

START 7:50 PM

END 9:50 PM

CHM 102  
Exam II

1. Suppose you come into the lab and find two reagent bottles whose labels have fallen off. You pick the labels up off the floor and one label reads 0.001 M NaOH while the other label reads pH 11 buffer.

a) Describe a simple test that you could perform to determine which bottle is which. You have at your disposal solutions of 0.1 M HCl, 0.1 M KOH, water, a pH meter, and any glassware you may need.

TAKE SAMPLE OF EACH SOLUTION AND ADD SOME  
0.1 M HCl TO EACH ONE. THE ONE THAT CHANGES pH  
MARKEDLY IS 0.001 M NaOH.

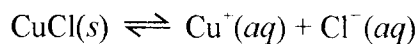
8

b) Briefly explain why your test works.

SMALL CHANGES IN  $[H^+]$  WILL PROVOKE LARGE pH CHANGES  
IN UNBUFFERED SOLUTIONS, BUT BUFFERS RESIST CHANGES IN pH.

7

2. Copper (I) chloride is a sparingly soluble salt which dissolves in water to form copper (I) ions and chloride ions:

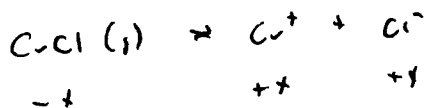


a) Write an equilibrium expression relating the equilibrium constant to the concentrations of the appropriate species for this system.

$$K_{sp} = [\text{Cu}^+][\text{Cl}^-]$$

5

b) If  $K_{sp} = 1.2 \times 10^{-6}$ , what is the molar solubility of copper (I) chloride?



$$1.2 \times 10^{-6} = x^2$$

$$x = \sqrt{1.2 \times 10^{-6}} = \boxed{0.00110 \text{ M}} \quad \text{molar solubility}$$

5

c) Suppose you have a saturated solution of CuCl and you add some sodium chloride to it. What would the effect on the concentration of  $\text{Cu}^+(aq)$  be? Explain.

When NaCl dissolves it dissociates into  $\text{Na}^+$  and  $\text{Cl}^-$ .

Adding chloride disturbs the CuCl solubility equilibrium.

So the equilibrium position shifts left and  $[\text{Cu}^+]$  decreases.

5

3. Calcium hydroxide, sometimes called slaked lime, is a reagent used frequently in chemical industries. Suppose you titrate a solution of calcium hydroxide of unknown concentration with a standard solution of hydrochloric acid.

a) Write a balanced chemical equation for this reaction. Under the equation, identify which species reacts as an acid, which species reacts as a base, which species is the conjugate acid, and which species is the conjugate base.

5



b) A 10.00 mL sample of calcium hydroxide reacts completely with 32.41 mL of 0.1037 M hydrochloric acid. What is the concentration of the calcium hydroxide solution?

4

$$\text{vol HCl} \rightarrow \text{mol HCl} \rightarrow \text{mol Ca(OH)}_2 \rightarrow \text{conc. Ca(OH)}_2$$

$$0.03241 \text{ L HCl} \cdot \frac{0.1037 \text{ mol HCl}}{1 \text{ L HCl}} \cdot \frac{1 \text{ mol Ca(OH)}_2}{2 \text{ mol HCl}} \cdot \frac{1}{0.0100 \text{ L Ca(OH)}_2} = \boxed{0.1680 \text{ M Ca(OH)}_2}$$

c) What is the concentration of  $\text{H}^+$  in the calcium hydroxide solution?

3

$$[\text{OH}^-] = 2(0.1680) = 0.336 \text{ M}$$

$$K_w = [\text{H}^+][\text{OH}^-]$$

$$1.00 \times 10^{-14} = [\text{H}^+](0.336)$$

$$[\text{H}^+] = \frac{1.00 \times 10^{-14}}{0.336} = \boxed{2.98 \times 10^{-14} \text{ M}}$$

d) What is the pH of the calcium hydroxide solution?

3

$$\text{pH} = -\log[\text{H}^+] = -\log(2.98 \times 10^{-14}) = \boxed{13.526}$$

4. Explain the following phenomena:

a) When 0.10 mol of HCl is dissolved in 1.0 L of water the pH of the solution is 1.00, but when 0.10 mol of CH<sub>3</sub>COOH is dissolved in 1.0 L of water the pH of the solution is 2.88.

HCl is a strong acid so it completely dissociates, but the weak acid CH<sub>3</sub>COOH does not completely dissociate so [H<sup>+</sup>] is lower and its pH is higher.

b) When a little acid is added to a solution of 1.0 M acetic acid, the pH drops from 2.37 to 1.00, but when the same amount of acid is added to a solution of 1.0 M acetic acid with 1.0 M sodium acetate, the pH drops from 4.76 to 4.66.

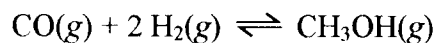
The solution of 1M CH<sub>3</sub>COOH / 1M CH<sub>3</sub>COONa is a buffer, so it resists changes in pH.

c) The concentration of CO<sub>2</sub>(g) over CaCO<sub>3</sub>(s) in a sealed container is essentially constant, regardless of how much CaCO<sub>3</sub>(s) is in the container. This system is governed by the equilibrium  $\text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g)$ .

For this heterogeneous equilibrium,  $K_{eq} = [\text{CO}_2]$ ,

so the conc. of CO<sub>2</sub> must be constant.

5. In the gas phase, carbon monoxide and hydrogen gas are in equilibrium with methanol:



a) Write an equilibrium expression for this reaction relating the equilibrium constant to the concentrations of the appropriate species involved in the reaction.

$$K_{eq} = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2}$$

b) At 500K, the equilibrium constant for this reaction has a value of  $K_{eq} = 6.5 \times 10^5$ . What does this tell you about the equilibrium position? Explain.

SINCE  $K_{eq} \gg 1$ ,  $[\text{CH}_3\text{OH}] > [\text{CO}][\text{H}_2]^2$  SO THERE ARE MORE PRODUCTS THAN REACTANTS AND THE EQUILIBRIUM POSITION LIES TO THE RIGHT.

c) If the concentration of  $[\text{CO}] = 0.0021 \text{ M}$  and  $[\text{H}_2] = 0.0041 \text{ M}$ , what is the concentration of methanol?

$$K_{eq} = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2}$$

$$6.5 \times 10^5 = \frac{[\text{CH}_3\text{OH}]}{[0.0021][0.0041]^2}$$

$$[\text{CH}_3\text{OH}] = 6.5 \times 10^5 (0.0021)(0.0041)^2$$

$$= \boxed{0.023 \text{ M}}$$

For the remaining questions, circle the letter corresponding to the best answer.

6. Which of the following statements are *false*?

- I. ✓ A strong acid always has a weak conjugate base.
- II. ✗ A weak base always has a strong conjugate acid.
- III. ✓ As acid strength increases, the conjugate base is less willing to accept hydrogen ions.
- IV. ✓ The strength of an acid is inversely related to the strength of its conjugate base.
- V. ✗ The dissociation equilibrium position for a weak base lies to the right.

- (A) II and III
- (B) II and V
- (C) I, III, and IV
- (D) I, II, and III
- (E) none of the above

For problems 7-10, consider the following disturbances to systems at equilibrium and predict the nature of the shift in the equilibrium position.

7. The volume is decreased on the system  $\text{CH}_4(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{Cl}(\text{g}) + \text{HCl}(\text{g})$

- (A) The equilibrium will shift left.
- (B) The equilibrium will shift right.
- (C) The equilibrium position will not change.

8. The pH is raised on  $2 \text{In}^{3+}(\text{aq}) + \text{H}_3\text{PO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{In}^{2+}(\text{aq}) + \text{H}_3\text{PO}_3(\text{aq}) + 2\text{H}^+(\text{aq})$

- (A) The equilibrium will shift left.
- (B) The equilibrium will shift right.
- (C) The equilibrium position will not change.

Raising pH lowers  $[\text{H}^+]$

9.  $\text{UO}_2(\text{s})$  is removed from the system  $\text{UO}_2(\text{s}) + 4 \text{HF}(\text{g}) \rightleftharpoons \text{UF}_4(\text{g}) + 2 \text{H}_2\text{O}(\text{g})$

- (A) The equilibrium will shift left.
- (B) The equilibrium will shift right.
- (C) The equilibrium position will not change.

10. The endothermic reaction  $\text{N}_2(\text{g}) + 2 \text{H}_2(\text{g}) \rightleftharpoons \text{N}_2\text{H}_4(\text{g})$  is heated

- (A) The equilibrium will shift left.
- (B) The equilibrium will shift right.
- (C) The equilibrium position will not change.

11. Which of the following are conjugate acid / base pairs?

- I. ✓  $C_2H_5N$  and  $C_2H_5NH^+$
- II. ✓  $HClO_4$  and  $ClO_4^-$
- III. ✗  $H^+$  and  $OH^-$
- IV. ✓  $H_2PO_4^-$  and  $HPO_4^{2-}$

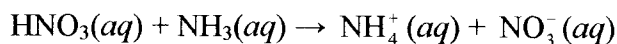
- (A) 3 I and II
- (B) 2 II and IV
- (C) III only
- (D) I, II, and IV
- (E) 2 II, III, and IV

12. Solution A has a pH of 10.00 and solution B has a pH of 11.00. Which of the following statements are *true*?

- I. ✗ Solution A has ten times as many  $OH^-$  ions as solution B.
- II. ✓ Solution B has ten times as many  $OH^-$  ions as solution A.
- III. ✓ Solution A has ten times as many  $H_3O^+$  ions as solution B.
- IV. ✗ There are no  $H_3O^+$  ions in either solution because they are both basic.

- (A) I only
- (B) I and III
- (C) II and III
- (D) I and IV
- (E) II and IV

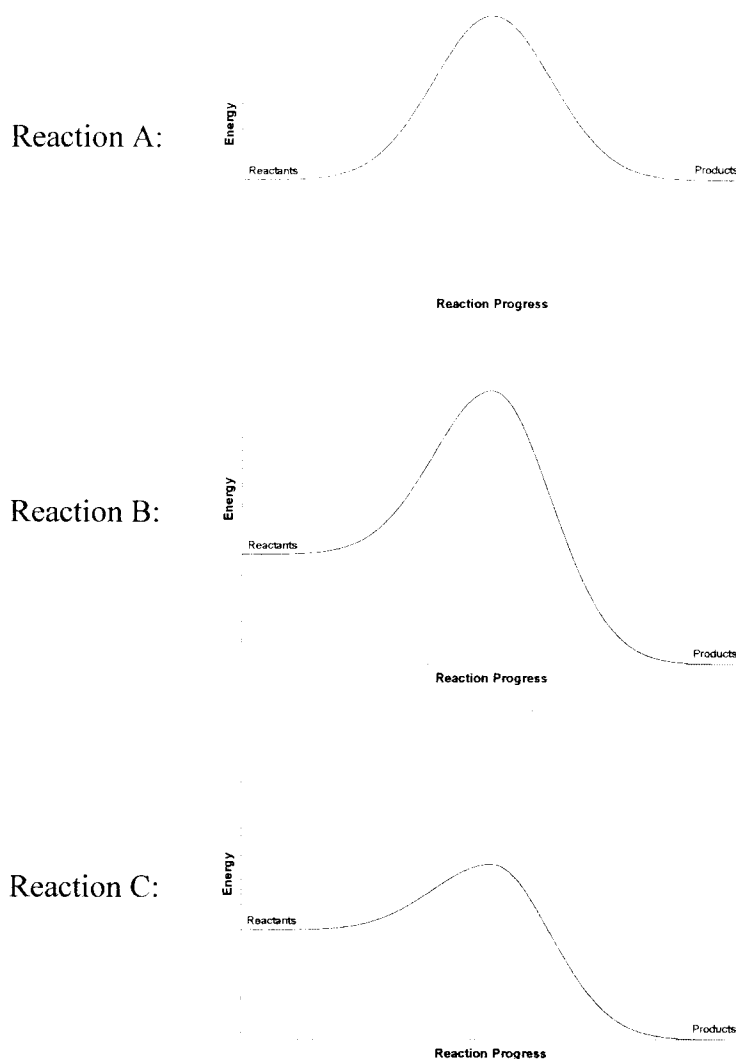
13. Nitric acid reacts with ammonia to produce aqueous ammonium nitrate:



Which one of the following statements is *false*?

- (A) ✓ Nitric acid donates a proton to ammonia.
- (B) ✓ The ammonium ion is acidic.
- (C) ✓ The nitrate ion is the conjugate base of  $HNO_3$ .
- (D) ✓ In this reaction, ammonia reacts as a Brønsted-Lowry base.
- (E) ✗ In this reaction, ammonia reacts as an Arrhenius base.

14. The reaction progress diagrams for several reactions are given:



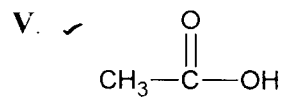
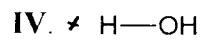
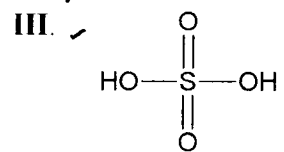
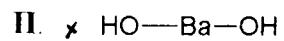
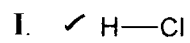
Which of the following statements are *true*?

- I. ✗ Reaction B may be the same as reaction A, but with a catalyst added.
- II. ✓ Reaction C may be the same as reaction B, but with a catalyst added.
- III. ✗ Reaction B will react faster than reaction A.
- IV. ✓ Reaction C will react faster than reaction B.
- V. ✓ Reaction A has the same activation energy as reaction B.

- (A) I and III
- (B) II and IV
- (C) II, IV, and V
- (D) I, III, and V
- (E) all of the above



15. Which of the following compounds will produce a solution with  $\text{pH} < 7$ ?



(A) **3** I and III

(B) **3** I and V

(C) II and IV

**(D)** I, III, and V

(E) all of the above