Chapter 9

Chemical Reactions
In a *physical change*,

- The identity and composition of the substance do not change
- The state can change or the material can be torn into smaller pieces
Chemical Change

In a chemical change,

• Reacting substances form new substances with different compositions and properties

• A chemical reaction takes place
Chemical Reaction

In a chemical reaction,

• Old bonds are broken and new bonds are formed
• Atoms in the reactants are rearranged to form one or more different substances
• Fe and O$_2$ form rust (Fe$_2$O$_3$)
Chemical Reaction

In a chemical reaction,

• A chemical change produces one or more new substances

• There is a change in the composition of one or more substances
Evidence of a Chemical Reaction

- Changes that can be seen are evidence of a chemical reaction.

### Table 9.2
**Types of Visible Evidence of a Chemical Reaction**

1. Change in the color
2. Formation of a solid (precipitate)
3. Formation of a gas (bubbles)
4. Heat (or a flame) is produced or heat is absorbed

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Writing a Chemical Reaction

• Chemists use a shorthand approach when writing the specifics of a chemical reaction. This approach is called the chemical equation.

Reactants -----> Products
Chemical Equations

A chemical equation,

- Gives the chemical formulas of the reactants on the left of an arrow and the products on the right

\[ \text{Reactants} \quad \text{Product} \]

\[ \text{C(s)} + \text{O}_2(g) \rightarrow \text{CO}_2(g) \]
Symbols Used in Equations

Symbols used in chemical equations show:

- The states of the reactants
- The states of the products
- The reaction conditions

Table 9.3

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Separates two or more formulas</td>
</tr>
<tr>
<td>→</td>
<td>Reacts to form products</td>
</tr>
<tr>
<td>Δ</td>
<td>The reactants are heated</td>
</tr>
<tr>
<td>(s)</td>
<td>Solid</td>
</tr>
<tr>
<td>(l)</td>
<td>Liquid</td>
</tr>
<tr>
<td>(g)</td>
<td>Gas</td>
</tr>
<tr>
<td>(aq)</td>
<td>Aqueous</td>
</tr>
</tbody>
</table>
Chemical Equations Are Balanced

In a balanced chemical reaction,
- Atoms are not gained or lost

Equation: \( \text{C(s)} + \text{O}_2(g) \rightarrow \text{CO}_2(g) \)
Chemical Equations Are Balanced

In a balanced chemical reaction,

- The number of reactant atoms are equal to the number of product atoms

\[ \text{C(s)} + \text{O}_2(g) \rightarrow \text{CO}_2(g) \]

Reactant atoms = Product atoms
Chemical Equations

• Chemical equations: symbolic descriptions of chemical reactions.
• Two parts to an equation: reactants and products
  \[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]

A Chemical Equation must also be balanced.

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

• Chemical Equations must be balanced
  – There must be equal numbers of atoms of each element on both sides of the equation (both sides of the arrow)
    1. Write the correct symbols and formulas for all of the reactants and products.
    2. Count the number of each type of atom on BOTH sides of the equation.
    3. Insert coefficients until there are the equal numbers of each kind of atom on both sides of the equation.
A Balanced Chemical Equation

\[ \text{Al} + \text{S} \rightarrow \text{Al}_2\text{S}_3 \quad \text{Not Balanced} \]

coefficients

\[ 2\text{Al} + 3\text{S} \rightarrow \text{Al}_2\text{S}_3 \quad \text{Balanced} \]

\[ 2 \text{ Al} = 2 \text{ Al} \]
\[ 3 \text{ S} = 3 \text{ S} \]
Learning Check

State the number of atoms of each element on the reactant and on the product sides of the equations:

\[ \text{P}_4(\text{s}) + 6 \text{ Br}_2(\ell) \rightarrow 4 \text{ PBr}_3(\text{g}) \]

- Reactant side:
  - 4 P
  - 12 Br

- Product side:
  - 4 P
  - 12 Br
Learning Check

State the number of atoms of each element on the reactant and on the product sides of the equations:

$$2\text{Al}(s) + \text{Fe}_2\text{O}_3(s) \rightarrow 2\text{Fe}(s) + \text{Al}_2\text{O}_3(s)$$

- Al: 2 on reactant, 2 on product
- Fe: 2 on reactant, 2 on product
- O: 3 on reactant, 3 on product
Learning Check

Check the balance of atoms in the following:

$\text{Fe}_3\text{O}_4(s) + 4\text{H}_2(g) \rightarrow 3\text{Fe}(s) + 4\text{H}_2\text{O}(l)$

1. Number of H atoms in reactants.
   - A) 2
   - B) 4
   - C) 8

2. Number of O atoms in reactants.
   - A) 2
   - B) 4
   - C) 8

3. Number of Fe atoms in reactants.
   - A) 1
   - B) 3
   - C) 4
Learning Check

Determine if each equation is balanced or not.

\[ 2\text{Na(s)} + 3\text{N}_2(g) \rightarrow 2\text{NaN}_3(s) \]

\[ \text{C}_2\text{H}_4(g) + \text{H}_2\text{O}(l) \rightarrow \text{C}_2\text{H}_5\text{OH}(l) \]
Balancing Equations

• Methane reacts with oxygen (combustion reaction) to form carbon dioxide and water.

Write a properly balanced chemical equation

1. Write out chemical formulas

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

2. Use coefficients to balance the equation
The Numbers in Chemical Equations

One methane molecule (\(CH_4\) with 1 C and 4 H) + Two oxygen molecules (2 \(O_2\) with 4 O) → One carbon dioxide molecule (\(CO_2\) with 1 C and 2 O) + Two water molecules (2 \(H_2O\) with 2 O and 4 H)

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More Practice: Balancing Reactions

\[ 2 \text{C}_2\text{H}_6 + 7 \text{O}_2 \rightarrow 4 \text{CO}_2 + 6 \text{H}_2\text{O} \]

\[ 2 \text{C}_3\text{H}_6 + 9 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} \]

\[ 4 \text{NH}_3 + 5 \text{O}_2 \rightarrow 4 \text{NO} + 6 \text{H}_2\text{O} \]
And more practice….

\[ \text{B}_2\text{H}_6 \ + \ 6 \text{H}_2\text{O} \rightarrow 2 \text{H}_3\text{BO}_3 \ + \ 6 \text{H}_2 \]

\[ 2 \text{C}_3\text{H}_8\text{O} \ + \ 9 \text{O}_2 \rightarrow 6 \text{CO}_2 \ + \ \frac{14}{8} \text{H}_2\text{O} \]
Balancing with Polyatomic Ions

$$3\text{MgCl}_2(aq) + 2\text{Na}_3\text{PO}_4(aq) \rightarrow 6\text{NaCl}(aq) + \text{Mg}_3(\text{PO}_4)_2(s)$$

- HINT: Balance $\text{PO}_4^{3-}$ as a unit.

A) $3, 2, 6, 1$
B) $3, 1, 2, 6$
C) $3, 2, 4, 2$
Guide to Balancing a Chemical Equation

STEP 1
Write an equation using the correct formulas of the reactants and products.

STEP 2
Count the atoms of each element in reactants and products.

STEP 3
Use coefficients to balance each element.

STEP 4
Check final equation for balance.

Review of steps to balance a chemical equation.
In Class QUIZ 6.1

Balance each equation and list the coefficients in the balanced equation going from reactants to products:

1. \(_{\text{Mg}}\text{(s)} + _{\text{N}_2}(g) \rightarrow _{\text{Mg}_3\text{N}_2}(s)\)
   A) 1, 3, 2    B) 3, 1, 2    C) 3, 1, 1

2. \(_{\text{Al}}\text{(s)} + _{\text{Cl}_2}(g) \rightarrow _{\text{AlCl}_3}(s)\)
   A) 3, 3, 2    B) 1, 3, 1    C) 2, 3, 2
In Class QUIZ  6.2

Balance and list the coefficients from reactants to products:

3. \(_{\text{Fe}_2\text{O}_3(s)} + \_\text{C(s)} \rightarrow \_\text{Fe(s)} + \_\text{CO}_2(g)\)
   A) 2, 3, 2,3         B) 2, 3, 4, 3         C) 1, 1, 2, 3

4. \(_{\text{Al(s)}} + \_\text{FeO(s)} \rightarrow \_\text{Fe(s)} + \_\text{Al}_2\text{O}_3(s)\)
   A) 2, 3, 3, 1         B) 2, 1, 1, 1         C) 3, 3, 3, 1

5. \(_\text{Al(s)} + \_\text{H}_2\text{SO}_4(aq) \rightarrow \_\text{Al}_2(\text{SO}_4)_3(aq) + \_\text{H}_2(g)\)
   A) 3, 2, 1, 2         B) 2, 3, 1, 3         C) 2, 3, 2, 3
Chapter 9

Types of Reactions
Type of Reactions

Chemical reactions can be classified as

- Combination reactions.
- Decomposition reactions.
- Single Replacement reactions.
- Double Replacement reactions.
- Combustion reactions.
Combination

In a combination reaction,

• Two or more elements form one product.
• Or simple compounds combine to form one product.

\[2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s)\]
\[2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(s)\]
\[\text{SO}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq)\]
Decomposition

In a decomposition reaction,

- One substance splits into two or more simpler substances.

\[
\begin{align*}
2\text{HgO}(s) & \rightarrow 2\text{Hg}(l) + \text{O}_2(g) \\
2\text{KClO}_3(s) & \rightarrow 2\text{KCl}(s) + 3\text{O}_2(g)
\end{align*}
\]
Learning Check

Classify the following reactions as A) combination or B) decomposition:

1. \( \text{H}_2(g) + \text{Br}_2(g) \rightarrow 2\text{HBr}(l) \)  \text{A}
2. \( \text{Al}_2(\text{CO}_3)_3(s) \rightarrow \text{Al}_2\text{O}_3(s) + 3\text{CO}_2(g) \)  \text{B}
3. \( 4\text{Al}(s) + 3\text{C}(s) \rightarrow \text{Al}_4\text{C}_3(s) \)  \text{A}
Single Replacement

In a **single replacement** reaction,

- One element takes the place of a different element in a reacting compound.

\[
\text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g)
\]

\[
\text{Fe}(s) + \text{CuSO}_4(aq) \rightarrow \text{FeSO}_4(aq) + \text{Cu}(s)
\]

\[
\text{Cl}_2 + 2\text{NaF} \rightarrow 2\text{NaCl} + \text{F}_2
\]
Double Replacement

In a **double replacement** reaction,
- Two elements in the reactants exchange places.

Double replacement

\[
\text{AgNO}_3(aq) + \text{NaCl}(aq) \rightarrow \text{AgCl}(s) + \text{NaNO}_3(aq)
\]

\[
\text{ZnS}(s) + 2\text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2\text{S}(g)
\]
Learning Check

Classify the following reactions as

A) single replacement   B) double replacement

1. $2\text{Al}(s) + 3\text{H}_2\text{SO}_4(aq) \rightarrow \text{Al}_2(\text{SO}_4)_3(s) + 3\text{H}_2(g)$  \hspace{1cm} A

2. $\text{Na}_2\text{SO}_4(aq) + 2\text{AgNO}_3(aq) \rightarrow \text{Ag}_2\text{SO}_4(s) + 2\text{NaNO}_3(aq)$  \hspace{1cm} B

3. $3\text{C}(s) + \text{Fe}_2\text{O}_3(s) \rightarrow 2\text{Fe}(s) + 3\text{CO}(g)$  \hspace{1cm} A
Combustion

In a combustion reaction,

- A compound such as carbon reacts with oxygen, $O_2$.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$
$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$
$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

- Fuels burned in oxygen produce $CO_2$, $H_2O$, and energy.
Learning Check

Balance the combustion equation

\[ \_\_C_5H_{12} + \_\_O_2 \rightarrow 5\ CO_2 + 6\ H_2O \]
### Summary of Reaction Types

<table>
<thead>
<tr>
<th>Reaction Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combination</td>
<td></td>
</tr>
<tr>
<td>A + B → AB</td>
<td>Ca(s) + Cl₂(g) → CaCl₂(s)</td>
</tr>
<tr>
<td>Decomposition</td>
<td></td>
</tr>
<tr>
<td>AB → A + B</td>
<td>Fe₂S₃(s) → 2Fe(s) + 3S(s)</td>
</tr>
<tr>
<td>Single Replacement</td>
<td></td>
</tr>
<tr>
<td>A + BC → AC + B</td>
<td>Cu(s) + 2AgNO₃(aq) → Cu(NO₃)₂(aq) + 2Ag(s)</td>
</tr>
<tr>
<td>Double Replacement</td>
<td></td>
</tr>
<tr>
<td>AB + CD → AD + CB</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BaCl₂(aq) + K₂SO₄(aq) → BaSO₄(s) + 2KCl(aq)</td>
</tr>
<tr>
<td>Combustion</td>
<td></td>
</tr>
<tr>
<td>AH₄ + 2O₂ → AO₂ + 2H₂O + heat</td>
<td></td>
</tr>
<tr>
<td>B + O₂ → BO₂</td>
<td>CH₄(g) + 2O₂(g) → CO₂(g) + 2H₂O(g) + heat</td>
</tr>
<tr>
<td></td>
<td>S(s) + O₂(g) → SO₂(g)</td>
</tr>
</tbody>
</table>
Chapter 9

Energy in Chemical Reactions

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The heat of reaction,

- Is the amount of heat absorbed or released during a reaction at constant pressure.
- Is the difference in the energy of the reactants and the products.
- Is shown as the symbol $\Delta H$.

$$\Delta H = H_{products} - H_{reactants}$$
Endothermic Reactions

In an endothermic reaction,

- Heat is absorbed.
- The sign of $\Delta H$ is +.
- The energy of the products is greater than the energy of the reactants.
- Heat is a reactant.

$$N_2(g) + O_2 (g) + 181 \text{ kJ} \rightarrow 2\text{NO}(g)$$

$\Delta H = +181 \text{ kJ}$ (heat added)
Exothermic Reactions

In an exothermic reaction,

- Heat is released.
- The sign of $\Delta H$ is -.
- The energy of the products is less than the energy of the reactants.
- Heat is a product.

$$C(s) + 2H_2(g) \rightarrow CH_4(g) + 75 \text{ kJ}$$

$\Delta H = -75 \text{ kJ}$ (heat given off)
Learning Check

Identify each reaction as 1) exothermic or 2) endothermic.

A. \( \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 + 92 \text{ kJ} \)

B. \( \text{CaCO}_3 + 556 \text{ kJ} \rightarrow \text{CaO} + \text{CO}_2 \)

C. \( 2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3 + \text{heat} \)