Chapter 3
Chemical Reactions

PRACTICING SKILLS
Balancing Equations

Balancing equations can be a matter of “running in circles” if a reasonable methodology is not employed. While there isn't one “right place” to begin, generally you will suffer fewer complications if you begin the balancing process using a substance that contains the greatest number of elements or the largest subscript values. Noting that you must have at least that many atoms of each element involved, coefficients can be used to increase the 'atomic inventory'. In the next few questions, you will see one emboldened substance in each equation. This emboldened substance is the one that I judge to be a “good” starting place. One last hint--modify the coefficients of uncombined elements, i.e. those not in compounds, after you modify the coefficients for compounds containing those elements -- not before!

1. Balanced equation for combustion of liquid pentane:
\[ \text{C}_5\text{H}_{12} (l) + 8 \text{O}_2 (g) \rightarrow 6 \text{H}_2\text{O} (l) + 5 \text{CO}_2 (g) \]
   1. A minimum of 5 C and 12 H (a C5H12 molecule) suggests coefficients of 5 for CO2 and 6 for H2O.
   2. Coefficients of 6 for H2O and 5 for CO2 will indicate a total of 16 O atoms or 8 molecules of the diatomic element, O2.

3. (a) 4 Cr (s) + 3 O2 (g) \rightarrow 2 \text{Cr}_2\text{O}_3 (s)
   1. Note the need for at least 2 Cr and 3 O atoms.
   2. Oxygen is diatomic -- we’ll need an even number of oxygen atoms, so try : 2 Cr2O3.
   3. 3 O2 would give 6 O atoms on both sides of the equation.
   4. 4 Cr would give 4 Cr atoms on both sides of the equation.

(b) Cu2S (s) + O2 (g) \rightarrow Cu(s) + SO2 (g)
   1. A minimum of 2 O in SO2 is required, and is provided with one molecule of elemental oxygen.
   2. 2 Cu atoms (on the right) indicates 2 Cu (on the left).

(c) C6H5CH3 (l) + 9 O2 (g) \rightarrow 4 H2O (l) + 7 CO2 (g)
   1. A minimum of 7 C and 8 H is required.
   2. 7 CO2 furnishes 7 C and 4 H2O furnishes 8 H atoms.
   3. 4 H2O and 7 CO2 furnish a total of 18 O atoms, making the coefficient of O2 = 9.
5. Balance and name the reactants and products:
   (a) \( \text{Fe}_2\text{O}_3(s) + 3 \text{Mg}(s) \rightarrow 3 \text{MgO}(s) + 2 \text{Fe}(s) \)
   1. Note the need for at least 2 Fe and 3 O atoms.
   2. 2 Fe atoms would provide the proper iron atom inventory.
   3. 3 MgO would give 3 O atoms on both sides of the equation.
   4. 3 Mg would give 3 Mg atoms on both sides of the equation.

   **Reactants:** iron(III) oxide and magnesium
   **Products:** magnesium oxide and iron

(b) \( \text{AlCl}_3(s) + 3 \text{NaOH}(aq) \rightarrow \text{Al(OH)}_3(s) + 3 \text{NaCl}(aq) \)
   1. Note the need for at least 1 Al and 3 Cl atoms.
   2. 3 NaCl molecules would provide the proper Cl atom inventory.
   3. 3 NaCl would require 3 Na atoms on the left side—a coefficient of 3 for NaOH is needed.
   4. 3 OH groups (from Al(OH)\(_3\)) would give 3 OH groups needed on both sides of the equation—so a coefficient of 3 for NaOH is needed to provide that balance.

   **Reactants:** aluminum chloride and sodium hydroxide
   **Products:** aluminum hydroxide and sodium chloride.

(c) \( 2 \text{NaNO}_3(s) + \text{H}_2\text{SO}_4(\text{l}) \rightarrow \text{Na}_2\text{SO}_4(s) + 2 \text{HNO}_3(\text{l}) \)
   1. Note the need for at least 2 Na and 1 S and 4 O atoms.
   2. 2 NaNO\(_3\) will provide the proper Na atom inventory.
   3. The coefficient of 2 in front of NaNO\(_3\) requires a coefficient of 2 for HNO\(_3\)—providing a balance for N atoms.
   4. The implied coefficient of 1 for Na\(_2\)SO\(_4\) suggests a similar coefficient for H\(_2\)SO\(_4\)—to balance the S atom inventory.
   5. O atom inventory is done "automatically" when we balanced N and S inventories.

   **Reactants:** sodium nitrate and sulfuric acid
   **Products:** sodium sulfate and nitric acid
   [...although nitric acid typically exists as an aqueous solution.]

(d) \( \text{NiCO}_3(s) + 2 \text{HNO}_3(\text{aq}) \rightarrow \text{Ni(NO}_3)_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \)
   1. Note the need for at least 1 Ni atom on both sides. This inventory will mandate 2 NO\(_3\) groups on the right—and also on the left. Since these come from HNO\(_3\) molecules, we'll need 2 HNO\(_3\) on the left.
   2. The 2 H from the acid and the CO\(_3\) from nickel carbonate, provide 2H, 1 C and 3 O atoms. 1 H\(_2\)O takes care of the 2H, and one of the O atoms, 1 CO\(_2\) consumes the 1 C and the remaining 2 O atoms.

   **Reactants:** nickel(II) carbonate and nitric acid
   **Products:** nickel(II) nitrate, carbon dioxide, and water
Chemical Equilibrium

7. The greater electrical conductivity of the HCl solution at equilibrium indicates a greater concentration of ions (H$_3$O$^+$ and Cl$^-$), indicating that the HCl solution is more product-favored at equilibrium than the HCO$_2$H solution.

Ions and Molecules in Aqueous Solution

9. What is an electrolyte? What are experimental means for discriminating between weak and strong electrolytes?

An electrolyte is a substance whose aqueous solution conducts an electric current.

As to experimental means for discriminating between weak and strong electrolytes, refer to the apparatus in the Active Figure 5.2. NaCl is a strong electrolyte and would cause the bulb to glow brightly—reflecting a large number of ions in solution while aqueous ammonia or vinegar (an aqueous solution of acetic acid) would cause the bulb to glow only dimly—indicating a smaller number of ions in solution.

11. Predict water solubility:
(a) CuCl$_2$ is expected to be soluble, while CuO and FeCO$_3$ are not. Chlorides are generally water soluble, while oxides and carbonates are not.
(b) AgNO$_3$ is soluble. AgI and Ag$_3$PO$_4$ are not soluble. Nitrate salts are soluble. Phosphate salts are generally insoluble. While halides are generally soluble, those of Ag$^+$ are not.
(c) K$_2$CO$_3$, KI and KMnO$_4$ are soluble. In general, salts of the alkali metals are soluble.

13. Ions produced when the compounds dissolve in water.

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<tr>
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<th>Cation</th>
<th>Anion</th>
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<tr>
<td>(a) KOH</td>
<td>K$^+$</td>
<td>OH$^-$</td>
</tr>
<tr>
<td>(b) K$_2$SO$_4$</td>
<td>2 K$^+$</td>
<td>SO$_4^{2-}$</td>
</tr>
<tr>
<td>(c) LiNO$_3$</td>
<td>Li$^+$</td>
<td>NO$_3^-$</td>
</tr>
<tr>
<td>(d) (NH$_4$)$_2$SO$_4$</td>
<td>2 NH$_4^+$</td>
<td>SO$_4^{2-}$</td>
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15. Compound

<table>
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<th>Cation</th>
<th>Anion</th>
</tr>
</thead>
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<tr>
<td>(a) Na$_2$CO$_3$</td>
<td>yes</td>
<td>2 Na$^+$</td>
<td>CO$_3^{2-}$</td>
</tr>
<tr>
<td>(b) CuSO$_4$</td>
<td>yes</td>
<td>Cu$^{2+}$</td>
<td>SO$_4^{2-}$</td>
</tr>
<tr>
<td>(c) NiS</td>
<td>no</td>
<td>Cu$^{2+}$</td>
<td>SO$_4^{2-}$</td>
</tr>
<tr>
<td>(d) BaBr$_2$</td>
<td>yes</td>
<td>Ba$^{2+}$</td>
<td>2 Br$^-$</td>
</tr>
</tbody>
</table>
Precipitation Reactions and Net Ionic Equations
17. \( \text{CdCl}_2(\text{aq}) + 2 \text{NaOH}(\text{aq}) \rightarrow \text{Cd(OH)}_2(\text{s}) + 2 \text{NaCl}(\text{aq}) \)
   
   Net ionic equation: \( \text{Cd}^{2+}(\text{aq}) + 2 \text{OH}^-(\text{aq}) \rightarrow \text{Cd(OH)}_2(\text{s}) \)

19. Balanced equations for precipitation reactions:
   (a) \( \text{NiCl}_2(\text{aq}) + (\text{NH}_4)_2\text{S}(\text{aq}) \rightarrow \text{NiS}(\text{s}) + 2 \text{NH}_4\text{Cl}(\text{aq}) \)
   
   Net ionic equation: \( \text{Ni}^{2+}(\text{aq}) + \text{S}^{2-}(\text{aq}) \rightarrow \text{NiS}(\text{s}) \)

   (b) \( 3 \text{Mn(NO}_3)_2(\text{aq}) + 2 \text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Mn}_3(\text{PO}_4)_2(\text{s}) + 6 \text{NaNO}_3(\text{aq}) \)
   
   Net ionic equation: \( 3 \text{Mn}^{2+}(\text{aq}) + 2 \text{PO}_4^{3-}(\text{aq}) \rightarrow \text{Mn}_3(\text{PO}_4)_2(\text{s}) \)

Acids and Bases and Their Reactions
21. \( \text{HNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{Ú}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{NO}_3^-(\text{aq}) \)
   
   alternatively: \( \text{HNO}_3(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{NO}_3^-(\text{aq}) \)

23. \( \text{H}_2\text{C}_2\text{O}_4(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{HC}_2\text{O}_4^-(\text{aq}) \)
   
   \( \text{HC}_2\text{O}_4^-(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{C}_2\text{O}_4^{2-}(\text{aq}) \)

25. \( \text{MgO}(\text{s}) + \text{H}_2\text{O}(\text{Ú}) \rightarrow \text{Mg(OH)}_2(\text{s}) \) (metal oxide reacts with water to form a base)

27. Complete and Balance
   (a) \( 2 \text{CH}_3\text{CO}_2\text{H}(\text{aq}) + \text{Mg(OH)}_2(\text{s}) \rightarrow \text{Mg(CH}_3\text{CO}_2)_2(\text{aq}) + 2 \text{H}_2\text{O}(\text{Ú}) \)
   
   acetic magnesiu magnesiu water
   acid hydroxide(base) acetate

   (b) \( \text{HClO}_4(\text{aq}) + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4\text{ClO}_4(\text{aq}) \)
   
   perchloric ammonia ammonium
   acid (base) perchlorate

29. Write and balance the equation for barium hydroxide reacting with nitric acid:
   \( \text{Ba(OH)}_2(\text{s}) + 2 \text{HNO}_3(\text{aq}) \rightarrow \text{Ba(NO}_3)_2(\text{aq}) + 2 \text{H}_2\text{O}(\text{Ú}) \)
   
   barium nitric barium water
   hydroxide acid nitrate

31. Two strong Brønsted acids and one strong Brønsted base:
   Many examples exist: Strong acids: HCl, HBr, HI, HNO\textsubscript{3}
   Strong bases: LiOH, NaOH, KOH
Writing Net Ionic Equations

33. (a) \((\text{NH}_4)_2\text{CO}_3(aq) + \text{Cu(NO}_3)_2(aq) \rightarrow \text{CuCO}_3(s) + 2 \text{NH}_4\text{NO}_3(aq)\)
   (net) \(\text{CO}_3^{2-}(aq) + \text{Cu}^{2+}(aq) \rightarrow \text{CuCO}_3(s)\)

   (b) \(\text{Pb(OH)}_2(s) + 2 \text{HCl}(aq) \rightarrow \text{PbCl}_2(s) + 2 \text{H}_2\text{O}(l)\)
   (net) \(\text{Pb(OH)}_2(s) + 2 \text{H}^+(aq) + 2 \text{Cl}^-(aq) \rightarrow \text{PbCl}_2(s) + 4 \text{H}_2\text{O}(l)\)

   (c) \(\text{BaCO}_3(s) + 2 \text{HCl}(aq) \rightarrow \text{BaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)\)
   (net) \(\text{BaCO}_3(s) + 2 \text{H}^+(aq) \rightarrow \text{Ba}^{2+}(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)\)
   Alternatively: \(\text{BaCO}_3(s) + 2 \text{H}_3\text{O}^+(aq) \rightarrow \text{Ba}^{2+}(aq) + 3 \text{H}_2\text{O}(l) + \text{CO}_2(g)\)

   (d) \(2 \text{CH}_3\text{CO}_2\text{H}(aq) + \text{Ni(OH)}_2(s) \rightarrow \text{Ni(CH}_3\text{CO}_2)_2(aq) + \text{H}_2\text{O}(l)\)
   net: \(2 \text{CH}_3\text{CO}_2\text{H}(aq) + \text{Ni(OH)}_2(s) \rightarrow \text{Ni}^{2+}(aq) + 2 \text{CH}_3\text{CO}_2^-(aq) + 2 \text{H}_2\text{O}(l)\)

35. (a) \(\text{AgNO}_3(aq) + \text{KI}(aq) \rightarrow \text{AgI}(s) + \text{KNO}_3(aq)\)
   (net) \(\text{Ag}^+(aq) + \text{I}^-(aq) \rightarrow \text{AgI}(s)\)

   (b) \(\text{Ba(OH)}_2(aq) + 2 \text{HNO}_3(aq) \rightarrow 2 \text{H}_2\text{O}(l) + \text{Ba(NO}_3)_2(aq)\)
   (net) \(\text{OH}^-(aq) + 2 \text{H}_3\text{O}^+(aq) \rightarrow 2 \text{H}_2\text{O}(l)\)

   (c) \(2 \text{Na}_3\text{PO}_4(aq) + 3 \text{Ni(NO}_3)_2(aq) \rightarrow \text{Ni}_3(\text{PO}_4)_2(s) + 6 \text{NaNO}_3(aq)\)
   (net) \(2 \text{PO}_4^{3-}(aq) + 3 \text{Ni}^{2+}(aq) \rightarrow \text{Ni}_3(\text{PO}_4)_2(s)\)

Gas-Forming Reactions

37. Write and balance the equation for iron(II) carbonate reacting with nitric acid:
   \(\text{FeCO}_3(s) + 2 \text{HNO}_3(aq) \rightarrow \text{Fe(NO}_3)_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)\)
   Iron(II) nitric iron(II) water carbon carbonate acid nitrate dioxide

39. Overall, balanced equation for reaction of \((\text{NH}_4)_2\text{S}\) with \(\text{HBr}\):
   \((\text{NH}_4)_2\text{S} + 2 \text{HBr} \rightarrow \text{H}_2\text{S} + 2 \text{NH}_4\text{Br}\)
   Ammonium Hydrogen Hydrogen Ammonium sulfide bromide sulfide bromide

Oxidation Numbers

41. For questions on oxidation number, read the symbol \(x\) as “the oxidation number of \(x\).”
   (a) \(\text{BrO}_3^-\)
   \((\text{Br}) + 3(\text{O}) = -1\)
   Since oxygen almost always has an oxidation number of -2, we can substitute this value and solve for the oxidation number of Br.
   \((\text{Br}) + 3(-2) = -1\)
   \((\text{Br}) = +5\)
(b) \( \text{C}_2\text{O}_4^{2-} \)

\[
\begin{align*}
2 (\text{C}) + 4 (\text{O}) &= -2 \\
2 (\text{C}) + 4 (-2) &= -2 \\
2 (\text{C}) + 8 &= -2 \\
2 (\text{C}) &= +6 \\
(\text{C}) &= +3
\end{align*}
\]

(c) \( \text{F}^- \)
The oxidation number for any monatomic ion is the charge on the ion. So \( (\text{F}) = -1 \)

(d) \( \text{CaH}_2 \)

\[
\begin{align*}
(\text{Ca}) + 2 (\text{H}) &= 0 \\
(\text{Ca}) + 2 (-1) &= 0 \\
(\text{Ca}) &= +2
\end{align*}
\]

(e) \( \text{H}_4\text{SiO}_4 \)

\[
\begin{align*}
4(\text{H}) + (\text{Si}) + 4(\text{O}) &= 0 \\
4(+1) + (\text{Si}) + 4(-2) &= 0 \\
(\text{Si}) &= +4
\end{align*}
\]

(f) \( \text{HSO}_4^- \)

\[
\begin{align*}
(\text{H}) + (\text{S}) + 4(\text{O}) &= -1 \\
(+1) + (\text{S}) + 4(-2) &= -1 \\
(\text{S}) &= +6
\end{align*}
\]

**Oxidation-Reduction Reactions**

43. (a) Oxidation-Reduction: \( \text{Zn}(s) \) has an oxidation number of 0, while \( \text{Zn}^{2+}(\text{aq}) \) has an oxidation number of +2—hence \( \text{Zn} \) is being oxidized. \( \text{N} \) in \( \text{NO}_3^- \) has an oxidation number of +5, while \( \text{N} \) in \( \text{NO}_2^- \) has an oxidation number of +4—hence \( \text{N} \) is being reduced.

(b) Acid-Base reaction: There is no change in oxidation number for any of the elements in this reaction—hence it is NOT an oxidation-reduction reaction. \( \text{H}_2\text{SO}_4 \) is an acid, and \( \text{Zn(OH)}_2 \) acts as a base.

(c) Oxidation-Reduction: \( \text{Ca}(s) \) has an oxidation number of 0, while \( \text{Ca}^{2+}(\text{aq}) \) has an oxidation number of +2—hence \( \text{Ca} \) is being oxidized. \( \text{H} \) in \( \text{H}_2\text{O} \) has an oxidation number of +1, while \( \text{H} \) in \( \text{H}_2 \) has an oxidation number of 0—hence \( \text{H} \) is being reduced.
45. Determine which reactant is oxidized and which is reduced:
   (a) \( \text{C}_2\text{H}_4(g) + 3 \text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 2 \text{H}_2\text{O}(g) \)

<table>
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<th>after</th>
<th>has experienced</th>
<th>functions as the</th>
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</thead>
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<td>C</td>
<td>-2</td>
<td>+4</td>
<td>oxidation</td>
<td>(C(_2)H(_4)) \text{ reducing agent}</td>
</tr>
<tr>
<td>H</td>
<td>+1</td>
<td>+1</td>
<td>no change</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>0</td>
<td>-2</td>
<td>reduction</td>
<td>(O(_2)) \text{ oxidizing agent}</td>
</tr>
</tbody>
</table>

   (b) \( \text{Si}(s) + 2 \text{Cl}_2(g) \rightarrow \text{SiCl}_4(l) \)

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<td>0</td>
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<td>oxidation</td>
<td>(Si) \text{ reducing agent}</td>
</tr>
<tr>
<td>Cl</td>
<td>0</td>
<td>-1</td>
<td>reduction</td>
<td>(Cl(_2)) \text{ oxidizing agent}</td>
</tr>
</tbody>
</table>

Types of Reactions in Aqueous Solution

47. Precipitation (PR), Acid-Base (AB), or Gas-Forming (GF)
   (a) \( \text{Ba(OH)}_2(s) + 2 \text{HCl(aq)} \rightarrow \text{BaCl}_2(\text{aq}) + 2 \text{H}_2\text{O}(l) \)  \text{ AB} 
   (b) \( 2 \text{HNO}_3(\text{aq}) + \text{CoCO}_3(s) \rightarrow \text{Co(NO}_3)_2(\text{aq}) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \)  \text{ GF} 
   (c) \( 2 \text{Na}_3\text{PO}_4(\text{aq}) + 3 \text{Cu(NO}_3)_2(\text{aq}) \rightarrow \text{Cu}_3(\text{PO}_4)_2(s) + 6 \text{NaNO}_3(\text{aq}) \)  \text{ PR} 

49. Precipitation (PR), Acid-Base (AB), or Gas-Forming (GF)
   (a) \( \text{MnCl}_2(\text{aq}) + \text{Na}_2\text{S(aq)} \rightarrow \text{MnS(s)} + 2 \text{NaCl(aq)} \)  \text{ PR} 
   (net) \( \text{Mn}^{2+}(\text{aq}) + \text{S}^{2-}(\text{aq}) \rightarrow \text{MnS(s)} \) 
   (b) \( \text{K}_2\text{CO}_3(\text{aq}) + \text{ZnCl}_2(\text{aq}) \rightarrow \text{ZnCO}_3(s) + 2 \text{KCl(aq)} \)  \text{ PR} 
   (net) \( \text{CO}_3^{2-}(\text{aq}) + \text{Zn}^{2+}(\text{aq}) \rightarrow \text{ZnCO}_3(s) \) 

51. Balance the following and classify them as PR, AB, GF, or OR:
   (a) \( \text{CuCl}_2(\text{aq}) + \text{H}_2\text{S(aq)} \rightarrow \text{CuS(s)} + 2 \text{HCl(aq)} \)  \text{ PR} 
   (b) \( \text{H}_3\text{PO}_4(\text{aq}) + 3 \text{KOH(aq)} \rightarrow 3 \text{H}_2\text{O(l)} + \text{K}_3\text{PO}_4(\text{aq}) \)  \text{ AB} 
   (c) \( \text{Ca(s)} + 2 \text{HBr(aq)} \rightarrow \text{H}_2(\text{g}) + \text{CaBr}_2(\text{aq}) \)  \text{ OR} 
   (d) \( \text{MgCl}_2(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow 3 \text{Mg(OH)}_2(s) + 2 \text{HCl(aq)} \)  \text{ PR} 

GENERAL QUESTIONS

53. Balance:
   (a) Synthesis of urea:
      \( \text{CO}_2(\text{g}) + 2 \text{NH}_3(\text{g}) \rightarrow \text{CO(NH}_2)_2(s) + \text{H}_2\text{O(l)} \)
      1. Note the need for two \text{NH}_3 in each molecule of urea, so multiply \text{NH}_3 by 2.
      2. \( 2 \text{NH}_3 \) provides the two \text{H} atoms for a molecule of \text{H}_2\text{O}.
      3. Each \text{CO}_2 provides the \text{O} atom for a molecule of \text{H}_2\text{O}.
Chapter 3

Chemical Reactions

(b) synthesis of uranium(VI) fluoride

\[ \text{UO}_2(\text{s}) + 4 \text{HF}(\text{aq}) \rightarrow \text{UF}_4(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \]
\[ \text{UF}_4(\text{s}) + \text{F}_2(\text{g}) \rightarrow \text{UF}_6(\text{s}) \]
1. The 4 F atoms in UF₄ requires 4 F atoms from HF. \hspace{1cm} \text{(equation 1)}
2. The H atoms in HF produce 2 molecules of H₂O. \hspace{1cm} \text{(equation 1)}
3. The 1:1 stoichiometry of UF₆ : UF₄ provides a simple balance. \hspace{1cm} \text{(equation 2)}

(c) synthesis of titanium metal from TiO₂:

\[ \text{TiO}_2(\text{s}) + 2 \text{Cl}_2(\text{g}) + 2 \text{C}(\text{s}) \rightarrow \text{TiCl}_4(\text{l}) + 2 \text{CO}(\text{g}) \]
\[ \text{TiCl}_4(\text{l}) + 2 \text{Mg}(\text{s}) \rightarrow \text{Ti}(\text{s}) + 2 \text{MgCl}_2(\text{s}) \]
1. The O balance mandates 2 CO for each TiO₂. \hspace{1cm} \text{(equation 1)}
2. A coefficient of 2 for C provides C balance. \hspace{1cm} \text{(equation 1)}
3. The Ti balance (TiO₂ : TiCl₄) requires 4 Cl atoms, hence 2 Cl₂ \hspace{1cm} \text{(equation 1)}
4. The Cl balance requires 2 MgCl₂, hence 2 Mg. \hspace{1cm} \text{(equation 2)}

55. Formula for the following compounds:

(a) soluble compound with Br⁻ ion: almost any bromide compound with the exception of Ag⁺, Hg₂²⁺ and Pb²⁺

(b) insoluble hydroxide: almost any hydroxide except salts of NH₄⁺ and the alkali metal ions

(c) insoluble carbonate: almost any carbonate except salts of NH₄⁺ and the alkali metal ions

(d) soluble nitrate-containing compound: all nitrate-containing compounds are soluble

The listing of soluble and insoluble compounds in your text will provide general guidelines for predicting the solubility of compounds.

(e) a weak Bronsted acid: the carboxylic acids are weak acids: CH₃CO₂H (acetic)

57. For the following copper salts:

Water soluble: Cu(NO₃)₂, CuCl₂ — nitrates and chlorides are soluble

Water insoluble: CuCO₃, Cu₃(PO₄)₂ — carbonates and phosphates are insoluble

59. **Spectator ions** in the following equation and the net ionic equation:

\[ 2 \text{H}_3\text{O}^+(\text{aq}) + 2 \text{NO}_3^-(\text{aq}) + \text{Mg(OH)}_2(\text{s}) \rightarrow 4 \text{H}_2\text{O}(\text{l}) + \text{Mg}^{2+}(\text{aq}) + 2 \text{NO}_3^-(\text{aq}) \]

The emboldened nitrate ions are the spectator ions. The net ionic equation would be the first equation shown above without the spectator ions:

\[ 2 \text{H}_3\text{O}^+(\text{aq}) + \text{Mg(OH)}_2(\text{s}) \rightarrow 4 \text{H}_2\text{O}(\text{l}) + \text{Mg}^{2+}(\text{aq}) \hspace{1cm} \text{[An acid-base exchange]} \]
61. For the reaction of chlorine with NaBr: \( \text{Cl}_2(g) + 2 \text{NaBr}(aq) \rightarrow 2 \text{NaCl}(aq) + \text{Br}_2(l) \)
   (a) Oxidized: **bromine’s** oxidation number is changed from -1 to 0
   Reduced: **chlorine’s** oxidation number is changed from 0 to -1
   (b) Oxidizing agent: **Cl}_2 removes the electrons from NaBr
   Reducing agent: **NaBr provides the electrons to the chlorine.

63. Reaction: \( \text{MgCO}_3(s) + 2 \text{HCl}(aq) \rightarrow \text{CO}_2(g) + \text{MgCl}_2(aq) + \text{H}_2\text{O}(l) \)
   (a) The net ionic equation: \( \text{MgCO}_3(s) + 2 \text{H}^+(aq) \rightarrow \text{CO}_2(g) + \text{Mg}^{2+}(aq) + 3 \text{H}_2\text{O}(l) \)
   The spectator ion is the chloride ion (Cl\(^{-}\)).
   (b) The production of \( \text{CO}_2(g) \) characterizes this as a gas-forming reaction.

65. Species present in aqueous solutions of:
<table>
<thead>
<tr>
<th>compound</th>
<th>types of species</th>
<th>species present</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) ( \text{NH}_3 )</td>
<td>molecules (weak base)</td>
<td>( \text{NH}_3, \text{NH}_4^+, \text{OH}^- )</td>
</tr>
<tr>
<td>(b) ( \text{CH}_3\text{CO}_2\text{H} )</td>
<td>molecules (weak acid)</td>
<td>( \text{CH}_3\text{CO}_2\text{H}, \text{CH}_3\text{CO}_2^-\text{H}^+ )</td>
</tr>
<tr>
<td>(c) ( \text{NaOH} )</td>
<td>ions (strong base)</td>
<td>( \text{Na}^+, \text{OH}^- )</td>
</tr>
<tr>
<td>(d) ( \text{HBr} )</td>
<td>ions (strong acid)</td>
<td>( \text{H}_3\text{O}^+, \text{Br}^- )</td>
</tr>
</tbody>
</table>
   In every case, \( \text{H}_2\text{O} \) will be present (but omitted in this list)

67. Balance and classify each as PR, AB, GF
   (a) \( \text{K}_2\text{CO}_3(aq) + 2 \text{HClO}_4(aq) \rightarrow 2 \text{KClO}_4(aq) + \text{CO}_2(g) + 2 \text{H}_2\text{O}(l) \) **GF**
   (b) \( \text{FeCl}_2(aq) + (\text{NH}_4)_2\text{S}(aq) \rightarrow \text{FeS(s)} + 2 \text{NH}_4\text{Cl}(aq) \) **PR**
   (c) \( \text{Fe(NO}_3)_2(aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow \text{FeCO}_3(s) + 2 \text{NaNO}_3(aq) \) **PR**
   (d) \( 3 \text{NaOH}(aq) + \text{FeCl}_3(aq) \rightarrow 3 \text{NaCl}(aq) + \text{Fe(OH)}_3(s) \) **PR**

**IN THE LABORATORY**

69. For the reaction:
   \( 2 \text{NaI(s)} + 2 \text{H}_2\text{SO}_4(aq) + \text{MnO}_2(s) \rightarrow \text{Na}_2\text{SO}_4(aq) + \text{MnSO}_4(aq) + \text{I}_2(g) + 2 \text{H}_2\text{O}(l) \)
   (a) Oxidation number of each atom in the equation: (ox.numbers shown in order)
   Reactants: \( \text{NaI} (+1,-1) \) \( \text{H}_2\text{SO}_4 (+1,+6,-2) \) \( \text{MnO}_2 (+4,-2) \)
   Products: \( \text{Na}_2\text{SO}_4 (+1,+6,-2) \) \( \text{MnSO}_4 (+2,+6,-2) \) \( \text{I}_2(0) \) \( \text{H}_2\text{O}(+1,-2) \)
   (b) Oxidizing agent: \( \text{MnO}_2 \) Oxidized: I in \( \text{NaI} \)
   Reducing agent: \( \text{NaI} \) Reduced: Mn (in \( \text{MnO}_2 \))
   (c) The formation of gaseous iodine “drives” the process – product-favored
(d) Names of reactants and products:

<table>
<thead>
<tr>
<th></th>
<th>NaI</th>
<th>H₂SO₄</th>
<th>MnO₂</th>
<th>Na₂SO₄</th>
<th>MnSO₄</th>
<th>I₂</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sodium iodide</td>
<td>sulfuric acid</td>
<td>manganese(IV) oxide</td>
<td>sodium sulfate</td>
<td>manganese(II) sulfate</td>
<td>iodine</td>
<td>water</td>
</tr>
</tbody>
</table>