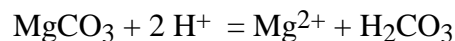


## Chemistry for Environmental Engineering and Science, 5th Edition

### CHAPTER 2 - PROBLEM SOLUTIONS

#### 2.1 (a) $\text{MgCO}_3$

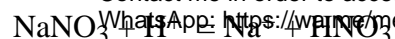
$$\text{FW} = 24.3 + 12 + 3(16) = \underline{84.3} \text{ g/mol}$$



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

#### (b) $\text{NaNO}_3$

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



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

#### (c) $\text{CO}_2$

$$\text{FW} = 12 + 2(16) = \underline{44} \text{ g/mol}$$



Note from above:  $\text{MgCO}_3 + 2\text{H}^+ = \text{Mg}^{2+} + \text{H}_2\text{CO}_3$  and  $\text{H}_2\text{CO}_3 = 2\text{H}^+ + \text{CO}_3^{2-}$

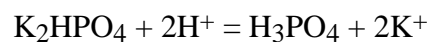
or:  $\text{CaCO}_3 + 2\text{H}^+ = \text{Ca}^{2+} + \text{H}_2\text{CO}_3$

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

\***Note:** In some reactions, Z might be considered to be 1 (i.e.,  $\text{H}_2\text{CO}_3 = \text{H}^+ + \text{HCO}_3^-$ )

#### (d) $\text{K}_2\text{HPO}_4$

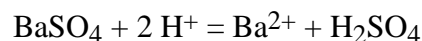
$$\text{FW} = 2(39.1) + 1 + 31 + 4(16) = \underline{174.2} \text{ g/mol}$$



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

#### 2.2 (a) $\text{BaSO}_4$

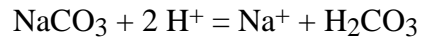
$$\text{FW} = 137.3 + 32.1 + 4(16) = \underline{233.4} \text{ g/mol}$$



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

#### (b) $\text{NaCO}_3$

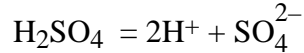
$$\text{FW} = 2(23) + 12 + 3(16) = \underline{106} \text{ g/mol}$$



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

(c)  $\text{H}_2\text{SO}_4$

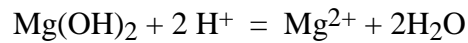
$$\text{FW} = 2(1) + 32.1 + 4(16) = \underline{98.1} \text{ g/mol}$$



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

(d)  $\text{Mg}(\text{OH})_2$

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



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

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

(b)  $\frac{10}{46+32+64} = \frac{10}{142} = \underline{0.0704}$  for  $\text{Na}_2\text{SO}_4$

(c)  $\frac{10}{78+104+7(16)} = \frac{10}{294} = \underline{0.034}$  for  $\text{K}_2\text{Cr}_2\text{O}_7$

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

**2.4** (a)  $\frac{X}{2} = 0.15 \text{ M}$ ,  $X = 0.30 \text{ mol KMnO}_4$

$$\text{FW} = 39.1 + 24.3 + 4(16) = 127.4 \text{ g/mol}$$

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

(b)  $\frac{X}{2} = 0.15 \text{ N}$ ,  $X = 0.30 \text{ equiv. KMnO}_4$

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

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

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

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

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

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

$$\begin{aligned} \text{Total Hardness} &= 2.20 + 1.56 = 3.76 \text{ meq/L} \\ &= 3.76(50 \text{ mg/meq}) = \underline{188} \text{ mg/L as CaCO}_3 \end{aligned}$$

**2.6** Note: for  $\text{HCO}_3^-$ ,  $\text{H}^+$ , and  $\text{OH}^-$ ,  $\text{mol/L} = \text{equiv/L}$  ( $Z = 1$ )

for  $\text{CO}_3^{2-}$ ,  $\text{equiv/L} = 2(\text{mol/L})$  ( $Z = 2$ )

$$\left. \begin{aligned} [\text{OH}^-][\text{H}^+] &= 10^{-14} \\ \text{pH} &= -\log [\text{H}^+] \end{aligned} \right\} \text{ for } [\text{H}^+] = 10^{-9.5}, [\text{OH}^-] = 10^{-4.5}$$

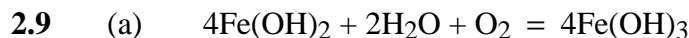
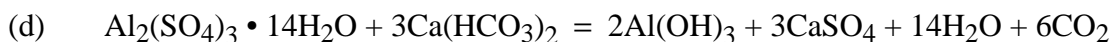
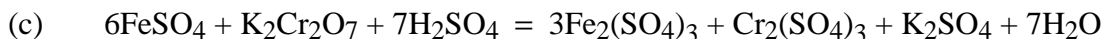
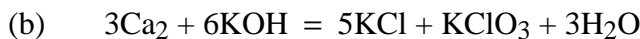
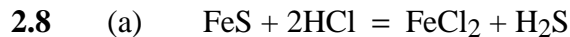
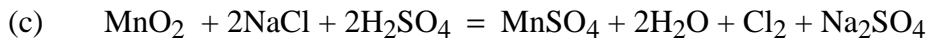
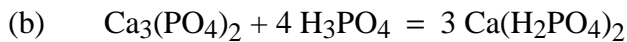
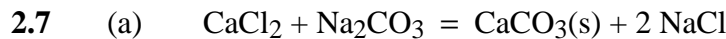
$$[\text{HCO}_3^-] = \frac{118 \text{ mg/L}}{61,000 \text{ mg/mol}} = 1.93 \times 10^{-3} \text{ M}$$

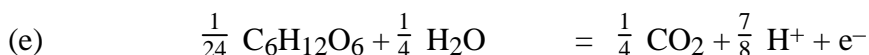
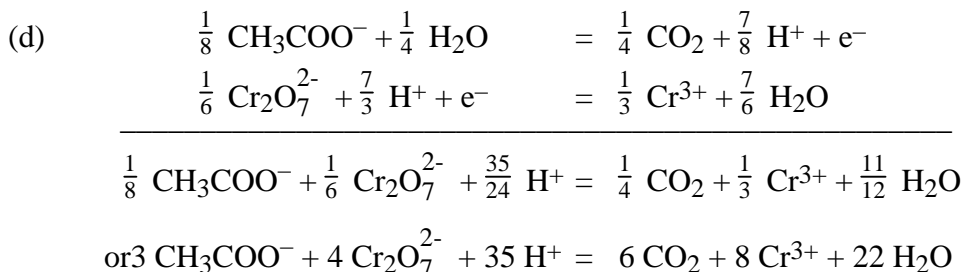
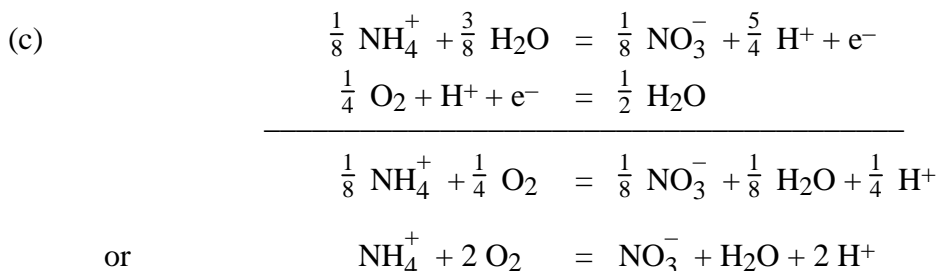
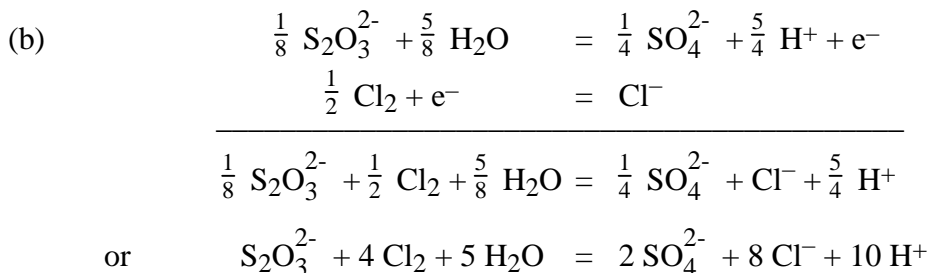
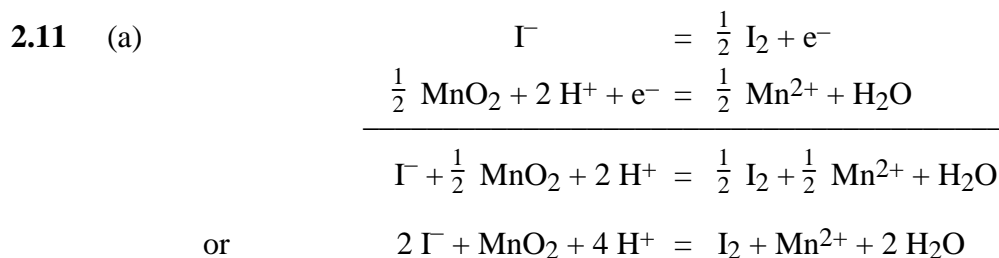
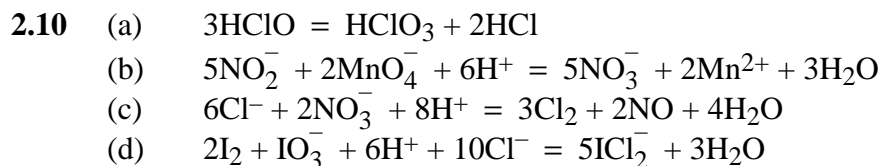
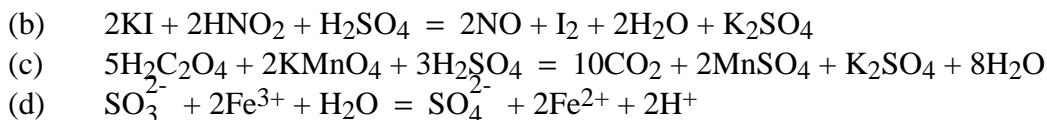
$$[\text{CO}_3^{2-}] = \frac{19 \text{ mg/L}}{60,000 \text{ mg/mol}} = 3.17 \times 10^{-4} \text{ M}$$

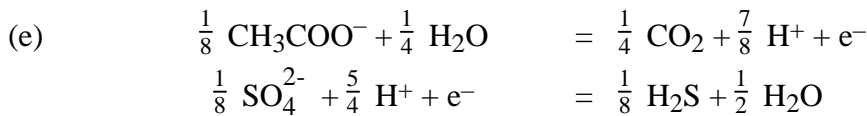
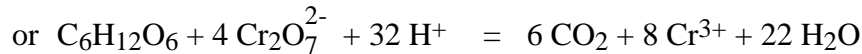
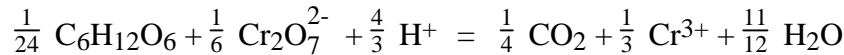
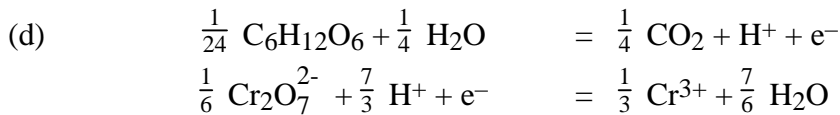
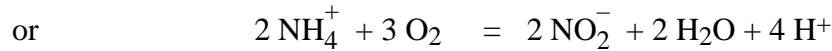
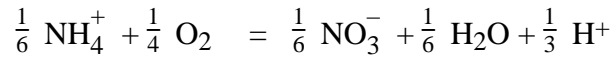
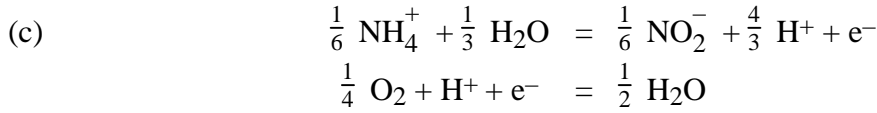
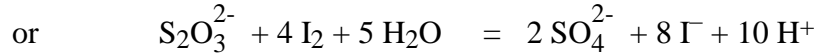
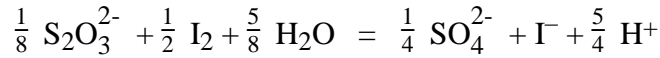
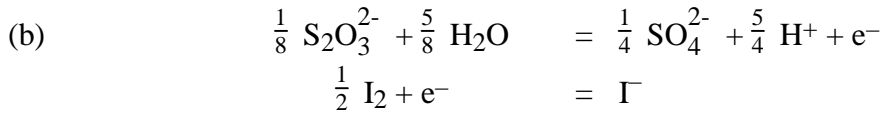
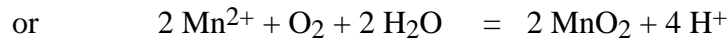
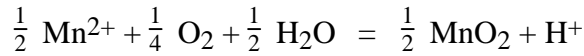
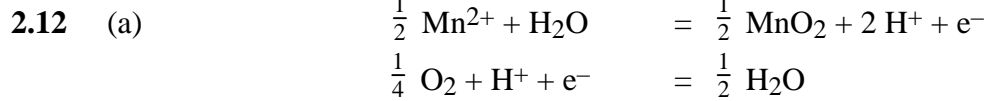
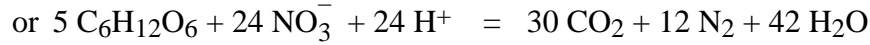
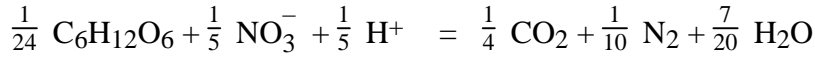
$$\text{equiv/L} \quad \text{Alk} = 1.93 \times 10^{-3} + 2(3.17 \times 10^{-4}) + 10^{-4.5} - 10^{-7.5}$$

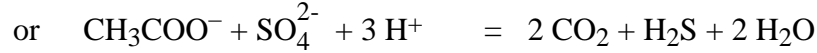
$$\text{Alk} = 2.60 \times 10^{-3} \text{ equiv/L (50,000 mg/equiv)}$$

$$\text{Alk} = \underline{130} \text{ mg/L as CaCO}_3$$

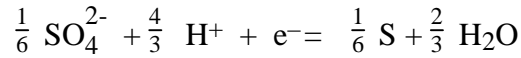
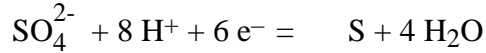




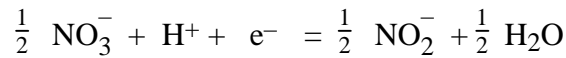
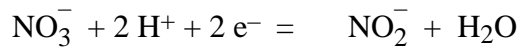
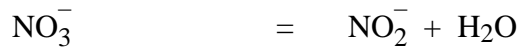




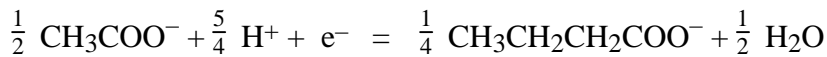
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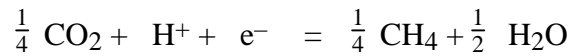
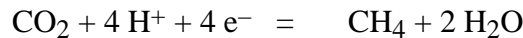
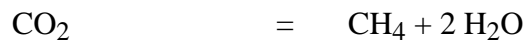
(b)



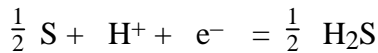
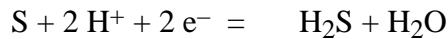
(c)



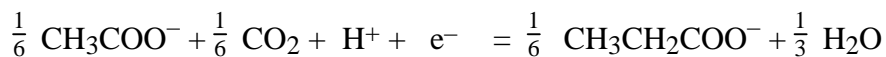
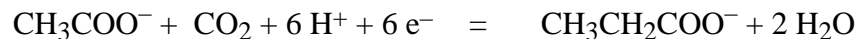
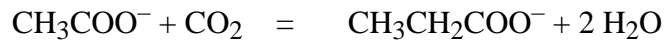
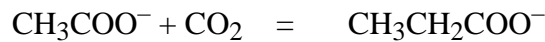
2.14 (a)



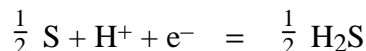
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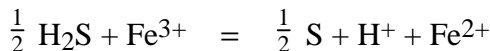
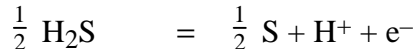


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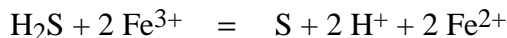


2.15

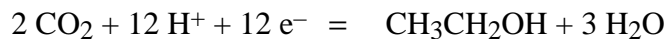




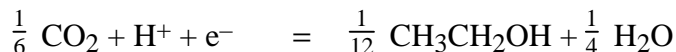
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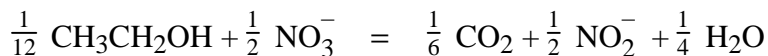
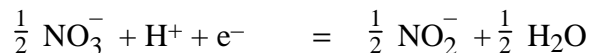
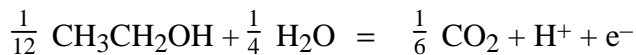
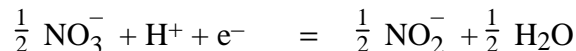
**2.16**



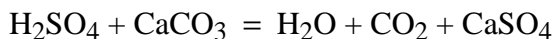
or



or



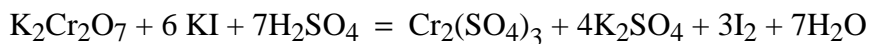
**2.17**



$$\text{F.W. CaCO}_4 = 40 + 32 + 4(16) = 136$$

$$\text{Moles H}_2\text{SO}_4 \text{ req'd} = \frac{65}{136} = \underline{\underline{0.478}}$$

**2.18**



$$\text{F.W. K}_2\text{Cr}_2\text{O}_7 = 2(39.1) + 2(52) + 7(16) = 294.2$$

$$\text{F.W. I}_2 = 2(126.9) = 253.8$$

$$\text{I}_2 \text{ Formed} = \frac{3(253.8)}{294.2} \times 6 = \underline{\underline{15.5}} \text{ g}$$

**2.19**

$$\text{F.W. CO}_2 = 12 + 32 = 44 \text{ g}$$

$$120 \text{ lb CO}_2 = \frac{120(1000)}{2.2} = 54,600 \text{ g}$$

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

$$PV = n RT$$

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

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

**2.20**  $PV = n RT$

$$n = \frac{PV}{RT} = \frac{5(10)}{(0.082)(273)} = 2.235 \text{ mol O}_2$$

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

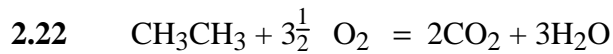


$$\text{Moles CH}_4 = \frac{25}{(12 + 4)} = 1.56 \text{ mol}$$

$$\text{Moles O}_2 \text{ req'd} = 1.56(2) = 3.12 \text{ mol}$$

$$PV = n RT$$

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



(a)  $\text{CH}_3\text{CH}_3 = \frac{6}{(24 + 6)} = 0.2 \text{ mol}$

$$\text{H}_2\text{O} = 3(0.2) = \underline{0.6} \text{ mol formed}$$

(b)  $\text{CO}_2 = 2(0.2) = \underline{0.4} \text{ mol formed}$

(c)  $PV = n RT$

$$V = \frac{0.4(0.082)(273 + 20)}{1} = \underline{9.6} \text{ liters CO}_2$$

**2.23**  $PV = n RT$  F.W.  $\text{H}_2\text{S} = 2 + 32 = 34$

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

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

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

2.24 (a)  $\text{CH}_4$  (F.W. = 16)  $\frac{12}{16} = \underline{0.75}$  mol  
 $\text{N}_2$  (F.W. = 28)  $\frac{1}{28} = \underline{0.0357}$  mol  
 $\text{CO}_2$  (F.W. = 44)  $\frac{15}{44} = \underline{0.341}$  mol

(b)  $PV = nRT$

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

$$\text{CH}_4 \quad P = 0.815(0.75) = \underline{0.611} \text{ atm}$$

$$\text{N}_2 \quad P = 0.815(0.0357) = \underline{0.029} \text{ atm}$$

$$\text{CO}_2 \quad P = 0.815(0.341) = \underline{0.278} \text{ atm}$$

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

(d)  $\text{CH}_4 = \frac{0.611}{0.918} = \underline{66.5}$  percent

$$\text{N}_2 = \frac{0.029}{0.918} = \underline{3.2}$$
 percent

$$\text{CO}_2 = \frac{0.278}{0.918} = \underline{30.3}$$
 percent

2.25  $C = \beta p_{\text{gas}}$   
 $= 2.0(0.3) = 0.6 \text{ g/L}$

5 liters contain  $0.6(5) = \underline{3.0}$  g  $\text{CO}_2$

2.26  $p_{\text{O}_2} = 0.21(0.81) = 0.17 \text{ atm}$

$$C = \beta p_{\text{O}_2} = 43.4(0.17) = \underline{7.4} \text{ mg/L}$$

		<u>FW</u>	<u>Moles</u>	<u>Mole fraction</u>
PCE	$\text{C}_2\text{Cl}_4$	$2(12) + 4(35.5) = 166$	$10^5/166 = 602$	$602/4291 = \underline{0.140}$

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

- 2.28** (a)  $P_{PCE} = 0.10(0.0251) = 0.002511 \text{ atm}$   
 $C_{PCE} = P_{PCE}/K_H = 0.002511 \text{ atm}/(26.9 \text{ atm-L/mol}) = 0.000093 \text{ M}$  or 0.093 mM
- (b)  $P_{PCE} = 0.10P_{PCE, \text{max}}$ , Solubility reduction =  $100(1-0.1) = \underline{90\%}$

- 2.29** FW TCE =  $2(12) + 3(35.5) + 1 = 131.5$   
 $C_{\text{equil}} = P_{TCE}/K_H = 0.0977/11.6 = 0.00842 \text{ M}$  or  $0.00842(131,500) = 1,107 \text{ mg/L}$   
 $X_{TCE} = 20/1,107 = \underline{0.018}$

- 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  $X \ll 0.10$ )  
 $[X] = \underline{\underline{2.11 \times 10^{-4}}} = \underline{\underline{[H^+]}}$   
% ionization =  $\frac{2.11 \times 10^{-4}}{0.10} (100) = \underline{\underline{0.211}}$  percent

- (b)  $\frac{[X][X]}{[0.01 - X]} = 4.45 \times 10^{-7}$   
 $[X]^2 \cong 4.45 \times 10^{-10}$   
 $[X] = \underline{\underline{6.67 \times 10^{-5}}} = \underline{\underline{[H^+]}}$   
% ionization =  $\frac{6.67 \times 10^{-5}}{0.01} (100) = \underline{\underline{0.067}}$  percent

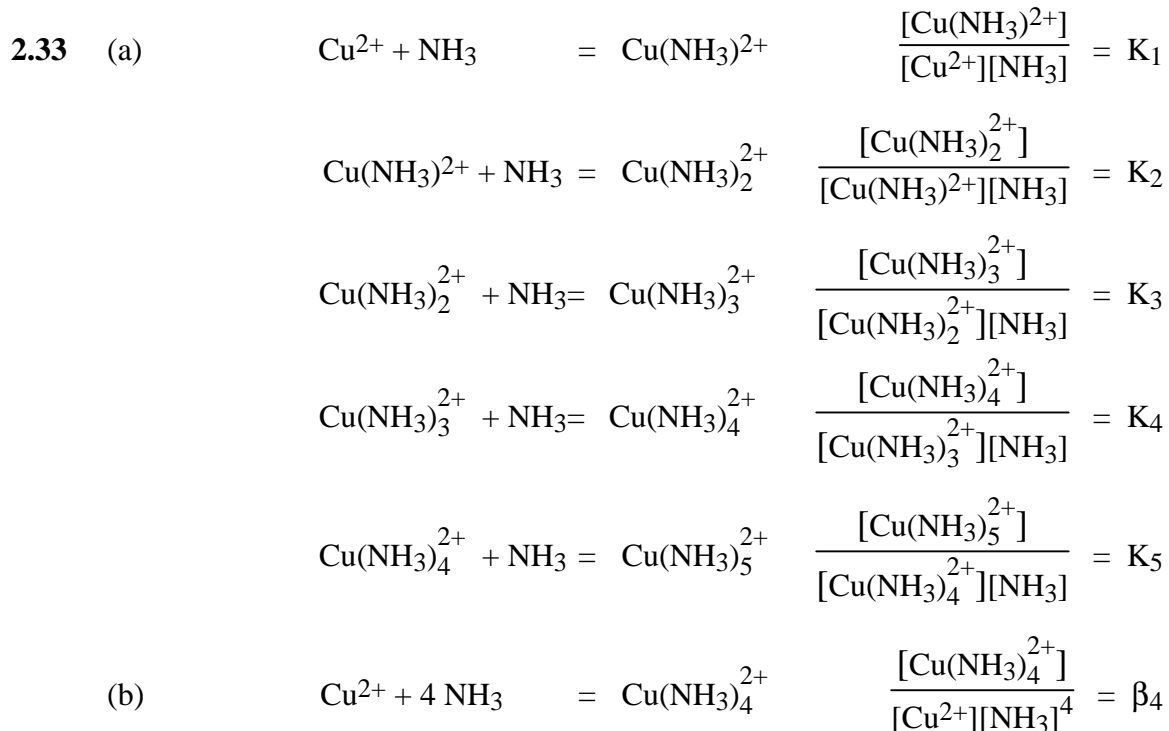
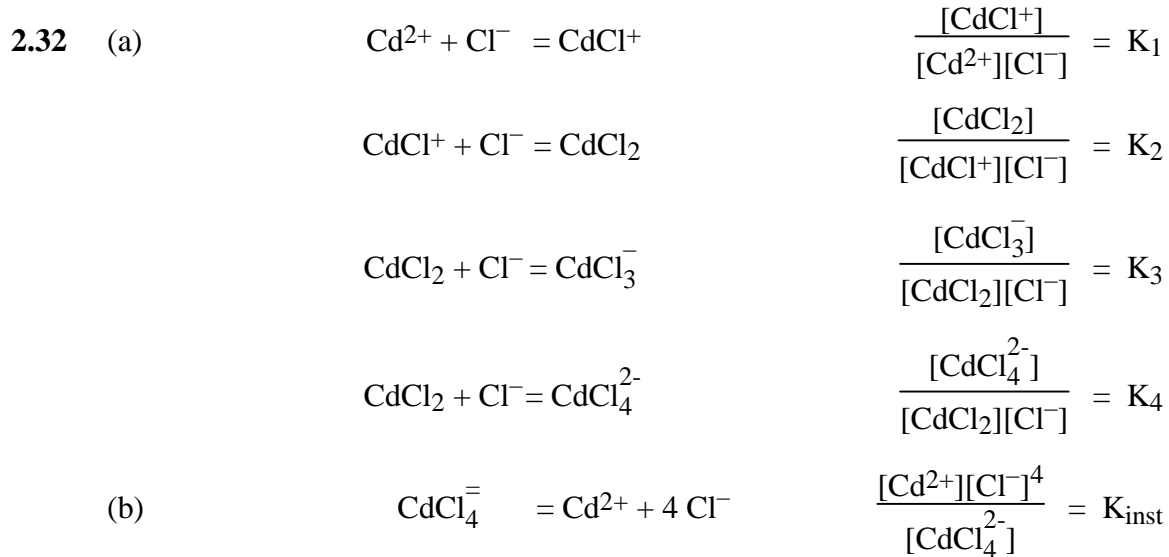
- 2.31**  $HOCl = H^+ + OCl^-$   
 $0.05 - X \quad X \quad X$

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

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

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

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



**2.34**

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

$$[\text{CdCl}_2] = K_2 [\text{CdCl}^+][\text{Cl}^-] = 4.0(10^{-9})(10^{-3}) = 4.0(10^{-12})$$

$$[\text{CdCl}_3^-] = K_3 [\text{CdCl}_2][\text{Cl}^-] = 0.63(4.0)(10^{-12})(10^{-3}) = 2.52(10^{-15})$$

$$[\text{CdCl}_4^{2-}] = K_4 [\text{CdCl}_3^-][\text{Cl}^-] = 0.20(2.52)(10^{-15})(10^{-3}) = 5.04(10^{-19})$$

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

**2.35**

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

$$[\text{CdCl}_2] = 4.0(5.0)(10^{-7})(0.5) = 10^{-6} \text{ M}$$

$$[\text{CdCl}_3^-] = 0.63(10^{-6})(0.5) = 3.15(10^{-7}) \text{ M}$$

$$[\text{CdCl}_4^{2-}] = 0.20(3.15)(10^{-7})(0.5) = 3.15(10^{-8}) \text{ M}$$

In this case,  $\text{CdCl}_2$  is the most prevalent species.

**2.36**

$$C_{\text{T,Cd}} = [\text{Cd}^{2+}] + [\text{CdCl}^+] + [\text{CdCl}_2] + [\text{CdCl}_3^-] + [\text{CdCl}_4^{2-}]$$

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

$$[\text{CdCl}_2] = \beta_2[\text{Cl}^-]^2[\text{Cd}^{2+}] = 10^{2.6}(0.5)^2[\text{Cd}^{2+}] = 99.5[\text{Cd}^{2+}]$$

$$[\text{CdCl}_3^-] = \beta_3[\text{Cl}^-]^3[\text{Cd}^{2+}] = 10^{2.4}(0.5)^3[\text{Cd}^{2+}] = 31.4[\text{Cd}^{2+}]$$

$$[\text{CdCl}_4^{2-}] = \beta_4[\text{Cl}^-]^4[\text{Cd}^{2+}] = 10^{1.7}(0.5)^4[\text{Cd}^{2+}] = 3.13[\text{Cd}^{2+}]$$

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

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

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

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

**2.37**

$$[\text{Ba}^{2+}][\text{SO}_4^{2-}] = \frac{1 \times 10^{-10}}{10^{-4}} = \underline{\underline{1 \times 10^{-6} \text{ mol/L}}}$$

(a)

$$[\text{SO}_4^{2-}] = \frac{1 \times 10^{-10}}{10^{-4}} = \underline{\underline{1 \times 10^{-6} \text{ mol/L}}}$$

(b)

$$96 \times 1000 \times 10^{-6} = \underline{\underline{0.096 \text{ mg/L}}}$$