Chapter 6
Chemical Reactions

Suggested problems: 1-18, 27-32, 45-48, 52

Objectives

• Be able to identify reactants and products in a chemical equation.
• Understand the relationships between chemical symbols, chemical formulas, and chemical equations.
• Be able to distinguish physical properties from chemical properties, and physical changes from chemical changes.
• Understand what subscripts mean in a chemical formula, and what coefficients mean in a chemical equation.
• Be able to balance a chemical equation.
• Be able to write a balanced equation given the names of products and reactants.

Changes of Matter

■ Physical changes

■ Chemical Changes
Chemical Equations

- Chemical equations show the ratio of reactants and products in a chemical reaction.
  
  \[ \text{reactants} \rightarrow \text{products} \]

  During a reaction, bonds in the reactants are broken.
  
  New bonds are formed to make the products.

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On Monday:

- Reactants → Products

  \[ 2 \text{ Bd} + \text{ Ch} \rightarrow \text{ Bd}_2\text{Ch} \]

- **Coefficients** ratios of molecules or atoms produced or consumed in a reaction. Coefficients not numerically shown are one (just like subscripts).

  From the equation, what is the ratio of bread atoms to sandwiches?

  How many sandwiches could be made from 10 atoms (slices) of bread?

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Chemical Equations

- Reactants → Products

  \[ 2 \text{ Na} + \text{ Cl}_2 \rightarrow 2 \text{ NaCl} \]

  \[ 2 \text{ H}_2 + \text{ O}_2 \rightarrow 2 \text{ H}_2\text{O} \]

  \[ \text{CH}_4 + 2 \text{ O}_2 \rightarrow \text{CO}_2 + 2 \text{ H}_2\text{O} \]
Law of Conservation of Mass

- Matter cannot be gained or destroyed.
- Atoms in the reactants must match atoms in the products.
  - Atoms may be bonded differently, but the number will be the same.
- The equation must be balanced to make the numbers of atoms match.

Balancing Equations

1. Make sure all chemical formulas are correct.
2. Count atoms in reactants and products.
   1. If polyatomic ions don’t change from reactant to product, count them as a group.
3. Balance the equation one element at a time using coefficients in front of the molecule containing that element. Do not change subscripts! Balance diatomic elements last.
4. Repeat steps 2 and 3 until all elements are balanced. Balancing one element will sometimes put another out of balance.
5. Make sure the coefficients are the smallest possible whole numbers. If you can divide the coefficients by 2 or any other whole number do so.

Balancing Equations

- Use coefficients as smallest whole number possible
  
  \[
  2 \text{Na} + \text{Cl}_2 \rightarrow 2 \text{NaCl}
  \]
  
  not: \[ 4 \text{Na} + 2 \text{Cl}_2 \rightarrow 4 \text{NaCl} \]
Balancing equations.

- Balance these equations:
  
  \[
  \begin{align*}
  \text{Fe} & + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 \\
  \text{SO}_2 & + \text{O}_2 \rightarrow \text{SO}_3 \\
  \text{FeI}_3 & + \text{MgCrO}_4 \rightarrow \text{Fe}_2(\text{CrO}_4)_3 + \text{Mgl}_2
  \end{align*}
  \]

Writing and Balancing equations

- Hydrogen and nitrogen react to form ammonia, NH₃

Balancing Equations

- Given the reaction, aluminum reacts with chlorine to give aluminum chloride,
  \[
  \text{Al} + \text{Cl}_2 \rightarrow \text{AlCl}_3
  \]
  
  What is wrong with balancing it as below?
  \[
  \text{Al} + \text{Cl}_2 \rightarrow \text{AlCl}_2
  \]
Summary

- Chemical equations represent chemical reactions.
- Subscripts tell the numbers of atoms in a molecule. They determine the identity of the compound.
- Coefficients tell the ratio of molecules or atoms produced or consumed in a chemical reaction.
- The equation is balanced when the numbers of atoms produced and consumed are equal.

Objectives

- Understand notation for the forms of matter in a chemical equation (s, l, g, aq).
- Be able to identify combination, decomposition, single-replacement, double-replacement, combustion, and neutralization reactions.
- Apply the Law of conservation of Energy to chemical reactions.
- Understand how endothermic and exothermic reactions relate to energy of reactants and products.
- Distinguish between activation energy and energy of reaction.

States of Matter

- Chemicals may have one of four forms in a reaction:
  - States of matter: solid (s), liquid (l), gas (g), aqueous (aq).
- Aqueous means that a molecule is dissolved in water solution.
- NaCl (s) added to water becomes NaCl (aq).
- CO₂ (g) dissolved in water becomes CO₂ (aq).
- Water can be formed in a reaction, water is never aqueous!
Types of Chemical Reactions

Chemical reactions can be grouped into different classes that describe how the reactants interact, or what types of products are formed.

The classes are:
- **Combination Reactions**: A + B -> AB
- **Decomposition Reactions**: AB -> A + B
- **Replacement Reactions**:
  - Double Replacement: AB + CD -> AD + CB
  - Single Replacement: AB + C -> CB + A
- **Combustion Reactions**: C XHY + O2 -> H2O + CO2
- **Neutralization Reactions**: HB + AOH -> AB + H2O

Combination Reactions

Combination reactions are reactions in which two or more elements or simple compounds bond to form one product.

- \(2 \text{Na} (s) + \text{Cl}_2 (g) \rightarrow 2 \text{NaCl} (s)\)
- \(\text{O}_2 (g) + 2 \text{H}_2 (g) \rightarrow 2 \text{H}_2\text{O} (g)\)

Solid phosphorus and gaseous oxygen combine to form solid tetraphosphorus decoxide.

Calcium metal and gaseous oxygen combine to form solid calcium oxide.

Decomposition Reactions

Decomposition reactions are reactions in which more complex compounds break down into simpler compounds.

- \(2 \text{H}_2\text{O} (l) \rightarrow 2 \text{H}_2 (g) + \text{O}_2 (g)\)
- \(\text{NaNO}_3 (s) \rightarrow \text{NaNO}_2 (s) + \text{O}_2 (g)\)

Aqueous hydrogen peroxide decomposes into water and gaseous oxygen.
Replacement Reactions

- Replacement reactions, ions and/or cations change bonding partners
  - Single Replacement Reactions:
    One element replaces an ion in the reacting compound.
    \[ \text{Fe (s)} + \text{CuSO}_4 (aq) \rightarrow \text{FeSO}_4 (aq) + \text{Cu (s)} \]
  - Double Replacement Reactions:
    Two ions switch places in reacting compounds.
    \[ \text{CaCl}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + 2 \text{NaCl} \]

A solid formed by mixing two aqueous solutions is called a precipitate.

Precipitates are in the solid state rather than the aqueous state because they are insoluble in water.

What will you observe when this reaction occurs?

Neutralization

- When water is formed in a double replacement reaction, the reaction is a special case of a D.R.R, a neutralization reaction
  \[ \text{HCl (aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl (aq)} + \text{H}_2\text{O (l)} \]
  
  What ions are switched in the above reaction?

  Acid-base neutralization:
Combustion Reactions

- Combustion reactions are reactions in which compounds react with oxygen to form carbon dioxide and water, and give off heat energy.

\[
\text{CH}_4 (g) + \text{O}_2 (g) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O} (g)
\]

Balance the equation.

How many molecules of \text{O}_2 are needed per methane to make \text{CO}_2?

If not enough \text{O}_2 is present, \text{CO} will be formed instead. **Incomplete combustion**

Combustion in our body

The metabolism of glucose can be written as

\[
\text{C}_6\text{H}_12\text{O}_6(s) + 6\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O} (g) + \text{energy}
\]

This is a combustion reaction, why do we not burn up from the heat released?
The reaction occurs in several steps, so energy is not released all at once.
Energy is used to make other molecules in side reactions.

Energy in Chemical reactions

- Two types of energies are involved in a chemical reaction.
- In a combustion reaction, heat is released, so the reaction is classified as ____________________.
  - Heat can be considered to be a product of the reaction.
- Where does the energy come from?

What kind of energy is in chemical bonds?
Energy diagram

- For an exothermic reaction, the reactants are holding on to energy which is released when the products form.
- The products are holding less energy.
- Energy of reaction: the difference in energy between reactants and products

Exothermic Reaction

- If a reaction absorbs energy, then consider energy as a reactant.
- Where does that energy come from?
  - Surroundings
  - The environment may be warm enough to supply energy.
  - A source such as a heater or flame may be needed.

Energy of Reaction

<table>
<thead>
<tr>
<th>Exothermic</th>
<th>Endothermic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat released</td>
<td></td>
</tr>
<tr>
<td>Reactants more energetic than products.</td>
<td></td>
</tr>
<tr>
<td>We “feel” it as warm.</td>
<td></td>
</tr>
<tr>
<td>Heat absorbed</td>
<td></td>
</tr>
<tr>
<td>Products more energetic than reactants.</td>
<td></td>
</tr>
<tr>
<td>We “feel” it as cool.</td>
<td></td>
</tr>
</tbody>
</table>
Activation Energy

- What is the little hill on the energy diagrams?
- Combustion of fuel is exothermic, but is the candle or gasoline going to just burn on its own?
- You have to start it with a spark or a match.
- The energy to get a reaction started is the activation energy.
- The activation energy does not affect whether a reaction is endothermic or exothermic.

Example

- Solid carbon reacts with oxygen gas to give carbon dioxide and 94 kcal of heat.
  - Write the balanced chemical equation and draw a relative energy diagram for the reaction.
  - What energy does the 94 kcal refer to?
  - Which energy on the diagram do you not know?