Chemical Reactions

Chapter 4

Interpreting a Chemical Equation:

- A chemical equation describes a chemical reaction much like a sentence describes some action.
  - Element Symbols - Letters
  - Formulas - Words
  - Equations - Sentences
- *Consider the following chemical reaction:*

$$2\ Na_{(s)} + 2\ H_2O_{(l)} \rightarrow 2\ NaOH_{(aq)} + H_{2(g)}$$

Sentence form:

Sodium metal reacts with water to form aqueous sodium hydroxide and hydrogen gas.

Symbols in Chemical Reactions

(s) = Solid

(l) = Liquid

(g) = Gas

(aq) = Aqueous (dissolved in water)

+ = "and"

$\longrightarrow$ = "reacts to form" or "yields"

$\xrightarrow{\Delta}$ = Heat added

$\xrightarrow{Pt}$ = Catalyst (in this example, platinum)

Balancing Chemical Equations

- Balancing chemical equations is an application of both the **Modern Atomic Theory** and the **Law of Conservation of Matter.**
- The number of one kind of atom on the reactants side must be equal to the number of the same kind of atom on the product side.

<u>Types of Reactions</u>

Reactions of Ionic compounds:

Double Replacement Reactions

- A double replacement reaction is a reaction in which two ***ionic*** compounds react to form two new compounds by simply trading cations.
- Also known as a *metathesis* reaction.
- In order for a double replacement reaction to actually occur, one of the products must **NOT** be aqueous – a driving force.

Double Replacement Reactions: Precipitation

- Usually, one of the products of a metathesis reaction is a precipitate (solid that falls out of solution).
- A precipitate will form if the ions in solution can combine to make a compound that is not soluble in water.
- Use the solubility chart to determine if one of the possible products is not soluble in water.

Double Replacement Reactions: Precipitation

Solubility Chart

Anions	Soluble (aq)	Precipitate (s)
nitrate	Most cations	No common cations
acetate	Most cations	Ag^+
fluoride chloride bromide iodide	Most cations	Ag^+, $Pb^{2+,4+}$, Hg_2^{2+}, Tl^+
sulfate	Most cations	Ba^{2+}, Sr^{2+}, $Pb^{2+,4+}$, Ag^+, Ca^{2+}
chromate	Most cations	Ba^{2+}, Sr^{2+}, $Pb^{2+,4+}$, Ag^+
sulfide hydroxide oxide	NH_4^+ & Cations of columns 1 and 2	Most other cations
carbonate phosphate	NH_4^+ & Cations of column 1 except Li^+	Most other cations

A closer look at a precipitation reaction:

Consider the DR reaction of calcium chloride and silver nitrate.

- When dissolved in water, aqueous ionic compounds are generally dissociated and solvated by the water molecules.
- Calcium chloride dissolved in water:

$$CaCl_{2(aq)} \rightarrow Ca^{2+}_{(aq)} + 2\ Cl^-_{(aq)}$$

- Silver nitrate dissolved in water:

$$AgNO_{3(aq)} \rightarrow Ag^+_{(aq)} + NO_3^-{}_{(aq)}$$

Ways of writing the reaction as an equation:

- **Molecular Equation:** A chemical equation that includes the complete, molecular formulas for all compounds in a chemical reaction.
- **Ionic Equation:** A chemical equation in which aqueous, ionic compounds are written as free ions in solution.
- **Net Ionic Equation:** A chemical equation in which only the species (ions, atoms, molecules) involved in the reaction are written. *Spectator ions* are cancelled.

Reaction of $CaCl_2$ with $AgNO_3$:

- Molecular:

$$CaCl_{2(aq)} + 2\ AgNO_{3(aq)} \rightarrow Ca(NO_3)_{2(aq)} + 2\ AgCl_{(s)}$$

- Ionic:

$$Ca^{+2}_{(aq)} + 2\ Cl^-_{(aq)} + 2\ Ag^+_{(aq)} + 2\ NO_3^-{}_{(aq)} \rightarrow$$

$$Ca^{+2}_{(aq)} + 2\ NO_3^-{}_{(aq)} + 2\ AgCl_{(s)}$$

- Net Ionic:

$$2\ Ag^+_{(aq)} + 2\ Cl^-_{(aq)} \rightarrow 2\ AgCl_{(s)}$$

$$Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$$

Writing Net Ionic Equations

- The net ionic equations shows only the species involved in a chemical change.
- Ca^{2+} and NO_3^- are **spectator ions**. They do not participate in the reaction.
- When both of the possible ionic products of a double replacement reaction are soluble in water, no reaction occurs, because all of the ions stay in solution.
- *Consider the mixing of a solution of sodium chloride and potassium bromide.*

Double Replacement Reactions: Acid – Base Neutralization

- An acid and a base will react to form a salt and water.

Double Replacement Reactions: Formation of a gas

- In some cases the double replacement reaction is followed by a decomposition reaction that forms a gas.

Oxidation – Reduction Reactions (REDOX)

- *Oxidation-reduction reactions* involve a transfer of electrons from one element to another.
- *Oxidation numbers (oxidation states)* are a way of keeping track of the electrons in a redox reaction.
- In a monatomic ion, the oxidation number is equal to the charge on the atom.
- In compounds and polyatomic ions, oxidation numbers assign electrons that are being shared in a bond to the more *electronegative* atom – the one that has a greater pull on the electron.

Oxidation – Reduction Reactions (cont.)

- *Oxidation* is the loss of electrons.
- *Reduction* is the gain of electrons.
- The *oxidizing agent* is the *species* (element or compound or ion) that is doing the oxidizing. In a redox reaction, the oxidizing agent is the species that is reduced.
- The *reducing agent* is the species that is doing the reducing. In a redox reaction, the reducing agent is the species that is oxidized.

Oxidation – Reduction Reactions (cont.)

- Many oxidation reactions are very easy to analyze and can be balanced by inspection.
- The simple oxidation reactions often fit conveniently into the following common categories:
  1) Synthesis
  2) Decomposition
  3) Single replacement
  4) Combustion
- Other redox reactions are more complex, do not fit these categories, and require more complex analysis to balance.

Synthesis (combination)

- A synthesis reaction occurs when two or more substances combine chemically to form a single compound.
- Consider the following three synthesis reactions:

1) $2\ Mg_{(s)} + O_{2(g)} \rightarrow 2\ MgO_{(s)}$

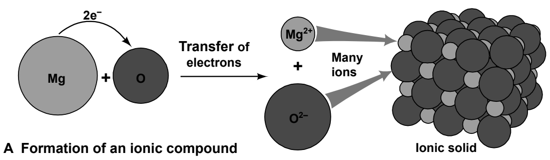
(for the following, predict the products and balance the equations)

2) $\_\_\ H_{2(g)} + \_\_\ Cl_{2(g)} \rightarrow$

4) $\_\_\ K_{(s)} + \_\_\ Cl_{2(g)} \rightarrow$

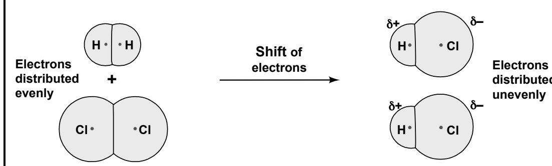
The redox process in compound formation

$$2\ Mg_{(s)} + O_{2(g)} \rightarrow 2\ MgO_{(s)}$$



The redox process in compound formation

Reaction of hydrogen and chlorine



Formation of a covalent compound

Decomposition Reactions

- A decomposition reaction is a reaction in which one compound breaks down into two or more substances.

Decomposition into elements:

- Thermal Decomposition:

$$2\ HgO_{(s)} \xrightarrow{\Delta} 2\ Hg_{(l)} + O_{2(g)}$$

- Electrolytic Decomposition: electrical energy drives the oxidation-reduction reactions

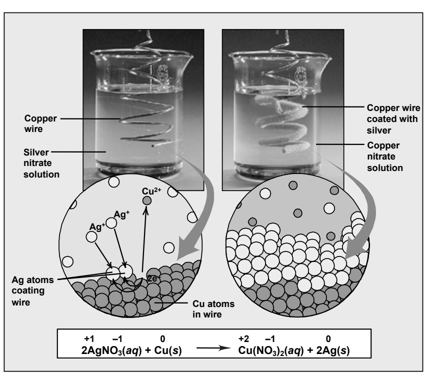
Predict products & balance:

$$\_\_\ KCl_{(l)} \xrightarrow{\text{electrolysis}}$$

Single Replacement Reactions

- A single replacement reaction is a reaction in which one element replaces another element in a compound.
- Consider the reaction that occurs when a copper wire is placed into a solution containing copper nitrate.

$$Cu_{(s)} + 2\ AgNO_{3(aq)} \rightarrow 2\ Ag_{(s)} + Cu(NO_3)_{2(aq)}$$



Single Replacement Reactions

- Not all possible single replacement reactions will occur.
- It depends on the reactivity of the element that is trying to displace the element in the compound.
- In order for a single replacement reaction to take place, the free element that is replacing the element in the compound must be higher in the activity series.

Metals

MOST Reactive

Lithium (Li)
Potassium (K)
Barium (Ba)
Calcium (Ca)
Sodium (Na)
Magnesium (Mg)
Aluminum (Al)
Manganese (Mn → Mn^{2+})
Zinc (Zn)
Chromium (Cr → Cr^{3+})
Iron (Fe → Fe^{2+})
Cadmium (Cd)
Cobalt (Co → Co^{2+})
Nickel (Ni → Ni^{2+})
Tin (Sn → Sn^{2+})
Lead (Pb → Pb^{2+})
Hydrogen (H_2)
Copper (Cu → Cu^{2+})
Silver (Ag)
Mercury (Hg → Hg^{+})
Platinum (Pt → Pt^{2+})
Gold (Au → Au^{3+})

LEAST Reactive

Reactivity Series

Nonmetals

MOST Reactive

Fluorine (F_2)
Oxygen (O_2)
Chlorine (Cl_2)
Bromine (Br_2)
Iodine (I_2)

LEAST Reactive

Note:
All reactivities are for the most common ion formed.In the cases of elements that can form more than one ion, the ion indicated is the most common ion.

Single Replacement Reactions

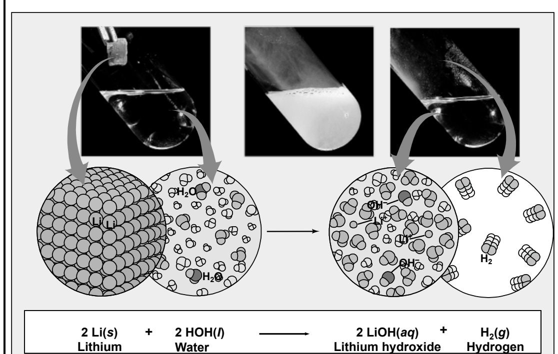
- *Predict whether or not the following reactions will occur:* (Refer to the reactivity series.)
- SR and net ionic equations: *Write the molecular, ionic, and net ionic equations for the reaction of magnesium metal with hydrochloric acid.*

Single Replacement Reactions

- When water reacts with a reactive metal, treat it as an H^+ ion and an OH^- to predict its reactivity.
- Predict the products for and balance the following chemical reaction:

__ $Li_{(s)}$ + __ $HOH_{(l)}$ →

Reaction of lithium with water



Combustion Reactions of Hydrocarbons & Carbohydrates

- In a complete combustion reaction of a compound containing C and H, or C, H, and O, the compound is burned in oxygen gas.
- The products of a complete combustion of a hydrocarbon are carbon dioxide and water.
- ***Special balancing rule for combustion:*** Balance Carbon first, Hydrogen second, and Oxygen last. CHECK.

Combustion Reactions of Hydrocarbons & Carbohydrates

Steps in writing a
Complete, Balanced Chemical Equation:

- ***Step 1:***
  Write the correct formula for the ***reactants*** with ***state symbols.***
- ***Step 2:***
  Determine the ***type*** of reaction that would likely occur.
- ***Step 3:***
  Predict what ***products*** would form if a reaction occurs.
  - If a *double replacement reaction*, use the solubility chart to see if a solid will form. (Unless acid-base, in which case water is the driving force of the reaction.)
  - If a *single replacement reaction*, use the activity chart to see if a reaction will occur.

Steps in writing a
Complete, Balanced Chemical Equation:

- *Step 4:*
  Write correct ***formulas*** for the products based on charges (if ionic).
- *Step 5:*
  Determine the correct ***states*** for the products.
- *Step 6:*
  Balance the equation.

Determining the TYPE of Reaction

- If the reaction has two elements as reactants, then it is likely a SYNTHESIS reaction.
- If one reactant only, then the reaction is likely a DECOMPOSITION reaction.
- If one reactant is an ionic compound and the other reactant is an element, then the reaction is likely a SINGLE REPLACEMENT reaction.
- If both reactants are ionic compounds, then the reaction is likely a DOUBLE REPLACEMENT reaction.
- If one reactant is a hydrocarbon (C,H) or carbohydrate (CHO), and O_2 gas is available, then the reaction is likely a COMBUSTION reaction.

Predicting States of Matter

Elements

- Mercury (Hg) and Bromine (Br_2) are the only elemental LIQUIDS at STP (standard temperature and pressure).
- All Metals (except Hg) and metalloids are SOLIDS in their elemental states at STP.
- C, P, S, Se, and I_2 are SOLID non-metals at STP.
- The other non-metals are GASES in their elemental forms at STP.

Ionic Compounds

- Ionic compounds are generally SOLIDS at room temperature if there is no water around.
- If water is available:
  - Ionic compounds that are soluble in water will be AQUEOUS.
  - Ionic compounds that are ***not*** soluble in water will be SOLIDS.
- In electrolytic decomposition reactions, ionic compounds must be melted (LIQUIDS).

Other Compounds

- Acids will be aqueous.
- Non-metal oxides (*e.g.* CO_2, SO_3) are generally gases at STP.
- Water is a liquid.
  (Unless at high temperature, as in a combustion, where it is generally a gas).