Phenol is a weak acid that partially dissociates in water, according to the equation above.

(a) What is the pH of a $0.75 \text{ M} \text{C}_6\text{H}_5\text{OH}(aq)$ solution?

\[
K_a = \frac{[\text{C}_6\text{H}_5\text{O}^-][\text{H}_3\text{O}^+]}{[\text{C}_6\text{H}_5\text{OH}]} = 1.12 \times 10^{-10}
\]

1.12 \times 10^{-10} = \frac{x^2}{(0.75 - x)} \quad \text{Assume that } x \ll 0.75.

\[x^2 = 8.4 \times 10^{-11}\]

\[x = \sqrt{8.4 \times 10^{-11}}\]

\[x = 9.2 \times 10^{-6} \text{ M}\]

\[\text{pH} = -\log[\text{H}^+] = -\log (9.2 \times 10^{-6}) = 5.04\]

(b) For a certain reaction involving $\text{C}_6\text{H}_5\text{OH}(aq)$ to proceed at a significant rate, the phenol must be primarily in its deprotonated form, $\text{C}_6\text{H}_5\text{O}^- (aq)$. In order to ensure that the $\text{C}_6\text{H}_5\text{OH}(aq)$ is deprotonated, the reaction must be conducted in a buffered solution. On the number scale below, circle each pH for which more than 50 percent of the phenol molecules are in the deprotonated form ($\text{C}_6\text{H}_5\text{O}^- (aq)$). Justify your answer.

Numbers 10 through 14 should be circled.

When $\text{pH} > pK_a$, the deprotonated form will predominate.

$pK_a = -\log(1.12 \times 10^{-10}) = 9.95$, therefore at pH 10 and above, $[\text{C}_6\text{H}_5\text{O}^-] > [\text{C}_6\text{H}_5\text{OH}]$.

1 point is earned for circling 10–14.

1 point is earned for the justification.
4. Phenol is a weak acid that partially dissociates in water according to the equation above.

\[ C_6H_5OH(aq) + H_2O(l) \rightleftharpoons C_6H_5O^-(aq) + H_3O^+(aq) \quad K_a = 1.12 \times 10^{-10} \]

(a) What is the pH of a 0.75 M \( C_6H_5OH(aq) \) solution?

(b) For a certain reaction involving \( C_6H_5OH(aq) \) to proceed at a significant rate, the phenol must be primarily in its deprotonated form, \( C_6H_5O^-(aq) \). In order to ensure that the \( C_6H_5OH(aq) \) is deprotonated, the reaction must be conducted in a buffered solution. On the number scale below, circle each pH for which more than 50 percent of the phenol molecules are in the deprotonated form (\( C_6H_5O^-(aq) \)). Justify your answer.

\[
\begin{array}{cccccccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 \\
\hline
1 & 0.75 & - & - & - & - & - & - & - & 10 & - & - & - & - \\
\hline
E & 0.75-x & - & +x & +x & - & - & - & - & - & - & - & - & - \\
\end{array}
\]

\[
1.12 \times 10^{-10} = \frac{x^2}{0.75-x} \quad \text{because} \quad x << 0.75 \quad \text{because} \quad \text{it is very small}
\]

\[
x^2 = 8.4 \times 10^{-11}
\]

\[
x = 9.2 \times 10^{-6} = [H^+]
\]

\[
\text{pH} = -\log(9.2 \times 10^{-6}) = 5.04
\]

\[
\text{pH} = \text{pK}_a + \log \left( \frac{[A^-]}{[HA]} \right) \quad \text{when} \quad \left( \frac{[A^-]}{[HA]} \right) > 1, \quad A^- > 50\%
\]

\[
\text{pH} = \text{pK}_a \quad \text{when} \quad \left( \frac{[A^-]}{[HA]} \right) = 1
\]

\[
= -\log(1.12 \times 10^{-10}) = 9.951
\]

\[
\text{when} \quad \left( \frac{[A^-]}{[HA]} \right) > 1, \quad \text{pH} > \text{pK}_a
\]

\[
\text{pH} > 9.951
\]

\[
\text{pH} = \{10, 11, 12, 13, 14\}
\]

\[
\text{when} \quad [C_6H_5O^-] = [C_6H_5OH], \quad \text{pH} = \text{pK}_a = 9.951
\]

For any solution where \( [C_6H_5O^-] > [C_6H_5OH] \),
pH > pK_a. In basic solutions with pH > pK_a, the equilibrium is shifted to the left enough so that [C_6H_5O^-] > [C_6H_5-OH].
4. Phenol is a weak acid that partially dissociates in water according to the equation above.

(a) What is the pH of a 0.75 M \( \text{C}_6\text{H}_5\text{OH}(aq) \) solution?

(b) For a certain reaction involving \( \text{C}_6\text{H}_5\text{OH}(aq) \) to proceed at a significant rate, the phenol must be primarily in its deprotonated form, \( \text{C}_6\text{H}_5\text{O}^-(aq) \). In order to ensure that the \( \text{C}_6\text{H}_5\text{OH}(aq) \) is deprotonated, the reaction must be conducted in a buffered solution. On the number scale below, circle each pH for which more than 50 percent of the phenol molecules are in the deprotonated form (\( \text{C}_6\text{H}_5\text{O}^-(aq) \)). Justify your answer.

\[
\text{C}_6\text{H}_5\text{OH}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_6\text{H}_5\text{O}^-(aq) + \text{H}_3\text{O}^+(aq) \quad K_a = 1.12 \times 10^{-10}
\]

\[
x^2 = \frac{1.12 \times 10^{-10}}{0.75} = 1.49 \times 10^{-10}
\]

\[
x = \sqrt{1.49 \times 10^{-10}} = 9.75 \times 10^{-6}
\]

\[
-\log(9.75 \times 10^{-6}) = 5.04
\]

\[
\text{pH} = 5.04
\]

\[
-\log([\text{H}_3\text{O}^+]) = -\log \left( \frac{[\text{C}_6\text{H}_5\text{O}^-]}{[\text{HA}]} \right) - \log \left( \frac{[\text{C}_6\text{H}_5\text{O}^-]}{[\text{HA}]} \right)
\]

\[
\text{pH} = 9.95 - \log \left( \frac{[\text{C}_6\text{H}_5\text{O}^-]}{[\text{HA}]} \right)
\]

According to this formula, whenever \( [\text{C}_6\text{H}_5\text{O}^-] \) is larger than the concentration of \( \text{HA} \), the pH will be below the pK\(_a\), or 9.95. As such, all pH's 9 or below will have a higher concentration of \( \text{C}_6\text{H}_5\text{O}^- \) than \( \text{H}_3\text{O}^+ \).
4. Phenol is a weak acid that partially dissociates in water according to the equation above.

(a) What is the pH of a 0.75 M \( C_6H_5OH(aq) \) solution?

(b) For a certain reaction involving \( C_6H_5OH(aq) \) to proceed at a significant rate, the phenol must be primarily in its deprotonated form, \( C_6H_5O^-(aq) \). In order to ensure that the \( C_6H_5OH(aq) \) is deprotonated, the reaction must be conducted in a buffered solution. On the number scale below, circle each pH for which more than 50 percent of the phenol molecules are in the deprotonated form (\( C_6H_5O^-(aq) \)). Justify your answer.

\[ C_6H_5OH(aq) + H_2O(l) \rightleftharpoons C_6H_5O^-(aq) + H_3O^+(aq) \quad K_a = 1.12 \times 10^{-10} \]

\[ \text{pH} = \log \left[ \frac{0.75 M}{\text{HA}} \right] \]

\[ \text{pH} = 0.125 \]

\[ \text{pH} = \text{pK}_a + \log \left[ \frac{\text{A}^-}{\text{HA}} \right] \]

\[ \text{pH} = 9.98 + 0 \]

\[ \text{pH} = 9.95 \]

6) deprotonated \( \rightarrow \) more electrons \( \rightarrow \) more products than reactants when the solution is more basic because \( [\text{A}^-] > [\text{HA}] \) so \( \log \left[ \frac{\text{A}^-}{\text{HA}} \right] > 0 \) which gets added to the \( \text{pK}_a \) making it more basic and greater than the original pH of 9.95.
Overview

Question 4 explored students’ knowledge of weak acid equilibrium conditions in aqueous solution and conjugate acid/base relationships in a buffered solution. Students were given two scenarios involving solutions of phenol, C₆H₅OH (aq). In part (a) students were to calculate the pH of a 0.75 M solution of phenol given the $K_a$ value for this weak acid. In part (b) students were asked to select pH values of a buffered solution that would ensure more than 50% of the phenol was in its deprotonated form, C₆H₅O⁻(aq).

**Sample: 4A**

**Score: 4**

In part (a) 1 point was earned for setting up and correctly calculating $[H^+]$, and 1 point was earned for setting up and correctly calculating the pH. In part (b) 1 point was earned for circling numbers 10–14, and 1 point was earned for a justification that clearly describes buffers with a greater concentration of conjugate base than conjugate acid corresponding to a pH > $pK_a$.

**Sample: 4B**

**Score: 3**

In part (a) 1 point was earned for setting up and correctly calculating $[H^+]$, and 1 point was earned for setting up and correctly calculating the pH. In part (b) no point was earned for circling numbers 1–9; however, 1 point was earned for a justification consistent with the circled numbers. The student makes a sign error using the Henderson-Hasselbalch equation and matches the increasing concentration of conjugate base with a decreasing pH.

**Sample: 4C**

**Score: 2**

In part (a) neither of the two possible points were earned; the student calculates $[H^+]$ incorrectly and bases the calculation of pH on an incorrect application of the Henderson-Hasselbalch equation. In part (b) 1 point was earned for circling numbers 10–14, and 1 point was earned for a consistent justification that describes the increase of conjugate base concentration and increased base/acid ratio when pH > $pK_a$. 