Chapter 7
Chemical Reactions

Chemical Reactions

- Reactions involve chemical changes in matter resulting in new substances.
- Reactions involve rearrangement and exchange of atoms to produce new molecules.

Combustion Reactions

- **Combustion reactions**
  - Reactions in which is consumed by combining with another substance.
  - Always release heat and/or other forms of energy.
  - Produce one or more oxygen-containing compounds.
- Combustion reactions are a subclass of **oxidation–reduction** reactions.

Precipitation Reactions

- **Precipitation reactions**
  - Some reactions involve the combining of ions resulting in formation of a material that is insoluble in water.
    - Formation of soap scum.
  - Usually, reactants are dissolved in water to allow the ions to move more freely.

Evidence of Chemical Reactions

- Visual clues (permanent).
- Other clues.

Practice—Decide Whether Each of the Following Involve a Chemical Reaction.

- Photosynthesis
- Heating sugar until it turns black
- Heating ice until it turns liquid
- Digestion of food
- Dissolving sugar in water
- Burning of alcohol in a flambé dessert.

Chemical Equations

- Short-hand way of describing a reaction.
- Provides information about the reaction.

Conservation of Mass

- Matter cannot be created or destroyed.
  - Therefore, the cannot change.
  - And will be
- In a chemical reaction, present at the beginning are still present at the end.

The Combustion of Methane

- Methane gas burns to produce carbon dioxide gas and gaseous water.
  - Whenever something burns it combines with $O_2(g)$.
  - Conservation of mass:
    - Neither create nor destroy mass

Combustion of Methane, Balanced

- To show the reaction obeys the Law of Conservation of Mass the equation must be **balanced**.
  - We adjust the numbers of molecules so there are equal numbers of atoms of each element on both sides of the arrow.

$$CH_4(g) + \mathbf{2}\ O_2(g) \rightarrow CO_2(g) + \mathbf{2}\ H_2O(g)$$

Chemical Equations

- Chemical equations are concise representations of chemical reactions.

$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$

Symbols Used in Equations

- Symbols used to indicate state after chemical.

- Energy symbols used above the arrow for decomposition reactions.
  - Δ = heat.
  - $h\nu$ = light.
  - shock = mechanical.
  - elec = electrical.

Writing Balanced Chemical Equations

1. Write a skeletal equation by writing the formula of each reactant and product.
2. Count the number of atoms of each element on each side of the equation.
   - Polyatomic ions may often be counted as if they are one ‘‘element’’.
3. Pick an element to balance.
   - If an element is found in only one compound on both sides, balance it first.
     - Metals before nonmetals.
   - Leave elements that are free elements somewhere in the equation until last.
     - Balance free elements by adjusting the coefficient where it is a free element.

Writing Balanced Chemical Equations, Continued

4. Find the least common multiple (LCM) of the number of atoms on each side.
   - The LCM of 3 and 2 is 6.
5. Multiply each count by a factor to make it equal to the LCM.
6. Use this factor as a coefficient in the equation.
   - If there is already a coefficient there, multiply it by the factor.
   - It must go in front of entire molecules, not between atoms within a molecule.
7. Recount and repeat until balanced.

Writing Balanced Chemical Equations

1.

2.

3.

4.

Example

1. Write a skeletal equation.
2. Set the coefficient of the ***most complicated*** *compound to* **"1".**
3. Pick an element in the balanced molecule which is found once on the other side of the equation.
4. Multiple a whole number.

- When magnesium metal burns in air, it produces a white, powdery compound magnesium oxide.

Another Example

1. Write a skeletal equation.
2. Set the coefficient of the ***most complicated*** *compound to* **"1".**
3. Pick an element in the balanced molecule which is found once on the other side of the equation.
4. Multiple a whole number.

- Under appropriate conditions at 1000 ° C, ammonia gas reacts with oxygen gas to produce gaseous nitrogen monoxide and steam

Practice

1. Write a skeletal equation.
2. Set the coefficient of the ***most complicated*** *compound to* **"1".**
3. Pick an element in the balanced molecule which is found once on the other side of the equation.
4. Multiple a whole number.

- Acetic acid reacts with the metal aluminum to make aqueous aluminum acetate and gaseous hydrogen.
- Combustion of ethyl alcohol (C_2H_5OH).
- Combustion of liquid butane (C_4H_{10}) in a lighter

Aqueous Solutions

- Many times, the chemicals we are reacting together are dissolved in water.
  - Mixtures of a chemical dissolved in water are called **aqueous solutions**.
- Dissolving the chemicals in water helps them to react together faster.
  - The water separates the chemicals into individual molecules or ions.
  - The separate, free-floating particles come in contact more frequently so the reaction speeds up.

Predicting Whether a Reaction Will Occur in Aqueous Solution

- "Forces" that drive a reaction:
  - Formation of
  - Formation of
  - Formation of
  - Transfer of
- When chemicals (dissolved in water) are mixed and one of the above-noted forces occur, the reaction will generally happen.

Dissociation

- **Dissociation**
  - Ionic compounds and some molecular compounds dissolve in water, the anions and cations are separated from each other.
- When compounds containing **polyatomic ions dissociate**, the polyatomic group stays together as one ion.

Dissociation, Continued

- Potassium iodide dissociates in water into potassium cations and iodide anions.
- Copper(II) sulfate dissociates in water into copper(II) cations and sulfate anions.

Dissociation, Continued

- Potassium sulfate dissociates in water into potassium cations and sulfate anions.

Electrolytes

- **Electrolytes**
  - Substances whose water solution is a conductor of electricity.
- All electrolytes have ions dissolved in water.

Electrolytes, Continued

- **Strong** electrolytes,
- **Non**electrolytes,
- **Weak** electrolytes,
  -

Types of Electrolytes

- **Salts**
- **Acids**
- **Bases**

When Will a Salt Dissolve?

- A compound is **soluble** in a liquid if it dissolves in that liquid.
- A compound is **insoluble** if a significant amount does not dissolve in that liquid.

When Will a Salt Dissolve?, Continued

- Predicting whether a compound will dissolve in water is not easy.
- The best way to do it is to do some experiments to test whether a compound will dissolve in water, then develop some rules based on those experimental results.

Solubility Rules:
Compounds that Are Generally Soluble in Water

Compounds containing the following ions are generally soluble	Exceptions (when combined with ions on the left the compound is insoluble)

Solubility Rules:
Compounds that Are Generally Insoluble

Compounds containing the following ions are generally insoluble	Exceptions (when combined with ions on the left the compound is soluble or slightly soluble)

Solubility Table

Ion	General Solubility Rule
NO_3^-	All nitrates are soluble
$C_2H_3O_2^-$	All acetates are soluble ($AgC_2H_3O_2$ only moderately)
Cl^-, Br^-, I^-	All chlorides, bromides and iodides are soluble except Ag^+, Pb^{2+} and Hg_2^{2+}. ($PbCl_2$ is slightly soluble in cold water and moderatel soluble in hot water.)
SO_4^{2-}	All sulfates are soluble except those of Ba^{2+}, Pb^{2+}, Ca^{2+} and Sr^{2+}
CO_3^{2-} and PO_4^{3-}	All carbonates and phosphates are insoluble except those of Na^+, K^+ and NH_4^+. (Many acid phosphates are soluble).
OH^-	All hydroxides are insoluble except those of Na^+ and K^+. Hydroxides of Ba^{2+} and Ca^{2+} are slightly soluble.
S^{2-}	All sulfides are insoluble except those of Na^+, K^+, NH_4^+ and those of the alkaline earths: Mg^{2+}, Ca^{2+}, Sr^{2+} and Ba^{2+}. (Sulfides of Al^{3+} and Cr^{3+} hydrolyze and precipiate as the corresponding hydroxides.
Na^+, K^+ and NH_4^+	All salts of sodium ion, potassium ion and ammonium ion are soluble except several uncommon ones.

Determine if Each of the Following Is Soluble in Water

- KOH
- AgBr
- $CaCl_2$
- $Pb(NO_3)_2$
- $PbSO_4$

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Na^+, K^+ and NH_4^+	All salts of sodium ion, potassium ion and ammonium ion are soluble except several uncommon ones.

Precipitation Reactions

$KI(aq) + Pb(NO_3)_2(aq)$

No Precipitate Formation = No Reaction

- $KI(aq) + NaCl(aq) \rightarrow$

Process for Predicting the Products of a Precipitation Reaction

1. Write the formula for the reactants and Determine what ions each aqueous reactant has.
2. Exchange ions.
   - (+) ion from one reactant with (-) ion from the other.
3. Balance charges of combined ions to get formula of each product.
4. Balance the equation.
   - Count atoms.
5. Determine solubility of each product in water.
   - Use the solubility rules.
   - If product is insoluble or slightly soluble, it will precipitate.
   - If neither product will precipitate, **no reaction.**

Example

- When an Aqueous Solution of Sodium Carbonate Is Added to an Aqueous Solution of Copper(II) Chloride, a White Solid Forms.

Practice–Predict the Products and Balance the Equation

- $KCl(aq) + AgNO_3(aq) \rightarrow$

- $Na_2S(aq) + CaCl_2(aq) \rightarrow$

Practice

- Write an Equation for the Reaction that Takes Place when an Aqueous Solution of $(NH_4)_2SO_4$ is Mixed with an Aqueous Solution of $Pb(C_2H_3O_2)_2$.

Ionic Equations

- **Molecular equations**
- **Complete ionic equations**

Writing Complete Ionic Equations

- Rewrite the molecular equation, but dissociate strong electrolytes into individual ions.
  - Strong electrolytes must be aqueous.
    - Solids, liquids, or gases cannot be electrolytes.
  - All soluble ionic compounds are strong electrolytes.
  - Strong acids are strong electrolytes.
    - HCl, HNO_3, H_2SO_4.
    - Weak acids are not written in the dissociated ion form.
  - Molecular compounds do not have ions, leave in the molecular form.

Ionic Equations

- **Spectator ions**
  - Ions are both reactants and products**.**
- An ionic equation in which the spectator ions are removed is called a **net ionic equation**.

Writing Net Ionic Equations

- First, identify the spectator ions in the complete ionic equation.
  - Identical ions on both sides of the equation.
- Cancel out the spectator ions—the result is the net ionic equation.

Summary

- A **molecular equation** is a chemical equation showing the complete, neutral formulas for every compound in a reaction.
- A **complete ionic equation** is a chemical equation showing all of the species as they are actually present in solution.
- A **net ionic equation** is an equation showing only the species that actually participate in the reaction.

Practice–Write the Ionic and Net Ionic Equation.

$K_2SO_4(aq) + Ba(NO_3)_2(aq) \rightarrow 2\ KNO_3(aq) + BaSO_4(s)$

$Na_2CO_3(aq) + 2\ HCl(aq) \rightarrow 2\ NaCl(aq) + CO_2(g) + H_2O(l)$

Properties of Acids

- Sour taste.
- Change color of vegetable dyes.
- React with "active" metals, not noble metals.

- Corrosive.
- React with
  - .
- React with

Common Acids

Chemical name	Formula	Old name	Strength
Nitric acid	HNO_3	Aqua fortis	Strong
Sulfuric acid	H_2SO_4	Vitriolic acid	Strong
Hydrochloric acid	HCl	Muriatic acid	Strong
Phosphoric acid	H_3PO_4		Moderate
Chloric acid	$HClO_3$		Moderate
Acetic acid	$HC_2H_3O_2$	Vinegar	Weak
Hydrofluoric acid	HF		Weak
Carbonic acid	H_2CO_3	Soda water	Weak
Boric acid	H_3BO_3		Weak

Properties of Bases

- A.k.a. alkalis.
- Taste bitter.
- Feel slippery.
- Change color of vegetable dyes.
  - Different color than acid.
  - Litmus = blue.
- React with
  - And often water.
  - **Neutralization.**

Common Bases

Chemical name	**Formula**	**Common name**	**Strength**
Sodium hydroxide	NaOH	Lye, caustic soda	Strong
Potassium hydroxide	KOH	Caustic potash	Strong
Calcium hydroxide	$Ca(OH)_2$	Slaked lime	Strong
Magnesium hydroxide	$Mg(OH)_2$	Milk of magnesia	Weak
Ammonium hydroxide	NH_4OH, $\{NH_3(aq)\}$	Ammonia water, aqueous ammonia	Weak

Acid–Base Reactions

- Also called **neutralization reactions** because the acid and base neutralize each other's properties.
- In the reaction of an acid with a base, the H^{+1} from the acid combines with the OH^{-1} from the base to make water.
- The cation from the base combines with the anion from the acid to make the salt.

- The net ionic equation for an acid-base reaction often is:
  - As long as the salt that forms is soluble in water.

Process for Predicting the Products of an Acid–Base Rxn

1. Determine what ions each aqueous reactant has.
2. Exchange ions.
   - (+) ion from one reactant with (-) ion from the other.
   - H^+ combines with OH^- to make water.
3. Balance charges of combined ions to get formula of the salt.
4. Balance the equation.
   - Count atoms.
5. Determine solubility of the salt.
   - Use the solubility rules.
   - If the salt is insoluble or slightly soluble, it will precipitate.

Example

- Write the Molecular, Ionic, and Net-Ionic Equation for the Reaction of Aqueous Nitric Acid with Aqueous Calcium Hydroxide.

Example 7.11—Write

- $HNO_3(aq) + Ca(OH)_2(aq) \rightarrow$

Practice—Complete and Balance These Acid–Base Rxns

$NH_4OH(aq) + H_2SO_4(aq) \rightarrow$

$Al(OH)_3(aq) + H_2SO_3(aq) \rightarrow$

$Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow$

Gas Evolution Reactions

- Reactions in which the driving force is the production of a material that escapes as a gas are called **gas evolution reactions**.
- Some reactions form a gas directly from the ion exchange.
- Other reactions form a gas by the decomposition of one of the ion exchange products into a gas and water.

Compounds that Undergo Gas Evolving Reactions

Reactant type	React with	Ion exchange product	Decom-pose?	Gas formed	Example
$Metal_nS$, metal HS	Acid				
$Metal_nCO_3$, metal HCO_3	Acid				
$Metal_nSO_3$ metal HSO_3	Acid				
$(NH_4)_n$anion	Base				

Process for Predicting the Products of a Gas-Evolving Rxn

1. Determine what ions each aqueous reactant has.
2. Exchange ions.
   - (+) ion from one reactant with (-) ion from the other.
3. Balance charges of combined ions to get formula of each product.
4. Check to see if either product is H_2S.
5. Check to see if either product decomposes. If so, rewrite as $H_2O(l)$ and a gas.
   - See Table 7.4
6. Balance the equation.
7. Determine solubility of other product in water.

Example

- When an Aqueous Solution of Sodium Sulfite Is Added to an Aqueous Solution of Nitric Acid, a Gas Evolves.

Practice—Complete the Following Reactions.

$PbS(s) + H_2SO_4(aq) \rightarrow$

$HNO_3(aq) + NaHCO_3(aq) \rightarrow$

Other Patterns in Reactions

- The precipitation, acid–base, and gas evolving reactions all involved exchanging the ions in the solution.
- Other kinds of reactions involve transferring electrons from one atom to another. These are called **oxidation**–**reduction reactions**.

Oxidation–Reduction Reactions

- **Oxidized**
- **Reduced**
- You cannot have one without the other.
- In combustion,

Combustion as Redox

- In the following reaction:

  $Mg(s) + O_2(g) \rightarrow MgO(s)$

- The magnesium atoms are

- The oxygen atoms are

Combustion as Redox, Continued

- Even though the following reaction does not involve ion formation, electrons are still transferred.

  $CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

- The carbon atoms are

- The oxygen atoms are

Summary

- Redox reactions occur when:
  - A substance reacts with O2.
  - A metal combines with a nonmetal.
  - In general, whenever electrons are transferred.

Reactions of Metals with Nonmetals (Oxidation–Reduction)

- Metals react with nonmetals to form ionic compounds.
  - Ionic compounds are solids at room temperature.
- The metal loses electrons and becomes a cation.
  - The metal undergoes **oxidation**.
- The nonmetal gains electrons and becomes an anion.
  - The nonmetal undergoes **reduction**.
- In the reaction, electrons are transferred from the metal to the nonmetal.

$$2\ Na(s) + Cl_2(g) \rightarrow NaCl(s)$$

Ionic Compound Formation as Redox

- In the reaction:

$$Mg(s) + Cl_2(g) \rightarrow MgCl_2(s)$$

- The magnesium atoms are

- The chlorine atoms are

Recognizing Redox Reactions

- Any reaction where electrons are transferred is redox.
  - When a free element gets combined into a compound, it will be either oxidized or reduced.
  - When a metal cation changes its charge, it will be either oxidized if its charge increases or reduced if its charge decreases.
- Any reaction where O_2 is a reactant or a product is a redox reaction.
- Any reaction between a metal and a nonmetal is redox.

Practice—Decide Whether Each of the Following Rxns Is a Redox Rxn.

$2\ Al(s) + 3\ Br_2(l) \rightarrow 2\ AlBr_3(s)$

$CaSO_3(s) + 2\ HCl(aq) \rightarrow CaCl_2(aq) + SO_2(g) + H_2O(l)$

$Fe_2O_3(s) + C(s) \rightarrow 2\ Fe(s) + 3\ CO(g)$

$SO_2(g) + O_2(g) + H_2O(l) \rightarrow H_2SO_4(aq)$

Combustion Reactions

- Reactions in which $O_2(g)$ is a reactant are called
- Combustion reactions release lots of energy. They are
- Combustion reactions are a subclass of oxidation–reduction reactions.
- Example:

$$C_8H_{18}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

Products of Combustion

- When a material burns that contains carbon and hydrogen, the products are always $CO_2(g)$ and $H_2O(g)$.
- The reaction for the combustion of ethylene, $C_2H_4(g)$ is:

- The reaction for the combustion of ethylene glycol, $C_2H_6O_2(g)$ is:

Combustion Products

- To predict the products of a combustion reaction, combine each element in the other reactant with oxygen.

Reactant	Combustion product
Contains C	$CO_2(g)$
Contains H	$H_2O(g)$
Contains S	$SO_2(g)$
Contains N	$NO(g)$ or $NO_2(g)$
Contains metal	$M_2O_n(s)$

Practice—Write the Equation for Each Reaction.

- Combustion of the anesthetic cyclopropane, C_3H_6.

- Combustion of the non-toxic antifreeze propylene glycol, $C_3H_8O_2$.

Classifying Reactions

- One way is based on the process that happens.
  - Precipitation, neutralization, formation of a gas, or transfer of electrons.

Classifying Reactions, Continued

- Another scheme classifies reactions by what the atoms do.

Type of reaction	General equation
Synthesis	
Decomposition	
Displacement	
Double displacement	

Synthesis Reactions

- Also known as **composition** or **combination** reactions.
- Two (or more) reactants combine together to make **one product**.
  - Simpler substances combining together.

Decomposition Reactions

- A large molecule is broken apart into smaller molecules or its elements.
  - Caused by addition of energy into the molecule.
- **Have only one reactant**, make 2 or more products.

Single Displacement Reactions

- Reactions that involve one atom displacing another and replacing it in a compound.
  - Reaction $Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$,
  - Other examples of displacement reactions are:

Displacement of Copper by Zinc

$$Zn(s) + CuCl_2(aq) \rightarrow Cu(s) + ZnCl_2$$

Double Displacement Reactions

- Two ionic compounds exchange ions.
- May be followed by decomposition of one of the products to make a gas.
- Precipitation, acid–base, and gas evolving reactions are also double displacement reactions.

Examples of Double Displacement

$CaCl_2(aq) + Na_2CO_3(aq) \rightarrow$

$Ba(OH)_2(s) + HNO_3(aq) \rightarrow$

$Li_2CO_3(aq) + HCl(aq) \rightarrow$

Classify the Following Rxns as Synthesis, Decomposition, SD, or DD.

$3\ Mg(s) + 2\ FeCl_3(aq) \rightarrow 3\ MgCl_2(aq) + 2\ Fe(s)$

$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$

$3\ KOH(aq) + H_3PO_4(aq) \rightarrow K_3PO_4(aq) + 3\ H_2O(l)$

Vocabularies

- Combustion reactions
- Precipitation reactions
- Evidence of chemical reactions
- Conservation of mass
- Balancing chemical equations
- Dissociation
- Electrolytes
- Molecular equations complete ionic equations
- Net ionic equations
- Neutralization reactions
- Gas evolution reactions.
- Oxidation–reduction reactions
- Exothermic
- Synthesis/composition/combination reactions
- Decomposition reactions
- Single displacement reactions
- Double displacement reactions