

Name KEY

Last 5 digits of Student Number: XXX – X \_\_\_ – \_\_\_

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**Chem 116**  
**Sample Examination #3**

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This exam consists of eight (8) pages, including this cover page. Be sure your copy is complete before beginning your work. If this test packet is defective, ask for another one.

Copies of the “Periodic Table” and the “Table of Acids and Bases and  $K_a$  Values” are attached at the back of the exam. You may remove these and use the back sides of these tables as scratch paper. No work on scratch paper will be graded or collected.

The following information may be useful:

Constants of nature

$$K_w = 1.0 \times 10^{-14} \text{ at } 25 \text{ }^\circ\text{C}$$

Equations

$$\text{pH} = -\log [\text{H}_3\text{O}^+]$$

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DO NOT WRITE BELOW THIS LINE

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Part I:

Questions 1-6 \_\_\_\_\_ (maximum 24)

Question 7 \_\_\_\_\_ (maximum 4)

Question 8 \_\_\_\_\_ (maximum 6)

Question 9 \_\_\_\_\_ (maximum 10)

Part II:

Question 1 \_\_\_\_\_ (maximum 20)

Question 2 \_\_\_\_\_ (maximum 20)

Part III:

Lab question \_\_\_\_\_ (maximum 16)

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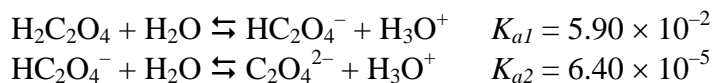
**Disclaimer:**

This is a copy of a typical Exam 3 given in Chem 116 during the academic year. Your test will be different. This test is being posted to give you a sense of the format, style, scope and level of a typical test on this material. This test may have questions on topics that may not be covered on your exam. Moreover, your test may have questions on topics not covered in this practice exam. Posting this test in no way limits the format, style, scope and level of the test that you will take. Do not limit your preparation to the material in this practice exam.

**Part I. Multiple-Choice or Short Response**

Points possible on each question are indicated in curly braces {...}. This part of the exam (Part I) is worth 44% of the exam grade.

- A 1. {4 pts} When the polyprotic acid, oxalic acid ( $\text{H}_2\text{C}_2\text{O}_4$ ), is added to water, it undergoes the following two-step dissociation process:



The majority of the hydronium ion concentration,  $[\text{H}_3\text{O}^+]$ , is produced in

- A) The first dissociation step  
 B) The second dissociation step  
 C) The amount that was present in the pure water prior to adding the oxalic acid  
 D) There is not enough information to tell

- B 2. {4 pts} A sample of 0.0200 moles of propanoic acid is added to 1.00 L of water. When the acid is fully dissolved and the solution comes to equilibrium, the solution is found to have a pH of 3.30. What is the value of  $K_a$  for propanoic acid?

- A)  $5.0 \times 10^{-4}$   
 B)  $1.3 \times 10^{-5}$   
 C)  $2.0 \times 10^{-2}$   
 D)  $3.3 \times 10^1$   
 E) There is not enough information to tell

pH = 3.30, so  $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 5.0 \times 10^{-4} \text{ M}$   
 From an I-C-E table,  

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} = \frac{x^2}{0.0200 - x} = \frac{(5.0 \times 10^{-4})^2}{(0.0200 - 0.00050)}$$
  

$$= 1.3 \times 10^{-5}$$

- E 3. {4 pts} Which of the following salts, if added to water in equal molar quantities, would produce the most acidic solution?

- A) KCl  
 B)  $\text{Na}_2\text{SO}_4$   
 C)  $\text{NH}_4\text{ClO}_4$   
 D)  $\text{ZnBr}_2$   
 E)  $\text{Cu}(\text{NO}_3)_2$

KCl has no weak acid or base as ions, so solution pH = 7 when added to water  
 $\text{Na}_2\text{SO}_4$  has  $\text{SO}_4^{2-}$  as a weak base that hydrolyzes to produce  $\text{OH}^-$ , so pH > 7  
 All of the remaining three have cations that are weak acids:  

$$\text{NH}_4^+ + \text{H}_2\text{O} \rightleftharpoons \text{NH}_3 + \text{H}_3\text{O}^+ \quad K_a = 5.65 \times 10^{-10}$$
  

$$[\text{Zn}(\text{H}_2\text{O})_4]^{2+} + \text{H}_2\text{O} \rightleftharpoons [\text{Zn}(\text{H}_2\text{O})_3(\text{OH})]^+ + \text{H}_3\text{O}^+ \quad K_a = 2.5 \times 10^{-10}$$
  

$$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + \text{H}_2\text{O} \rightleftharpoons [\text{Cu}(\text{H}_2\text{O})_5(\text{OH})]^+ + \text{H}_3\text{O}^+ \quad K_a = 1.6 \times 10^{-7}$$
  
 Of these, the copper complex produces the most  $\text{H}^+$  ions because its  $K_a$  value is the largest, so it forms the most acidic solution.

B

4. {4 pts} A student has set up the following I-C-E table to aid in solving this problem  
 “What is the pH of a 0.0010 M solution of a weak acid with  $K_a = 3.4 \times 10^{-4}$ ?”

	HA (aq)	+	H <sub>2</sub> O (l)	↔	A <sup>-</sup> (aq)	H <sub>3</sub> O <sup>+</sup> (aq)
Initial	0.0010 M				0 M	$1.0 \times 10^{-7}$ M
Change	-x				+x	+x
Equilibrium	$0.0010 - x$				x	$(1.0 \times 10^{-7}) + x$

The student considers the following approximations:

- I.  $x \ll 0.0010$ , so  $(0.0010 - x)$  is approximately equal to 0.0010  
 II.  $x \gg 1.0 \times 10^{-7}$ , so  $[(1.0 \times 10^{-7}) + x]$  is approximately equal to x

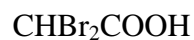
Which of these answers lists all the approximations that are valid for the student to make?

- A) I only  
 B) II only  
 C) I and II both  
 D) neither I nor II

Approximation (I) is not valid because the concentration of weak acid (0.0010) is not more than 100 times the  $K_a$  value (0.00034).  
 Approximation (II) is valid because x will be somewhere on the order of  $10^{-4}$ , which is several orders of magnitude larger than  $10^{-7}$ , so when it is added to  $10^{-7}$ , x will dominate.

5. Which of the following acids is strongest? CBr<sub>3</sub>COOH

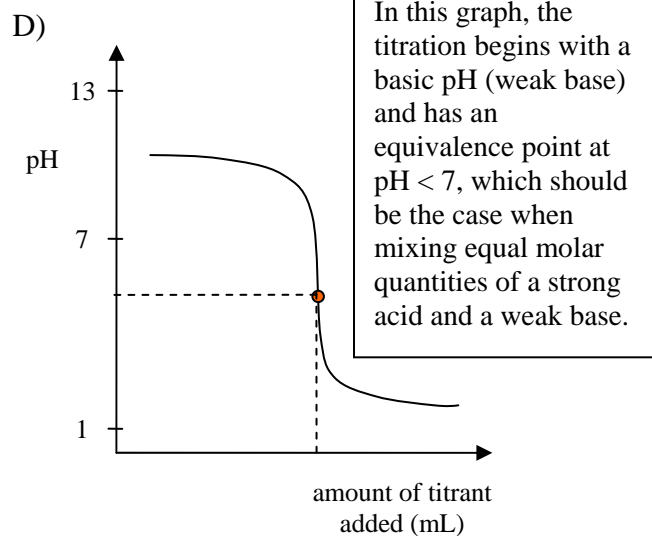
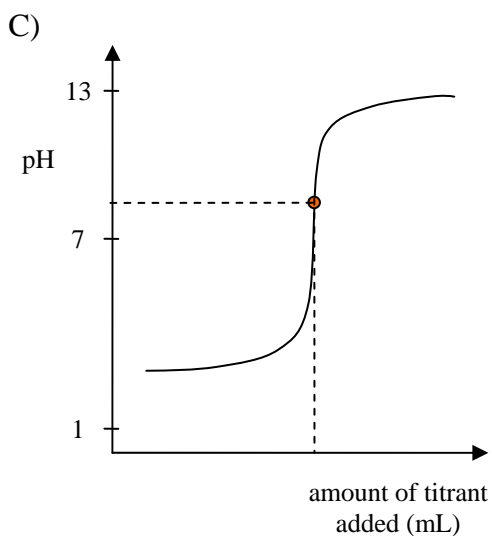
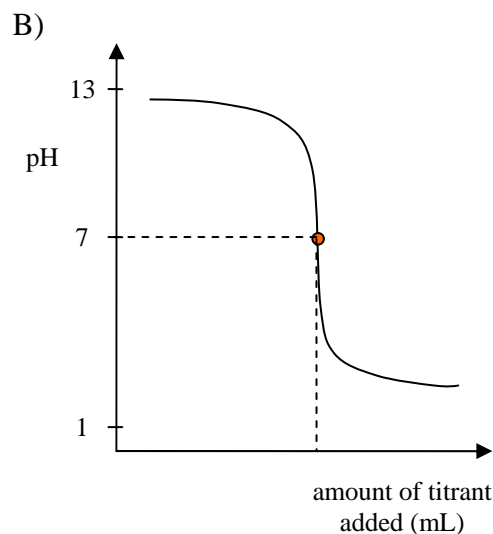
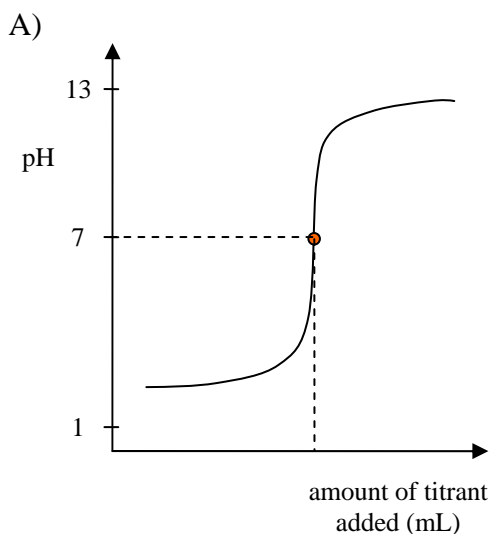
{4 points. No partial credit will be awarded on this question. However, it may help you to draw the molecular structures, so I've left room here to do that.}



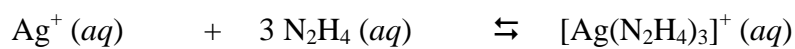
This acid has three Br atoms in the “R” group, which when compared to the other choices draw the most electron density away from the acidic H.

D

6. {4 pts} Which of the following graphs represents the titration of a strong acid (located in the burette) into a weak base (located in the Erlenmeyer flask below)? The equivalence point is marked on all the graphs.



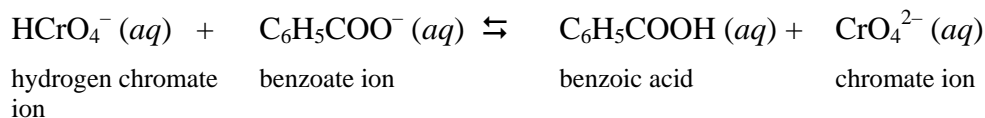
7. {4 pts} For the following reaction, indicate which reactant is a Lewis acid and which reactant is a Lewis base.



Lewis acid

Lewis base

8. Is the following reaction reactant-favored or product-favored? reactant-favored  
{6 points, with partial credit possible for written part}



Justify your answer:

Compare  $K_a$  values for the two acids. Whichever is larger determines which direction the equilibrium lies.

$K_a$  for  $\text{HCrO}_4^-$  is  $3.20 \times 10^{-7}$

$K_a$  for benzoic acid is  $6.46 \times 10^{-5}$

So, benzoic acid wins and the equilibrium lies to the left (toward reactants).

9. Quick calculations. Be sure to attend to significant digits.  
{2 points for each answer, no partial credit}

- a) The pH of a solution is 10.36. What are the hydronium ion and hydroxide ion concentrations?

$$[\text{H}_3\text{O}^+] = \underline{4.4 \times 10^{-11} \text{ M}}$$

$$[\text{OH}^-] = \underline{2.3 \times 10^{-4} \text{ M}}$$

- b) What is the value of  $\text{p}K_a$  for hydrogen sulfide ( $\text{H}_2\text{S}$ )?  $\text{p}K_a = \underline{6.92}$

- c) For the weak base,  $\text{CH}_3\text{NH}_2$ , the value of  $K_b$  is  $4.4 \times 10^{-4}$ . Answer the following two questions based on this information.

- What is the formula of the conjugate acid?  $\text{CH}_3\text{NH}_3^+$

- What is the value of  $K_a$  for the conjugate acid?  $2.3 \times 10^{-11}$

## Part II. Problems

Each problem is worth 20 points. Points possible per part are indicated in curly braces { ... }.

1. Cyanic acid (HOCN) is a weak acid and has  $K_a = 3.5 \times 10^{-4}$ . The titration is begun with 0.0400 moles of HOCN (aq) in 1.00 L of solution in an Erlenmeyer flask below a burette holding KOH (aq). Gradually KOH (aq) in the burette is added to the acid to titrate it. Assume that the base concentration is high enough that it contributes a negligible volume to the titration mixture.

- a) What is the pH of the initial 0.0400 M solution of cyanic acid? {5 pts}

Using the  $K_a$  reaction

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} = \frac{(x)(x)}{(0.0400 - x)} \approx \frac{x^2}{0.0400} = 3.5 \times 10^{-4}$$

Solving for  $x$  yields  $x = [\text{H}_3\text{O}^+] = 0.00374$ , so pH = 2.43 (2 sig figs)

- b) What is the pH after 0.0200 moles of KOH have been added to the solution? {5 pts}

This is the titration midpoint, so pH =  $\text{p}K_a = -\log(3.5 \times 10^{-4}) = 3.46$  (2 sig figs)

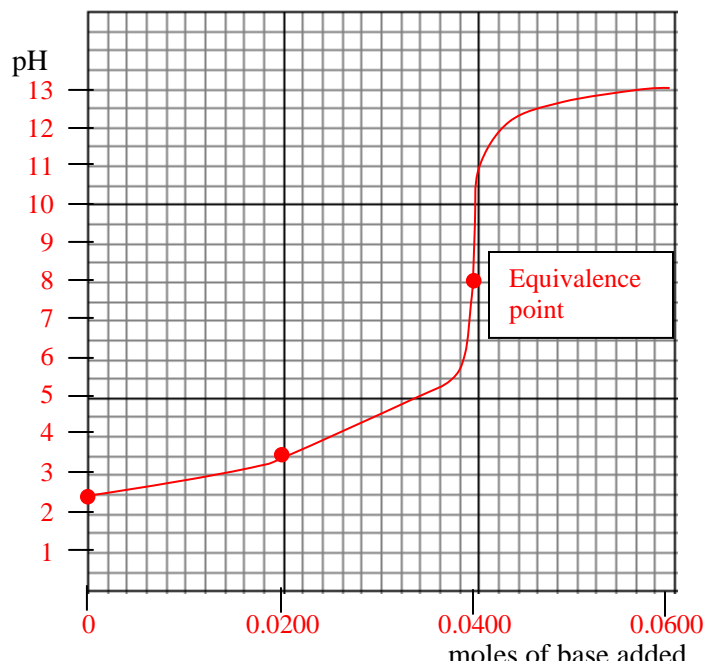
- c) What is the pH after 0.0400 moles of KOH have been added to the solution? {5 pts}

Using the  $K_b$  reaction, now with 0.0400 moles of  $\text{A}^-$  that hydrolyzes, and  $K_b = \frac{K_w}{K_a}$

$$K_b = \frac{[\text{OH}^-][\text{HA}]}{[\text{A}^-]} = \frac{(x)(x)}{(0.0400 - x)} \approx \frac{x^2}{0.0400} = 2.86 \times 10^{-11}$$

Solving for  $x$  yields  $x = [\text{OH}^-] = 1.07 \times 10^{-6}$ , so pOH = 5.97, and pH = 8.03 (2 sig figs)

- d) On the graph at the right, sketch the titration curve. Label the equivalence point. {5 pts}



2. Calculate the pH of each solution. Show your work. Be mindful of significant digits.  
{ 10 pts for each part }

a) A 0.0100 M solution of NaOH  
(show your work)

NaOH is a strong base, so it dissociates completely.  
[OH<sup>-</sup>] = the NaOH concentration = 0.0100 M  
pOH = 2.000  
So, pH = 14 - 2.000 = 12.000 (3 sig figs)

b) A solution made by adding 0.020 moles of HCl to 1.00 L of a 0.040 M ammonia solution  
(NH<sub>3</sub>,  $K_b = 1.76 \times 10^{-5}$ )  
(show your work)

This is the titration midpoint, since the moles of strong acid added equal half the moles of weak base initially present.  
At the titration midpoint for a base titration with acid, pOH = pK<sub>b</sub> = 4.75  
So, pH = 14 - pOH = 9.25 (2 sig figs)

Alternatively, pH = pK<sub>a</sub>, and you could calculate  $K_a = K_w / K_b$

### Part III. Laboratory

This part is worth 16 points. Points possible per part are indicated in curly braces { ... }.

For a particular laboratory assay, you require a buffer that maintains a pH of 4.25. On your shelf, you have the following chemicals available:

Solutions	Solids
hypochlorous acid, HOCl (aq), 1.00 M solution	sodium hypochlorite, NaOCl (s), crystals
formic acid, HCOOH (aq), 1.00 M solution	benzoic acid, C <sub>6</sub> H <sub>5</sub> COOH (s), crystals
	sodium benzoate, Na(C <sub>6</sub> H <sub>5</sub> COO) (s), crystals
	sodium formate, NaHCOO (s), crystals
	sodium bicarbonate, NaHCO <sub>3</sub> (s), crystals
	sodium carbonate, Na <sub>2</sub> CO <sub>3</sub> (s), crystals

- a) Identify the four conjugate acid-base pairs among the chemicals available. You can write either the name or the formula. If the acid or base is an ion you can identify either the compound or the ion. If you identify an ion by formula you must get the charge correct. {8 pts}

Conjugate acid	Conjugate base partner	$K_a$	$pK_a$
1. bicarbonate ion or HCO <sub>3</sub> <sup>-</sup> or sodium bicarbonate or NaHCO <sub>3</sub>	carbonate ion or CO <sub>3</sub> <sup>2-</sup> or sodium carbonate or Na <sub>2</sub> CO <sub>3</sub>	$5.61 \times 10^{-11}$	10.251
2. hypochlorous acid or HOCl	hypochlorite ion or OCl <sup>-</sup> or sodium hypochlorite or NaOCl	$3.0 \times 10^{-8}$	7.52
3. benzoic acid or C <sub>6</sub> H <sub>5</sub> COOH	benzoate ion or C <sub>6</sub> H <sub>5</sub> COO <sup>-</sup> or sodium benzoate or NaC <sub>6</sub> H <sub>5</sub> COO	$6.46 \times 10^{-5}$	4.190
4. formic acid or HCOOH	formate ion or HCOO <sup>-</sup> or sodium formate or NaHCOO	$1.8 \times 10^{-4}$	3.74

- b) Which two chemicals should you use to prepare the buffer solution? Explain. {4 pts}

Use benzoic acid and sodium benzoate.  $pK_a$  value of benzoic acid is closest to desired pH of 4.25.

- c) What ratio of conjugate base [A<sup>-</sup>] to weak acid [HA] (*i.e.*, the ratio [A<sup>-</sup>]/[HA]) should you use to prepare the buffer solution? Show your work. {4 pts}

For a weak acid in the buffer zone:  $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} \approx \frac{[\text{H}_3\text{O}^+][\text{A}^-]_o}{[\text{HA}]_o}$

Solving for the ratio requested,  $\frac{[\text{A}^-]_o}{[\text{HA}]_o} = \frac{K_a}{[\text{H}_3\text{O}^+]}$ , and  $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-4.25} = 5.62 \times 10^{-5}$

Substituting and solving:

$$\frac{[\text{A}^-]_o}{[\text{HA}]_o} = \frac{K_a}{[\text{H}_3\text{O}^+]} = \frac{6.46 \times 10^{-5}}{5.62 \times 10^{-5}} = 1.1 \quad (\text{answer is only good to 2 sig figs, since pH was})$$



Bonus: If you want the buffer to be able to withstand the addition of 0.0010 moles of strong acid or strong base and maintain the pH, what amounts of the two chemicals should you use? (Show your work. You may continue your work on the back of this page.) {up to 4 pts possible}

If you want the buffer to withstand addition of 0.0010 moles of strong acid or base, then there needs to be at least 100 times as much HA and  $A^-$  present so that conversion of HA to  $A^-$  or the reverse will not affect the HA and  $A^-$  concentrations very much. So, you need about 0.10 moles of either one. If you have 0.10 moles of HA (benzoic acid), then the amount of  $A^-$  (sodium benzoate) needed is  $1.1 \times (0.10 \text{ moles}) = 0.11 \text{ moles}$ .