Choose the one best answer. Please note: answer key is on the last page.

1. Which of the following ions will react with H₂O to produce H₃O⁺?
   a. Na⁺
   b. NH₄⁺
   c. CO₃²⁻
   d. Ca²⁺
   e. Cs⁺

2. At 25°C, K_p for the following reaction is 1.9×10³:  2NO(g) + Cl₂(g) ⇌ 2NOCl(g)
   What is K_p for the reaction:  NOCl(g) ⇌ NO(g) + 1/2Cl₂(g)?
   a. 5.3×10⁻⁴
   b. 1.1×10⁻³
   c. 9.5×10¹
   d. 2.3×10⁻²
   e. 2.6×10⁻⁴

3. The conjugate acid of HSO₄⁻ is ____________, while the conjugate base of H₂PO₄⁻ is ____________.
   a. H₂SO₃, HPO₄²⁻
   b. H₂SO₃, H₃PO₄
   c. SO₃²⁻, HPO₄²⁻
   d. SO₃²⁻, H₂PO₄⁻
   e. HSO₃⁻, H₂PO₄⁻

4. Which of the following stresses will lead to an increase in SO₃ concentration in this equilibrium?
   2SO₂(g) + O₂(g) ⇌ 2SO₃(g)  ΔH = -197.8 kJ
   a. Remove O₂.
   b. Lower the temperature.
   c. Raise the pressure by decreasing the volume.
   d. Add a catalyst.
   e. Raise the pressure by adding an inert gas.
5. Given the following reactions:

\[
\begin{align*}
\text{HF} & \rightleftharpoons \text{H}^+ + \text{F}^- & K_c &= 3.5 \times 10^{-4} \\
\text{H}^+ + \text{OH}^- & \rightleftharpoons \text{H}_2\text{O} & K_c &= 1.0 \times 10^{14}
\end{align*}
\]

What is \( K_c \) for the following reaction: \( \text{HF} + \text{OH}^- \rightleftharpoons \text{F}^- + \text{H}_2\text{O} \)?

a. \( 3.5 \times 10^{10} \)

b. \( 1.0 \times 10^{14} \)

c. \( 3.5 \times 10^4 \)

d. \( 2.9 \times 10^{17} \)

e. \( 3.5 \times 10^{-18} \)

6. Write the equilibrium constant expression for the following reaction.

\[
\text{C(s) } + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_4(\text{g})
\]

a. \( K = \frac{[\text{CH}_4]}{[\text{C}][\text{H}_2]^2} \)

b. \( K = \frac{[\text{CH}_4]}{[\text{C}][\text{H}_2]^2} \)

c. \( K = \frac{[\text{CH}_4]}{[\text{H}_2]^2} \)

d. \( K = \frac{[\text{C}][\text{H}_2]^2}{[\text{CH}_4]} \)

e. \( K = \frac{[\text{H}_2]^2}{[\text{CH}_4]} \)

7. If the pOH of a solution is 5.45, the \([\text{H}^+]\) is __________.

a. \( 2.8 \times 10^{-5} \text{ M} \)

b. \( 3.5 \times 10^{-5} \text{ M} \)

c. \( 3.5 \times 10^{-6} \text{ M} \)

d. \( 2.8 \times 10^{-9} \text{ M} \)

e. \( 3.5 \times 10^{-5} \text{ M} \)
8. Which of the following statements is false according to Bronsted-Lowry Theory?
   a. An acid is a H⁺ donor.
   b. A strong acid has a strong conjugate base.
   c. H₂O can act as an acid as well as a base.
   d. The strongest acid that can exist in H₂O is H₃O⁺.
   e. A weak base has a weak conjugate acid.

9. At equilibrium, the following concentrations were determined.

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

   1.0 M  2.0 M  4.0 M

   Calculate the equilibrium constant.

   a. 8.0
   b. 4.0
   c. 2.0
   d. 0.50
   a. 0.12

10. Ethyl acetate is synthesized in an inert solvent (not water) by the following reaction:

   \( \text{CH}_3\text{COOH} + \text{CH}_3\text{CH}_2\text{OH} \rightleftharpoons \text{CH}_3\text{COOCH}_2\text{CH}_3 + \text{H}_2\text{O} \quad \text{K}_c = 2.2 \)

   Acetic acid ethanol ethyl acetate

   A mixture contains 0.010 M acetic acid, 0.010 M ethanol, 0.22 M ethyl acetate, and 0.10 M water. Which of the following statements is true?

   a. The mixture is at equilibrium.
   b. More ethyl acetate will form.
   c. The concentration of water will decrease.
   d. Adding water will increase the amount of ethyl acetate.

11. If \( \text{K}_p = 10 \) at 727°C, calculate \( \text{K}_c \).

   \[ 2\text{CO}(g) + \text{O}_2(g) \rightleftharpoons 2\text{CO}_2(g) \]

   a. 0.12
   b. 0.17
   c. 10.
   d. 600
   e. 820
12. Which of the following ions do not react with H₂O to form OH⁻?

a. NO₂⁻
b. CH₃COO⁻
c. ClO₄⁻
d. SO₃²⁻
e. F⁻

13. If 6.0 mol of N₂ and 8.0 mol of H₂ were entered in an empty 1.0 L cylinder and 2.0 moles of NH₃ were found at equilibrium, the equilibrium constant would be ____________.

\[
\text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g)
\]

a. \( K = \frac{(2.0 \text{ M})^2}{(6.0)(8.0 \text{ M})^3} \)
b. \( K = \frac{(6.0 \text{ M})(8.0 \text{ M})^3}{(2.0 \text{ M})^2} \)
c. \( K = \frac{(2.0 \text{ M})}{(6.0 \text{ M})(8.0 \text{ M})} \)
d. \( K = \frac{(5.0 \text{ M})(5.0 \text{ M})^3}{(2.0 \text{ M})^2} \)
e. \( K = \frac{(2.0 \text{ M})^2}{(5.0 \text{ M})(5.0 \text{ M})^3} \)

14. Calculate the pH of a 0.010 M Ba(OH)₂ solution.

a. 1.70  
b. 2.00  
c. 7.00  
d. 12.00  
e. 12.30
15. What is the Lewis acid in the following reaction: \( \text{Al(OH)}(s) + \text{OH}^- = \text{Al(OH)}_4^- \)?

a. \( \text{Al(OH)}(s) \)

b. \( \text{OH}^- \)

c. \( \text{Al(OH)}_4^- \)

d. None of the above; this is a Bronsted-Lowry reaction.

16. In the following equilibrium, _________ the pressure of \( \text{CO}_2 \) and _________ the temperature will increase the yield of \( \text{CaO} \).

\[ \text{CaCO}_3(s) + \text{heat} \rightarrow \text{CaO}(s) + \text{CO}_2(g) \]

a. raising, raising

b. lowering, lowering

c. raising, lowering

d. lowering, raising

17. If the pH of a solution is 3.33, what is the hydrogen ion concentration?

a. 0.300 M

b. \( 2.1 \times 10^3 \) M

c. \( 4.7 \times 10^{-4} \) M

d. 10.67 M

e. \( 2.1 \times 10^{-11} \) M

18. What is the pH of a 10. M \( \text{NaOH} \) solution?

a. 10.00

b. 1.00

c. \(-1.00\)

d. 15.00

e. 13.00
19. If K for the following reaction is 36, calculate \([\text{Cl}_2]\) if initially two mole of \(\text{ICl}(g)\) was entered into a 1.0L cylinder.

\[
\text{I}_2(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{ICl}(g)
\]

a. 0.25 M  

b. 0.50 M  

c. 1.0 M  

d. 1.5 M  

e. 1.75 M  

20. If \(\text{SO}_2\text{Cl}_2(g)\) was entered into an empty cylinder at a pressure of 3.0 atm, what is the partial pressure of \(\text{Cl}_2\) at equilibrium? \(K_p = 4.0\) atm.

\[
\text{SO}_2\text{Cl}_2(g) \rightleftharpoons \text{SO}_2(g) + \text{Cl}_2(g)
\]

a. 4.0 atm  

b. 2.5 atm  

c. 2.0 atm  

d. 1.0 atm  

e. 0.50 atm  

**Answers**

1. b. \(\text{Na}^+, \text{Ca}^{2+}, \& \text{Cs}^+\) are neutral, \(\text{CO}_3^{2-}\) is basic.  

2. d. Reverse the reaction; \(K' = 1/K\). Multiply by \(\frac{1}{2}\), \(K' = K^{\frac{1}{2}}\). \(K' = 1/(1.9\times10^3)^{\frac{1}{2}} = 2.3\times10^{-2}\).  

3. a. Conjugate acid, add \(\text{H}^+\). Conjugate base, remove \(\text{H}^+\).  

4. b. Answers a & c decrease \(\text{SO}_3\) conc., d & e have no effect.  

5. a. \(K' = K_1K_2 = (3.5\times10^{-4})(1.0\times10^{14}) = 3.5\times10^{10}\).  

6. c. Products over reactants. Coefficients become exponents. Pure solids are omitted.  

7. d. \(\text{pH} = 14.00 - 5.45 = 8.55\). \([\text{H}^+] = 10^{-8.55} = 2.8\times10^{-9}\) M.  

8. b. A strong acid has a very weak conjugate base.  

9. a. \(K_c = [\text{NO}_2]^2/[\text{[NO]}^2[\text{O}_2]] = (4.0)^2/(1.0)^2(2.0) = 8.0\)  

10. c. \(Q = {(0.22)(0.10)}/ {(0.010)(0.010)} = 220\). \(Q < K_c\), so more reactants form and products decrease.  

11. e. \(T = 727^\circ\text{C} + 273^\circ\text{C} = 1000\text{K}\). \(K_p = K_c(RT)^n\). \(\Delta n = 2 - 3 = -1\). \(K_c = (10)(82.06) = 820\).
12. c. ClO$_4^-$ is the conjugate base of a strong acid; the other anions are conjugate bases of weak acids.

13. e. \[ \text{N}_2 + 3\text{H}_2 = 2\text{NH}_3 \]
Init. 6.0 M 8.0 M 0
$\Delta$ -1.0 -3.0 +2.0 (follows stoichiometry of reaction)
Fnl. 5.0 5.0 2.0

14. e. Since Ba(OH)$_2$ ---\(\rightarrow\) Ba$^{2+}$ + 2OH$^-$, [OH$^-$] = 2(0.010 M) = 0.020 M. pOH = $-\log$(0.020) = 1.70. pH = 14.00 - 1.70 = 12.30.

15. a. Al(OH)$_3$ accepts the lone pair of electrons from the OH$^-$.

16. d.

17. c. [H$^+$] = 10$^{-3.33}$ = 4.7×10$^{-4}$M.

18. d. [OH$^-$] = 10. M; pOH = $-\log$(10.) = -1.00; pH = 14.00 - (-1.00) = 15.00.

19. a. I$_2$ + Cl$_2$ $\rightarrow$ 2ICl
Init. 0 0 2.0 M
$\Delta$ +x +x -2x
Fnl x x 2.0 - 2x
$K_c = [\text{ICl}]^2/[\text{I}_2][\text{Cl}_2]$; 36 = (2.0 - 2x)$^2$/x$^2$; 6.0 = (2.0 - 2x)/x (take positive root); x = 0.25 M = [Cl$_2$]

20. c. SO$_2$Cl$_2$ $\rightarrow$ SO$_2$ + Cl$_2$
Init. 3.0 atm 0 0
$\Delta$ -x +x +x
Fnl 3.0 - x x x
$K_p = P_{SO_2}P_{Cl_2}/P_{SO_2Cl_2}$; 4.0 = $x^2/(3.0 - x)$. Use quadratic formula; choose the positive root. $x = 2.0$ atm = [Cl$_2$].