### USEFUL CONSTANTS/EQUATIONS

\[ K_w = K_a K_b \]
\[ K_w = [H^+] [OH^-] \]
\[ K_w = 1.0 \times 10^{-14} \text{ (at 25°C)} \]
\[ \text{pH} + \text{pOH} = 14.00 \text{ (at 25°C)} \]
\[ \text{pK}_a + \text{pK}_b = 14.00 \text{ (at 25°C)} \]
\[ \text{pH} = -\log [H^+], \quad [H^+] = 10^{-\text{pH}} \]
\[ \text{pH} = \text{pK}_a + \log \left( \frac{[\text{base}]}{[\text{acid}]} \right) \]
\[ \text{pOH} = -\log [OH^-], \quad [OH^-] = 10^{-\text{pOH}} \]
\[ \text{pK}_a = -\log K_a; \quad \text{pK}_b = -\log K_b; \quad K_b = 10^{-\text{pK}_b} \]
\[ K_a = 10^{-\text{pK}_a} \]
\[ M_A V_A = M_B V_B \]

### Acid

<table>
<thead>
<tr>
<th>Acid</th>
<th>( K_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>(7.2 \times 10^{-4})</td>
</tr>
<tr>
<td>HOCl</td>
<td>(3.5 \times 10^{-8})</td>
</tr>
<tr>
<td>HCN</td>
<td>(6.2 \times 10^{-10})</td>
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</table>

### Base

<table>
<thead>
<tr>
<th>Base</th>
<th>( K_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃</td>
<td>(1.8 \times 10^{-5})</td>
</tr>
</tbody>
</table>

\[ \% \text{ dissociation} = \frac{\text{amount reacted}}{\text{initial concentration}} \times 100 \]
\[ \text{pH} = -\frac{\text{pK}_a + \text{pK}_b}{2} \]
\[ \text{pH} = -\frac{\text{pK}_a + \text{pK}_b}{2} \]

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### PERIODIC TABLE OF THE ELEMENTS

<table>
<thead>
<tr>
<th>1A</th>
<th>Atomic Number</th>
<th>2A</th>
<th>Atomic Mass</th>
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<tr>
<td>Na</td>
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<td>Xe</td>
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<tr>
<td>19</td>
<td>Kr</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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*lanthanides*

- Ce (140.1)
- Pr (140.9)
- Nd (144.2)
- Pm (145)
- Sm (150.4)
- Eu (152.0)
- Gd (157.3)
- Tb (158.9)
- Dy (162.5)
- Ho (164.9)
- Er (167.3)
- Tm (168.9)
- Yb (173.0)
- Lu (175.0)

*actinides*

- Th (232.0)
- Pa (231)
- U (238.0)
- Pu (244)
- Am (243)
- Cm (247)
- Bk (257)
- Cf (251)
- Es (252)
- Fm (258)
- Md (259)
- No (260)
- Lr (260)
1. My answers for this Chemistry 102 exam should be graded with the answer sheet associated with:

   a. Form A  b. Form B  c. Form C  d. Form D  e. Form E

Consider the following plot representing the titration of a triprotic weak acid (H₃A) by KOH for questions 2 and 3.

![Titration Plot]

2. What are the major species present at point C on the plot after the KOH has reacted to completion?

   d. H₂A⁻, HA²⁻, H₂O, K⁺  e. HA²⁻, A³⁻, H₂O, K⁺

3. For H₃A, $K_{a1}$ is $1 \times 10^{-2}$ and $K_{a2}$ is $1 \times 10^{-7}$. If the [H⁺] at point D is $3 \times 10^{-10}$ M, what is the $K_{a3}$ value for this triprotic acid?

   a. $1 \times 10^{-12}$  b. $5 \times 10^{-11}$  c. $1 \times 10^{-11}$  d. $5 \times 10^{-10}$  e. $3 \times 10^{-10}$
4. Consider the species present at equilibrium in a 0.10 \textit{M} H_2SO_4 solution. Which of the following correctly orders the species present from \textbf{smallest} to \textbf{largest} concentration? For H_2SO_4, \( K_a_1 \gg 1 \) and \( K_a_2 = 1.2 \times 10^{-2} \).

a. \( \text{H}_3\text{O}^+ < \text{HSO}_4^- < \text{SO}_4^{2-} \)

b. \( \text{HSO}_4^- < \text{H}_3\text{O}^+ < \text{SO}_4^{2-} \)

c. \( \text{SO}_4^{2-} < \text{HSO}_4^- < \text{H}_3\text{O}^+ \)

d. \( \text{SO}_4^{2-} < \text{H}_3\text{O}^+ < \text{HSO}_4^- \)

5. A solution containing an unknown monoprotic acid has pH = 4.27. If the acid is 0.80\% dissolved, what is the \( K_a \) value for the acid?

a. \( 5.4 \times 10^{-5} \)  
b. \( 1.8 \times 10^{-10} \)  
c. \( 4.3 \times 10^{-5} \)  
d. \( 1.5 \times 10^{-12} \)  
e. \( 4.3 \times 10^{-7} \)

6. Rank the following 1.0 \( M \) solutions from \textbf{highest} to \textbf{lowest} pH.

LiCl, HClO_4, NaOH, NH_4Br, NaF, KCN

a. NaOH > KCN > NaF > LiCl > NH_4Br > HClO_4

b. NaOH > NaF > KCN > LiCl > NH_4Br > HClO_4

c. HClO_4 > NH_4Br > LiCl > KCN > NaF > NaOH

d. LiCl > HClO_4 > NaOH > KCN > NaF > NH_4Br

e. NaOH > NH_4Br > NaF > KCN > LiCl > HClO_4

7. A 1.00 L flask was initially filled with 3.00 mol N_2 and 3.00 mol F_2, which then reacts by the following equation:

\[
\text{N}_2(\text{g}) + 3 \text{F}_2(\text{g}) \rightleftharpoons 2 \text{NF}_3(\text{g}) \quad \text{K} = ?
\]

At equilibrium, 2.75 mol of N_2 remains. Calculate the value of K for the above reaction.

a. 0.43  
b. \( 2.6 \times 10^{-2} \)  
c. \( 1.8 \times 10^{-5} \)  
d. \( 8.0 \times 10^{-3} \)  
e. \( 6.5 \times 10^{-2} \)
8. Separate 2.0 M aqueous solutions of the following three substances are prepared. Rank the resulting three solutions from largest to smallest \([H^+]\).

\[
\text{CaO} \quad \text{NH}_4\text{C}_2\text{H}_5\text{O}_2 \quad \text{CO}_2
\]

a. \(\text{CO}_2 > \text{NH}_4\text{C}_2\text{H}_5\text{O}_2 > \text{CaO}\)

b. \(\text{CaO} > \text{NH}_4\text{C}_2\text{H}_5\text{O}_2 > \text{CO}_2\)

c. \(\text{CaO} > \text{CO}_2 > \text{NH}_4\text{C}_2\text{H}_5\text{O}_2\)

d. \(\text{NH}_4\text{C}_2\text{H}_5\text{O}_2 > \text{CaO} > \text{CO}_2\)

e. \(\text{NH}_4\text{C}_2\text{H}_5\text{O}_2 > \text{CO}_2 > \text{CaO}\)

9. When 5.0 mmol of a monoprotic acid are placed in 350.0 mL of water and titrated with 0.20 M NaOH, pH = 6.00 after 20.0 mL of the NaOH solution has been added. Calculate the \(K_a\) value for the acid.

<table>
<thead>
<tr>
<th></th>
<th>a. (2.5 \times 10^{-7})</th>
<th>b. (1.0 \times 10^{-8})</th>
<th>c. (4.0 \times 10^{-6})</th>
<th>d. (1.0 \times 10^{-6})</th>
<th>e. (5.0 \times 10^{-7})</th>
</tr>
</thead>
</table>

At 50.°C, the equilibrium constant for the autoionization of water (also known as the dissociation constant for water, \(K_w\)), is \(5.47 \times 10^{-14}\). Use this information to answer the next two questions.

10. Which of the following statements best explains whether the autoionization of water is an endothermic or an exothermic reaction?

a. It is endothermic because as temperature increases, \(K\) increases.

b. It is endothermic because as temperature increases, \(K\) decreases.

c. It is exothermic because as temperature increases, \(K\) increases.

d. It is exothermic because as temperature increases, \(K\) decreases.

11. What is the pH of a neutral solution of water at 50.°C?

<table>
<thead>
<tr>
<th></th>
<th>a. 0.74</th>
<th>b. 6.63</th>
<th>c. 7.00</th>
<th>d. 7.37</th>
<th>e. 13.26</th>
</tr>
</thead>
</table>

12. Calculate the equilibrium \([H^+]\) of a solution made by mixing 200.0 mL of 0.10 M HI and 500.0 mL of 0.050 M HCl.

<table>
<thead>
<tr>
<th></th>
<th>a. 0.15 M</th>
<th>b. 0.21 M</th>
<th>c. 0.029 M</th>
<th>d. 0.036 M</th>
<th>e. 0.064 M</th>
</tr>
</thead>
</table>
13. Which of the following solutions would be most resistant to changes in pH?
   a. 0.050 M NaHCO₃ / 0.050 M Na₂CO₃
   b. 0.10 M NaHCO₃ / 0.10 M Na₂CO₃
   c. 0.50 M NaHCO₃ / 0.50 M Na₂CO₃
   d. 1.0 M NaHCO₃ / 1.0 M Na₂CO₃
   e. All are equally resistant to changes in pH.

14. Which of the following titrations will have the lowest pH at the equivalence point?
   a. 2.0 M HCl titrated by 2.0 M KOH.
   b. 2.0 M C₅H₅N (Kₐ = 1.7 × 10⁻₅) titrated by 1.0 M HClO₄.
   c. 2.0 M NH₃ (Kₐ = 1.8 × 10⁻₅) titrated by 2.0 M HCl.
   d. 2.0 M HC₃H₅O₃ (Kₐ = 1.38 × 10⁻⁴) titrated by 1.0 M NaOH.
   e. All the above titrations have the same pH at the equivalence point.

15. Which of the following titrations has a pH closest to 5 at the halfway point to equivalence?
   a. 2.0 M HCl titrated by 2.0 M KOH.
   b. 2.0 M C₅H₅N (Kₐ = 1.7 × 10⁻₅) titrated by 1.0 M HClO₄.
   c. 2.0 M NH₃ (Kₐ = 1.8 × 10⁻₅) titrated by 2.0 M HCl.
   d. 2.0 M HC₃H₅O₃ (Kₐ = 1.38 × 10⁻⁴) titrated by 1.0 M NaOH.
   e. All the above titrations have the same pH at the halfway point to equivalence point.

16. The hydrogen sulfate ion, HSO₄⁻, has both a conjugate acid and a conjugate base. What are the conjugate acid and the conjugate base of HSO₄⁻, respectively?

<table>
<thead>
<tr>
<th>Conjugate Acid</th>
<th>Conjugate Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. H₂SO₄</td>
<td>HSO₄⁻</td>
</tr>
<tr>
<td>b. HSO₄⁻</td>
<td>SO₄²⁻</td>
</tr>
<tr>
<td>c. HSO₄⁻</td>
<td>H₂SO₄</td>
</tr>
<tr>
<td>d. SO₄²⁻</td>
<td>HSO₄⁻</td>
</tr>
<tr>
<td>e. H₂SO₄</td>
<td>SO₄²⁻</td>
</tr>
</tbody>
</table>
17. The pH of a solution is lowered from 5.0 to 3.0. Which of the following statements describing this process is false?

a. The pOH will be raised from 9.0 to 11.0.
b. The [H⁺] will be increased by a factor of 100.
c. The initial [OH⁻] (at pH = 5.00) is 1 × 10⁻⁹ M.
d. The final [H⁺] (at pH = 3.00) is 1 × 10⁻³ M.
e. The initial solution could be 1 × 10⁻¹¹ M NaOH

18. Consider a buffer solution containing HCN and NaCN. Which of the following statements is false?

a. If [CN⁻] = [HCN], then the pH of the solution equals the pKₐ value for HCN.
b. If [CN⁻] > [HCN], then the pH of the solution is greater than the pKₐ value for HCN.
c. If [CN⁻] > [HCN], then the Kₐ value for HCN is greater than [H⁺] for the solution.
d. If HCl is added to the buffer, then the [CN⁻] of the resulting solution should increase.
e. If NaOH is added to the buffer, then the pH of the resulting solution should increase.

Consider the titration of 200.00 mL of 0.10 M HClO₄ titrated by 0.20 M Ca(OH)₂ for the next two questions.

19. Calculate the [H⁺] of the resulting solution after 25.0 mL of 0.20 M Ca(OH)₂ has been added.

a. 0.067 M   b. 0.050 M  c. 0.044 M  d. 0.022 M  e. 0.010 M

20. At what volume of Ca(OH)₂ added will the [H⁺] = 1.0 × 10⁻⁷ M for the resulting solution?

a. 50.0 mL   b. 75.0 mL   c. 100.0 mL  d. 150.0 mL  e. 200.0 mL

21. How many of the following four compounds are strong bases when dissolved in water?

NaOH, Ba(OH)₂, IOH, C₆H₅OH

a. 0  b. 1  c. 2  d. 3  e. 4 (All are strong bases.)

22. Consider the following reaction:

2 CO₂(g) ⇌ 2 CO(g) + O₂(g) \quad K = 2.0 \times 10^{-6}

If 2.0 mol of CO₂ are initially placed in a 1.0 L container, calculate the equilibrium CO concentration ([CO] = ?).

a. 1.3 × 10⁻² M  b. 1.0 M  c. 2.8 × 10⁻³ M  d. 1.4 × 10⁻³ M  e. 2.5 × 10⁻² M
Consider the titration of 100.0 mL of 0.100 M \( \text{HC}_2\text{H}_3\text{O}_2 \) by 0.100 M \( \text{NaOH} \) for the next five questions. \( K_a \) for \( \text{HC}_2\text{H}_3\text{O}_2 = 1.8 \times 10^{-5} \).

23. Calculate the pH when 0.0 mL of \( \text{NaOH} \) has been added.
   a. 1.00  b. 2.87  c. 7.00  d. 11.13  e. 13.00

24. Calculate the pH after 25.0 mL of \( \text{NaOH} \) has been added.
   a. 2.98  b. 4.27  c. 4.74  d. 5.22  e. 11.02

25. Calculate the pH after 50.0 mL of \( \text{NaOH} \) has been added.
   a. 2.87  b. 4.27  c. 4.74  d. 7.00  e. 5.22

26. Calculate the pH after 100.0 mL of \( \text{NaOH} \) has been added.
   a. 5.28  b. 4.74  c. 10.15  d. 8.72  e. 9.26

27. Calculate the pH after 125.0 mL of \( \text{NaOH} \) has been added.
   a. 9.26  b. 10.15  c. 0.72  d. 13.28  e. 12.05

28. A 1.0 L buffer solution with a pH of 9.50 is prepared from \( \text{HCN} \) and \( \text{Sr(CN)}_2 \). If the buffer contains 2.5 mol of \( \text{HCN} \), how many mol of \( \text{Sr(CN)}_2 \) must be added to prepare this buffer solution? (Assume strontium cyanide is soluble.) \( K_a \) for \( \text{HCN} = 6.2 \times 10^{-10} \).
   a. 2.45 mol  b. 3.25 mol  c. 1.28 mol  d. 7.00 mol  e. 0.64 mol

29. Consider the following reaction at some temperature:

\[
2 \text{ NOBr(g)} \rightleftharpoons \text{ Br}_2(\text{g}) + 2 \text{ NO(g)} \quad K = 3.67
\]

If a student mixes 1.0 \( M \) \( \text{NOBr} \), 1.0 \( M \) \( \text{Br}_2 \), and 2.0 \( M \) \( \text{NO} \) together in a reaction container, what is the value of the reaction quotient \( Q \), and which way does the reaction shift to establish equilibrium?

a. \( Q = 4.0 \) so the reaction shifts to reactants (shifts left) to reach equilibrium.
b. \( Q = 2.0 \) so the reaction shifts to products (shifts right) to reach equilibrium.
c. \( Q = 4.0 \) so the reaction shifts to products (shifts right) to reach equilibrium.
d. \( Q = 2.0 \) so the reaction shifts to reactants (shifts left) to reach equilibrium.
Consider the following five solutions for the next four questions.

I. 50.0 mL of 0.250 M NaOCl
II. 25.0 mL of 0.500 M HClO₄
III. 50.0 mL of 0.250 M HOCl \( (K_a \text{ for } \text{HOCl} = 3.5 \times 10^{-8}). \)
IV. 50.0 mL of 0.250 M KOH
V. 25.0 mL of 0.500 M KBr

30. Calculate the pH of solution I.
   a. 3.57   b. 4.03   c. 7.00   d. 9.97   e. 10.43

31. Calculate the pH of the resulting solution when solutions I and II are mixed together.
   a. 0.30   b. 4.12   c. 7.00   d. 9.88   e. 13.70

32. Calculate the pH of the resulting solution when solutions II, IV, and V are mixed together.
   a. 0.30   b. 0.60   c. 7.00   d. 13.40   e. 13.70

33. Calculate the pH of the resulting solution when solutions I, II, III, IV, and V are mixed together.
   a. 0.30   b. 6.54   c. 7.00   d. 7.46   e. 13.70

34. Consider the following reaction:

\[
\text{CH}_4(g) + 2 \text{O}_2(g) \rightleftharpoons \text{CO}_2(g) + 2 \text{H}_2\text{O}(l) \quad \Delta H = -891 \text{ kJ}
\]

How many of the following five statements are true?

I. If CH₄ is added, the reaction shifts right and K decreases.
II. If CO₂ is added, the reaction shifts left and K decreases.
III. If the temperature is increased, the reaction shifts left and K decreases.
IV. If the pressure is increased by decreasing the volume, the reaction shifts right.
V. If the pressure is increased by adding argon gas, the reaction shifts right.

a. 1   b. 2   c. 3   d. 4   e. 5 (All are true.)