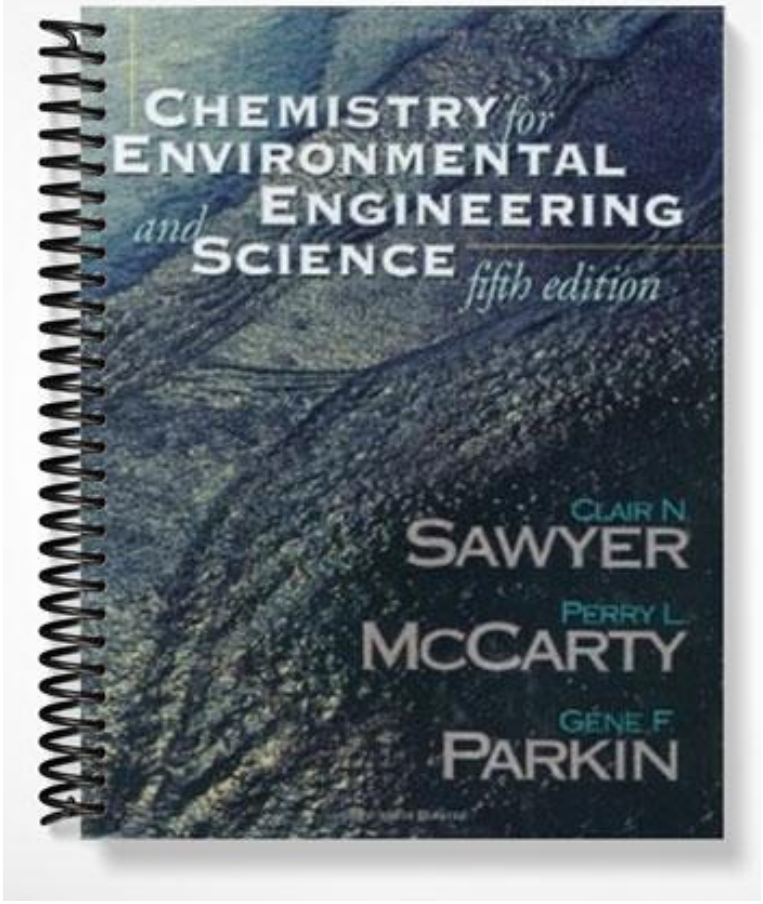
SOLUTIONS MANUAL



Chemistry for Environmental Engineering and Science, 5th Edition

CHAPTER 2 - PROBLEM SOLUTIONS

2.1 (a) $MgCO_3$

$FW = 24.3 + 12 + 3(16) = \underline{\underline{84.3}}$ g/mol

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

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

(b) $NaNO_3$

$FW = 23 + 14 + 3(16) = \underline{\underline{85}}$ g/mol

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

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

(c) CO_2

$FW = 12 + 2(16) = \underline{\underline{44}}$ 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: $CaCO_3 + 2H^+ = Ca^{2+} + H_2CO_3$

$EW = \frac{44}{2} = \underline{\underline{22}}$ 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

$FW = 2(39.1) + 1 + 31 + 4(16) = \underline{\underline{174.2}}$ g/mol

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

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

2.2 (a) $BaSO_4$

$FW = 137.3 + 32.1 + 4(16) = \underline{\underline{233.4}}$ g/mol

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

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

(b) $NaCO_3$

FW = 2(23) + 12 + 3(16) = 106 g/mol

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

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

(c) H_2SO_4

FW = 2(1) + 32.1 + 4(16) = 98.1 g/mol

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

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

(d) $Mg(OH)_2$

FW = 24.3 + 2(16) + 2(1) = 58.3 g/mol

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

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

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

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

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

(d) $\frac{10}{39+35.5} = \frac{10}{74.5} = 0.134$ 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) = 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) = 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$) = \underline{\underline{188}}$ 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 $= 2.60 \times 10^{-3}$ equiv/L (50,000 mg/equiv)

Alk $= \underline{\underline{130}}$ 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) $Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 = 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$

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)

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

or

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

(b)

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

or

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

(c)

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

or

$$NH_4^+ + 2\, O_2 = NO_3^- + H_2O + 2\, H^+$$

(d)

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

or

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

(e)

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

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

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

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

2.12 (a)

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

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

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

(b)

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

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

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

(c)

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

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

$$\text{or}\quad 2\ NH_4^+ + 3\ O_2 = 2\ NO_2^- + 2\ H_2O + 4\ H^+$$

(d)

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

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

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

(e)

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

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

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

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

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

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

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

$= \dfrac{54{,}600}{44} = 1{,}240$ 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 $CH_4 + 2O_2 = CO_2 + 2H_2O$

Moles $CH_4 = \frac{25}{(12 + 4)} = 1.56$ 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. $H_2S = 2 + 32 = 34$

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

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

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

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) $H_2CO_3 = H^+ + HCO_3^-$

$0.10 - X \quad X \quad X$

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

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

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

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

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

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

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

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

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

$0.05 - X \quad X \quad X$

$$\frac{[X][X\}}{[0.05-X]} = 2.85\times10^{-8}$$

$$[X]^2 \cong 14.25\times10^{-10}$$

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

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

2.32 (a)

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

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

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

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

(b)

$$CdCl_4^{=} = Cd^{2+} + 4\,Cl^- \qquad \frac{[Cd^{2+}][Cl^-]^4}{[CdCl_4^{2-}]} = K_{inst}$$

2.33 (a)

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

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

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

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

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

(b)

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

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 <u>will not be below 10^{-7} M</u>

(b) $[Cd^{2+}] =$ <u>5.4×10^{-7} M</u>

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

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

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

(c) $(1 \times 10^{-6})(6.02 \times 10^{23}) = \underline{6.02 \times 10^{17}/L}$

2.38 $[Ag^+][Cl^-] = 3 \times 10^{-10}$

(a) $[Cl^-] = \dfrac{3 \times 10^{-10}}{10^{-4}} = \underline{3 \times 10^{-6}}$ mol/L

(b) $35.5 \times 1000 \times 3 \times 10^{-6} = \underline{0.107}$ mg/L

(c) $(3 \times 10^{-6})(6.02 \times 10^{23}) = 18.1 \times 10^{17}$ or $\underline{1.81 \times 10^{18}/L}$

2.39 (a) (1) $[Ag^+][Cl^-] = K_{sp}$ (b) Cl^-

(2) $[Cu^{2+}][S^{2-}] = K_{sp}$ $S^{=}$

(3) $[Mg^{2+}][NH_4^+][PO_4^{3-}] = K_{sp}$ PO_4^{3-}

(4) $[Au^{3+}][OH^-]^3 = K_{sp}$ OH^-

(5) $[Ag^+]^2[CrO_4^{2-}] = K_{sp}$ $CrO_4^{=}$

(6) $[Ba^{2+}][CO_3^{2-}] = K_{sp}$ $CO_3^{=}$

2.40 Complex ion formation

2.41 See text

2.42 (a) $(3 \times 6.1 \times 10^{-5})^3 (2 \times 6.1 \times 10^{-5})^2 = 6.15 \times 1.49 \times 10^{-20}$

$= \underline{9.1 \times 10^{-20}}$

(b) $(6.3 \times 10^{-9})(6.3 \times 10^{-9}) = \underline{4.0 \times 10^{-17}}$

(c) $(3 \times 1.6 \times 10^{-7})^3 (2 \times 1.6 \times 10^{-7})^2 = 110 \times 10.25 \times 10^{-35} = \underline{1.1 \times 10^{-32}}$

(d) $(7.4 \times 10^{-3})(2 \times 7.4 \times 10^{-3})^2 = 7.4 \times 219 \times 10^{-9} = \underline{1.6 \times 10^{-6}}$

2.43 Sodium carbonate – $CaCO_3$ is less soluble than $Ca(OH)_2$

2.44 Sodium hydroxide – $Mg(OH)_2$ is less soluble than $MgCO_3$

2.45 Ignore complexes. Strategy is to calculate S for each, then the smallest S will be the best!

(a) Adding NaOH will give $Ca(OH)_2(s)$. From Table 2.5, K^{sp} = 8 x 10-6

If S = $[Ca^{2+}]$, then [OH-] = 2S $K_{sp} = 8 \times 10^{-6} = [Ca^{2+}][OH^-]^2 = S(2S)^2 = 4S^3$

S = 1.26 x 10^{-2} M

(b) Adding K_2CO_3 will give $CaCO_3(s)$. From Table 2-5, $K_{sp} = 5 \times 10^{-9}$

If S = $[Ca^{2+}]$, then $[CO_3^{2-}] = S$ $K_{sp} = 5 \times 10^{-9} = [Ca^{2+}][CO_3^{2-}] = S^2$

S = 7.07 x 10^{-5} M

(c) Adding K_2SO_4 will give $CaSO_4(s)$. From Table 2-5, $K_{sp} = 2 \times 10^{-5}$

If S = $[Ca^{2+}]$, then $[SO_4^{2-}] = S$ $K_{sp} = 2 \times 10^{-5} = [Ca^{2+}][SO_4^{2-}] = S^2$

S = 4.47 x 10^{-3} M

(d) Adding KF will give $CaF_2(s)$. From Table 2-5, $K_{sp} = 3 \times 10^{-11}$

If S = $[Ca^{2+}]$, then $[F^-] = 2S$ $K_{sp} = 3 \times 10^{-11} = [Ca^{2+}][F^-]^2 = S(2S)^2 = 4S^3$

S = 1.96 x 10^{-4} M

Since S is the smallest for $CaCO_3(s)$, **Add potassium carbonate**

2.46 (a) Decrease OH^- by adding acid, decrease NH_4^+ perhaps by precipitation as with $Mg(NH_4)PO_4$ or by complex formation.

(b) Remove gaseous NH_3 by boiling or by complex formation; or increase $[OH^-]$ by addition of a strong base such as NaOH.

(c) If NH_3 or OH^- were decreased close to zero.

2.47 (a) $[Mg^{2+}][OH^-]^2 = 9 \times 10^{-12}$

$$[Mg^{2+}] = \frac{9 \times 10^{-12}}{(10^{-5})^2} = 9 \times 10^{-2} \text{ mol/L} = \underline{2{,}190} \text{ mg/L}$$

(b) $$[Mg^{2+}] = \frac{9 \times 10^{-12}}{(10^{-3})^2} = 9 \times 10^{-6} \text{ mol/L} = \underline{0.2} \text{ mg/L}$$

2.48 $[Cu^{2+}][OH^-]^2 = 2 \times 10^{-19}$

$$[Cu^{2+}] = \frac{0.5}{63{,}500} = 7.86 \times 10^{-6}$$

$$[OH^-] = \left[\frac{2 \times 10^{-19}}{7.86 \times 10^{-6}}\right]^{1/2} = [2.55 \times 10^{-14}]^{1/2} = \underline{1.6 \times 10^{-7}} \text{ mol/L}$$

2.49 $[Zn^{2+}][OH^-]^2 = 3 \times 10^{-17}$

$$[Zn^{2+}] = \frac{1.0}{65400} = 1.53 \times 10^{-5}$$

$$[OH^-] = \left[\frac{3 \times 10^{-17}}{1.53 \times 10^{-5}}\right]^{1/2} = [1.96 \times 10^{-12}]^{1/2} = 1.4 \times 10^{-6} \text{ mol/L}$$

$$pOH = \log \frac{1}{1.4 \times 10^{-6}} = 5.85$$

$$pH = 14 - 5.85 = \underline{\underline{8.15}}$$

Zn will go back into solution as ZnO_2^{2-}.

2.50 0.03 mg/l Fe $= \frac{0.03}{55900} = 5.38 \times 10^{-7}$ mol/L

(a) $[Fe^{2+}][OH^-]^2 = 5 \times 10^{-15}$

$$[OH^-] = \left[\frac{5 \times 10^{-15}}{5.38 \times 10^{-7}}\right]^{1/2} = 9.6 \times 10^{-5}$$

$$pOH = \log \frac{1}{9.6 \times 10^{-5}} = 4.01$$

$$pH = \underline{\underline{10.0}}$$

(b) $[Fe^{3+}][OH^-]^3 = 6 \times 10^{-38}$

$$[OH^-] = \left[\frac{6 \times 10^{-38}}{5.38 \times 10^{-7}}\right]^{1/3} = 4.8 \times 10^{-11}$$

$$pOH = \log \frac{10^{11}}{4.8} = 10.32$$

$$pH = 14 - 10.32 = \underline{\underline{3.7}}$$

2.51 0.01 mg/l Mn $= \frac{0.01}{54950} = 1.82 \times 10^{-7}$ mol/L

(a) $[Mn^{2+}][OH^-]^2 = 8 \times 10^{-14}$

$$[OH^-] = \left[\frac{8 \times 10^{-14}}{1.82 \times 10^{-7}}\right]^{1/2} = [44 \times 10^{-8}]^{1/2} = 6.6 \times 10^{-4}$$

$$pOH = \log \frac{10^4}{6.6} = 3.18$$

$$pH = 14 - 3.18 = \underline{\underline{10.82}}$$

(b) $[Mn^{+2}][OH^-]^3 = 10^{-36}$

$$[OH^-] = \left[\frac{10^{-36}}{1.82 \times 10^{-7}}\right]^{1/3} = [5.5 \times 10^{-30}]^{1/3} = 1.8 \times 10^{-10}$$

$$pOH = \log \frac{10^{10}}{1.8} = 9.74$$

$$pH = 14 - 9.74 = \underline{\underline{4.26}}$$

2.52 $[F^-] = \frac{1}{19000} = 5.26 \times 10^{-5}$

$[Ca^{2+}] = \frac{200}{40000} = 5 \times 10^{-3}$

$[Ca^{2+}][F^-]^2 = (5)(5.26)^2 \times 10^{-3} \times 10^{-10} = 138 \times 10^{-13} = 1.38 \times 10^{-11}$

$K_{sp} = 3 \times 10^{-11}$

Since $1.38 \times 10^{-11} < 3 \times 10^{-11}$, <u>fluoride will be soluble</u>.

2.53 $[Ca^{2+}]^3[PO_4^{=}]^2 = 1 \times 10^{-27}$

$$[Ca^{2+}] = \left[\frac{1 \times 10^{-27}}{(10^{-5})^2}\right]^{1/3} = [10^{-15}]^{1/3} = 10^{-5}$$

$10^{-5} \times 40{,}000 = \underline{\underline{0.4}}$ mg/L Ca^{2+}

2.54 F.W. $CO_3^{2-} = 60$

$[CO_3^{2-}] = \frac{100}{60000} = 1.67 \times 10^{-3}$

(a) $[Ca^{2+}][CO_3^{2-}] = 5 \times 10^{-9}$

$$[Ca^{2+}] = \frac{5 \times 10^{-9}}{1.67 \times 10^{-3}} = 3 \times 10^{-6}$$

$Ca^{2+} = 3 \times 10^{-6} \times 40{,}000 = \underline{\underline{0.12}}$ mg/L

(b) $[Mg^{2+}][CO_3^{2-}] = 4 \times 10^{-5}$

$$[Mg^{2+}] = \frac{4 \times 10^{-5}}{1.67 \times 10^{-3}} = 2.4 \times 10^{-2}$$

$Mg^{2+} = 2.4 \times 10^{-2} \times 24{,}300 = \underline{\underline{583}}$ mg/L

2.55 (a) $[Ag^+][Cl^-] = 3 \times 10^{-10}$

$[Ag^+] = [Cl^-]$

$[Ag^+] = [3 \times 10^{-10}]^{1/2} = 1.73 \times 10^{-5}$

$Ag^+ = 1.73 \times 10^{-5} \times 107{,}900 = \underline{1.87}$ mg/L

(b) $\dfrac{[Ag(NH_3)_2^+][Cl^-]}{[NH_3]^2} = 5 \times 10^{-3}$

Assume $[Ag(NH_3)_2^+] = [Cl^-]$

$[Ag(NH_3)_2^+] = [(5 \times 10^{-3})(0.01)^2]^{1/2} = (5 \times 10^{-7})^{1/2} = 7.07 \times 10^{-4}$

$Ag = 7.07 \times 10^{-4} (107{,}900) = \underline{76}$ mg/L