CHEMISTRY 204
Hour Exam II
March 27, 2025
Dr. D. DeCoste

Name ______________________________

Signature ____________________________

T.A. _______________________________

Section _____________________________

This exam contains 23 questions on 9 numbered pages. Check now to make sure you have a complete exam. You have two hours to complete the exam. Determine the **best** answer to the first 20 questions and enter these on the special answer sheet. Also, circle your responses in this exam booklet. **Show all of your work and provide complete answers to questions 21, 22 and 23.**

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|---|---|---|
| 1-20 | (60 pts.) | ____________ |
| 21 | (10 pts.) | ____________ |
| 22 | (20 pts) | ____________ |
| 23 | (30 pts) | ____________ |
| Total | (120 pts) | ____________ |

Useful Information:

- Unless otherwise noted, all solutions referred to on this exam are aqueous solutions at 25°C.
- On this exam, $H_3O^+$ and $H^+$ are used interchangeably.

$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ at 25°C.

For $ax^2 + bx + c = 0$, $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$pH = -\log[H_3O^+] = -\log[H^+]$

$$K_a = \frac{[H^+]^2 - K_w}{[HA]_o - \dfrac{[H^+]^2 - K_w}{[H^+]}}$$

1. You go to the stockroom and find four bottles containing different aqueous weak acid solutions. The relative initial concentrations of each are such that the percent dissociation is the same in all of the samples. Which solution has the **lowest pH**?

   a) $HNO_2$  b) HCN  c) HF  d) $HC_2H_3O_2$  e) All pH values are the same.

2. You go to the stockroom and find four bottles containing different aqueous weak acid solutions at the same concentration. You add concentrated HCl(*aq*) to each until the pH of each solution is 1.00. For which solution is the concentration of the conjugate base the **smallest**?

   a) $HNO_2$  b) HCN  c) HF  d) $HC_2H_3O_2$  e) All concentrations are the same.

3. You dilute an aqueous solution by doubling the volume with water. The pH of the diluted solution increases by 0.3 compared to the original solution. How many of the following could correctly describe the original solution?

   - A weak acid.
   - A weak base
   - A strong acid
   - A strong base
   - A buffered solution

   a) 1  b) 2  c) 3  d) 4  e) 5

4. Methylamine ($CH_3NH_2$) is an organic precursor to both pharmaceuticals and pesticides. It is water soluble and acts as a base in water ($K_b = 4.4 \times 10^{-4}$). Suppose you titrate a $2.00 \times 10^{-3}$ *M* aqueous solution of methylamine to the equivalence point with a $2.00 \times 10^{-3}$ *M* solution of HCl(*aq*). Determine the pH at equivalence.

   a) 6.67  b) 6.74  c) 6.82  d) 7.18  e) 7.33

5. You dissolve 3.14 mg of NaOH in 314 L of aqueous solution. Determine the pH of this solution.

   a) 7.40  b) 7.42  c) 7.45  d) 7.49  e) 7.54

6. Consider 0.010*M* solutions of four different aqueous acids. Which of the acid solutions has the **lowest pH**?

   a) $H_3PO_4$  b) $H_2SO_4$  c) HCl  d) HF  e) Two or more are equally low.

7. Your lab partner is up to it again! Instead of diluting a 2.00*M* sulfuric acid solution with water, your lab partner used 2.00*M* hydrochloric acid. That is, 1.00 L of 2.00*M* $H_2SO_4$(*aq*) was mixed with 1.00 L of 2.00*M* HCl(*aq*). Determine $[SO_4^{2-}]$ in this mixture at equilibrium.

   a) 0.0059*M*  b) 0.012*M*  c) 0.023*M*  d) 0.11*M*  e) 0.15*M*

8. Determine the pH of a 1.00*M* aqueous solution of $NaHSO_3$.

a) 3.50 b) 4.41 c) 6.09 d) 8.91 e) 10.50

9. You titrate 100.0 mL of a 0.500*M* HCN(*aq*) solution with 1.00*M* NaOH(*aq*). Determine the pH at the equivalence point.

a) 9.16 b) 9.25 c) 10.31 d) 11.36 e) 11.45

10. You discover an unlabeled solution of HCN(*aq*) and find that it has a pH of 6.79. What should the label read?

a) $1.6 \times 10^{-5}$ *M*
b) $2.6 \times 10^{-5}$ *M*
c) $4.2 \times 10^{-5}$ *M*
d) $6.8 \times 10^{-5}$ *M*
e) $8.3 \times 10^{-5}$ *M*

11. Approximately what mass of NaOH(s) must be added to 100.0mL of 1.00*M* $HC_2H_3O_2$(*aq*) to result in a solution with pH = 3.14? Assume the solid sodium hydroxide does not appreciable change the volume.

a) 28 mg b) 63 mg c) 96 mg d) 117 mg e) 142 mg

12. About how much water **must be added** to 100.0mL of 1.00*M* $HC_2H_3O_2$(aq) to result in a solution with pH = 3.14?

a) 489 mL b) 589 mL c) 3.25 L d) 4.95 L e) 6.28 L

13. You are titrating 50.0 mL of a 0.100*M* aqueous solution of a weak diprotic acid with 0.100*M* NaOH(*aq*). Which of the following volumes of 0.100*M* NaOH(*aq*) does **not** constitute a “special point” at which we can determine the pH of the solution simply by using one or both of the $K_a$ values of the acid?

a) 25.0 mL b) 50.0 mL c) 75.0 mL d) 100.0 mL e) They are all “special”.

14. How many of the following will **not** produce a buffered solution?

- 100.0 mL of 0.100*M* $Na_2CO_3$(*aq*) and 50.0 mL of 0.100*M* NaOH(*aq*)
- 100.0 mL of 0.100*M* $Na_2CO_3$(*aq*) and 50.0 mL of 0.100*M* HCl(*aq*)
- 100.0 mL of 0.100*M* $Na_2CO_3$(*aq*) and 25.0 mL of 0.200*M* HCl(*aq*)
- 100.0 mL of 0.100*M* $Na_2CO_3$(*aq*) and 75.0 mL of 0.200*M* HCl(*aq*)
- 50.0 mL of 0.200*M* $Na_2CO_3$(*aq*) and 5.00 mL of 1.00*M* HCl(*aq*)

a) 1 b) 2 c) 3 d) 4 e) 5

15, 16. Recall the demonstration from lecture in which we produced the solids silver chromate and silver chloride by adding $AgNO_3(aq)$ to a solution containing aqueous sodium chromate, $Na_2CrO_4(aq)$, and aqueous sodium chloride, $NaCl(aq)$.

15. Determine the solubility of $Ag_2CrO_4(s)$ ($K_{sp} = 9.0 \times 10^{-12}$) in pure water at 25°C.

a) $9.0 \times 10^{-12}$ *M*
b) $3.0 \times 10^{-6}$ *M*
c) $1.3 \times 10^{-4}$ *M*
d) $1.7 \times 10^{-4}$ *M*
e) $2.6 \times 10^{-4}$ *M*

16. Determine the solubility of $Ag_2CrO_4(s)$ ($K_{sp} = 9.0 \times 10^{-12}$) in 1.00*M* $NaCl(aq)$ 25°C. The $K_{sp}$ for AgCl = $1.6 \times 10^{-10}$.

a) $1.6 \times 10^{-10}$ *M*
b) $2.6 \times 10^{-4}$ *M*
c) 0.046 *M*
d) 0.50 *M*
e) 1.00 *M*

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17-18. Consider the formation of the complex ion $Ag(NH_3)_2^+(aq)$ when $Ag^+(aq)$ and $NH_3(aq)$ react:

$$Ag^+(aq) + NH_3(aq) \rightleftharpoons Ag(NH_3)^+(aq) \qquad K_1 = 2.1 \times 10^3$$
$$Ag(NH_3)^+(aq) + NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad K_2 = 8.2 \times 10^3$$

50.0 mL of $1.00 \times 10^{-3}$ *M* $AgNO_3$ is reacted with 50.0 mL of 15.00 *M* $NH_3$.

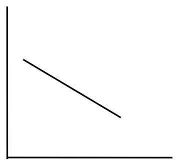
17. Determine the equilibrium concentration of $Ag^+$.

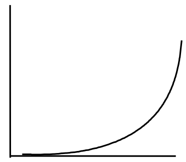
a) $5.2 \times 10^{-13}$ *M*
b) $3.9 \times 10^{-12}$ *M*
c) $2.6 \times 10^{-11}$ *M*
d) $3.2 \times 10^{-9}$ *M*
e) $3.2 \times 10^{-8}$ *M*

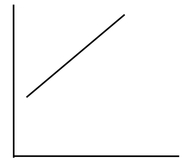
18. Assuming that none of the silver containing species have an effect on the pH, determine the pH of the solution. ($K_b$ for $NH_3 = 1.8 \times 10^{-5}$).

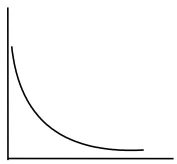
a) 7.00 b) 9.26 c) 11.63 d) 12.06 e) 12.22

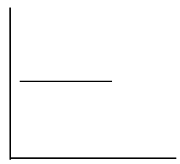
19-20. Indicate which of the graphs below **best** represents each plot described. A graph may be used once, more than once, or not at all.

a)


b)


c)


d)


e)


19. $[A^{2-}]$ (y) vs. $[H_2A]$ (x) for which $H_2A$ is a typical weak aqueous diprotic acid.

20. pH (y) vs. [NaHA] (x) for which $H_2A$ is a typical weak aqueous diprotic acid.

21. As we discussed in class, we make assumptions when solving acid-bases problems, which is fine as long as we know what these assumptions are and how to check them. For example, in solving problems with a **weak acid (HA) in water**, we often simplify our calculations and make the assumption that at equilibrium, $[H_3O^+] = [A^-]$. Let's evaluate this assumption under various conditions. Please address the following questions in your answer:

- Why is the assumption $[H_3O^+] = [A^-]$ **not exactly true**? Why are we able to **generally** make this assumption?
- As we **dilute** the acid, does this assumption become **more or less valid**?
- Consider two solutions each with a **different weak acid** at the **same initial concentration**. Is the assumption **more or less valid** for the acid with the **higher $K_a$ value**?

**Explain your answers** without using sample calculations. **Full credit** is reserved for a **coherent, legible, and logical discussion** that is **limited to this page**. [**10 points**]

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22. In this problem you will compare aqueous solutions of the weak acids HF ($K_a$ = 7.2 x $10^{-4}$), and $HC_2H_3O_2$ ($K_a$ = 1.8 x $10^{-5}$). Consider two 1.00-L solutions, one of 1.00*M* HF, and the other of 1.00*M* $HC_2H_3O_2$.

a. We discussed how diluting a weak acid increases the percent dissociation. Consider that we dilute each 1.00-L sample of acid such that it is 99.0% dissociated.

- Determine the **final volume** of each solution.
- Determine the following **ratio** in each solution:

$\frac{[H_3O^+]}{[A^-]}$ (where $A^-$ is the conjugate base of each acid)

**Show all work**. **Full credit** is reserved for a **coherent and logical approach that we can follow.** [**10 points**]

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22. b. As we discussed, the concentration for any given species cannot go to zero at equilibrium, so an acid will not dissociate completely. Determine the **theoretical maximum percent dissociation** for **each** acid (HF, $K_a = 7.2 \times 10^{-4}$, and $HC_2H_3O_2$, $K_a = 1.8 \times 10^{-5}$) when we dilute them.

**Show all work** and **briefly explain your reasoning**. **Full credit** is reserved for a **coherent and logical approach that we can follow.** Please report your answer with **five significant figures**. [**10 points**]

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23. When sending samples away to Waste Management, we need to specify the identities and amounts of everything in the container. Let's consider the waste generated from the world famous "water to Kool-Aid to milk" demonstration that I performed in lecture. In cleaning up this demonstration, we pour everything back into the "pitcher" (Erlenmeyer flask). Forgetting about the few drops of phenolphthalein (which will not significantly change our calculations), we use the following for the demonstration:

- 970.0 mL deionized water
- 10.00 mL of 1.000*M* NaOH(*aq*)
- 10.00 mL of 6.000*M* $H_2SO_4$(*aq*) ($K_{a2}$ = 1.2 x $10^{-2}$)
- 10.00 mL saturated (that is, maximum concentration) $BaCl_2$(*aq*)

Knowing that the $K_{sp}$ for $BaCl_2$ = 22.45, the $K_{sp}$ for $Ba(OH)_2$ = 5.0 x $10^{-3}$, and the $K_{sp}$ for $BaSO_4$ = 1.5 x $10^{-9}$, **determine the identities and concentrations of all species** in the solution, the **pH of the solution**, and **the mass of any solid(s) present**, after all solutions have been returned to the flask and reach equilibrium.

**Show all work** and **briefly explain your reasoning/approach**. **Full credit** is reserved for a **systematic, coherent** solution that **we can follow**. Please use the next page if needed. **[30 points].**

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23. Please continue any work for #23 on this page.