol solute}}{0.0161 \text{ kg solvent}} = 6.46\text{m}$ (0.25 point)

d) Mole fraction of water = 0.643; Molarity (M) = ...

- X (again, you would need to know the density of the solute)

e) 14.5 %w/v Sodium hydroxide to Molarity (M) (no partial)

- $14.5 \frac{\text{g}}{\text{L}} * \frac{1\text{mol}}{40 \text{ g}} = 0.363 \text{ M}$

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6) Nomenclature/Solubility: Write the IUPAC name if the formula is given, and write the chemical formula if the name is given. Also write S if the compound is soluble, N if the compound is not soluble, and SS if the compound is marginally soluble (**4 pts total, 0.5-0.75 pt each**)

a) MgSO_4 **Magnesium Sulfate, S**

b) NaNO_2 **Sodium Nitrite, S**

c) $\text{Fe}(\text{ClO}_4)_3$ **Iron (III) perchlorate, S**

d) Aluminum hexafluoromanganate (II) (**0.75 points**) $\text{Al}_4(\text{MnF}_6)_3$, **S**

e) Butanal $\text{C}_4\text{H}_8\text{O}$ OR $\text{CH}_3(\text{CH}_2)_2\text{CHO}$, **SS (0.75 points)**

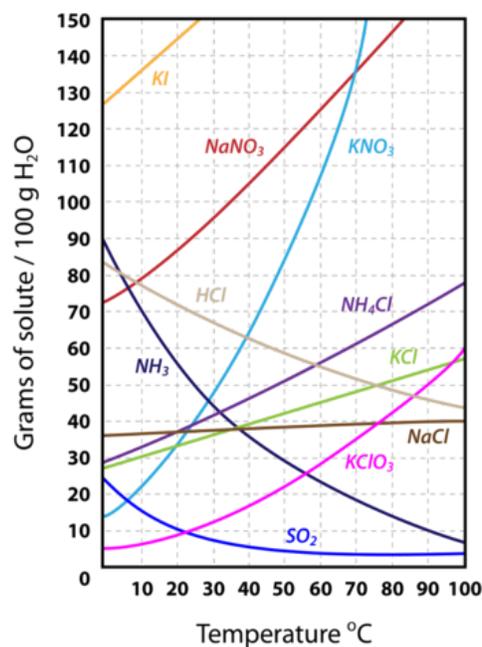
f) Manganese (II) hydroxide $\text{Mn}(\text{OH})_2$, **SS**

g) Sodium thiosulfate $\text{Na}_2\text{S}_2\text{O}_3$, **S**

7) Analyze the solubility curve below and answer the following questions.

a) Why does the solubility of HCl decrease as the temperature increases? Why is its solubility much greater than that of SO_2 at a given temperature? (**2 points**)

- HCl (hydrogen chloride) is a gas at STP. Gases are less soluble at higher temperatures due to the fact that their increased kinetic energies allow them to escape the solution more easily. (**1 point**)
- HCl is relatively more soluble than SO_2 , because while SO_2 is nonpolar due to canceling dipole moments, HCl has a relatively large dipole moment due to a large electronegativity difference between hydrogen and chlorine.



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Therefore HCl molecules are more easily hydrated by water and can thus more easily dissolve. (1 point)

b) Based on the curve, put the following salts in order from greatest relative solubility to least relative solubility: NH_4Cl , KCl , KNO_3 , KClO_3 , KI . (1 pt)

Relative solubility of salts (from greatest to least) KI , KNO_3 , NH_4Cl , KCl , KClO_3 .

Ionic radii of the following species (ClO_3^- , Cl^- , NH_4^+ , K^+) respectively: 171pm, 175pm, 175pm, 152pm.

c) Based on the information above regarding the radii of certain species and your knowledge of chemistry, explain the relative solubility of the salts in **part 2** as a result of their chemical properties. In other words, how might one be able to order the salts from greatest to least solubility **without using a solubility curve**? (*Be sure to include in your explanation the ideas of lattice energy, heat of solution, enthalpy of hydration, atomic radius, and electrostatic attractions.*) (5 pts)

- In this question, you must notice that all the salts except ammonium chloride have potassium as their cation, and only the anions are different.
 - You must explain that in terms of their radii $\text{I}^- > \text{NO}_3^- > \text{Cl}^- > \text{ClO}_3^-$ (1.5 pts)
 - Between NH_4Cl and KCl , $\text{NH}_4^+ > \text{K}^+$ (0.5 pt)
 - When the ions are smaller, the compound has a larger lattice energy (due to Coulomb's law). (1 pt)
 - In order for an ionic compound to dissolve, ions in the lattice must break apart into their gaseous state ions and these ions must be hydrated. Thus, there are two energies involved: the heat of solution and the enthalpy of hydration.
 - The energy required in order to break apart the lattice will be the opposite of the lattice energy. Therefore, more energy will be required to break apart lattices of compounds with atoms of smaller ionic radii, since their lattice energies are more negative. (1 pt)

- Consequently compounds w/ atoms of smaller ionic radii will have a more endothermic heat of solution since the exothermic enthalpy of hydration will not release enough energy to compensate for their negative lattice energies. **(1 pt)**

d) A saturated solution is formed by dissolving 39 grams of a substance in 50. mL of water at 280K. If the final solution is neutral and conducts electricity very well, what is the substance? **(1 pt)**

- 39 g in 50. ml → 78 g in 100. ml
- Could be ammonia, HCl, or NaNO_3
- The only compound that is neutral and conducts electricity is NaNO_3 .

e) 50 grams of a substance is dissolved in a solution at 358K. For a solution of each of the following compounds, would the solution be saturated, supersaturated, or unsaturated. Write S for saturated, SS for supersaturated and US for unsaturated. **(1 pt)**

- First convert from K to °C: $358 \text{ K} \rightarrow 85^\circ\text{C}$

KI **US** KClO_3 **SS** NaCl **SS** HCl **SS** **(0.25 points for each substance)**

8) **Tiebreaker #3:** What is the only substance for which its molarity **exactly** equals its molality. What is the molarity (or molality) of this substance? **(no partial)**

- The only substance for which molarity exactly equals molality is **water**. **(+1 pt)**
- To find the concentration of water in M/m, assume there is one liter of water.
- Using the density of water, we know that 1L of water contains 1000g of water.
- $1000\text{g} * \frac{1\text{mol}}{18.016\text{g}} = 55.5\text{mol}$
- $55.5\text{mol/L} = \mathbf{55.5 \text{ M}}$

9) **Qualitative analysis:** Qualitative analysis is a common technique used in chemistry to precipitate metal ions out of solution in a sequential order through the use of specific reagents that selectively precipitate the metal ions. **(10 points)**

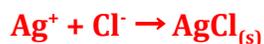
a) Imagine that you have a solution containing the following six ions. Using no more than 4 reagents given below, how might you separate these ions from each other? (Assume that these reagents are at their maximum concentration) Make sure to explain your reasoning and write important chemical reactions that are involved. **(6 points)**

Reagents available (at highest concentrations): NaOH, NH₃, EDTA, HCl, H₂S, Na₂CO₃

Ag⁺, Ba²⁺, Zn²⁺, Pb²⁺, Cu²⁺, Mn²⁺

Sample Answer (answers will vary): (1 point for each ion/group of ions separated. E.g. if the ions are separated into two groups of three, or one group of two and one group of four, only two points will be earned)

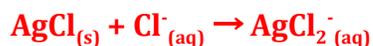
- 1) Use dilute hydrochloric acid to precipitate silver chloride and lead (II) chloride**



There are two possible ways to separate AgCl and PbCl₂ at this point (only one of these needs to be shown if this path is taken)

Heating the PbCl₂ will dissolve it while AgCl will remain insoluble.

OR, you can add concentrated HCl or NaCl, which will dissolve AgCl through a complexation reaction.



- 2) Add Sodium hydroxide to the solution of the four remaining ions. Ba(OH)₂ will remain in solution while all other three ions will precipitate as hydroxides.**

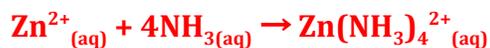


- 3) Add diluted hydrochloric acid with bubbled hydrosulfuric acid to the solution with the three remaining ions.**

Only Cu²⁺ will precipitate due to its classification as a Group II insoluble sulfide (in acidic solution)

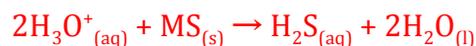
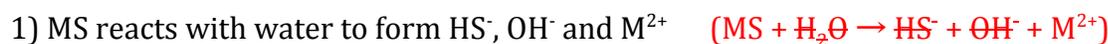


4) Bubble $\text{NH}_3(\text{g})$ into the remaining solution containing Zn^{2+} and Mn^{2+} . Zn^{2+} will complex with NH_3 while Mn^{2+} will precipitate out of solution due to the basic nature of NH_3 .



b) K_{spa} is an equilibrium constant that can be used in qualitative analysis to determine whether a metal sulfide will precipitate in acidic or basic solution. (2 points)

The constant is derived by the summation of three separate chemical equations. (MS represents a divalent metal sulfide)



What is the simplified equilibrium expression for K_{spa} given the three reactions above?

$$K_{\text{spa}} = \frac{[\text{M}^{2+}][\text{H}_2\text{S}]}{[\text{H}_3\text{O}^+]^2}$$

c) Q_{spa} is the same for all metal ions in solution given that their concentrations ($[\text{M}^{2+}]$) are all the same. If $[\text{M}^{2+}] = 0.010\text{M}$, $[\text{H}_2\text{S}] = 0.10\text{M}$, and $[\text{H}^+] = 0.30\text{M}$, what is the Q_{spa} for metal sulfides in this particular solution? (1 point)

Substitute into the equation above and $Q_{\text{spa}} = 1.1 * 10^{-2}$

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d) Based on the Q_{spa} that you calculated above, circle the two out of the four metal sulfides below that are soluble only in basic solution. **(2 points)**

Metal Sulfide	K_{spa}
CoS	3
FeS	600.
HgS	$6 \cdot 10^{-16}$
CuS	$2 \cdot 10^{-32}$

Since for HgS and CuS, $Q_{\text{spa}} > K_{\text{spa}}$, equilibrium will shift to the reactants side in acidic solution, which means that they will precipitate in acidic solution. On the other hand, in basic solution, they will be soluble.