Chemistry 192
Recitation Session Questions
March 5, 2018
Solutions

1. The solubility product of bismuth iodide (BiI_3) is 7.7×10^{-19}. Determine if a precipitate forms when 0.125 L of a solution that has $[Bi^{3+}]$=0.0035 M is mixed with 0.259 L of a solution that has $[I^-] = 5.5 \times 10^{-6}$ M.

Answer

$$n_{Bi^{3+}} = (0.0035 \text{ mol L}^{-1})(0.125 \text{ L}) = 4.4 \times 10^{-4} \text{ mol}$$

$$[Bi^{3+}] = \frac{4.4 \times 10^{-4} \text{ mol}}{0.125 \text{ L} + 0.259 \text{ L}} = 1.1 \times 10^{-3} \text{ M}$$

$$n_{I^-} = (5.5 \times 10^{-6} \text{ mol L}^{-1})(0.259 \text{ L}) = 1.4 \times 10^{-6} \text{ mol}$$

$$[I^-] = \frac{1.4 \times 10^{-6} \text{ mol}}{0.125 \text{ L} + 0.259 \text{ L}} = 3.6 \times 10^{-6} \text{ M}$$

$$Q = [Bi^{3+}][I^-]^3 = (1.1 \times 10^{-3})(3.6 \times 10^{-6})^3 = 5.1 \times 10^{-20} < K_{sp}$$

No precipitate forms.

2a. Cadmium hydroxide, $Cd(OH)_2$ is slightly soluble in water with a solubility product constant of $K_{sp} = 2.5 \times 10^{-14}$. Calculate the solubility of cadmium hydroxide in water and the pH of a saturated cadmium hydroxide solution.

Answer:

$$Cd(OH)_{2(s)} \rightleftharpoons Cd^{2+}_{(aq)} + 2OH^-_{(aq)}$$

	$[Cd^{2+}]$	$[OH^-]$
initial	0 M	0 M
change	s	$2s$
equilibrium	s	$2s$

$$s(2s)^2 = 4s^3 = 2.5 \times 10^{-14}$$

$$s = 1.8 \times 10^{-5} \text{ M} \qquad [OH^-] = 2s = 3.6 \times 10^{-5}$$

$$\text{pOH} = -\log_{10}(3.6 \times 10^{-5}) = 4.43 \qquad \text{pH} = 14.00 - \text{pOH} = 9.57$$

b. Calculate the solubility of cadmium hydroxide in a buffer whose pH is fixed at 6.00.

Answer:

Method I:

$$\mathrm{Cd(OH)}_{2(s)} + 2\mathrm{H_3O}^+_{(aq)} \rightleftharpoons \mathrm{Cd}^{2+}_{(aq)} + 4\mathrm{H_2O}_{(\ell)}$$

Let K be the associated equilibrium constant so that

$$K = \frac{[\mathrm{Cd}^{2+}]}{[\mathrm{H_3O}^+]^2}$$

Now

$$\mathrm{Cd(OH)}_{2(s)} \rightleftharpoons \mathrm{Cd}^{2+}_{(aq)} + 2\mathrm{OH}^-_{(aq)} \qquad K_{sp}$$

$$2\mathrm{OH}^-_{(aq)} + 2\mathrm{H_3O}^+_{(sq)} \rightleftharpoons 4\mathrm{H_2O}_{(\ell)} \qquad 1/K_w^2$$

add to give the first reaction. Then

$$K = \frac{K_{sp}}{K_w^2} = \frac{2.5 \times 10^{-14}}{(1.0 \times 10^{-14})^2} = 2.5 \times 10^{14}$$

$$\frac{[\mathrm{Cd}^{2+}]}{(1.0 \times 10^{-6})^2} = 2.5 \times 10^{14}$$

$$[\mathrm{Cd}^{2+}] = s = 2.5 \times 10^2 \text{ M}$$

Method II:

$$[\mathrm{Cd}^{2+}][\mathrm{OH}^-]^2 = 2.5 \times 10^{-14}$$

$$[\mathrm{Cd}^{2+}](1.0 \times 10^{-8})^2 = 2.5 \times 10^{-14}$$

$$[\mathrm{Cd}^{2+}] = s = 2.5 \times 10^2 \text{ M}$$

3. Cadmium hydroxide, $Cd(OH)_2$ is slightly soluble in water with a solubility product constant of $K_{sp} = 2.5 \times 10^{-14}$. Cadmium ions form a coordination complex with chloride ions according to the reaction

$$Cd^{2+}_{(aq)} + 4Cl^{-}_{(aq)} \rightleftharpoons CdCl^{2-}_{4(aq)}$$

with associated formation constant of $K_f = 6.3 \times 10^2$. Calculate the solubility of $Cd(OH)_2$ in an aqueous 0.0100 M NaCl solution.

Answer:

$$Cd(OH)_{2(s)} \rightleftharpoons Cd^{2+}_{(aq)} + 2OH^{-}_{(aq)} \qquad K_{sp} = 2.5 \times 10^{-14}$$

$$\underline{Cd^{2+}_{(aq)} + 4Cl^{-}_{(aq)} \rightleftharpoons CdCl^{2-}_{4(aq)} \qquad K_f = 6.3 \times 10^2}$$

$$Cd(OH)_{2(s)} + 4Cl^{-}_{(aq)} \rightleftharpoons CdCl^{2-}_{4(aq)} + 2OH^{-}_{(aq)} \qquad K = K_{sp}K_f = 1.6 \times 10^{-11}$$

$$K = \frac{[CdCl_4^{2-}][OH^-]^2}{[Cl^-_{(aq)}]^4}$$

	$[Cl^-]$	$[CdCl_4^{2-}]$	$[OH^-]$
initial	0.0100 M	0 M	0 M
change	-4s	s	2s
equilibrium	(0.0100 - 4s) M	s M	2s M

$$K = 1.6 \times 10^{-11} = \frac{s(2s)^2}{(0.0100 - 4s)^4} \approx \frac{4s^3}{1.0 \times 10^{-6}}$$

$$s = 1.6 \times 10^{-6} \text{ M}$$