Instructions:
1. This exam consists of 25 questions.
2. No scratch paper is allowed. You may do the work in the test margins and on the backs of the test pages.
3. Mark the answers you choose on the test itself for your own information and also on the standard answer sheet you provided. Scoring will be based on the answer sheet.
4. When you finish, turn in both the test form and the answer form. The test form and your personal report will be returned to you at the next class. Write your name on both forms.

Write the test version (A, B, C, etc.) on the top of the answer form.

Useful Information:  \( R = 0.08206 \text{ L atm/mol K} = 8.314 \text{ J/mol K} \)

1. When an equilibrium has been established for a reaction
   a) no products are being formed, and no reactants are being formed.
   b) the total concentration of reactants equals the total concentration of products.
   c) the rate of the forward reaction becomes zero.
   d) the reactants have been completely consumed.
   e) the rate of consumption of reactants equals the rate of production of reactants.

2. Consider the following gas-phase equilibrium system:
\[
N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)
\]

If an equilibrium mixture of these gases contains 1.5 mol of nitrogen, 2.7 mol of hydrogen, and 4.0 mol of ammonia in a 1.0 L vessel, what is the value of the equilibrium constant, \(K_c\)?

a) 2.2  
b) 0.54  
c) 1.8  
d) 0.46  
e) 0.83

3. The value of the equilibrium constant for the following reaction is \(K_c = 17.1\) at 2025 K:

\[
HCN(g) \rightleftharpoons \frac{1}{2} H_2(g) + \frac{1}{2} N_2(g) + C(s) \quad K_c = 17.1
\]

What is the value of \(K_c\) for the reaction shown below?

\[
2H_2(g) + 2N_2(g) + 4C(s) \rightleftharpoons 4HCN(g) \quad K_c = ???
\]

a) 292  
b) 4.12  
c) 0.0585  
d) 1.17 \times 10^5  
e) 3.42 \times 10^3

4. 0.600 mol each of \(N_2\) and \(O_2\) gas were placed in a 3.00 L vessel, and the system was allowed to reach equilibrium at 3900°C. What is the equilibrium concentration of \(N_2(g)\)?

\[
N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \quad K_c = 0.0121 \text{ at } 3900°C
\]

a) 0.569 M  
b) 0.168 M  
c) 0.177 M  
d) 0.190 M  
e) 0.0104 M

5. Methanol, CH_3OH, is prepared industrially from synthesis gas (CO and H_2):

\[
CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H° = -90.7 \text{ kJ}
\]

Which of these changes would increase the equilibrium yield of methanol?

I. adding more CO  
II. removing some \(H_2\)  
III. lowering the temperature  
IV. increasing the pressure by decreasing the volume  
V. using a catalyst

a) I and V  
b) I, III, and IV  
c) II, IV, and V  
d) I, IV, and V  
e) I, III, IV, and V

6. What is the pH of a 0.062 M nitric acid solution?
7. What is the pH of a 0.025 M strontium hydroxide solution?
   a) 12.70  b) 1.60  c) 12.25  d) 12.40  e) 1.30

8. What is the hydroxide ion concentration of an aqueous solution with a pH of 5.25?
   a) 5.6 x 10^{-6} M  b) 5.6 x 10^{-8} M  c) 1.8 x 10^{-9} M  d) 4.0 x 10^{-9} M  e) 4.0 x 10^{-10} M

9. What is the pH of a 0.25 M solution of hydrocyanic acid, HCN(aq)?  
   (K_a for HCN is 6.2 x 10^{-10}.)
   a) 4.90  b) 4.19  c) 2.30  d) 9.81  e) 9.10

10. Hydroxylamine, HONH_2, is a weak base with K_b = 1.1 x 10^{-8}. What is the pH of a 0.15 M solution of hydroxylamine?
    a) 9.61  b) 8.78  c) 4.39  d) 5.22  e) 7.96

11. Vitamin C, also called ascorbic acid, is a diprotic acid with the formula C_6H_8O_6. What is the pH of a 0.050 M solution of Vitamin C?  
    (K_{a1} = 7.9 x 10^{-5}; K_{a2} = 1.6 x 10^{-12}.)
    a) 4.10  b) 5.40  c) 2.70  d) 6.55  e) 2.85

12. Determine the concentration of the ascorbate ion, C_6H_8O_6^{2-}, in the solution described in question 11 above.
    a) 1.6 x 10^{-12}  b) 7.9 x 10^{-4}  c) 2.8 x 10^{-7}
13. Which of the following are conjugate acid/base pairs?

I. HF, F\(^-\)
II. HPO\(_4\)\(^2-\), PO\(_4\)\(^3-\)
III. NH\(_4\)\(^+\), NH\(_3\)
IV. H\(_2\)CO\(_3\), CO\(_3\)\(^2-\)
V. H\(_3\)O\(^+\), H\(_2\)O

a) none of these
b) I and IV
c) I, II, and III
d) I, II, III, and V
e) I, II, III, IV, and V

14. All of these acids are arranged in order of increasing acid strength, except

a) NH\(_3\) < H\(_2\)O < HF
b) HCl < HBr < HI
c) HClO\(_4\) < HBrO\(_4\) < HIO\(_4\)
d) HPO\(_4\)\(^2-\) < H\(_2\)PO\(_4\)\(^-\) < H\(_3\)PO\(_4\)
e) H\(_3\)PO\(_4\) < H\(_2\)SO\(_4\) < HClO\(_4\)

15. All of the following would make good Lewis acids except

a) AlCl\(_3\)
b) O\(^2-\)
c) BF\(_3\)
d) SO\(_3\)
e) H\(^+\)

16. All of the following have a pH ≥ 7 except

a) 0.10 M NaF
b) 0.10 M NH\(_4\)ClO\(_4\)
c) 0.10 M KCN
d) 0.10 M KBr
e) 0.10 M Ba(NO\(_2\))\(_2\)

17. What is the equilibrium constant expression for K\(_c\) for the equilibrium shown below?

\[
\text{Ni(CO)}_4(\text{g}) \rightleftharpoons \text{Ni(s)} + 4\text{CO(}\text{g})
\]

a) \[K_c = \frac{[\text{Ni(CO)}_4]}{[\text{Ni}] [\text{CO}]^4}\]
b) \[K_c = \frac{[\text{Ni}] [\text{CO}]^4}{[\text{Ni(CO)}_4]}\]
c) \[K_c = \frac{[\text{Ni}] [4[\text{CO}]]}{[\text{Ni(CO)}_4]}\]
d) \[K_c = \frac{[\text{Ni(CO)}_4]}{[\text{Ni}] (4[\text{CO}])}\]
e) \[K_c = \frac{[\text{CO}]^4}{[\text{Ni(CO)}_4]}\]

18. What is the pH of a 0.085 M solution of potassium acetate, KC\(_2\)H\(_3\)O\(_2\)?
(The $K_a$ for acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, is $1.8 \times 10^{-5}$.)

a) 8.84
b) 2.91
c) 9.26
d) 5.16
e) 11.09

19. For the reaction, $2\text{NO}(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}_2(g)$, $K_c = 6.9 \times 10^5$ at 227°C. What is the value of $K_p$ for the reaction at this temperature?

a) $6.9 \times 10^5$
b) $3.7 \times 10^4$
c) $2.8 \times 10^7$
d) $1.7 \times 10^4$
e) $1.3 \times 10^7$

20. When comparing equal concentrations of each of the following in water at the same temperature, which one would have the lowest pH?

a) $\text{HC}_2\text{H}_3\text{O}_2$, $K_a = 1.8 \times 10^{-5}$
b) $\text{HCN}$, $K_a = 4.9 \times 10^{-10}$
c) $\text{HNO}_2$, $K_a = 6.0 \times 10^{-5}$
d) $\text{HOI}$, $K_a = 2.3 \times 10^{-11}$
e) $\text{HCOOH}$, $K_a = 1.9 \times 10^4$

21. A 0.20 M solution of a certain monoprotic acid has a pH = 3.72 at 25°C. What is the $K_a$ for this acid?

a) $1.9 \times 10^{-4}$
b) $3.8 \times 10^{-3}$
c) $8.2 \times 10^6$
d) $5.4 \times 10^{-6}$
e) $1.8 \times 10^{-7}$

22. 0.70 mol of $\text{NO}_2(g)$ was placed in a 1.00 L container. When the reaction shown below had reached equilibrium, the concentration of $\text{NO}_2$ was found to be 0.28 mol/L. What is the value of the equilibrium constant $K_c$?

$$2\text{NO}_2(g) \rightleftharpoons 2\text{NO}(g) + \text{O}_2(g)$$

a) 1.9
b) 0.47
c) 0.14
d) 0.32
e) 0.94

23. The equilibrium constant, $K_{p}$, for the reaction

$$\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g)$$

is 55.2 at 425°C. A rigid cylinder at that temperature contains 0.500 atm of hydrogen, 0.500 atm of iodine, and 5.00 atm of hydrogen iodide at 425°C. Which of the following statements is correct?

a) The system is at equilibrium.
b) The forward reaction must proceed in order to establish equilibrium.
c) The reverse reaction must proceed in order to establish equilibrium.
24. What is the pH of 1.0 x 10^{-10} M HCl?
   a) 2.00  
   b) 4.00  
   c) 6.00  
   d) 7.00  
   e) 10.00

25. What is the pH of 0.085 M AlCl_3?
   (K_a for Al(H_2O)_6^{3+} = 1.4 x 10^{-5}.)
   a) 5.11  
   b) 11.04 
   c) 8.89  
   d) 7.00  
   e) 2.96

27. Which of the acids listed below is the weakest acid?
   a) HClO_4 
   b) HClO_3 
   c) HClO_2 
   d) HClO 
   e) HCl

28. Which of the acids listed below is the strongest acid?
   a) HF   
   b) HCl   
   c) HBr   
   d) HI    
   e) H_2S 

29. Which of the statements below are true?
   I. If a reaction occurs faster, the products must be more stable thermodynamically.
   II. The kinetic regime is independent of the thermodynamic regime.
   III. K, a thermodynamic parameter, depends on how fast a reaction progresses.
   IV. K depends only on the relative stabilities of the reactants and products.
   a) I and II 
   b) I, II and IV 
   c) II and IV 
   d) II, III, and IV 
   e) I, II, III, and IV

Answers
1. e         6. e         11. c         16. b         21. e         26. no question
2. b         7. a         12. a         17. e         22. b         27. d
3. d         8. c         13. d         18. a         23. c         28. d
5. b         10. a        15. b         20. c         25. e