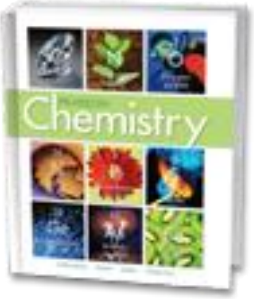


Chapter 11
Chemical Reactions

11.1 Describing Chemical Reactions

11.2 Types of Chemical Reactions

11.3 Reactions in Aqueous Solution

PEARSON

What happens to the wax when you burn a candle?

When you burn a candle, a chemical reaction called combustion takes place.

Classifying Reactions

What are the five general types of reactions?

Classifying Reactions

By classifying chemical reactions, you can more easily predict what products are likely to form.

The five general types of reactions include combination, decomposition, single-replacement, double-replacement, and combustion.

Classifying Reactions

Not all chemical reactions fit uniquely into one category.

- Occasionally, a reaction may fit equally well into two categories.
- Patterns of chemical behavior will become apparent and allow you to predict the products of reactions.

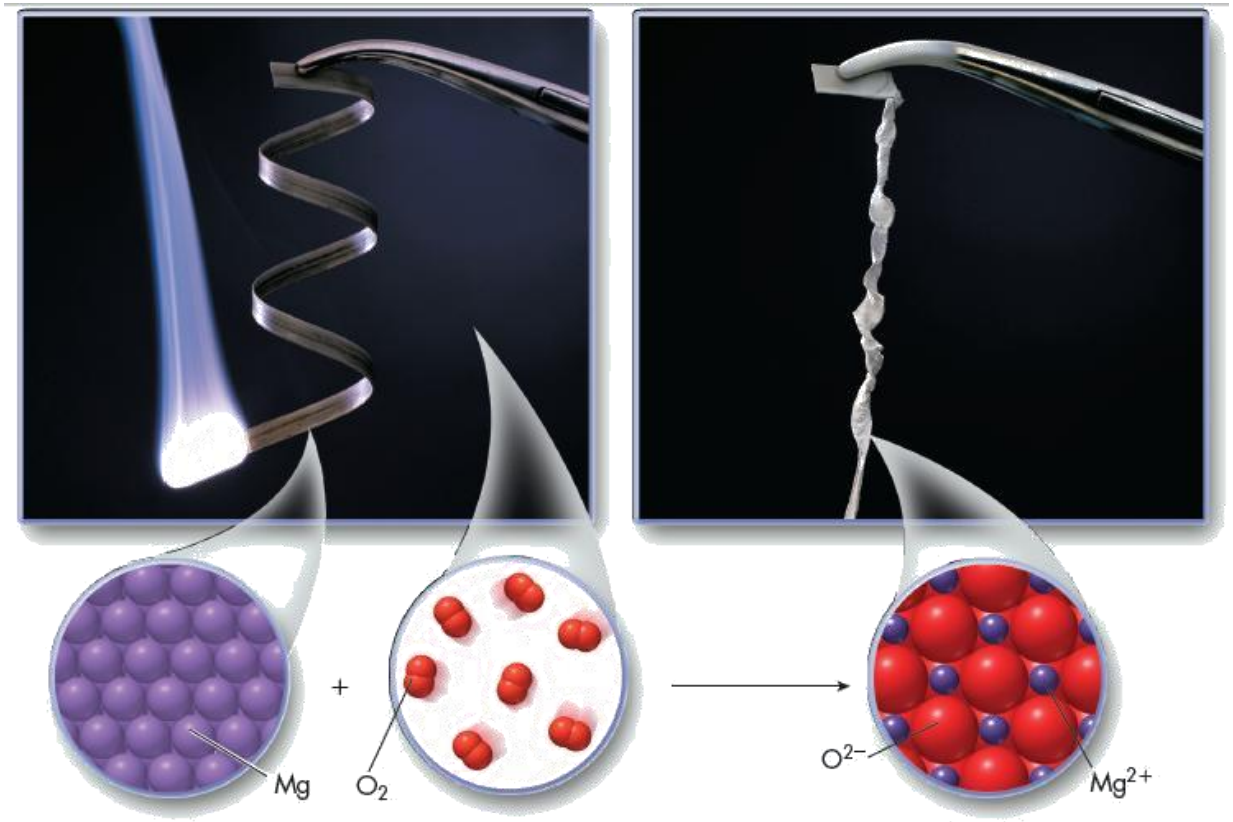
Combination Reactions

The first type of reaction is the combination, or synthesis, reaction.

- A **combination reaction** is a chemical change in which two or more substances react to form a single new substance.

Combination Reactions

Magnesium metal and oxygen gas combine to form the compound magnesium oxide.



$$2Mg(s) + O_2 \rightarrow 2\ MgO(s)$$

Combination Reactions

Notice that in this reaction, as in all combination reactions, the product is a single substance (MgO), which is a compound.

- The reactants in this combination reaction (Mg and O_2) are two elements, which is often the case.
- Two compounds may also combine to form a single substance.

Combination Reactions

When a Group A metal and a nonmetal react, the product is a binary ionic compound.

$$2K(s) + Cl_2(g) \rightarrow 2KCl(s)$$

Combination Reactions

When two nonmetals react in a combination reaction, more than one product is often possible.

$$S(s) + O_2(g) \rightarrow SO_2(g)$$ sulfur dioxide

$$2S(s) + 3O_2(g) \rightarrow 2SO_3(s)$$ sulfur trioxide

Combination Reactions

More than one product may also result from the combination reaction of a transition metal and a nonmetal.

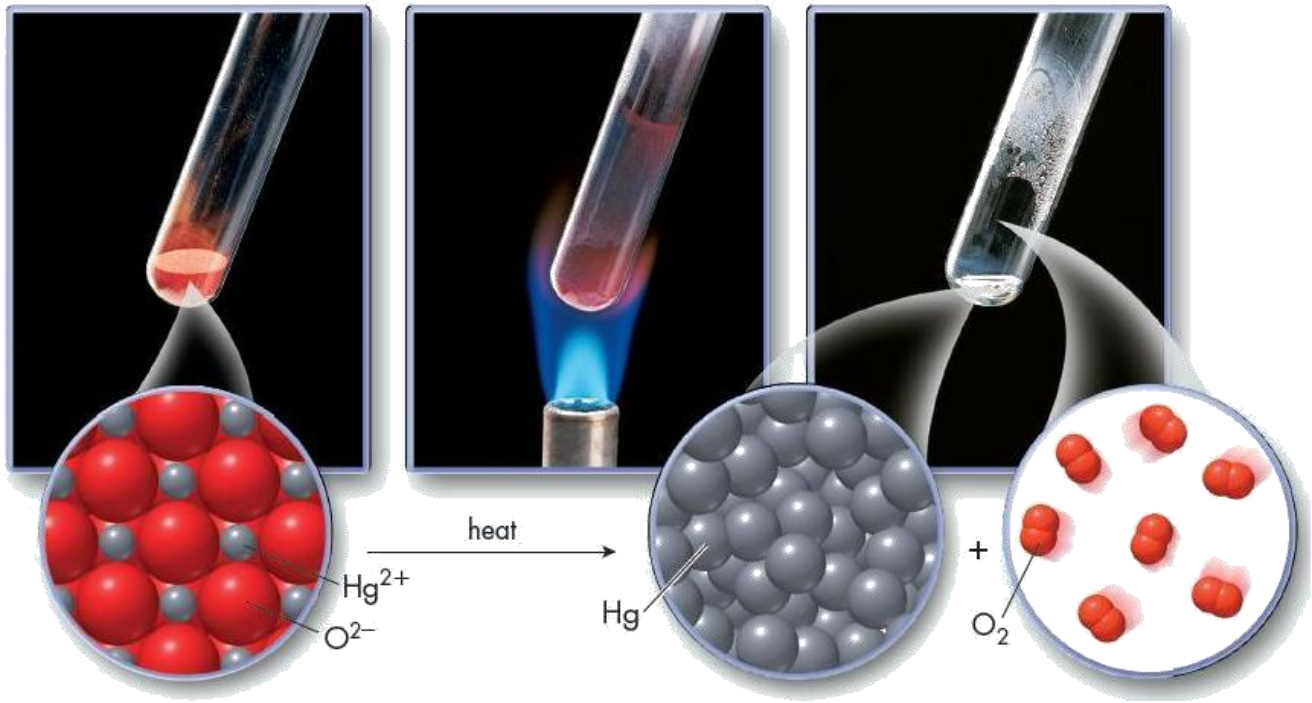
$$Fe(s) + S(s) \rightarrow FeS(s) \text{ iron(II) sulfide}$$

$$2Fe(s) + 3S(g) \rightarrow Fe_2S_3(s) \text{ iron(III) sulfide}$$

Decomposition Reactions

Some chemical reactions are the opposite of combination reactions.

- When mercury(II) oxide is heated, it decomposes or breaks down into two simpler substances.



$$2HgO(s) \xrightarrow{heat} 2Hg(l) + O_2(g)$$

Decomposition Reactions

A **decomposition reaction** is a chemical change in which a single compound breaks down into two or more simpler products.

- Decomposition reactions involve only one reactant and two or more products.
- The products can be any combination of elements and compounds.
- Most decomposition reactions require energy in the form of heat, light, or electricity.

Decomposition Reactions

Did you know that a decomposition reaction happens when a vehicle's air bag inflates?

- A device that triggers the reaction is placed in the air bag along with sodium azide pellets.
- When the device is triggered, the sodium azide pellets decompose and release nitrogen gas, which inflates the air bag quickly.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Writing Equations for Combination and Decomposition Reactions

Write a balanced equation for each of the following reactions.

a. Combination of copper and sulfur:
$Cu(s) + S(s) \rightarrow$ (two reactions possible)

b. Decomposition of water:
$H_2O(l) \xrightarrow{\text{electricity}}$

1 Analyze Identify the relevant concepts.

Two combination reactions are possible because copper is a transition metal and has more than one common ionic charge (Cu^{+} and Cu^{2+}).

2 Solve Apply concepts to this problem.

Write the formula for the product(s) in each reaction.

a. Copper(I) sulfide $Cu_2S(s)$
Copper(II) sulfide $CuS(s)$

b. $H_2(g)$
$O_2(g)$

Note that Cu_2S and CuS represent different products from different reactions.

2 Solve Apply concepts to this problem.

Write a skeleton equation for each reaction.

a. For Copper(I):

$$Cu(s) + S(s) \rightarrow Cu_2S(s)$$

For Copper(II):

$$Cu(s) + S(s) \rightarrow CuS(s)$$

b. $H_2O \xrightarrow{\text{electricity}} H_2(g) + O_2(g)$

2 Solve Apply concepts to this problem.

Apply the rules for balancing equations.

a. For Copper(I):

$2Cu(s) + S(s) \rightarrow Cu_2S(s)$

For Copper(II): the skeleton equation is already balanced.

$Cu(s) + S(s) \rightarrow CuS(s)$

2 Solve Apply concepts to this problem.

Apply the rules for balancing equations.

b. $H_2O(l) \xrightarrow{\text{electricity}} H_2(g) + O_2(g)$

The hydrogen is balanced, but the oxygen is not. After balancing the oxygen, you must rebalance the hydrogen atoms.

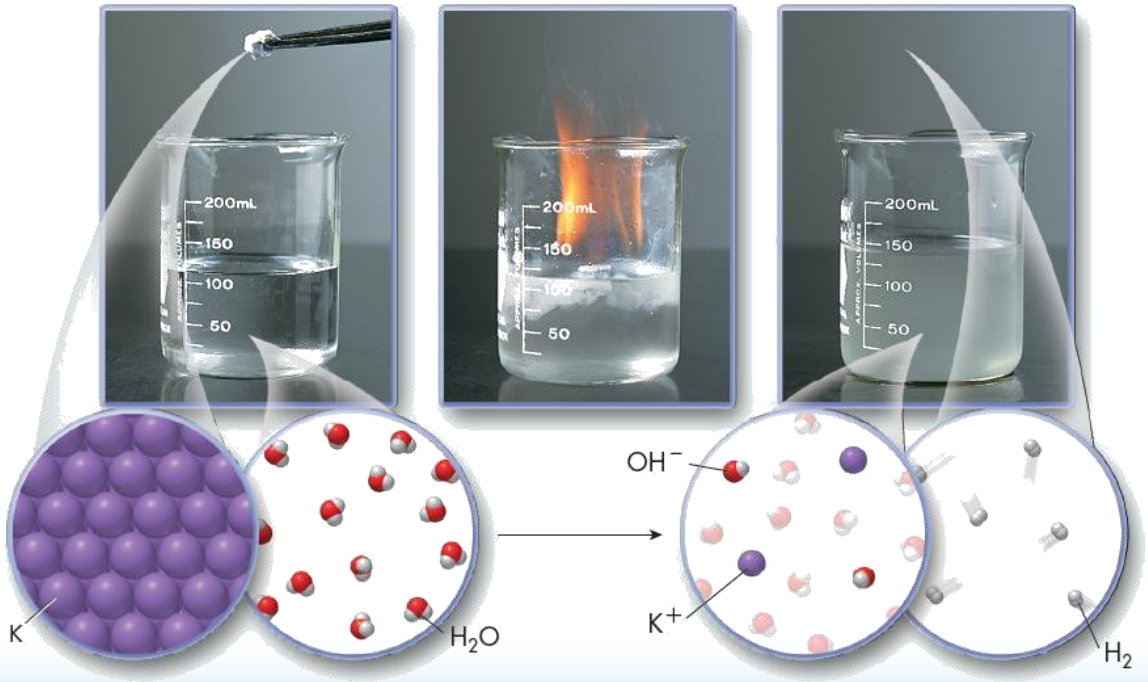
$$2H_2O(l) \xrightarrow{\text{electricity}} H_2(g) + O_2(g)$$

$$2H_2O(l) \xrightarrow{\text{electricity}} 2H_2(g) + O_2(g)$$

Single-Replacement Reactions

Dropping a small piece of potassium into a beaker of water creates the vigorous reaction.

$$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2$$



- The released hydrogen gas can ignite explosively.

Single-Replacement Reactions

If you drop a piece of zinc into a solution of copper nitrate, this reaction occurs:

$$Zn(s) + Cu(NO_3)_2(aq) \rightarrow Cu(s) + Zn(NO_3)_2(aq)$$

Single-Replacement Reactions

These equations describe two examples of single-replacement reaction.

$$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$$

$$Zn(s) + Cu(NO_3)_2(aq) \rightarrow Cu(s) + Zn(NO_3)_2$$

- A **single-replacement reaction** is one in which one element replaces a second element in a compound.
  - You can identify a single-replacement reaction by noting that both the reactants and the products consist of an element and a compound.

Single-Replacement Reactions

$$Zn(s) + Cu(NO_3)_2(aq) \rightarrow Cu(s) + Zn(NO_3)_2$$

In the equation above, zinc and copper change places.

- The reacting element Zn replaces copper in the reactant compound $Cu(NO_3)_2$.
- The products are the element Cu and the compound $Zn(NO_3)_2$.

Writing Equations for Single-Replacement Reactions

Write a balanced equation for the single-replacement reaction.

$$Cl_2(aq) + NaBr(aq) \rightarrow$$

Sample Problem 11.5

1 Analyze Identify the relevant concepts.

Chlorine is more reactive than bromine and displaces bromine from its compounds.

Hint: You're starting with an unequal number of atoms:

reactants:
- 2 chlorine atoms
- 1 sodium atom
- 1 bromine atom

products:
- 1 chlorine atom
- 1 sodium atom
- 2 bromine atoms

2 Solve Apply concepts to this problem.

- Write the skeleton equation.

$$Cl_2(aq) + NaBr(aq) \rightarrow NaCl(aq) + Br_2(aq)$$

- Apply the rules for balancing equations.

$$Cl_2(aq) + 2NaBr(aq) \rightarrow 2NaCl(aq) + Br_2(aq)$$

(balanced)

Single-Replacement Reactions

Whether one metal will displace another metal from a compound depends upon the relative reactivities of the two metals.

- Iron will displace copper from a copper compound in solution, but iron does not similarly displace zinc or calcium.

Activity Series of Metals

Decreasing reactivity ↓

Name	Symbol
Lithium	Li
Calcium	Ca
Sodium	Na
Magnesium	Mg
Aluminum	Al
Zinc	Zn
Iron	Fe
Lead	Pb
Copper	Cu
Mercury	Hg
Silver	Ag

Single-Replacement Reactions

Whether one metal will displace another metal from a compound depends upon the relative reactivities of the two metals.

- The **activity series** of metals lists metals in order of decreasing reactivity.
- A reactive metal will replace any metal listed below it in the activity series.

Activity Series of Metals

Decreasing reactivity ↓

Name	Symbol
Lithium	Li
Calcium	Ca
Sodium	Na
Magnesium	Mg
Aluminum	Al
Zinc	Zn
Iron	Fe
Lead	Pb
Copper	Cu
Mercury	Hg
Silver	Ag

Single-Replacement Reactions

A halogen can also replace another halogen from a compound.

- The activity of halogens decreases as you go down Group 7A of the periodic table—fluorine, chlorine, bromine, and iodine.
- Bromine is more active than iodine, so this reaction occurs:

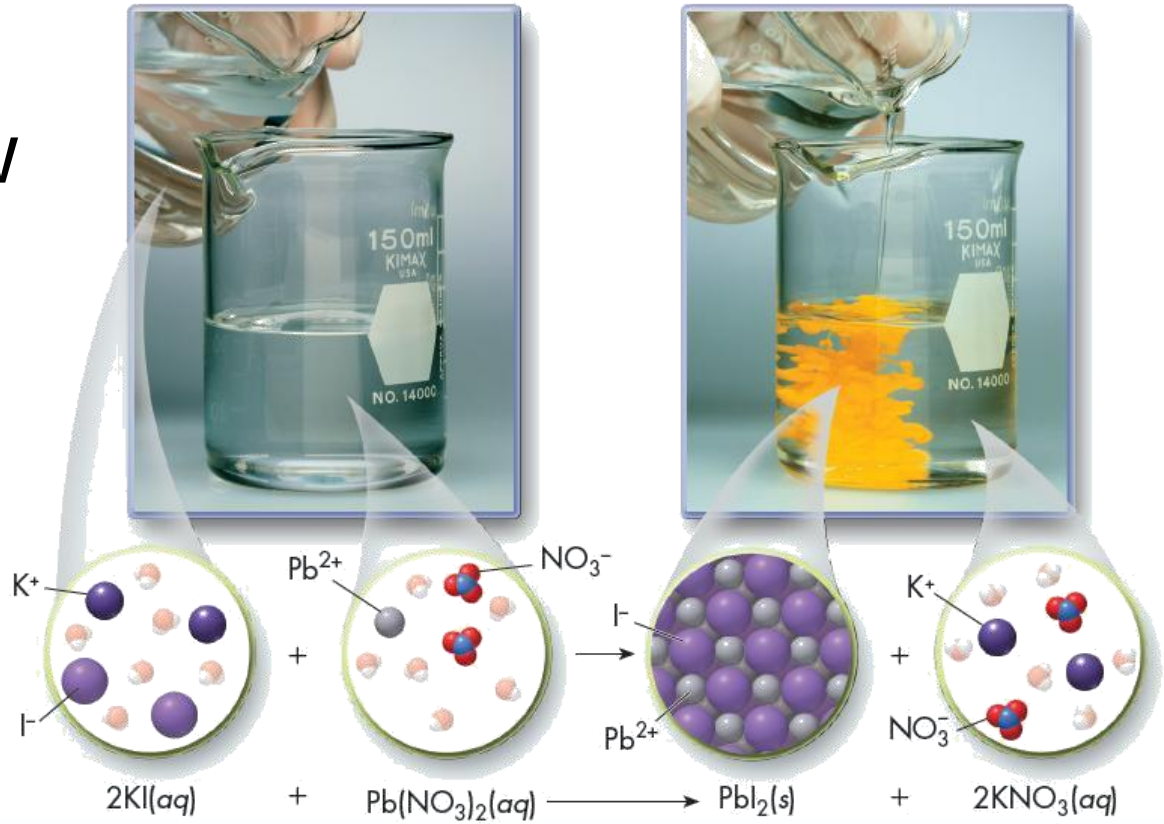
$$Br_2(aq) + 2NaI(aq) \rightarrow 2NaBr(aq) + I_2(aq)$$

- But bromine is less active than chlorine, so this reaction does not occur:

$$Br_2(aq) + NaCl(aq) \rightarrow \text{No reaction}$$

Double-Replacement Reactions

Mixing aqueous solutions of potassium iodide and lead(II) nitrate results in a chemical reaction in which a yellow precipitate of solid lead(II) iodide is formed.



Double-Replacement Reactions

$$2KI(aq) + Pb(NO_3)_2(aq) \rightarrow PbI_2 + 2KNO_3(aq)$$

This is an example of a **double-replacement reaction**, which is a chemical change involving an exchange of positive ions between two compounds.

- Double-replacement reactions are also referred to as double-displacement reactions.
- They generally take place in aqueous solution and often produce a precipitate, a gas, or a molecular compound such as water.

Double-Replacement Reactions

For a double-replacement reaction to occur, one of the following is usually true:

1. One of the products is only slightly soluble and precipitates from solution.
2. One of the products is a gas.
3. One product is a molecular compound such as water.

Writing Equations for Double-Replacement Reactions

A precipitate of barium carbonate is formed when aqueous solutions of barium chloride react with potassium carbonate. Write a balanced chemical equation for the double-replacement reaction.

$$K_2CO_3(aq) + BaCl_2(aq) \rightarrow$$

1 Analyze Identify the relevant concepts.

The driving force behind the reaction is the formation of a precipitate.

- Write correct formulas of the products using ionic charges.
- Then balance the equation.

2 Solve Apply concepts to this problem.

- Write the skeleton equation.

$$K_2CO_3(aq) + BaCl_2(aq) \rightarrow KCl(aq) + BaCO_3(s)$$

- Apply the rules for balancing equations.

$$K_2CO_3(aq) + BaCl_2(aq) \rightarrow 2KCl(aq) + BaCO_3(s)$$

(balanced)

Combustion Reactions

The flames of a campfire, candle, or gas grill are evidence that a combustion reaction is taking place.

Combustion Reactions

A **combustion reaction** is a chemical change in which an element or a compound reacts with oxygen, often producing energy in the form of heat and light.

- A combustion reaction always involves oxygen as a reactant.
- Often the other reactant is a hydrocarbon, which is a compound composed of hydrogen and carbon.

Combustion Reactions

The complete combustion of a hydrocarbon produces carbon dioxide and water.

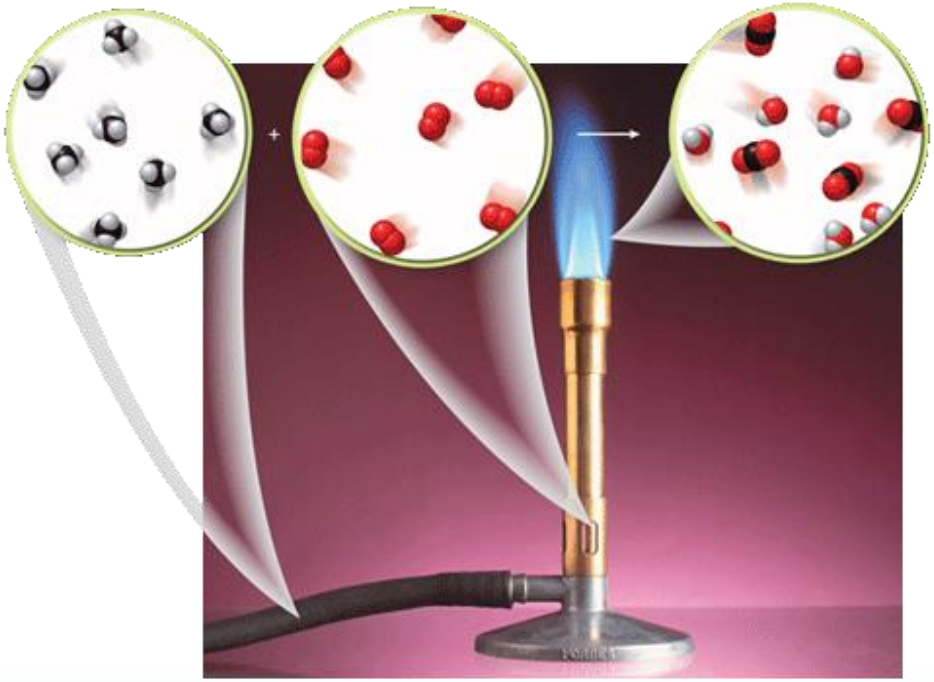
- But if the supply of oxygen is limited during a reaction, the combustion will not be complete.
- Elemental carbon (soot) and toxic carbon monoxide gas may be additional products.

Combustion Reactions

The complete combustion of a hydrocarbon releases a large amount of energy as heat.

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

- That's why hydrocarbons such as methane (CH_4), propane (C_3H_8), and butane (C_4H_{10}) are important fuels.



Combustion Reactions

Gasoline is a mixture of hydrocarbons that can be approximately represented by the formula C_8H_{18}.

- The complete combustion of gasoline in a car engine is shown by this equation:

$$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$$

Combustion Reactions

The reactions between oxygen and some elements other than carbon are also examples of combustion reactions.

- Both magnesium and sulfur will burn in the presence of oxygen.
- Notice that the reactions could also be classified as combination reactions.

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

$$S(s) + O_2(g) \rightarrow SO_2(s)$$

CHEMISTRY & YOU

Materials such as candle wax contain hydrogen and carbon. One type of wax has a formula of $C_{25}H_{53}$. The wax reacts with oxygen in the air. So, what happens to the wax as it burns?

CHEMISTRY & YOU

Materials such as candle wax contain hydrogen and carbon. One type of wax has a formula of $C_{25}H_{53}$. The wax reacts with oxygen in the air. So, what happens to the wax as it burns?

The wax undergoes a combustion reaction with oxygen and is converted into carbon dioxide and water.

$$4C_{25}H_{53}(s) + 103O_2(g) \rightarrow 100CO_2(g) + 106H_2O(g)$$

Writing Equations for Combustion Reactions

An alcohol lamp often uses ethanol as its fuel. Write a balanced equation for the complete combustion of ethanol.

$C_2H_6O(l)$

1 Analyze Identify the relevant concepts.

- Oxygen is the other reactant in a combustion reaction.
- The products are CO_2 and H_2O.

2 Solve Apply concepts to this problem.

- Write the skeleton equation.

$$C_2H_6O(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

- Apply the rules for balancing equations.

$$C_2H_6O(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

(balanced)

Classifying Reactions

Now that you have learned about some of the basic reaction types, you can predict the products of many reactions.

- The number of elements and/or compounds reacting is a good indicator of possible reaction type and, thus, possible products.

Classifying Reactions

In a combination reaction, two or more reactants (elements or compounds) combine to form a single product.

1 Combination Reaction

General Equation: R + S ⟶ RS

Reactants: Generally two elements, or two compounds (where at least one compound is a molecular compound)

Probable Products: A single compound

Example: Burning magnesium in air

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

Classifying Reactions

In a decomposition reaction, a single compound is the reactant; two or more substances are the products.

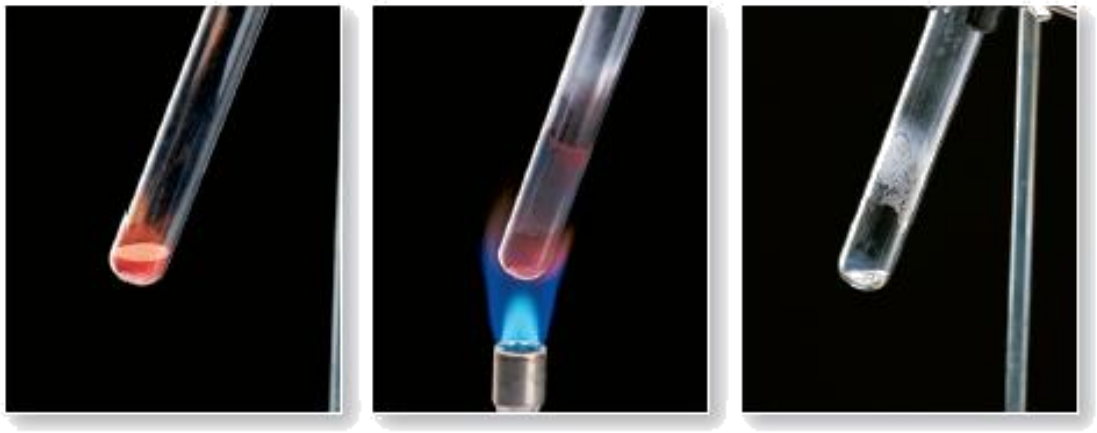
2 Decomposition Reaction

General Equation: RS ⟶ R + S

Reactants: Generally a single binary compound or a compound with a polyatomic ion

Probable Products: Two elements (for a binary compound), or two or more elements and/or compounds (for a compound with a polyatomic ion)

Example: Heating mercury(II) oxide



$$2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$$

Classifying Reactions

An element and a compound are the reactants in a single-replacement reaction.

3 Single-Replacement Reaction

General Equation: $T + RS \longrightarrow TS + R$

Reactants: An element and a compound

In a single-replacement reaction, an element replaces another element from a compound in aqueous solution. For a single-replacement reaction to occur, the element that is displaced must be less active than the element that is doing the displacing.

Probable Products: A different element and a new compound

Example: Potassium in water

$$2K(s) + 2H_2O(l) \longrightarrow 2KOH(aq) + H_2(g)$$

In a double-replacement reaction, two ionic compounds are the reactants; two new compounds are the products.

4 Double-Replacement Reaction

General Equation: $R^+ S^- + T^+ U^- \longrightarrow R^+ U^- + T^+ S^-$

Reactants: Two ionic compounds

In a double-replacement reaction, two ionic compounds react by exchanging cations to form two different compounds.

Probable Products: Two new compounds

Double-replacement reactions are driven by the formation of a precipitate, a gaseous product, or water.

Example: Reaction of aqueous solutions of potassium iodide and lead(II) nitrate.

$2KI(aq) + Pb(NO_3)_2(aq) \longrightarrow PbI_2(s) + 2KNO_3(aq)$

Classifying Reactions

The reactants in a combustion reaction are oxygen and usually a hydrocarbon. The products of most combustion reactions are carbon dioxide and water.

5 Combustion Reaction

General Equation: $C_x H_y + (x + y/4)\ O_2 \longrightarrow xCO_2 + (y/2)H_2O$

Reactants: Oxygen and a compound of C, H, (O)
When oxygen reacts with an element or compound, combustion may occur.

Probable Products: CO_2 and H_2O
With incomplete combustion, C and CO may also be products.

Example: The combustion of methane gas in air

$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$

Checkpoint

Why might you want to classify a chemical reaction?

PEARSON

Checkpoint

Why might you want to classify a chemical reaction?

Classifying a chemical reaction helps you predict what products will form.

- **The five general types of reactions are combination, decomposition, single-replacement, double-replacement, and combustion.**

- **The number of elements and/or compounds reacting is a good indicator of possible reaction type and, thus, possible products.**

- **In a combination reaction, there is always a single product.**

- **A decomposition reaction involves the breakdown of a single compound into two or more simpler substances.**
- **In a single-replacement reaction, both the reactants and the products are an element and a compound.**
- **A double-replacement reaction generally takes place between two ionic compounds in aqueous solution.**
- **A combustion reaction always involves oxygen as a reactant.**

 Glossary Terms

- **combination reaction**: a chemical change in which two or more substances react to form a single new substance; also called a synthesis reaction
- **decomposition reaction**: a chemical change in which a single compound is broken down into two or more simpler products
- **single-replacement reaction**: a chemical change in which one element replaces a second element in a compound; also called a displacement reaction

- **activity series**: a list of elements in order of decreasing activity; the activity series of halogens is Fl, Cl, Br, I
- **double-replacement reaction**: a chemical change that involves an exchange of positive ions between two compounds
- **combustion reaction**: a chemical change in which an element or a compound reacts with oxygen, often producing energy in the form of heat and light

END OF 11.2