Chemistry for Environmental Engineering and Science, 5th Edition

CHAPTER 2 - PROBLEM SOLUTIONS

2.1 (a) $MgCO_3$

FW = 24.3 + 12 + 3(16) = 84.3 g/mol

$MgCO_3 + 2\,H^+ = Mg^{2+} + H_2CO_3$

$$EW = \frac{84.3}{2} = \underline{\underline{42.15}} \text{ g/equiv}$$

(b) $NaNO_3$

FW = 23 + 14 + 3(16) = 85 g/mol

$NaNO_3 + H^+ = Na^+ + HNO_3$

$$EW = \frac{85}{1} = \underline{\underline{85}} \text{ g/equiv}$$

(c) CO_2

FW = 12 + 2(16) = 44 g/mol

$CO_2 + H_2O = H_2CO_3$

Note from above: $MgCO_3 + 2H^+ = Mg^{2+} + H_2CO_3$ and $H_2CO_3 = 2H^+ + CO_3^{2-}$

or: $CaCO_3 + 2H^+ = Ca^{2+} + H_2CO_3$

$$EW = \frac{44}{2} = \underline{\underline{22}} \text{ g/equiv}$$

***Note**: In some reactions, Z might be considered to be 1 (i.e., $H_2CO_3 = H^+ + HCO_3^-$)

(d) K_2HPO_4

FW = 2(39.1) + 1 + 31 + 4(16) = 174.2 g/mol

$K_2HPO_4 + 2H^+ = H_3PO_4 + 2K^+$

$$EW = \frac{174.2}{2} = \underline{\underline{87.1}} \text{ g/equiv}$$

2.2 (a) $BaSO_4$

FW = 137.3 + 32.1 + 4(16) = 233.4 g/mol

$BaSO_4 + 2\,H^+ = Ba^{2+} + H_2SO_4$

$$EW = \frac{233.4}{2} = \underline{\underline{116.7}} \text{ g/equiv}$$

(b) $NaCO_3$

$FW = 2(23) + 12 + 3(16) = \underline{\underline{106}}$ g/mol

$NaCO_3 + 2\ H^+ = Na^+ + H_2CO_3$

$EW = \frac{106}{2} = \underline{\underline{53}}$ g/equiv

(c) H_2SO_4

$FW = 2(1) + 32.1 + 4(16) = \underline{\underline{98.1}}$ g/mol

$H_2SO_4 = 2H^+ + SO_4^{2-}$

$EW = \frac{98.1}{2} = \underline{\underline{49.05}}$ g/equiv

(d) $Mg(OH)_2$

$FW = 24.3 + 2(16) + 2(1) = \underline{\underline{58.3}}$ g/mol

$Mg(OH)_2 + 2\ H^+ = Mg^{2+} + 2H_2O$

$EW = \frac{58.3}{2} = \underline{\underline{29.15}}$ g/equiv

2.3 (a) $\frac{10}{23+17} = \underline{\underline{0.25}}$ for NaOH

(b) $\frac{10}{46+32+64} = \frac{10}{142} = \underline{\underline{0.0704}}$ for Na_2SO_4

(c) $\frac{10}{78+104+7(16)} = \frac{10}{294} = \underline{\underline{0.034}}$ for $K_2Cr_2O_7$

(d) $\frac{10}{39+35.5} = \frac{10}{74.5} = \underline{\underline{0.134}}$ for KCl.

2.4 (a) $\frac{X}{2} = 0.15$ M, $X = 0.30$ mol $KMnO_4$

$FW = 39.1 + 24.3 + 4(16) = 127.4$ g/mol

$0.30(127.4) = \underline{\underline{38.22}}$ g

(b) $\frac{X}{2} = 0.15$ N, $X = 0.30$ equiv. $KMnO_4$

$EW = \frac{127.4}{2} = 63.7$ g/equiv

$0.30(63.7) = \underline{\underline{19.11}}$ g

2.5 Ca^{2+}: $EW = \frac{40}{2} = 20$ g/equiv

$meq/l = \frac{44}{20} = 2.2$ meq/L

Mg^{2+}: $EW = \frac{24.3}{2} = 12.15$ g/equiv

$meq/l = \frac{19}{12.15} = 1.56$ meq/L

Total Hardness = 2.20 + 1.56 = 3.76 meq/L
= 3.76(50 mg/meq) = 188 mg/lL as $CaCO_3$

2.6 Note: for HCO_3^-, H^+, and OH^-, mol/L = equiv/L (Z = 1)
for CO_3^{2-}, equiv/L = 2(mol/L) (Z = 2)

$[OH^-][H^+] = 10^{-14}$
$pH = -\log [H^+]$ } for $[H^+] = 10^{-9.5}$, $[OH^-] = 10^{-4.5}$

$[HCO_3^-] = \frac{118 \text{ mg/L}}{61{,}000 \text{ mg/mol}} = 1.93 \times 10^{-3}$ M

$[CO_3^{2-}] = \frac{19 \text{ mg/L}}{60{,}000 \text{ mg/mol}} = 3.17 \times 10^{-4}$ M

equiv/L Alk = $1.93 \times 10^{-3} + 2(3.17 \times 10^{-4}) + 10^{-4.5} - 10^{-7.5}$

Alk = 2.60×10^{-3} equiv/L (50,000 mg/equiv)

Alk = 130 mg/L as $CaCO_3$

2.7 (a) $CaCl_2 + Na_2CO_3 = CaCO_3(s) + 2\,NaCl$
(b) $Ca_3(PO_4)_2 + 4\,H_3PO_4 = 3\,Ca(H_2PO_4)_2$
(c) $MnO_2 + 2NaCl + 2H_2SO_4 = MnSO_4 + 2H_2O + Cl_2 + Na_2SO_4$
(d) $Ca(H_2PO_4)_2 + 2NaHCO_3 = CaHPO_4 + Na_2HPO_4 + 2H_2O + 2CO_2$

2.8 (a) $FeS + 2HCl = FeCl_2 + H_2S$
(b) $3Ca_2 + 6KOH = 5KCl + KClO_3 + 3H_2O$
(c) $6FeSO_4 + K_2Cr_2O_7 + 7H_2SO_4 = 3Fe_2(SO_4)_3 + Cr_2(SO_4)_3 + K_2SO_4 + 7H_2O$
(d) $Al_2(SO_4)_3 \bullet 14H_2O + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$

2.9 (a) $4Fe(OH)_2 + 2H_2O + O_2 = 4Fe(OH)_3$

(b) $2KI + 2HNO_2 + H_2SO_4 = 2NO + I_2 + 2H_2O + K_2SO_4$

(c) $5H_2C_2O_4 + 2KMnO_4 + 3H_2SO_4 = 10CO_2 + 2MnSO_4 + K_2SO_4 + 8H_2O$

(d) $SO_3^{2-} + 2Fe^{3+} + H_2O = SO_4^{2-} + 2Fe^{2+} + 2H^+$

2.10 (a) $3HClO = HClO_3 + 2HCl$

(b) $5NO_2^- + 2MnO_4^- + 6H^+ = 5NO_3^- + 2Mn^{2+} + 3H_2O$

(c) $6Cl^- + 2NO_3^- + 8H^+ = 3Cl_2 + 2NO + 4H_2O$

(d) $2I_2 + IO_3^- + 6H^+ + 10Cl^- = 5ICl_2^- + 3H_2O$

2.11 (a)

$$I^- = \frac{1}{2} I_2 + e^-$$
$$\frac{1}{2} MnO_2 + 2 H^+ + e^- = \frac{1}{2} Mn^{2+} + H_2O$$
$$I^- + \frac{1}{2} MnO_2 + 2 H^+ = \frac{1}{2} I_2 + \frac{1}{2} Mn^{2+} + H_2O$$

or $$2 I^- + MnO_2 + 4 H^+ = I_2 + Mn^{2+} + 2 H_2O$$

(b)

$$\frac{1}{8} S_2O_3^{2-} + \frac{5}{8} H_2O = \frac{1}{4} SO_4^{2-} + \frac{5}{4} H^+ + e^-$$
$$\frac{1}{2} Cl_2 + e^- = Cl^-$$
$$\frac{1}{8} S_2O_3^{2-} + \frac{1}{2} Cl_2 + \frac{5}{8} H_2O = \frac{1}{4} SO_4^{2-} + Cl^- + \frac{5}{4} H^+$$

or $$S_2O_3^{2-} + 4 Cl_2 + 5 H_2O = 2 SO_4^{2-} + 8 Cl^- + 10 H^+$$

(c)

$$\frac{1}{8} NH_4^+ + \frac{3}{8} H_2O = \frac{1}{8} NO_3^- + \frac{5}{4} H^+ + e^-$$
$$\frac{1}{4} O_2 + H^+ + e^- = \frac{1}{2} H_2O$$
$$\frac{1}{8} NH_4^+ + \frac{1}{4} O_2 = \frac{1}{8} NO_3^- + \frac{1}{8} H_2O + \frac{1}{4} H^+$$

or $$NH_4^+ + 2 O_2 = NO_3^- + H_2O + 2 H^+$$

(d)

$$\frac{1}{8} CH_3COO^- + \frac{1}{4} H_2O = \frac{1}{4} CO_2 + \frac{7}{8} H^+ + e^-$$
$$\frac{1}{6} Cr_2O_7^{2-} + \frac{7}{3} H^+ + e^- = \frac{1}{3} Cr^{3+} + \frac{7}{6} H_2O$$
$$\frac{1}{8} CH_3COO^- + \frac{1}{6} Cr_2O_7^{2-} + \frac{35}{24} H^+ = \frac{1}{4} CO_2 + \frac{1}{3} Cr^{3+} + \frac{11}{12} H_2O$$

or $$3 CH_3COO^- + 4 Cr_2O_7^{2-} + 35 H^+ = 6 CO_2 + 8 Cr^{3+} + 22 H_2O$$

(e)

$$\frac{1}{24} C_6H_{12}O_6 + \frac{1}{4} H_2O = \frac{1}{4} CO_2 + \frac{7}{8} H^+ + e^-$$

$$\frac{1}{5}\ NO_3^- + \frac{6}{5}\ H^+ + e^- = \frac{1}{10}\ N_2 + \frac{3}{5}\ H_2O$$

$$\frac{1}{24}\ C_6H_{12}O_6 + \frac{1}{5}\ NO_3^- + \frac{1}{5}\ H^+ = \frac{1}{4}\ CO_2 + \frac{1}{10}\ N_2 + \frac{7}{20}\ H_2O$$

or $5\ C_6H_{12}O_6 + 24\ NO_3^- + 24\ H^+ = 30\ CO_2 + 12\ N_2 + 42\ H_2O$

2.12 (a)

$$\frac{1}{2}\ Mn^{2+} + H_2O = \frac{1}{2}\ MnO_2 + 2\ H^+ + e^-$$
$$\frac{1}{4}\ O_2 + H^+ + e^- = \frac{1}{2}\ H_2O$$

$$\frac{1}{2}\ Mn^{2+} + \frac{1}{4}\ O_2 + \frac{1}{2}\ H_2O = \frac{1}{2}\ MnO_2 + H^+$$

or $2\ Mn^{2+} + O_2 + 2\ H_2O = 2\ MnO_2 + 4\ H^+$

(b)

$$\frac{1}{8}\ S_2O_3^{2-} + \frac{5}{8}\ H_2O = \frac{1}{4}\ SO_4^{2-} + \frac{5}{4}\ H^+ + e^-$$
$$\frac{1}{2}\ I_2 + e^- = I^-$$

$$\frac{1}{8}\ S_2O_3^{2-} + \frac{1}{2}\ I_2 + \frac{5}{8}\ H_2O = \frac{1}{4}\ SO_4^{2-} + I^- + \frac{5}{4}\ H^+$$

or $S_2O_3^{2-} + 4\ I_2 + 5\ H_2O = 2\ SO_4^{2-} + 8\ I^- + 10\ H^+$

(c)

$$\frac{1}{6}\ NH_4^+ + \frac{1}{3}\ H_2O = \frac{1}{6}\ NO_2^- + \frac{4}{3}\ H^+ + e^-$$
$$\frac{1}{4}\ O_2 + H^+ + e^- = \frac{1}{2}\ H_2O$$

$$\frac{1}{6}\ NH_4^+ + \frac{1}{4}\ O_2 = \frac{1}{6}\ NO_3^- + \frac{1}{6}\ H_2O + \frac{1}{3}\ H^+$$

or $2\ NH_4^+ + 3\ O_2 = 2\ NO_2^- + 2\ H_2O + 4\ H^+$

(d)

$$\frac{1}{24}\ C_6H_{12}O_6 + \frac{1}{4}\ H_2O = \frac{1}{4}\ CO_2 + H^+ + e^-$$
$$\frac{1}{6}\ Cr_2O_7^{2-} + \frac{7}{3}\ H^+ + e^- = \frac{1}{3}\ Cr^{3+} + \frac{7}{6}\ H_2O$$

$$\frac{1}{24}\ C_6H_{12}O_6 + \frac{1}{6}\ Cr_2O_7^{2-} + \frac{4}{3}\ H^+ = \frac{1}{4}\ CO_2 + \frac{1}{3}\ Cr^{3+} + \frac{11}{12}\ H_2O$$

or $C_6H_{12}O_6 + 4\ Cr_2O_7^{2-} + 32\ H^+ = 6\ CO_2 + 8\ Cr^{3+} + 22\ H_2O$

(e)

$$\frac{1}{8}\ CH_3COO^- + \frac{1}{4}\ H_2O = \frac{1}{4}\ CO_2 + \frac{7}{8}\ H^+ + e^-$$
$$\frac{1}{8}\ SO_4^{2-} + \frac{5}{4}\ H^+ + e^- = \frac{1}{8}\ H_2S + \frac{1}{2}\ H_2O$$

$$\frac{1}{8}\ CH_3COO^- + \frac{1}{8}\ SO_4^{2-} + \frac{3}{8}\ H^+ = \frac{1}{4}\ CO_2 + \frac{1}{8}\ H_2S + \frac{1}{4}\ H_2O$$

or $CH_3COO^- + SO_4^{2-} + 3\,H^+ = 2\,CO_2 + H_2S + 2\,H_2O$

2.13 (a)

$$SO_4^{2-} = S$$
$$SO_4^{2-} = S + 4\,H_2O$$
$$SO_4^{2-} + 8\,H^+ + 6\,e^- = S + 4\,H_2O$$
$$\tfrac{1}{6}\,SO_4^{2-} + \tfrac{4}{3}\,H^+ + e^- = \tfrac{1}{6}\,S + \tfrac{2}{3}\,H_2O$$

(b)

$$NO_3^- = NO_2^-$$
$$NO_3^- = NO_2^- + H_2O$$
$$NO_3^- + 2\,H^+ + 2\,e^- = NO_2^- + H_2O$$
$$\tfrac{1}{2}\,NO_3^- + H^+ + e^- = \tfrac{1}{2}\,NO_2^- + \tfrac{1}{2}\,H_2O$$

(c)

$$2\,CH_3COO^- = CH_3CH_2CH_2COO^-$$
$$2\,CH_3COO^- = CH_3CH_2CH_2COO^- + 2\,H_2O$$
$$2\,CH_3COO^- + 5\,H^+ + 4\,e^- = CH_3CH_2CH_2COO^- + 2\,H_2O$$
$$\tfrac{1}{2}\,CH_3COO^- + \tfrac{5}{4}\,H^+ + e^- = \tfrac{1}{4}\,CH_3CH_2CH_2COO^- + \tfrac{1}{2}\,H_2O$$

2.14 (a)

$$CO_2 = CH_4$$
$$CO_2 = CH_4 + 2\,H_2O$$
$$CO_2 + 4\,H^+ + 4\,e^- = CH_4 + 2\,H_2O$$
$$\tfrac{1}{4}\,CO_2 + H^+ + e^- = \tfrac{1}{4}\,CH_4 + \tfrac{1}{2}\,H_2O$$

(b)

$$S = H_2S$$
$$S + 2\,H^+ + 2\,e^- = H_2S + H_2O$$
$$\tfrac{1}{2}\,S + H^+ + e^- = \tfrac{1}{2}\,H_2S$$

(c)

$$CH_3COO^- + CO_2 = CH_3CH_2COO^-$$
$$CH_3COO^- + CO_2 = CH_3CH_2COO^- + 2\,H_2O$$
$$CH_3COO^- + CO_2 + 6\,H^+ + 6\,e^- = CH_3CH_2COO^- + 2\,H_2O$$
$$\tfrac{1}{6}\,CH_3COO^- + \tfrac{1}{6}\,CO_2 + H^+ + e^- = \tfrac{1}{6}\,CH_3CH_2COO^- + \tfrac{1}{3}\,H_2O$$

2.15

$$\tfrac{1}{2}\,S + H^+ + e^- = \tfrac{1}{2}\,H_2S$$

$$Fe^{3+} + e^- = Fe^{2+}$$

$$\tfrac{1}{2}\, H_2S = \tfrac{1}{2}\, S + H^+ + e^-$$
$$Fe^{3+} + e^- = Fe^{2+}$$

$$\tfrac{1}{2}\, H_2S + Fe^{3+} = \tfrac{1}{2}\, S + H^+ + Fe^{2+}$$

or $$H_2S + 2\, Fe^{3+} = S + 2\, H^+ + 2\, Fe^{2+}$$

2.16 $$2\, CO_2 + 12\, H^+ + 12\, e^- = CH_3CH_2OH + 3\, H_2O$$

or $$\tfrac{1}{6}\, CO_2 + H^+ + e^- = \tfrac{1}{12}\, CH_3CH_2OH + \tfrac{1}{4}\, H_2O$$

$$NO_3^- + 2\, H^+ + 2\, e^- = NO_2^- + H_2O$$

or $$\tfrac{1}{2}\, NO_3^- + H^+ + e^- = \tfrac{1}{2}\, NO_2^- + \tfrac{1}{2}\, H_2O$$

$$\tfrac{1}{12}\, CH_3CH_2OH + \tfrac{1}{4}\, H_2O = \tfrac{1}{6}\, CO_2 + H^+ + e^-$$
$$\tfrac{1}{2}\, NO_3^- + H^+ + e^- = \tfrac{1}{2}\, NO_2^- + \tfrac{1}{2}\, H_2O$$

$$\tfrac{1}{12}\, CH_3CH_2OH + \tfrac{1}{2}\, NO_3^- = \tfrac{1}{6}\, CO_2 + \tfrac{1}{2}\, NO_2^- + \tfrac{1}{4}\, H_2O$$

2.17 $H_2SO_4 + CaCO_3 = H_2O + CO_2 + CaSO_4$

F.W. $CaCO_4 = 40 + 32 + 4(16) = 136$

$$\text{Moles } H_2SO_4 \text{ req'd} = \frac{65}{136} = \underline{\underline{0.478}}$$

2.18 $K_2Cr_2O_7 + 6\, KI + 7H_2SO_4 = Cr_2(SO_4)_3 + 4K_2SO_4 + 3I_2 + 7H_2O$

F.W. $K_2Cr_2O_7 = 2(39.1) + 2(52) + 7(16) = 294.2$
F.W. $I_2 = 2(126.9) = 253.8$

$$I_2 \text{ Formed} = \frac{3(253.8)}{294.2} \times 6 = \underline{\underline{15.5}}\text{ g}$$

2.19 F.W. $CO_2 = 12 + 32 = 44$ g

$$120 \text{ lb } CO_2 = \frac{120(1000)}{2.2} = 54{,}600 \text{ g}$$

$$= \frac{54{,}600}{44} = 1{,}240 \text{ mol}$$

$$PV = n\,RT$$

$$V = \frac{1{,}240(0.082)\,(273 + 40)}{1.5} = 21{,}220 \text{ liters}$$

$$= \frac{21{,}220}{28.3} = \underline{\underline{750}} \text{ cu ft}$$

2.20 $PV = n\,RT$

$$n = \frac{PV}{RT} = \frac{5(10)}{(0.082)(273)} = 2.235 \text{ mol } O_2$$

Weight = 32(2.235) = $\underline{\underline{71.5}}$ g

2.21 $CH_4 + 2O_2 = CO_2 + 2H_2O$

$$\text{Moles } CH_4 = \frac{25}{(12 + 4)} = 1.56 \text{ mol}$$

Moles O_2 req'd = 1.56(2) = 3.12 mol

$PV = n\,RT$

$$V = \frac{n\,RT}{p} = \frac{3.12(0.082)(273 + 25)}{0.21} = \underline{\underline{363}} \text{ liters}$$

2.22 $CH_3CH_3 + 3\frac{1}{2}\ O_2 = 2CO_2 + 3H_2O$

(a) $CH_3CH_3 = \frac{6}{(24 + 6)} = 0.2$ mol

H_2O = 3(0.2) = $\underline{\underline{0.6}}$ mol formed

(b) CO_2 = 2(0.2) = $\underline{\underline{0.4}}$ mol formed

(c) $PV = n\,RT$

$$V = \frac{0.4(0.082)(273 + 20)}{1} = \underline{\underline{9.6}} \text{ liters } CO_2$$

2.23 $PV = n\,RT$ F.W. H_2S = 2 + 32 = 34

$$P = \frac{n\,RT}{V} \quad n = \frac{100}{34 \times 1000} = 2.94 \times 10^{-3}$$

$$P = \frac{2.94(10^{-3})(8.2)(10^{-2})(273 + 25)}{1}$$

$$= 2.94(8.2)(2.98)(10^{-3}) = \underline{\underline{0.072}} \text{ atm}$$

2.24 (a) CH_4 (F.W. = 16) $\frac{12}{16}$ = $\underline{\underline{0.75}}$ mol

N_2 (F.W. = 28) $\frac{1}{28}$ = $\underline{\underline{0.0357}}$ mol

CO_2 (F.W. = 44) $\frac{15}{44}$ = $\underline{\underline{0.341}}$ mol

(b) PV = n RT

$$P = \frac{n(0.082)(273 + 25)}{30} = 0.815\ n$$

CH_4 P = 0.815(0.75) = $\underline{\underline{0.611}}$ atm

N_2 P = 0.815(0.0357) = $\underline{\underline{0.029}}$ atm

CO_2 P = 0.815(0.0341) = $\underline{\underline{0.278}}$ atm

(c) Total P = 0.611 + 0.029 + 0.278 = $\underline{\underline{0.918}}$ atm

(d) $CH_4 = \frac{0.611}{0.918}$ = $\underline{\underline{66.5}}$ percent

$N_2 = \frac{0.029}{0.918}$ = $\underline{\underline{3.2}}$ percent

$CO_2 = \frac{0.278}{0.918}$ = $\underline{\underline{30.3}}$ percent

2.25 C = $\beta\ p_{gas}$

= 2.0(0.3) = 0.6 g/L

5 liters contain 0.6(5) = $\underline{\underline{3.0}}$ g CO_2

2.26 p_{O_2} = 0.21(0.81) = 0.17 atm

C = $\beta\ p_{O_2}$ = 43.4(0.17) = $\underline{\underline{7.4}}$ mg/L

2.27

		FW	Moles	Mole fraction
PCE	C_2Cl_4	2(12) + 4(35.5) = 166	10^5/166 = 602	602/4291 = $\underline{\underline{0.140}}$

Benzene	C_6H_6	6(12) + 6	= 78	$10^5/78$ = 1282	1282/4291 = 0.299
Toluene	C_7H_8	7(12) + 6	= 96	$10^5/96$ = 1087	1087/4291 = 0.253
Ethylbenzene	C_8H_{10}	8(12) + 10	= 106	$10^5/106$ = 754	754/4291 = 0.176
Xylene	C_8H_{10}	8(12) + 10	= 106	$10^5/106$ = 566	566/4291 = 0.132
				Σ = 4291	Σ = 1.000

2.28 (a) P_{PCE} = 0.10(0.0251) = 0.002511 atm

$C_{PCE} = P_{PCE}/K_H$ = 0.002511 atm/(26.9 atm-L/mol) = 0.000093 M or 0.093 mM

(b) $P_{PCE} = 0.10P_{PCE,max}$, Solubility reduction = 100(1-0.1) = 90%

2.29 FW TCE = 2(12) + 3(35.5) + 1 = 131.5

$C_{equil} = P_{TCE}/K_H$ = 0.0977/11.6 = 0.00842 M or 0.00842(131,500) = 1,107 mg/L

X_{TCE} = 20/1,107 = 0.018

2.30 (a) $H_2CO_3 = H^+ + HCO_3^-$

0.10 – X X X

$$\frac{[X][X\}}{[0.10 - X]} = 4.45 \times 10^{-7}$$

$[X]^2 \cong 4.45 \times 10^{-8}$ (since X << 0.10)

$[X] = 2.11 \times 10^{-4} = [H^+]$

$$\% \text{ ionization} = \frac{2.11 \times 10^{-4}}{0.10}(100) = 0.211 \text{ percent}$$

(b) $$\frac{[X][X\}}{[0.01 - X]} = 4.45 \times 10^{-7}$$

$[X]^2 \cong 4.45 \times 10^{-10}$

$[X] = 6.67 \times 10^{-5} = [H^+]$

$$\% \text{ ionization} = \frac{6.67 \times 10^{-5}}{0.01}(100) = 0.067 \text{ percent}$$

2.31 $HOCl = H^+ + OCl^-$

0.05 – X X X

$$\frac{[X][X\}}{[0.05-X]} = 2.85\text{x}10^{-8}$$

$[X]^2 \cong 14.25\text{x}10^{-10}$

$[X] = \underline{\underline{3.78 \text{ x } 10^{-5}}} = \underline{\underline{[H^+]}}$

$$\%\text{ ionization} = \frac{3.78 \text{ x } 10^{-5}}{0.05}(100) = \underline{\underline{0.076}} \text{ percent}$$

2.32 (a)

$Cd^{2+} + Cl^- = CdCl^+$ $\quad \frac{[CdCl^+]}{[Cd^{2+}][Cl^-]} = K_1$

$CdCl^+ + Cl^- = CdCl_2$ $\quad \frac{[CdCl_2]}{[CdCl^+][Cl^-]} = K_2$

$CdCl_2 + Cl^- = CdCl_3^-$ $\quad \frac{[CdCl_3^-]}{[CdCl_2][Cl^-]} = K_3$

$CdCl_2 + Cl^- = CdCl_4^{2-}$ $\quad \frac{[CdCl_4^{2-}]}{[CdCl_2][Cl^-]} = K_4$

(b) $CdCl_4^{=} = Cd^{2+} + 4\, Cl^-$ $\quad \frac{[Cd^{2+}][Cl^-]^4}{[CdCl_4^{2-}]} = K_{inst}$

2.33 (a)

$Cu^{2+} + NH_3 = Cu(NH_3)^{2+}$ $\quad \frac{[Cu(NH_3)^{2+}]}{[Cu^{2+}][NH_3]} = K_1$

$Cu(NH_3)^{2+} + NH_3 = Cu(NH_3)_2^{2+}$ $\quad \frac{[Cu(NH_3)_2^{2+}]}{[Cu(NH_3)^{2+}][NH_3]} = K_2$

$Cu(NH_3)_2^{2+} + NH_3 = Cu(NH_3)_3^{2+}$ $\quad \frac{[Cu(NH_3)_3^{2+}]}{[Cu(NH_3)_2^{2+}][NH_3]} = K_3$

$Cu(NH_3)_3^{2+} + NH_3 = Cu(NH_3)_4^{2+}$ $\quad \frac{[Cu(NH_3)_4^{2+}]}{[Cu(NH_3)_3^{2+}][NH_3]} = K_4$

$Cu(NH_3)_4^{2+} + NH_3 = Cu(NH_3)_5^{2+}$ $\quad \frac{[Cu(NH_3)_5^{2+}]}{[Cu(NH_3)_4^{2+}][NH_3]} = K_5$

(b) $Cu^{2+} + 4\, NH_3 = Cu(NH_3)_4^{2+}$ $\quad \frac{[Cu(NH_3)_4^{2+}]}{[Cu^{2+}][NH_3]^4} = \beta_4$

2.34 $[CdCl^+] = K_1 [Cd^{2+}][Cl^-] = 100(10^{-8})(10^{-3}) = 10^{-9}$

$[CdCl_2] = K_2 [CdCl^+][Cl^-] = 4.0(10^{-9})(10^{-3}) = 4.0(10^{-12})$

$[CdCl_3^-] = K_3 [CdCl_2][Cl^-] = 0.63(4.0)(10^{-12})(10^{-3}) = 2.52(10^{-15})$

$[CdCl_4^{=}] = K_4 [CdCl_3^-][Cl^-] = 0.20(2.52)(10^{-15})(10^{-3}) = 5.04(10^{-19})$

Cd^{2+} is the most prevalent species @ 10^{-8} M, but $CdCl^-$ is the most prevalent complex @ 10^{-9} M.

2.35 $[CdCl^+] = 100(10^{-8})(0.5) = 5.0(10^{-7})$ M

$[CdCl_2] = 4.0(5.0)(10^{-7})(0.5) = 10^{-6}$ M

$[CdCl_3^-] = 0.63(10^{-6})(0.5) = 3.15(10^{-7})$ M

$[CdCl_4^{2-}] = 0.20(3.15)(10^{-7})(0.5) = 3.15(10^{-8})$ M

In this case, $CdCl_2$ is the most prevalent species.

2.36 $C_{T,Cd} = [Cd^{2+}] + [CdCl^+] + [CdCl_2] + [CdCl_3^-] + [CdCl_4^{2-}]$

$[CdCl^+] = \beta_1[Cl^-][Cd^{2+}] = 10^2(0.5)[Cd^{2+}] = 50[Cd^{2+}]$

$[CdCl_2] = \beta_2[Cl^-]^2[Cd^{2+}] = 10^{2.6}(0.5)^2[Cd^{2+}] = 99.5[Cd^{2+}]$

$[CdCl_3^-] = \beta_3[Cl^-]^3[Cd^{2+}] = 10^{2.4}(0.5)^3[Cd^{2+}] = 31.4[Cd^{2+}]$

$[CdCl_4^{2-}] = \beta_4[Cl^-]^4[Cd^{2+}] = 10^{1.7}(0.5)^4[Cd^{2+}] = 3.13[Cd^{2+}]$

$10^{-4} = [Cd^{2+}](1 + 50 + 99.53 + 31.40 + 3.13) = 185.06[Cd^{2+}]$

$[Cd^{2+}] = 10\text{-}4/185.06 = 5.4 \times 10^{-7}$ M >> 10^{-7}

(a) No, concentration will not be below 10^{-7} M

(b) $[Cd^{2+}] = 5.4 \times 10^{-7}$ M

2.37 $[Ba^{2+}][SO_4^{2-}] = 1 \times 10^{-10}$

(a) $[SO_4^{2-}] = \dfrac{1 \times 10^{-10}}{10^{-4}} = 1 \times 10^{-6}$ mol/L

(b) $96 \times 1000 \times 10^{-6} = 0.096$ mg/L