12. a. $HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$

b. $HNO_3(l) \rightarrow H^+(aq) + NO_3^-(aq)$

c. $Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2\ OH^-(aq)$

d. $KOH(s) \rightarrow K^+(aq) + OH^-(aq)$

16. a. $$\frac{16.45\text{ g NaCl}}{1.000\text{ L}} \times \frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}} = 0.2815\ M\text{ NaCl}$$

b. $$853.5\text{ mg } KIO_3 \times \frac{1\text{ g}}{1000\text{ mg}} \times \frac{1\text{ mol } KIO_3}{214.0\text{ g } KIO_3} = 3.988 \times 10^{-3}\text{ mol } KIO_3$$

$$\frac{3.988 \times 10^{-3}\text{ mol}}{250.0\text{ mL}} \times \frac{1000\text{ mL}}{\text{L}} = 1.595 \times 10^{-2}\ M\ KIO_3$$

c. $$0.4508\text{ g Fe} \times \frac{1\text{ mol Fe}}{55.85\text{ g Fe}} = 8.072 \times 10^{-3}\text{ mol Fe} = 8.072 \times 10^{-3}\text{ mol } Fe^{3+}$$

$$\frac{8.072 \times 10^{-3}\text{ mol } Fe^{2+}}{500.0\text{ mL}} \times \frac{1000\text{ mL}}{\text{L}} = 1.614 \times 10^{-2}\ M\ Fe^{3+}$$

20. $NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$, 2 total mol of ions (1 mol Na^+ and 1 mol Cl^-) per mol NaOH.

$$0.1000\text{ L} \times \frac{0.100\text{ mol NaOH}}{\text{L}} \times \frac{2\text{ mol ions}}{\text{mol NaOH}} = 2.0 \times 10^{-2}\text{ mol ions}$$

$BaCl_2(s) \rightarrow Ba^{2+}(aq) + 2\ Cl^-(aq)$, 3 total mol of ions per mol $BaCl_2$.

$$0.0500\text{ L} \times \frac{0.200\text{ mol}}{\text{L}} \times \frac{3\text{ mol ions}}{\text{mol } BaCl_2} = 3.0 \times 10^{-2}\text{ mol ions}$$

$Na_3PO_4(s) \rightarrow 3\ Na^+(aq) + PO_4^{3-}(aq)$, 4 total mol of ions per mol Na_3PO_4.

$$0.0750\text{ L} \times \frac{0.150\text{ mol } Na_3PO_4}{\text{L}} \times \frac{4\text{ mol ions}}{\text{mol } Na_3PO_4} = 4.50 \times 10^{-2}\text{ mol ions}$$

75.0 mL of 0.150 M Na_3PO_4 contains the largest number of ions.

26. $$\text{mol } Na_2CO_3 = 0.0700\text{ L} \times \frac{3.0\text{ mol } Na_2CO_3}{\text{L}} = 0.21\text{ mol } Na_2CO_3$$

$Na_2CO_3(s) \rightarrow 2\ Na^+(aq) + CO_3^{2-}(aq)$; mol $Na^+ = 2(0.21) = 0.42$ mol

$$\text{mol } NaHCO_3 = 0.0300\text{ L} \times \frac{1.0\text{ mol } NaHCO_3}{\text{L}} = 0.030\text{ mol } NaHCO_3$$

$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$; mol $Na^+ = 0.030$ mol

$$M_{Na^+} = \frac{\text{total mol } Na^+}{\text{total volume}} = \frac{0.42\text{ mol} + 0.030\text{ mol}}{0.0700\text{ L} + 0.0300\text{ L}} = \frac{0.45\text{ mol}}{0.1000\text{ L}} = 4.5\ M\ Na^+$$

30. a. Possible products = $FeCl_2$ and K_2SO_4; Both salts are soluble so no precipitate forms.
b. Possible products = $Al(OH)_3$ and $Ba(NO_3)_2$; precipitate = $Al(OH)_3(s)$
c. Possible products = $CaSO_4$ and NaCl; precipitate =$CaSO_4(s)$
d. Possible products = KNO_3 and NiS; precipitate = NiS(s)

34. a. AgCl is insoluble. $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

b. FeS is insoluble. $Fe^{2+}(aq) + S^{2-}(aq) \rightarrow FeS(s)$

c. No reaction

d. $Hg_2(NO_3)_2$ is made up of Hg_2^{2+} and NO_3^- ions. Hg_2Cl_2, mercury(I) chloride or mercurous chloride, is insoluble. $Hg_2^{2+}(aq) + 2\ Cl^-(aq) \rightarrow Hg_2Cl_2(s)$

42. The balanced equation is: $3\ BaCl_2(aq) + Fe_2(SO_4)_3(aq) \rightarrow 3\ BaSO_4(s) + 2\ FeCl_3(aq)$

$$100.0\ mL\ BaCl_2 \times \frac{1\ L}{1000\ mL} \times \frac{0.100\ mol\ BaCl_2}{L} = 1.00 \times 10^{-2}\ mol\ BaCl_2$$

$$100.0\ mL\ Fe_2(SO_4)_3 \times \frac{1\ L}{1000\ mL} \times \frac{0.100\ mol\ Fe_2(SO_4)_3}{L\ Fe_2(SO_4)_3} = 1.00 \times 10^{-2}\ mol\ Fe_2(SO_4)_3$$

The required mol $BaCl_2$ to mol $Fe_2(SO_4)_3$ ratio from the balanced reaction is 3:1. The actual mol ratio is 0.0100/0.0100 = 1 (1:1). This is well below the required mol ratio so $BaCl_2$ is the limiting reagent.

$$0.0100\ mol\ BaCl_2 \times \frac{3\ mol\ BaSO_4}{3\ mol\ BaCl_2} \times \frac{233.4\ g\ BaSO_4}{mol\ BaSO_4} = 2.33\ g\ BaSO_4$$

46. a. $3\ HNO_3(aq) + Al(OH)_3(s) \rightarrow 3\ H_2O(l) + Al(NO_3)_3(aq)$

$3\ H^+(aq) + 3\ NO_3^-(aq) + Al(OH)_3(s) \rightarrow 3\ H_2O(l) + Al^{3+}(aq) + 3\ NO_3^-(aq)$

$3\ H^+(aq) + Al(OH)_3(s) \rightarrow 3\ H_2O(l) + Al^{3+}(aq)$

b. $HC_2H_3O_2(aq) + KOH(aq) \rightarrow H_2O(l) + KC_2H_3O_2(aq)$

$HC_2H_3O_2(aq) + K^+(aq) + OH^-(aq) \rightarrow H_2O(l) + K^+(aq) + C_2H_3O_2^-(aq)$

$HC_2H_3O_2(aq) + OH^-(aq) \rightarrow H_2O(l) + C_2H_3O_2^-(aq)$

50. We begin with 25.00 mL of 0.200 *M* HCl or 25.00×10^{-3} L × 0.200 mol/L = 5.00×10^{-3} mol HCl.

a. $HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$

$$5.00 \times 10^{-3} \text{ mol HCl} \times \frac{1 \text{ mol NaOH}}{\text{mol HCl}} \times \frac{1 \text{ L}}{0.100 \text{ mol NaOH}} = 5.00 \times 10^{-2} \text{ L or } 50.0 \text{ mL}$$

b. $2\ HCl(aq) + Ba(OH)_2(aq) \rightarrow 2\ H_2O(l) + BaCl_2(aq)$

$$5.00 \times 10^{-3} \text{ mol HCl} \times \frac{1 \text{ mol Ba(OH)}_2}{2 \text{ mol HCl}} \times \frac{1 \text{ L}}{0.0500 \text{ mol Ba(OH)}_2} = 5.00 \times 10^{-2} \text{ L} = 50.0 \text{ mL}$$

c. $HCl(aq) + KOH(aq) \rightarrow H_2O(l) + KCl(aq)$

$$5.00 \times 10^{-3} \text{ mol HCl} \times \frac{1 \text{ mol KOH}}{\text{mol HCl}} \times \frac{1 \text{ L}}{0.250 \text{ mol KOH}} = 2.00 \times 10^{-2} \text{ L or } 20.0 \text{ mL}$$

58. a. UO_2^{2+}: O, -2; For U, $x + 2(-2) = +2$, $x = \underline{+6}$

b. As_2O_3: O, -2; For As, $2(x) + 3(-2) = 0$, $x = \underline{+3}$

c. $NaBiO_3$: Na, +1; O, -2; For Bi, $+1 + x + 3(-2) = 0$, $x = \underline{+5}$

d. As_4: As, 0

e. $HAsO_2$: assign H = +1 and O = -2; For As, $+1 + x + 2(-2) = 0$; $x = \underline{+3}$

f. $Mg_2P_2O_7$: Composed of Mg^{2+} ions and $P_2O_7^{4-}$ ions. Oxidation states are:

Mg, +2; O, -2; P, +5

g. $Na_2S_2O_3$: Composed of Na^+ ions and $S_2O_3^{2-}$ ions. Na, +1; O, -2; S, +2

h. Hg_2Cl_2: Hg, +1; Cl, -1

i. $Ca(NO_3)_2$: Composed of Ca^{2+} ions and NO_3^- ions. Ca, +2; O, -2; N, +5

62.

	Redox?	Oxidizing Agent	Reducing Agent	Substance Oxidized	Substance Reduced
a.	Yes	Ag^+	Cu	Cu	Ag^+
b.	No	-	-	-	-
c.	No	-	-	-	-
d.	Yes	$SiCl_4$	Mg	Mg	$SiCl_4$ (Si)
e.	No	-	-	-	-

In b, c, and e, no oxidation numbers change.

64. a. $(Cu \rightarrow Cu^{2+} + 2\ e^-) \times 3$

$$NO_3^- \rightarrow NO + 2\ H_2O$$
$$(3\ e^- + 4\ H^+ + NO_3^- \rightarrow NO + 2\ H_2O) \times 2$$

Adding the two balanced half-reactions so electrons cancel:

$$3\ Cu \rightarrow 3\ Cu^{2+} + 6\ e^-$$
$$6\ e^- + 8\ H^+ + 2\ NO_3^- \rightarrow 2\ NO + 4\ H_2O$$

$$3\ Cu(s) + 8\ H^+(aq) + 2\ NO_3^-(aq) \rightarrow 3\ Cu^{2+}(aq) + 2\ NO(g) + 4\ H_2O(l)$$

b. $(2\ Cl^- \rightarrow Cl_2 + 2\ e^-) \times 3$

$$Cr_2O_7^{2-} \rightarrow 2\ Cr^{3+} + 7\ H_2O$$
$$6\ e^- + 14\ H^+ + Cr_2O_7^{2-} \rightarrow 2\ Cr^{3+} + 7\ H_2O$$

Add the two half-reactions with six electrons transferred:

$$6\ Cl^- \rightarrow 3\ Cl_2 + 6\ e^-$$
$$6\ e^- + 14\ H^+ + Cr_2O_7^{2-} \rightarrow 2\ Cr^{3+} + 7\ H_2O$$

$$14\ H^+(aq) + Cr_2O_7^{2-}(aq) + 6\ Cl^-(aq) \rightarrow 3\ Cl_2(g) + 2\ Cr^{3+}(aq) + 7\ H_2O(l)$$

c. $Pb \rightarrow PbSO_4$

$$Pb + H_2SO_4 \rightarrow PbSO_4 + 2\ H^+$$
$$Pb + H_2SO_4 \rightarrow PbSO_4 + 2\ H^+ + 2\ e^-$$

$$PbO_2 \rightarrow PbSO_4$$
$$PbO_2 + H_2SO_4 \rightarrow PbSO_4 + 2\ H_2O$$
$$2\ e^- + 2\ H^+ + PbO_2 + H_2SO_4 \rightarrow PbSO_4 + 2\ H_2O$$

Add the two half-reactions with two electrons transferred:

$$2\ e^- + 2\ H^+ + PbO_2 + H_2SO_4 \rightarrow PbSO_4 + 2\ H_2O$$
$$Pb + H_2SO_4 \rightarrow PbSO_4 + 2\ H^+ + 2\ e^-$$

$$Pb(s) + 2\ H_2SO_4(aq) + PbO_2(s) \rightarrow 2\ PbSO_4(s) + 2\ H_2O(l)$$

This is the reaction that occurs in an automobile lead storage battery.

d. $Mn^{2+} \rightarrow MnO_4^-$

$$(4\ H_2O + Mn^{2+} \rightarrow MnO_4^- + 8\ H^+ + 5\ e^-) \times 2$$

$$NaBiO_3 \rightarrow Bi^{3+} + Na^+$$
$$6\ H^+ + NaBiO_3 \rightarrow Bi^{3+} + Na^+ + 3\ H_2O$$
$$(2\ e^- + 6\ H^+ + NaBiO_3 \rightarrow Bi^{3+} + Na^+ + 3\ H_2O) \times 5$$

$$8\ H_2O + 2\ Mn^{2+} \rightarrow 2\ MnO_4^- + 16\ H^+ + 10\ e^-$$
$$10\ e^- + 30\ H^+ + 5\ NaBiO_3 \rightarrow 5\ Bi^{3+} + 5\ Na^+ + 15\ H_2O$$

$$8\ H_2O + 30\ H^+ + 2\ Mn^{2+} + 5\ NaBiO_3 \rightarrow 2\ MnO_4^- + 5\ Bi^{3+} + 5\ Na^+ + 15\ H_2O + 16\ H^+$$

Simplifying :

$$14\ H^+(aq) + 2\ Mn^{2+}(aq) + 5\ NaBiO_3(s) \rightarrow 2\ MnO_4^-(aq) + 5\ Bi^{3+}(aq) + 5\ Na^+(aq) + 7\ H_2O(l)$$

e. $H_3AsO_4 \rightarrow AsH_3$

$$H_3AsO_4 \rightarrow AsH_3 + 4\ H_2O$$
$$8\ e^- + 8\ H^+ + H_3AsO_4 \rightarrow AsH_3 + 4\ H_2O$$

$$(Zn \rightarrow Zn^{2+} + 2\ e^-) \times 4$$

$$8\ e^- + 8\ H^+ + H_3AsO_4 \rightarrow AsH_3 + 4\ H_2O$$
$$4\ Zn \rightarrow 4\ Zn^{2+} + 8\ e^-$$

$$8\ H^+(aq) + H_3AsO_4(aq) + 4\ Zn(s) \rightarrow 4\ Zn^{2+}(aq) + AsH_3(g) + 4\ H_2O(l)$$

66. a. $Cr \rightarrow Cr(OH)_3$

$3\ H_2O + Cr \rightarrow Cr(OH)_3 + 3\ H^+ + 3\ e^-$

$CrO_4^{2-} \rightarrow Cr(OH)_3$

$3\ e^- + 5\ H^+ + CrO_4^{2-} \rightarrow Cr(OH)_3 + H_2O$

$$3\ H_2O + Cr \rightarrow Cr(OH)_3 + 3\ H^+ + 3\ e^-$$
$$3\ e^- + 5\ H^+ + CrO_4^{2-} \rightarrow Cr(OH)_3 + H_2O$$

$$2\ OH^- + 2\ H^+ + 2\ H_2O + Cr + CrO_4^{2-} \rightarrow 2\ Cr(OH)_3 + 2\ OH^-$$

Two OH^- were added above to each side to convert to basic solution. The two OH^- react with the 2 H^+ on the reactant side to produce 2 H_2O. The overall balanced equation is:

$$4\ H_2O(l) + Cr(s) + CrO_4^{2-}(aq) \rightarrow 2\ Cr(OH)_3(s) + 2\ OH^-(aq)$$

b. $S^{2-} \rightarrow S$

$(S^{2-} \rightarrow S + 2\ e^-) \times 5$

$MnO_4^- \rightarrow MnS$

$MnO_4^- + S^{2-} \rightarrow MnS$

$(5\ e^- + 8\ H^+ + MnO_4^- + S^{2-} \rightarrow MnS + 4\ H_2O) \times 2$

Common factor is a transfer of 10 e^-.

$$5\ S^{2-} \rightarrow 5\ S + 10\ e^-$$
$$10\ e^- + 16\ H^+ + 2\ MnO_4^- + 2\ S^{2-} \rightarrow 2\ MnS + 8\ H_2O$$

$$16\ OH^- + 16\ H^+ + 7\ S^{2-} + 2\ MnO_4^- \rightarrow 5\ S + 2\ MnS + 8\ H_2O + 16\ OH^-$$

$$16\ H_2O + 7\ S^{2-} + 2\ MnO_4^- \rightarrow 5\ S + 2\ MnS + 8\ H_2O + 16\ OH^-$$

Reducing gives: $8\ H_2O(l) + 7\ S^{2-}(aq) + 2\ MnO_4^-(aq) \rightarrow 5\ S(s) + 2\ MnS(s) + 16\ OH^-(aq)$

c. $CN^- \rightarrow CNO^-$

$(H_2O + CN^- \rightarrow CNO^- + 2\ H^+ + 2\ e^-) \times 3$

$MnO_4^- \rightarrow MnO_2$

$(3\ e^- + 4\ H^+ + MnO_4^- \rightarrow MnO_2 + 2\ H_2O) \times 2$

Common factor is a transfer of 6 electrons.

$$3\ H_2O + 3\ CN^- \rightarrow 3\ CNO^- + 6\ H^+ + 6\ e^-$$
$$6\ e^- + 8\ H^+ + 2\ MnO_4^- \rightarrow 2\ MnO_2 + 4\ H_2O$$

$$2\ OH^- + 2\ H^+ + 3\ CN^- + 2\ MnO_4^- \rightarrow 3\ CNO^- + 2\ MnO_2 + H_2O + 2\ OH^-$$

Reducing gives:

$$H_2O(l) + 3\ CN^-(aq) + 2\ MnO_4^-(aq) \rightarrow 3\ CNO^-(aq) + 2\ MnO_2(s) + 2\ OH^-(aq)$$