

Chemistry - Acid-Base Equilibria

Problem Statement

Calculate the concentrations of CO_3^{2-} , H_3O^+ , and OH^- in a 0.180 M solution of H_2CO_3 given that $K_{a1} = 4.3 \times 10^{-7}$ and $K_{a2} = 5.6 \times 10^{-11}$.

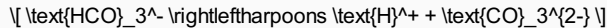
Given:

- Concentration of H_2CO_3 (C) = 0.180 M
- $K_{a1} = 4.3 \times 10^{-7}$
- $K_{a2} = 5.6 \times 10^{-11}$

Step-by-Step Solution

Step 1: Introduction and Given Data

This problem involves calculating the concentrations of various species in a diprotic acid solution. Here, the diprotic acid is H_2CO_3 which dissociates in two steps:



Step 2: Calculate the concentration of H_3O^+ from the first ionization



$$K_{a1} = 4.3 \times 10^{-7}$$

Using the approximation method:

- Let's assume x is the concentration of H^+ formed in the first dissociation.
- H^+ and HCO_3^- will both have concentration x .
- $[\text{H}_2\text{CO}_3] \approx 0.180 \text{ M} - x \approx 0.180 \text{ M}$

$$K_{a1} = \frac{[\text{H}^+][\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]}$$

$$4.3 \times 10^{-7} = \frac{x^2}{0.180}$$

Step 3: Solve for x

$$x^2 = 4.3 \times 10^{-7} \times 0.180$$

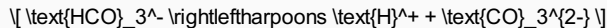
$$x^2 = 7.74 \times 10^{-8}$$

$$x = \sqrt{7.74 \times 10^{-8}}$$

$$x \approx 8.80 \times 10^{-4} \text{ M}$$

Thus, $[\text{H}_3\text{O}^+] \approx 8.80 \times 10^{-4} \text{ M}$

Step 4: Calculate CO_3^{2-} concentration from the second ionization



$$K_{a2} = 5.6 \times 10^{-11}$$

Using approximation:

- Let's assume y is the concentration of CO_3^{2-} formed from the second dissociation.
- H^+ concentration from the second dissociation will be small compared to the first.
- $y = [\text{CO}_3^{2-}]$
- $[\text{HCO}_3^-] \approx x$

$$K_{a2} = \frac{[y][\text{H}^+]}{[\text{HCO}_3^-]}$$

$$5.6 \times 10^{-11} = \frac{y \cdot 8.80 \times 10^{-4}}{8.80 \times 10^{-4}}$$

$$y = 5.6 \times 10^{-11}$$

Thus, $[\text{CO}_3^{2-}] \approx 5.6 \times 10^{-11} \text{ M}$

Step 5: Calculate OH^- concentration using K_w

$$K_w = [\text{H}_3\text{O}^{+}] [\text{OH}^{-}] = 1.0 \times 10^{-14}$$

$$1.0 \times 10^{-14} = 8.80 \times 10^{-4} [\text{OH}^{-}]$$

$$[\text{OH}^{-}] = \frac{1.0 \times 10^{-14}}{8.80 \times 10^{-4}}$$

$$[\text{OH}^{-}] \approx 1.14 \times 10^{-11} \text{ M}$$

Final Concentrations

$$[\text{CO}_3^{2-}] \approx 5.6 \times 10^{-11} \text{ M}$$

$$[\text{H}_3\text{O}^{+}] \approx 8.80 \times 10^{-4} \text{ M}$$

$$[\text{OH}^{-}] \approx 1.14 \times 10^{-11} \text{ M}$$

Final Answer

$$\left[\text{CO}_3^{2-}, \text{H}_3\text{O}^{+}, \text{OH}^{-} \right] = 5.6 \times 10^{-11} \text{ M}, 8.80 \times 10^{-4} \text{ M}, 1.14 \times 10^{-11} \text{ M}$$