Chapter 7 Challenge Problem Solutions

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a. The principal equilibrium in a solution of $NaHCO_3$ is

$$HCO_3^-(aq) + HCO_3^-(aq) \rightleftharpoons H_2CO_3(aq) + CO_3^{2-}(aq)$$

Calculate the value of the equilibrium constant for this reaction.

b. At equilibrium, what is the relationship between $[H_2CO_3]$ and $[CO_3^{2-}]$?

c. Using the equilibrium

$$H_2CO_3(aq) \rightleftharpoons 2\,H^+(aq) + CO_3^{2-}(aq)$$

and the result from part b, derive an expression for the pH of the solution in terms of K_{a_1} and K_{a_2}

Solution: This problem does not initially give information that is necessary to solve the problem. These are the K_{a1} and K_{a2} values for H_2CO_3, which are instead provided in the appendices of the textbook. The values are as follows

$$K_{a1} = 4.3 \times 10^{-7} \qquad H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$$
$$K_{a2} = 4.8 \times 10^{-11} \qquad HCO_3^- + H_2O \rightleftharpoons CO_3^{2-} + H_3O^+$$

The equilibrium constant (K_{eq}) for the solution is

$$K_{eq} = \frac{[H_2CO_3][CO_3^{2-}]}{[HCO_3^-]^2}$$

In order to find K_{eq}, we must relate the K_a values, which can be done by seperating

the K_{eq} expression into seperate parts

$$\begin{aligned} K_{eq} &= \frac{[\mathrm{H_2CO_3}][\mathrm{CO_3}^{2-}]}{[\mathrm{HCO_3}^{-}]^2} \\ K_{eq} &= \frac{[\mathrm{H_2CO_3}]}{[\mathrm{HCO_3}^{-}][\mathrm{H}^{+}]} \times \frac{[\mathrm{CO_3}^{2-}][\mathrm{H}^{+}]}{[\mathrm{HCO_3}^{-}]} \\ &= \frac{1}{K_{a2}} \times K_{a2} \end{aligned}$$

Which yields a final answer of

$$K_{eq} = 1.1 \times 10^{-4}$$