Unless otherwise stated, solutions are aqueous and equilibria are measured at 25 °C.

1. Which answer gives the acid ionization reaction and strength for the acid listed?

   A.  $\text{H}_2\text{SO}_3(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{HSO}_4^-(aq)$  
      strong
   B.  $\text{HCl}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq)$  
      weak
   C.  $\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{C}_2\text{H}_3\text{O}_2^-(aq)$  
      strong
   D.  $\text{H}_3\text{PO}_4(aq) + 3 \text{H}_2\text{O}(l) \rightarrow 3 \text{H}_3\text{O}^+(aq) + \text{PO}_4^{3-}(aq)$  
      weak

2. A 0.20 M solution of a monoprotic acid has a percent ionization of 4.5%. Determine the $K_a$ value of the acid.

   A.  $4.5 \times 10^{-3}$  
   B.  $1.8 \times 10^{-5}$  
   C.  $4.2 \times 10^{-4}$  
   D.  $1.3 \times 10^{-2}$

3. Calculate the pH of a solution that contains 0.020 M HCl and 0.40 M HOCl (hypochlorous acid, $K_a = 2.9 \times 10^{-8}$).

   A.  1.45  
   B.  1.70  
   C.  1.89  
   D.  2.19

4. What is the final pH when 25.0 mL of 0.0100 M KOH is mixed with 75.0 mL of 0.0200 M Sr(OH)$_2$?

   A.  1.502  
   B.  6.995  
   C.  10.236  
   D.  12.512
5. Use the appropriate $K_a$ value given below to determine the $K_b$ of ClO$^-$.

$$K_a (\text{HClO}_2) = 1.1 \times 10^{-2} \quad K_a (\text{HClO}) = 2.9 \times 10^{-8}$$

A. $3.4 \times 10^{-7}$  
B. $1.0 \times 10^{-7}$  
C. $2.9 \times 10^{-8}$  
D. HClO is a strong acid; therefore, ClO$^-$ has no measurable base strength.

6. Which of the following salts dissolves in water to give a solution in the indicated pH range?

A. LiNO$_3$, pH > 7  
B. KC$_2$H$_3$O$_2$, pH > 7  
C. NH$_4$Cl, pH = 7  
D. NaF, pH < 7

7. Rank the following three acids from strongest to weakest acid.

H$_2$O (first ionization), HCl, HF

A. H$_2$O > HF > HCl  
B. HCl = HF > H$_2$O  
C. HF > HCl > H$_2$O  
D. HCl > HF > H$_2$O

8. Which of the following acids has the smallest $K_a$ value?

A. HBrO  
B. HBrO$_2$  
C. HBrO$_3$  
D. HBrO$_4$

9. Which statement is true for the reaction given below:

$$\text{Ag}^+ (aq) + 2 \text{NH}_3(aq) \rightleftharpoons \text{Ag(NH}_3)_2^+(aq)$$

A. Ag$^+$ is a Lewis base; it is an electron pair donor.  
B. Ag$^+$ is a Lewis acid; it is an electron pair acceptor.  
C. NH$_3$ is a Lewis acid; it is an electron pair donor.  
D. NH$_3$ is a Lewis acid; it is an electron pair acceptor.
10. Which of the following describes a solution that resists changes in pH when an acid or a base is added?

A. An electrolytic solution
B. A neutral solution comprised of a strong acid and strong base in equal molar amounts
C. A solution that contains significant amounts of a weak acid and its conjugate base
D. A solution that contains significant amounts of a strong acid and its conjugate base

11. A buffer made of benzoic acid (HC$_7$H$_5$O$_2$, $K_a = 6.5 \times 10^{-5}$) and sodium benzoate (NaC$_7$H$_5$O$_2$) has a pH of 4.99. What is true about the ratio of base to acid for this buffer?

A. $[C_7H_5O_2^-] = 2[HC_7H_5O_2]$  
B. $[C_7H_5O_2^-] = [HC_7H_5O_2]$  
C. $[C_7H_5O_2^-] < [HC_7H_5O_2]$  
D. $[C_7H_5O_2^-] > [HC_7H_5O_2]$

12. A few milliliters of 0.10 M HBr is added to 100.0 mL of a buffer containing 0.10 M HC$_2$H$_3$O$_2$ (acetic acid) and 0.15 M NaC$_2$H$_3$O$_2$ (sodium acetate). Which of the following reactions represents the neutralization of the strong acid?

A. $H_2O(l) + HC_2H_3O_2(aq) \rightarrow C_2H_3O_2^-(aq) + H_3O^+(aq)$  
B. $H_3O^+(aq) + C_2H_3O_2^-(aq) \rightarrow HC_2H_3O_2(aq) + H_2O(l)$  
C. $H^+(aq) + HC_2H_3O_2(aq) \rightarrow H_2C_2H_3O_2^+(aq)$  
D. $OH^-(aq) + H_3O^+(aq) \rightarrow H_2O(l)$

13. Below are four different sodium acetate/acetic acid buffer solutions. Which would be the most effective buffer for the addition of a strong acid?

A. 0.10 M NaC$_2$H$_3$O$_2$/0.10 M HC$_2$H$_3$O$_2$  
B. 0.10 M NaC$_2$H$_3$O$_2$/0.20 M HC$_2$H$_3$O$_2$  
C. 0.20 M NaC$_2$H$_3$O$_2$/0.10 M HC$_2$H$_3$O  
D. 0.020 M NaC$_2$H$_3$O$_2$/0.010 M HC$_2$H$_3$O$_2$
A flask containing 25.0 mL of 0.100 M strong base is titrated with a 0.100 M strong acid. Which graph below best represents the change in pH during the titration?

A. Graph I  
B. Graph II  
C. Graph III  
D. Graph IV
15. Calculate the pH of a solution at the point when 20.20 mL of 0.10 M HCl is titrated with 10.10 mL of 0.20 M NH₃. \( K_b(NH_3) = 1.8 \times 10^{-5} \).

A. 9.33  
B. 4.62  
C. 8.70  
D. 5.22

16. Calculate the pH after 10.0 mL of 0.450 M HI is added to 10.0 mL of a 0.225 M nicotine solution. \( K_b(nicotine) = 1.0 \times 10^{-6} \).

A. 8.379  
B. 12.468  
C. 0.949  
D. 2.062

17. An indicator is red in its acid form and yellow in its ionized (conjugate base) form. When an acidic solution containing this indicator is titrated with a basic solution, what color changes will occur?

A. red \( \rightarrow \) orange \( \rightarrow \) yellow  
B. yellow \( \rightarrow \) orange \( \rightarrow \) red  
C. orange \( \rightarrow \) red \( \rightarrow \) yellow  
D. red \( \rightarrow \) yellow \( \rightarrow \) orange

18. Which of the following salts is the least soluble?

A. \( BaF_2, K_{sp} = 2.45 \times 10^{-5} \)  
B. \( CaF_2, K_{sp} = 1.46 \times 10^{-10} \)  
C. \( PbCl_2, K_{sp} = 1.17 \times 10^{-5} \)  
D. \( PbBr_2, K_{sp} = 4.67 \times 10^{-6} \)
19. Calculate the molar solubility of Cd(OH)$_2$ in pure water. $K_{sp}$ of Cd(OH)$_2$ is $7.2 \times 10^{-15}$.

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<td>A. $3.23 \times 10^{-6}$ M</td>
<td>C. $6.67 \times 10^{-12}$ M</td>
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<tr>
<td>B. $7.44 \times 10^{-20}$ M</td>
<td>D. $1.22 \times 10^{-5}$ M</td>
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20. Which of the following salts is/are more soluble in an acidic solution than in pure water?

- BaF$_2$, CaF$_2$, PbBr$_2$, PbCl$_2$

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<td>A. PbCl$_2$ and PbBr$_2$</td>
<td>B. CaF$_2$ only</td>
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<td>C. BaF$_2$ and CaF$_2$</td>
<td>D. All salts are equally soluble in acid and in pure water.</td>
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21. A solution is $1.50 \times 10^{-4}$ M in Ca(NO$_3$)$_2$ and $3.40 \times 10^{-5}$ M in NaF. $K_{sp}$ (CaF$_2$) = $1.46 \times 10^{-10}$. Which of the following statements is true?

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<td>A. $Q = 1.73 \times 10^{-13}$ and a precipitate will form.</td>
<td>B. $Q = 1.73 \times 10^{-13}$ and no precipitate will form.</td>
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<tr>
<td>C. $Q = 5.10 \times 10^{-9}$ and a precipitate will form.</td>
<td>D. $Q = 5.10 \times 10^{-9}$ and no precipitate will form.</td>
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22. An aqueous solution is 0.010 M in Ag⁺ and 0.010 M in Al³⁺. When sufficient PO₄³⁻ is added to the solution, both Ag₃PO₄ (Ksp = 8.89 × 10⁻¹⁷) and AlPO₄ (Ksp = 9.84 × 10⁻²¹) will precipitate from the solution. What minimum concentration of PO₄³⁻ is needed to begin precipitation of the salt that precipitates first?

A. 9.8 × 10⁻¹⁹ M
B. 8.2 × 10⁻¹³ M
C. 5.4 × 10⁻²¹ M
D. 8.2 × 10⁻¹³ M

23. Which of the following reaction equations is associated with the formation constant (K_f) below?

\[ K_f (CdI_2^2-) = 2 \times 10^6 \]

A. \( CdI_2^2-(aq) \rightleftharpoons Cd^{2+}(aq) + 4I^-(aq) \)
B. \( CdI_2^2-(aq) \rightleftharpoons CdI_2(s) + 2I^-(aq) \)
C. \( Cd^{2+}(aq) + 4I^-(aq) \rightleftharpoons CdI_2^2-(aq) \)
D. \( CdI_2(s) + I_2(s) \rightleftharpoons CdI_2^2-(aq) \)

24. Which species does not increase the solubility of AgI?

A. NH₃
B. SCN⁻
C. F⁻
D. SO₄²⁻

25. Select the true statement from the choices below.

A. A spontaneous process occurs rapidly and without outside intervention.
B. A nonspontaneous process occurs slowly and without outside intervention.
C. A nonspontaneous process occurs without outside intervention, but nonspontaneity does not determine the rate of the process.
D. A spontaneous process occurs without outside intervention, but spontaneity does not determine the rate of the process.
26. Which statement is **true**?

A. All exothermic reactions are spontaneous.
B. All endothermic reactions are nonspontaneous.
C. The increase in disorder or randomness in the universe drives reactions.
D. The increase in order in the universe drives reactions.

27. Which of the following processes is accompanied by a **decrease** in entropy of the system?

A. Freezing of water  
B. Evaporation of water  
C. Mixing of methanol and water  
D. Sublimation of dry ice

28. Which balanced chemical equation shows the **greatest increase** in entropy for the reaction?

A. \(2 \text{NO}_2(g) \rightarrow \text{N}_2\text{O}_4(g)\)
B. \(2 \text{(NH}_4)_2\text{CO}_3(s) \rightarrow 2 \text{NH}_3(g) + \text{CO}_2(g) + \text{H}_2\text{O}(g)\)
C. \(\text{CO}(g) + 2 \text{H}_2(g) \rightarrow \text{CH}_3\text{OH}(g)\)
D. \(\text{SnO}_2(s) + \text{H}_2(g) \rightarrow \text{Sn}(s) + \text{H}_2\text{O}(g)\)

29. Which statement is **true**?

A. The entropy change of the surroundings is positive for exothermic reactions.
B. The entropy change of the surroundings is negative for exothermic reactions.
C. If the entropy change of a reaction is negative, the entropy change of the surroundings is necessarily negative.
D. If the entropy change of a reaction is positive, the entropy change of the surroundings is necessarily negative.

30. What is the change in the entropy of the surroundings for the following reaction conducted at 35.0 °C?

\[4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \quad \Delta H = -902 \text{ kJ}\]

A. 22.4 kJ/K  
B. 1.78 kJ/K  
C. 78.6 kJ/K  
D. 2.93 kJ/K
Answer Key:

1. A
2. C
3. B
4. D
5. A
6. B
7. D
8. A
9. B
10. C
11. D
12. B
13. C
14. B
15. D
16. C
17. A
18. B
19. D
20. C
21. B
22. A
23. C
24. D
25. D
26. C
27. A
28. B
29. A
30. D