1. For the stepwise dissociation of aqueous H₃PO₄, which of the following is NOT a conjugate acid-base pair?

   a. HPO₄²⁻ and PO₄³⁻
   b. H₂PO₄⁻ and H₃PO₄⁻¹
   c. H₃PO₄⁻¹ and HPO₄²⁻
   d. H₂PO₄⁻¹ and PO₄³⁻
   e. H₃O⁺¹ and H₂O

\[
\begin{align*}
\text{H}_3\text{PO}_4 + \text{H}_2\text{O} &\rightleftharpoons \text{H}_3\text{O}^{+1} + \text{H}_2\text{PO}_4^{-1} \\
\text{acid} &\quad \text{base} \quad \text{c.a.} \quad \text{c.b.} \\
\text{H}_2\text{PO}_4^{-1} + \text{H}_2\text{O} &\rightleftharpoons \text{H}_3\text{O}^{+1} + \text{HPO}_4^{-2} \\
\text{acid} &\quad \text{base} \quad \text{c.a.} \quad \text{c.b.} \\
\text{HPO}_4^{-2} + \text{H}_2\text{O} &\rightleftharpoons \text{H}_3\text{O}^{+1} + \text{PO}_4^{-3} \\
\text{acid} &\quad \text{base} \quad \text{c.a.} \quad \text{c.b.}
\end{align*}
\]

2. What is the equilibrium constant for the following reaction?

   \[\text{N}_3^{-1} + \text{H}_3\text{O}^{+1} \rightleftharpoons \text{HN}_3 + \text{H}_2\text{O}\]

   The \(K_a\) value for HN₃ = 1.9 x 10⁻⁵
   a. 5.3 x 10⁻¹⁰
   b. 1.9 x 10⁻⁹
   c. 1.9 x 10⁻⁵
   d. 5.3 x 10⁻⁴
   e. 1.9 x 10⁰

   The reaction is
   \[\text{HN}_3 + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^{+1} + \text{N}_3^{-1}\]

   \(K_a = 1.9 \times 10^{-5}\)

   So \(K\) for the given rxn is \(1/K_a\) or

   \[K = 1/K_a = 1/(1.9 \times 10^{-5}) = 5.3 \times 10^4\]

3. The hydrogen sulfate (or bisulfate) ion HSO₄⁻¹ can act as either an acid or a base in water solution. In which of the following equations does HSO₄⁻¹ act as an acid?

   a. HSO₄⁻¹ + H₂O → H₂SO₄ + OH⁻¹
   b. HSO₄⁻¹ + H₃O⁺¹ → SO₃ + 2 H₂O
   c. HSO₄⁻¹ + OH⁻¹ → H₂SO₄ + O²⁻
   d. HSO₄⁻¹ + H₂O → SO₄²⁻ + H₃O⁺¹
   e. none of these

\[
\begin{align*}
\text{HSO}_4^{-1} + \text{H}_2\text{O} &\rightarrow \text{H}_2\text{SO}_4 + \text{OH}^{-1} \\
\text{base} &\quad \text{acid} \quad \text{c.a.} \quad \text{c.b.} \\
\text{HSO}_4^{-1} + \text{H}_3\text{O}^{+1} &\rightarrow \text{SO}_3 + 2 \text{H}_2\text{O} \\
\text{base} &\quad \text{acid} \quad \text{c.a.} \quad \text{c.b.} \\
\text{HSO}_4^{-1} + \text{OH}^{-1} &\rightarrow \text{H}_2\text{SO}_4 + \text{O}^{-2} \\
\text{base} &\quad \text{acid} \quad \text{c.a.} \quad \text{c.b.} \\
\text{HSO}_4^{-1} + \text{H}_2\text{O} &\rightarrow \text{SO}_4^{2-} + \text{H}_3\text{O}^{+1} \\
\text{acid} &\quad \text{base} \quad \text{c.b.} \quad \text{c.a.}
\end{align*}
\]

4. Using the following \(K_a\) values, indicate the correct order of base strength.

   \[
   \begin{align*}
   \text{HNO}_2 &\quad K_a = 4.0 \times 10^{-4} \\
   \text{HF} &\quad K_a = 7.2 \times 10^{-4} \\
   \text{HCN} &\quad K_a = 6.2 \times 10^{-10}
   \end{align*}
   \]

   \[
   \begin{align*}
   \text{HCl} &\quad \text{HF} > \text{HNO}_2 > \text{H}_2\text{O} > \text{HCN} \\
   \text{Because} &\quad K_{a\text{HCl}} > K_{a\text{HF}} > K_{a\text{HNO}_2} > K_{a\text{H}_2\text{O}} > K_{a\text{HCN}} \\
   \text{Therefore} &\quad \text{Cl}^{-1} < \text{F}^{-1} < \text{NO}_2^{-1} < \text{H}_2\text{O} < \text{CN}^{-1}
   \end{align*}
   \]
5. Which of the following is the equilibrium constant expression for the dissociation of the weak acid HOCl?

   a. \( K = \frac{[H^+] [OCl^-]}{[HOCl]} \)

   b. \( K = [H^+] [OCl^-] \)

   c. \( K = \frac{[HOCl]}{[H^+] [OCl^-]} \)

   d. \( K = \frac{[H^+] [Cl^-]}{[HOCl]} \)

   e. none of these

Use the following equations for questions 6 and 7. The following three equations represent equilibria that lie far to the right.

\[
\text{HNO}_3 (aq) + \text{CN}^- (aq) \leftrightarrow \text{HCN} (aq) + \text{NO}_3^- (aq)
\]

acid \hspace{1cm} base \hspace{1cm} c.a. \hspace{1cm} c.b.

\[
\text{HCN} (aq) + \text{OH}^- (aq) \leftrightarrow \text{H}_2\text{O} (ℓ) + \text{CN}^- (aq)
\]

acid \hspace{1cm} base \hspace{1cm} c.a. \hspace{1cm} c.b.

\[
\text{H}_2\text{O} (ℓ) + \text{CH}_3\text{O}^- (aq) \leftrightarrow \text{CH}_3\text{OH} (aq) + \text{OH}^- (aq)
\]

acid \hspace{1cm} base \hspace{1cm} c.a. \hspace{1cm} c.b.

6. Identify the strongest acid.

   a. HCN – weak acid

   b. HNO\textsubscript{3} – strong acid

   c. H\textsubscript{2}O – neutral

   d. OH\textsuperscript{-} – strong base

   e. CH\textsubscript{3}OH – weak acid

7. Identify the strongest base.

   a. CH\textsubscript{3}O\textsuperscript{-}1

   b. CH\textsubscript{3}OH

   c. CN\textsuperscript{-1}

   d. H\textsubscript{2}O

   e. NO\textsubscript{3}\textsuperscript{-1}

8. In which of the following reactions does the H\textsubscript{2}PO\textsubscript{4}\textsuperscript{-1} ion act as an acid?

   a. H\textsubscript{2}PO\textsubscript{4} + H\textsubscript{2}O \leftrightarrow H\textsubscript{3}O\textsuperscript{+1} + H\textsubscript{2}PO\textsubscript{4}\textsuperscript{-1}

   b. H\textsubscript{2}PO\textsubscript{4}\textsuperscript{-1} + H\textsubscript{2}O \leftrightarrow H\textsubscript{3}O\textsuperscript{+1} + HPO\textsubscript{4}\textsuperscript{2-}

   c. H\textsubscript{2}PO\textsubscript{4}\textsuperscript{-1} + OH\textsuperscript{-} \leftrightarrow H\textsubscript{3}PO\textsubscript{4} + O\textsuperscript{2-}

   d. The ion cannot act as an acid.

   e. Two of these

See work on question #1

Acid Strength:

\[ \text{HNO}_3 > \text{HCN} \text{ or } \text{CH}_3\text{OH} > \text{H}_2\text{O} > \text{OH}^- \]

Therefore, Base Strength:

\[ \text{NO}_3^- < \text{CN}^- \text{ or } \text{CH}_3\text{O}^- < \text{OH}^- < \text{O}^{2-} \]

Because the equilibriums lie far to the right:

\[ \text{CN}^- \text{ is a stronger base then } \text{NO}_3^- \]
\[ \text{OH}^- \text{ is a stronger base then } \text{CN}^- \]
\[ \text{CH}_3\text{O}^- \text{ is a stronger base then } \text{OH}^- \]

therefore, the strongest base is CH\textsubscript{3}O\textsuperscript{-1}
9. Which of the following is true for the dissociation of a weak acid?
   a. $K_a$ is large.
   b. The equilibrium lies far to the right.
   c. The equilibrium lies far to the left.
   d. $[H^+] >>[HA]$
   e. The conjugate base will be weak.

   \[
   \text{HA} \rightleftharpoons H^+ + A^- \\
   K_a = \frac{[H^+][A^-]}{[HA]}
   \]

   A weak acid’s equilibrium will lie to the left.
   (For the equilibrium to lie to the right, it has to be a strong acid. For a strong acid, $[H^+] >>[HA]$.)

10. Which of the following reactions is associated with the definition of $K_b$?
   a. $\text{Zn(OH)}_6^{2+} \rightleftharpoons [\text{Zn(OH)}_5(\text{OH})]^+ + \text{H}^+$
   b. $\text{CN}^- + \text{H}_2\text{O} \rightleftharpoons \text{HCN}$
   c. $\text{Cr}^{3+} + 6 \text{H}_2\text{O} \rightleftharpoons \text{Cr(OH)}_2^6^{3+}$
   d. $\text{none of these}$

   $K_b$ always refers to the reaction of a base with water to form the conjugate acid and the hydroxide ion (conjugate base.)

11. Use the following $K_a$’s to answer the question.

<table>
<thead>
<tr>
<th>Acid</th>
<th>$K_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAc</td>
<td>$1.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>$\text{H}_2\text{CO}_3$</td>
<td>$K_{a1} = 4.3 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

   a. HAc
   b. NaAc
   c. Na$_2$CO$_3$
   d. $\text{H}_2\text{CO}_3$
   e. NaHCO$_3$

12. The conjugate acid and conjugate base of the bicarbonate ion, $\text{HCO}_3^{-1}$, are, respectively:
   a. $\text{H}_3\text{O}^{+1}$ and $\text{OH}^{-1}$
   b. $\text{H}_2\text{O}^{+1}$ and $\text{CO}_3^{-2}$
   c. $\text{H}_2\text{CO}_3$ and $\text{OH}^{-1}$
   d. $\text{HCO}_3^{-1}$ and $\text{CO}_3^{-2}$
   e. $\text{CO}_3^{-2}$ and $\text{OH}^{-1}$

   See work on question #11

13. Which of the following species is present in the greatest concentration in a 0.100 M $\text{H}_2\text{SO}_4$ solution in $\text{H}_2\text{O}$?
   a. $\text{H}_3\text{O}^{+1}$
   b. HSO$_4^{-1}$
   c. $\text{H}_2\text{SO}_4$
   d. All species are in equilibrium and therefore have the same concentration.
   e. $\text{SO}_4^{-2}$

   \[
   \text{H}_2\text{SO}_4 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^{+1} + \text{HSO}_4^{-1} \text{ dissociates}
   \]

   \[
   \text{HSO}_4^{-1} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^{+1} + \text{SO}_4^{2-}
   \]
14. The sodium salt, NaA, of a weak acid is dissolved in water; no other substance is added. Which of these statements (to a close approximation) is true?

a. \([H^+] = [A^-]\)  
NaA → Na\(^+\) + A\(^-\) dissolves completely  
So [A\(^-\)] is large. [H\(^+\)] is not in either reaction.

b. \([H^+] = [OH^-]\)  
A\(^-\) + H\(_2\)O ↔ HA + OH\(^-\)

\([HA] = [OH^-]\), 1:1 ratio; The exact concentration depends on the percent dissociation.

c. \([A^-] = [OH^-]\)

d. \([HA] = [OH^-]\)

e. none of these

15. The hydrogen halides (HF, HCl, HBr, and HI) are all polar molecules. The strength of the acid each forms in water is based on which of the following?

a. the polarity of the molecule  
As electronegativity increases, acid strength increases.

b. the size of the molecule  
As the strength of the H-X bond increases, acid strength increases.

c. the strength of the bond  
(Answers “a” and “c” are correct.)

d. two of these

e. none of these

16. Which factor listed below is most important in determining the strength of an oxyacid?

a. the size of the molecule  
Acid strength increases with an increase in the number of oxygen atoms attached to the central atom.

b. the ability of the molecule to change atomic orientation

c. the identity of the central atom in the molecule

d. the number of oxygen atoms present in the molecule  
This is a tug-of-war. Strong-strong is a tie (neutral).

e. none of these

For questions 17-19, use the following information.

If the following substance is dissolved in pure water, will the solution be acidic, neutral, or basic?

a. Acidic  
This is a tug-of-war. Strong-strong is a tie (neutral).

b. Neutral  
In a weak-strong situation, the strong one always wins.

c. Basic

17. solid sodium nitrate  b. Neutral  
NaNO\(_3\)  
Na comes from NaOH, a strong base and NO\(_3\) comes from HNO\(_3\), a strong acid.

18. solid silver chloride  a. Acidic  
AgCl  
Ag comes from AgOH, a weak base and Cl comes from HCl, a strong acid.

19. solid sodium carbonate  c. Basic  
Na\(_2\)CO\(_3\)  
Na comes from NaOH, a strong base; CO\(_3\) comes from H\(_2\)CO\(_3\), a strong acid.

20. As water is heated, its pH decreases. This means that

a. the water is no longer neutral.

b. the Ka value is decreasing.

c. the water has a lower [OH\(^-\)] than cooler water.

d. the dissociation of water is an endothermic process.

e. none of these