

## Solubility and Dissociation Equilibria Problems

### Solution Equilibrium - Part I Henry's Law, Solubility Product and Dissociation Constant

#### ANSWERS

#### Henry's Law

1. Calculate the amount of  $\text{H}_2\text{CO}_3$  which is dissolved in water at  $20^\circ\text{C}$  if the pressure of the  $\text{CO}_2$  over the solution is 0.050 atm. The  $K_H$  for  $\text{CO}_2$  in water is 79.

$$K_H = \frac{P_{\text{CO}_2}}{[\text{CO}_2]} \quad 79 = \frac{0.050}{[\text{CO}_2]}$$

Ans:          $6.3 \times 10^{-4}$         

2. What is the  $K_H$  for  $\text{H}_2\text{S}$  dissolving in water if 0.10 M  $\text{H}_2\text{S}$  is present at equilibrium when 0.33 atm of  $\text{H}_2\text{S}$  gas is in contact with the solution?

$$K_H = \frac{P_{\text{H}_2\text{S}}}{[\text{H}_2\text{S}]} \quad K_H = \frac{0.33}{0.10}$$

Ans:         3.3        

3. What is the expected oxygen content, in molarity, of water that one would find in a pure stream at sea level (1 atm total pressure and  $\text{O}_2$  is 20% of the gases). The  $K_H$  for  $\text{O}_2$  in water is  $2.15 \times 10^3$ .

$$K_H = \frac{P_{\text{O}_2}}{[\text{O}_2]} \quad 2.15 \times 10^3 = \frac{0.20}{[\text{O}_2]}$$

Ans:          $9.3 \times 10^{-5}$         

## Solubility and Dissociation Equilibria Problems

4. Calculate the calcium ion concentration for a solution in contact with  $\text{CaF}_2$  if the fluoride concentration is 0.010 M and the  $K_{sp}$  for  $\text{CaF}_2$  is  $3.0 \times 10^{-11}$ .

$$K_{sp} = [\text{Ca}^{2+}][\text{F}^-]^2 \quad 3.0 \times 10^{-11} = [\text{Ca}^{2+}][0.010]^2$$

Ans:          $3.0 \times 10^{-7}$

Solubility and Dissociation Equilibria Problems

5. What is the molar solubility of  $\text{CaF}_2$ ? The  $K_{sp}$  for  $\text{CaF}_2$  is  $3.0 \times 10^{-11}$ .

	mf $\text{CaF}_2$	$[\text{Ca}^{2+}]$	$[\text{F}^-]$
before equilibrium	1	0	0
at equilibrium	1	1x	2x

$$K_{sp} = [\text{Ca}^{2+}][\text{F}^-]^2 \quad 3.0 \times 10^{-11} = [x][2x]^2 \quad 3.0 \times 10^{-11} = 4x^3$$

Ans:            $3.9 \times 10^{-4}$           

6. What is the resultant concentration of both  $\text{Ca}^{2+}$  and  $\text{F}^-$  ions if solid  $\text{CaF}_2$  is added to a solution which is originally  $7.5 \times 10^{-4}$  M in  $\text{Ca}(\text{NO}_3)_2$ ? The  $K_{sp}$  for  $\text{CaF}_2$  is  $3.0 \times 10^{-11}$ .

		$[\text{Ca}^{2+}]$	$[\text{F}^-]$
before equilibrium		$7.5 \times 10^{-4}$	
at equilibrium		$7.5 \times 10^{-4} + x$	2x

$$3.0 \times 10^{-11} = [7.5 \times 10^{-4} + x][2x]^2 \quad x = \underline{9.4 \times 10^{-5}}$$

Ans:  $[\text{Ca}^{2+}] =$             $8.4 \times 10^{-4}$           

Ans:  $[\text{F}^-] =$             $1.8 \times 10^{-4}$           

7. To a 0.10 M solution of  $\text{Ca}(\text{NO}_3)_2$  is added enough  $\text{Na}_2\text{CO}_3$  to make the solution 0.10 M in  $\text{CO}_3^{2-}$  ion. What is the resulting  $\text{Ca}^{2+}$  concentration? The  $K_{sp}$  for  $\text{CaCO}_3$  is  $4.8 \times 10^{-9}$ .

$$K_{sp} = [\text{Ca}^{2+}][\text{CO}_3^{2-}] \quad \text{Type I since } [\text{CO}_3] = 0.10 \text{ when finished.}$$

$$4.8 \times 10^{-9} = [\text{Ca}^{2+}](0.10)$$

Ans:            $4.8 \times 10^{-8}$

Introduction to Solution Equilibria -

Henry's Law, Solubility Product and Dissociation Constant

8. The  $K_d$  for  $\text{CdCl}_4^{2-}$  is  $1.0 \times 10^{-4}$ . What is the concentration of  $\text{Cd}^{2+}$  in a solution of chloride which has 0.010 M of the  $\text{CdCl}_4^{2-}$  ion present. The  $\text{Cl}^-$  concentration in this solution was measured and found to be 0.10 M.

$$K_d = \frac{[\text{Cd}^{2+}][\text{Cl}^-]^4}{[\text{CdCl}_4^{2-}]} \quad 1.0 \times 10^{-4} = \frac{[\text{Cd}^{2+}](0.10)^4}{(0.010)}$$

Ans:            $[\text{Cd}^{2+}] = 0.010$           

9. A solution is 0.010 M in total silver and 0.010 M in  $\text{NH}_3$ . What is the  $\text{Ag}^+$  ion concentration? The  $K_d$  for  $\text{Ag}(\text{NH}_3)_2^+$  is  $6.3 \times 10^{-8}$ . (Note - the total silver concentration is  $[\text{Ag}^+] + [\text{Ag}(\text{NH}_3)_2^+]$ .)

$$K_d = \frac{[\text{Ag}^+][\text{NH}_3]^2}{[\text{Ag}(\text{NH}_3)_2^+]} \quad \text{Let } x = [\text{Ag}^+] \quad 6.3 \times 10^{-9} = \frac{x(0.010)^2}{(0.010 + x)}$$

Ans:            $x = 6.3 \times 10^{-7}$           

10. At what  $[\text{OH}^-]$  will a 0.10 M solution of  $\text{Zn}(\text{NO}_3)_2$  develop a precipitate of  $\text{Zn}(\text{OH})_2(\text{s})$ ? The  $K_{sp}$  for  $\text{Zn}(\text{OH})_2$  is  $4.5 \times 10^{-17}$ .

$$K_{sp} = [\text{Zn}^{2+}][\text{OH}^-]^2 \quad 4.5 \times 10^{-17} = (0.10)[\text{OH}^-]^2$$

Ans:            $[\text{OH}^-] = 2.1 \times 10^{-8}$           

11. Calculate the  $[\text{NH}_3]$  required to redissolve 0.10 mol of  $\text{Zn}(\text{OH})_2$  in 1.0 L of pure water if the concentration of  $\text{OH}^-$  is kept constant at  $1.8 \times 10^{-5}$  M. The  $K_{sp}$  for  $\text{Zn}(\text{OH})_2$  is  $4.5 \times 10^{-17}$  and the  $K_d$  for  $\text{Zn}(\text{NH}_3)_4^{2+}$  is  $3.4 \times 10^{-10}$ .

The relevant reaction is:  $\text{Zn}(\text{OH})_2 + 4\text{NH}_3(\text{aq}) \rightleftharpoons \text{Zn}(\text{NH}_3)_4^{2+} + 2\text{OH}^-$

$$K_{RXN} = \frac{K_{sp}}{K_d} = \frac{[\text{Zn}(\text{NH}_3)_4^{2+}][\text{OH}^-]^2}{[\text{NH}_3]^4} \quad \text{Sub: } 1.3 \times 10^{-7} = \frac{(0.10)(1.8 \times 10^{-5})^2}{[\text{NH}_3]^4}$$

ANS            $[\text{NH}_3] = 0.126$

Introduction to Solution Equilibria -

Henry's Law, Solubility Product and Dissociation Constant

12. Calculate the concentration of the  $\text{OH}^-$  ion at which 0.10 mol of the precipitate  $\text{Zn}(\text{OH})_2$  will dissolve into 1.0 L of pure water. The  $K_{sp}$  for  $\text{Zn}(\text{OH})_2$  is  $4.5 \times 10^{-17}$  and  $K_d$  for  $\text{Zn}(\text{OH})_4^{2-}$  is  $3.5 \times 10^{-16}$ .

The reaction:  $\text{Zn}(\text{OH})_2 + 2\text{OH}^- \rightleftharpoons \text{Zn}(\text{OH})_4^{2-}$

$$K_{RXN} = \frac{K_{sp}}{K_d} = \frac{[\text{Zn}(\text{OH})_4^{2-}]}{[\text{OH}^-]^2} \quad \text{Sub: } \frac{4.5 \times 10^{-17}}{3.5 \times 10^{-16}} = 0.128 = \frac{0.10}{[\text{OH}^-]^2}$$

ANS  $[\text{OH}^-] = 0.88$

13. What concentration of cyanide ion,  $\text{CN}^-$ , is needed to dissolve  $\text{AuCl}$  solid into a water solution to yield a solution which is 1.0 M in  $\text{Au}(\text{CN})_2^-$  ions. The  $K_{sp}$   $\text{AuCl}(\text{s})$  is  $2.0 \times 10^{-13}$  and the  $K_d$  for the  $\text{Au}(\text{CN})_2^-$  ion is  $5.0 \times 10^{-39}$ . The relevant reaction is:

$\text{AuCl}(\text{s}) + 2\text{CN}^- \rightleftharpoons \text{Au}(\text{CN})_2^- + \text{Cl}^-$ . (Notice that as much  $\text{Cl}^-$  goes into solution as does gold in the form  $\text{Au}(\text{CN})_2^-$ .)

$$K_{RXN} = \frac{K_{sp}}{K_d} = \frac{[\text{Au}(\text{CN})_2^-][\text{Cl}^-]}{[\text{CN}^-]^2} \quad \text{Sub: } \frac{2.0 \times 10^{-13}}{5.0 \times 10^{-39}} = 4.0 \times 10^{25} = \frac{(1.0)(1.0)}{[\text{CN}^-]^2}$$

ANS  $[\text{CN}^-] = 1.6 \times 10^{-13}$

14. The most insoluble form of nickel sulfide is the  $\gamma$  (gamma) form. The  $K_{sp}$  for the  $\text{NiS}(\gamma)$  is  $2.0 \times 10^{-28}$ . What concentration of  $\text{CN}^-$  ion would be required to dissolve this sulfide to the extent of obtaining 0.10 M  $\text{Ni}(\text{CN})_4^{2-}$  ions in solution? The  $K_d$  for  $\text{Ni}(\text{CN})_4^{2-}$  is  $1.0 \times 10^{-31}$ .

$\text{NiS}(\gamma) + 4\text{CN}^- \rightleftharpoons \text{Ni}(\text{CN})_4^{2-} + \text{S}^{2-}$

$$K_{RXN} = \frac{K_{sp}}{K_d} = \frac{[\text{Ni}(\text{CN})_4^{2-}][\text{S}^{2-}]}{[\text{CN}^-]^4} \quad \text{Sub: } \frac{2.0 \times 10^{-28}}{1.0 \times 10^{-31}} = 2.0 \times 10^3 = \frac{(0.10)(0.10)}{[\text{CN}^-]^4}$$

ANS  $[\text{CN}^-] = 5.0 \times 10^{-6}$

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Ans:          $6.3 \times 10^{-4}$         

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$$K_{sp} = [\text{Ca}^{2+}][\text{F}^-]^2 \quad 3.0 \times 10^{-11} = [\text{Ca}^{2+}][0.010]^2$$

Ans:          $3.0 \times 10^{-7}$

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$$3.0 \times 10^{-11} = [7.5 \times 10^{-4} + x][2x]^2 \quad x = 9.4 \times 10^{-5}$$

Ans:  $[\text{Ca}^{2+}] = 8.4 \times 10^{-4}$

Ans:  $[\text{F}^-] = 1.8 \times 10^{-4}$

7. To a 0.10 M solution of  $\text{Ca}(\text{NO}_3)_2$  is added enough  $\text{Na}_2\text{CO}_3$  to make the solution 0.10 M in  $\text{CO}_3^{2-}$  ion. What is the resulting  $\text{Ca}^{2+}$  concentration? The  $K_{sp}$  for  $\text{CaCO}_3$  is  $4.8 \times 10^{-9}$ .

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$$4.8 \times 10^{-9} = [\text{Ca}^{2+}](0.10)$$

Ans:  $4.8 \times 10^{-8}$

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Ans:            $[\text{Cd}^{2+}] = 0.010$           

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$\text{NiS}(\gamma) + 4\text{CN}^- \rightleftharpoons \text{Ni}(\text{CN})_4^{2-} + \text{S}^{2-}$

$$K_{RXN} = \frac{K_{sp}}{K_d} = \frac{[\text{Ni}(\text{CN})_4^{2-}][\text{S}^{2-}]}{[\text{CN}^-]^4} \quad \text{Sub: } \frac{2.0 \times 10^{-28}}{1.0 \times 10^{-31}} = 2.0 \times 10^3 = \frac{(0.10)(0.10)}{[\text{CN}^-]^4}$$

ANS  $[\text{CN}^-] = 5.0 \times 10^{-6}$