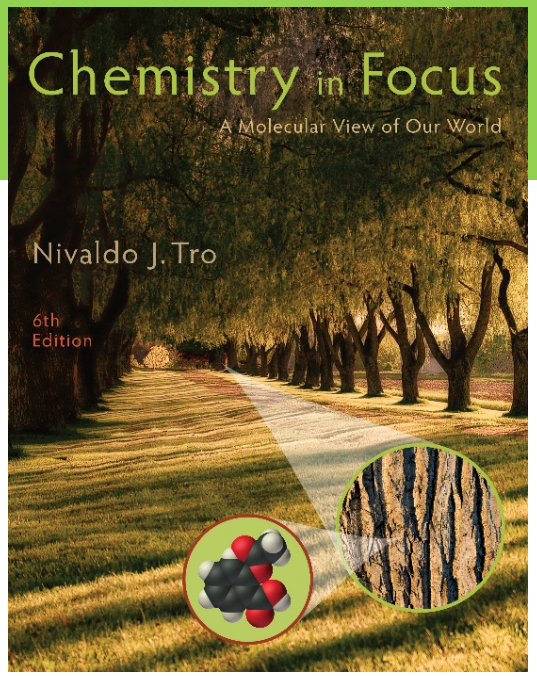
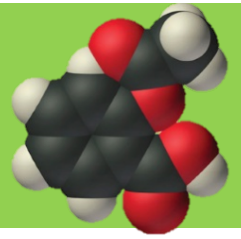


Nivaldo J. Tro

Chapter 4
Molecules, Compounds, and Chemical Reactions

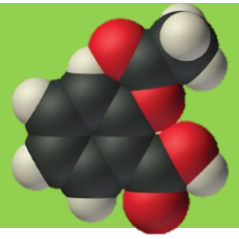
Mark Erickson • Hartwick College

Why Do Compounds Form?



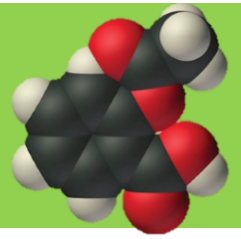
- Most elements have unstable electron configurations
- They form compounds with other elements to become more stable.
- This can be accomplished by the transfer of electrons (ionic compounds) or by the sharing of electrons (molecular compounds).

Types of Compounds

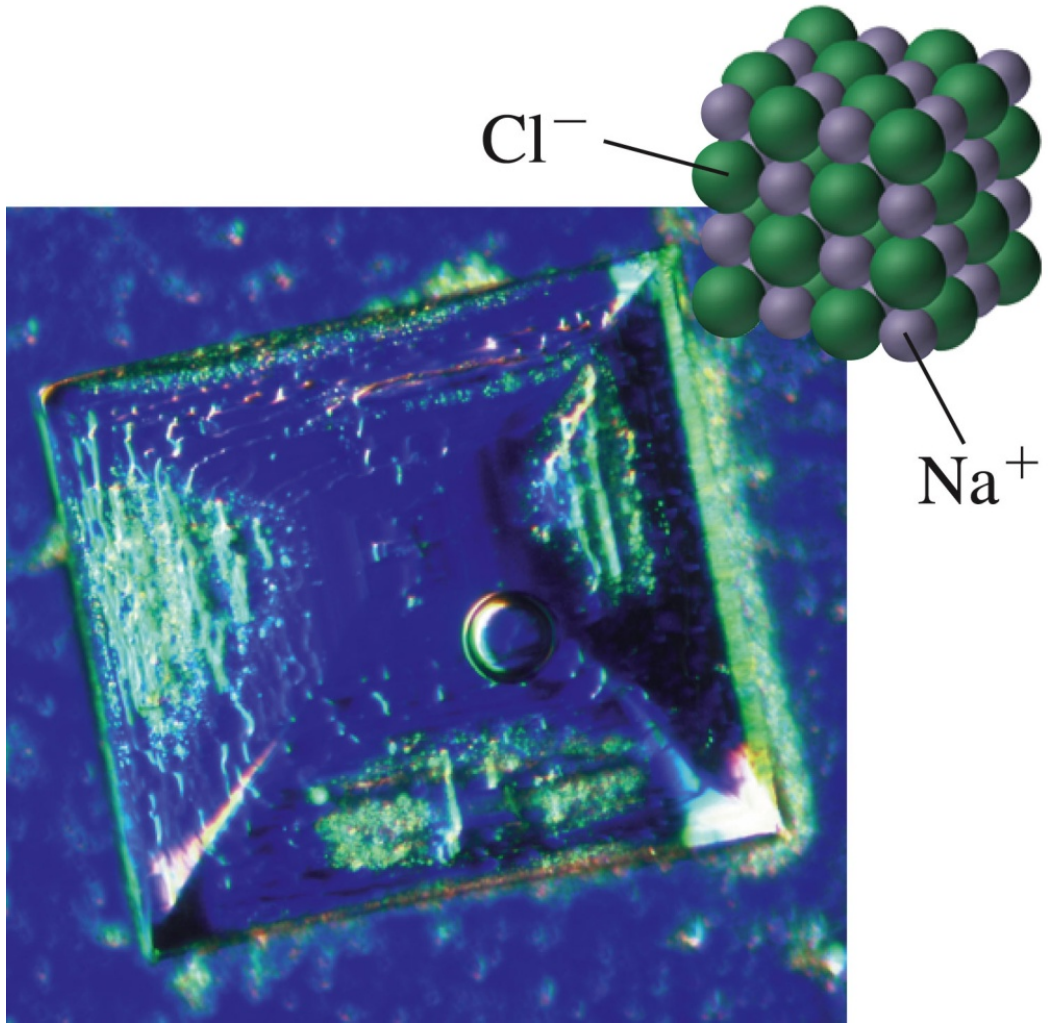


- We will study two major types of compounds in this class.
- Ionic compounds are formed when electrons are transferred from a metal to a non-metal.
- Molecular compounds are formed when atoms from two or more elements share electrons.

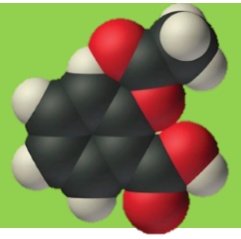
Ionic Compounds



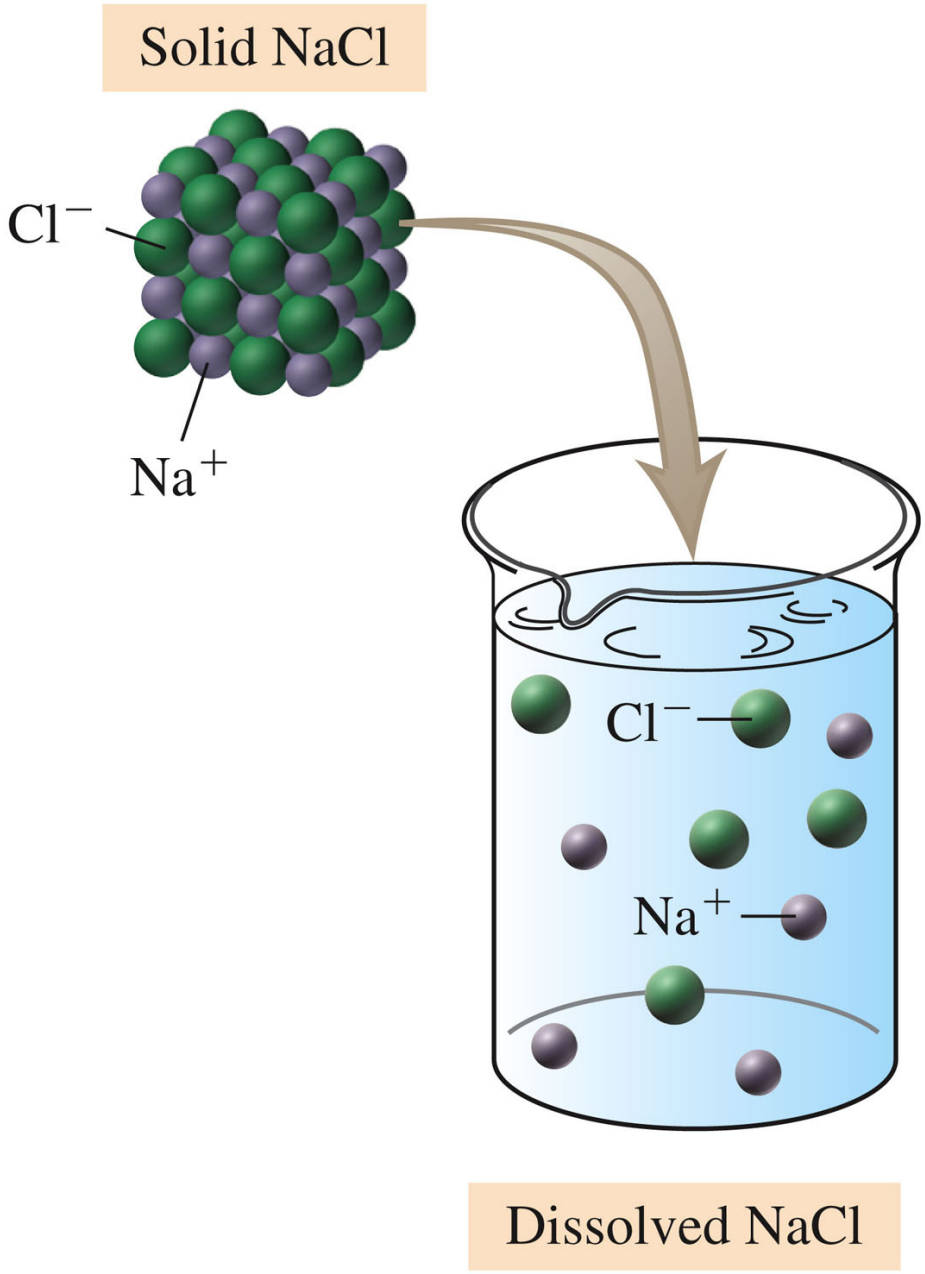
- Ionic compounds contain ions made from a metal and a non-metal.
- Metals prefer to lose electrons to become more stable.
- Nonmetals prefer to gain electrons to become more stable.



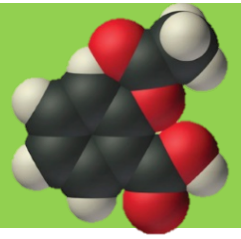
Sodium Chloride: An Ionic Compound



- Sodium chloride is an ionic compound.
- Ionic compounds are made up of ions.
- Some ionic compounds can dissolve in water.
- Aqueous solutions containing dissolved ions conduct electricity.
- Solutions that conduct electricity are called *electrolytes*.

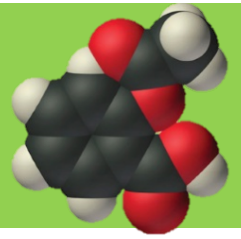


Naming Ionic Compounds



- The first word in the name is the cation.
- The cation has the name of the metal unchanged.
- The second word is the name of the anion.
- The anion has the name of the non-metal, with a slight modification:
  - bromine becomes bromide
  - oxygen becomes oxide
  - chlorine becomes chloride

Examples of Ionic Compounds

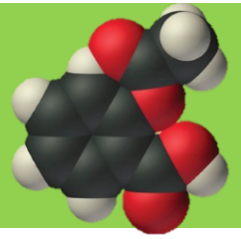


- $NaBr$ sodium bromide
- $MgBr_2$ magnesium bromide
- $NaCl$ sodium chloride
- CaO calcium oxide
- Na_2O sodium oxide
- BeI_2 beryllium iodide
- Li_3N lithium nitride
- Al_2O_3 aluminium oxide

metal ion

nonmetal ion

Practice



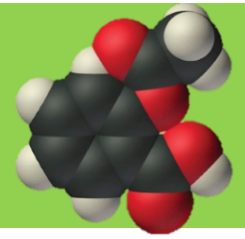
Name the following ionic compounds:

a) Li_2O

b) $CaBr_2$

c) KI

Practice

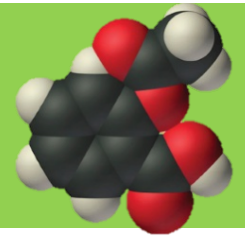


a) Li_2O: lithium + ox(ide) = **lithium oxide**

b) $CaBr_2$: calcium + brom(ide) = **calcium bromide**

c) KI: potassium + iod(ide) = **potassium iodide**

Anions Containing More Than One Atom



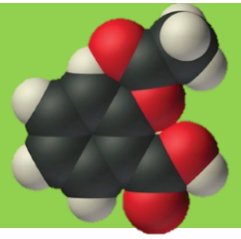
- Some anions that are composed of two or more atoms bonded together.
- The bonded atoms behave as a single ion.
- These are called *polyatomic* ions.
- Each polyatomic ion has a unique name.

TABLE 4-2

Some Common Polyatomic Ions

Name	Formula
Carbonate	CO_3^{2-}
Bicarbonate	HCO_3^-
Hydroxide	OH^-
Nitrate	NO_3^-
Phosphate	PO_4^{3-}
Sulfate	SO_4^{2-}

Examples of Ionic Compounds



- Na_2CO_3 sodium carbonate
- Li_3PO_4 lithium phosphate
- $Al(OH)_3$ aluminium oxide
- $Mg(OH)_2$ magnesium hydroxide
- Na_2SO_4 sodium sulfate

Naming Anions for Ionic Compounds

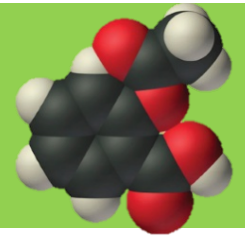


TABLE 4-1

Some Common Anions

Nonmetal	Symbol for Ion	Base Name	Anion Name
Fluorine	F^-	Fluor	Fluoride
Chlorine	Cl^-	Chlor	Chloride
Bromine	Br^-	Brom	Bromide
Iodine	I^-	Iod	Iodide
Oxygen	O^{2-}	Ox	Oxide
Sulfur	S^{2-}	Sulf	Sulfide
Nitrogen	N^{3-}	Nitr	Nitride

Tables from the Textbook

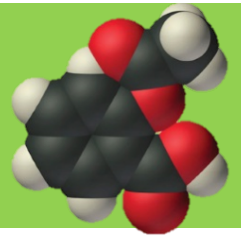


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TABLE 4-2

Some Common Polyatomic Ions

Name	Formula
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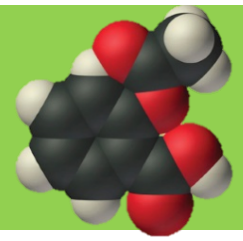
Hydroxide	OH^-
Nitrate	NO_3^-
Phosphate	PO_4^{3-}
Sulfate	SO_4^{2-}

Practice



Name the following ionic compounds

1) $Mg(OH)_2$

2) Na_2SO_4

TABLE 4-2

Some Common Polyatomic Ions

Name	Formula
Carbonate	CO_3^{2-}
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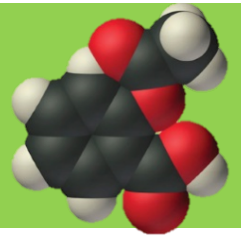
Practice

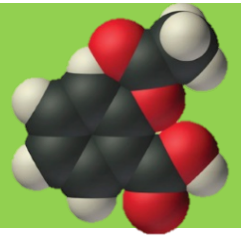


Simply combine the name of the metal and the polyatomic ion to form the name.

1) $Mg(OH)_2$: magnesium, hydroxide → magnesium hydroxide

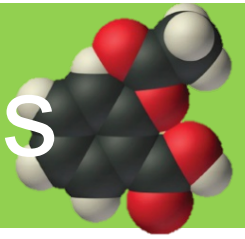
2) Na_2SO_4: sodium, sulfate → sodium sulfate

Molecular Compounds



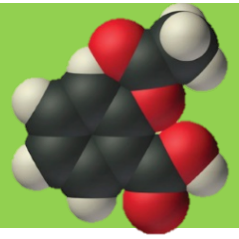
- Made up of nonmetals
- Formed when atoms share electrons
- Chemical bonds are formed between the atoms

Examples of Molecular Compounds



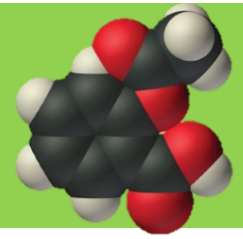
- CO_2 carbon dioxide
- CH_4 methane
- C_3H_8 propane
- C_4H_{10} butane
- C_8H_{18} octane
- $C_{12}H_{22}O_{11}$ sucrose
- H_2O water
- H_2O_2 hydrogen peroxide
- SO_2 sulfur dioxide
- NO_2 nitrogen dioxide

Practice



- Classify each compound as ionic or molecular.
  a) NaBr
  b) CO_2
  c) MgF_2
  d) CH_4

Practice



Compounds formed between a metal and at least one nonmetal are **ionic**. Compounds formed between nonmetals have a **covalent bond** and considered **molecular**.

a) NaBr: ionic

Na (metal) and Br (nonmetal)

b) SO_2: molecular

S and O (nonmetals)

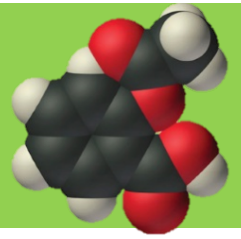
c) MgF_2

Mg (metal) and F (nonmetal)

d) CH_4

C and H (nonmetals)

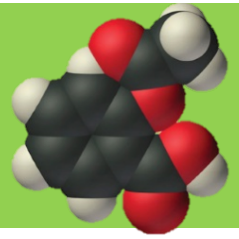
Chemical Reactions



- Compounds are created as the result of chemical reactions.
- Compounds can also undergo chemical reactions
- Chemical reactions are represented by chemical equations.
- Reactants are written on the left side of the equation.
- Products are written on the right side of the equation.
- The number/types of atoms must be balanced.

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

Types of Chemical Reactions



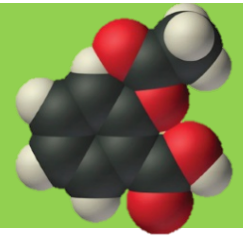
Classified according to how atoms are rearranging

- combination
- decomposition
- displacement

Classified according to what types of substances are reacting/forming

- precipitation
- combustion
- acid-base
- oxidation-reduction

Combination Reaction



- Two or more reactants <u>combine</u> to form one product

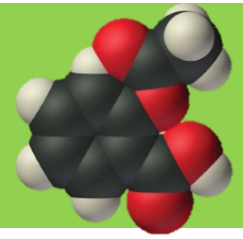
$$2Na\,(s) + Cl_2\,(g) \rightarrow 2NaCl\,(s)$$

$$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g)$$

$$N_2\,(g) + 3H_2\,(g) \rightarrow 2NH_3\,(g)$$

$$CO_2(g) + CaO(s) \rightarrow CaCO_3(s)$$

Decomposition Reaction

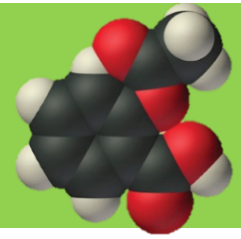


- One reactant forms more than one product

$$CaCO_3\,(s) \rightarrow CaO\,(s) + CO_2\,(g)$$

$$2NH_3\,(g) \rightarrow N_2\,(g) + 3H_2\,(g)$$

Displacement Reaction



- The cations and anions switch places

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

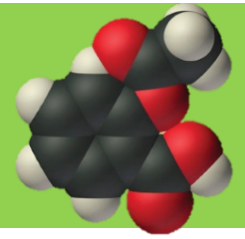
$AgNO_3\ (aq) + KCl\ (aq) \rightarrow AgCl\ (s) + KNO_3\ (aq)$ double

$Na_2SO_4\ (aq) + Pb(NO_3)_2\ (aq) \rightarrow PbSO_4\ (s) + 2NaNO_3\ (aq)$ double

This reaction also sort of looks like displacement, but there's a better name for it: combustion.

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

Precipitation Reaction

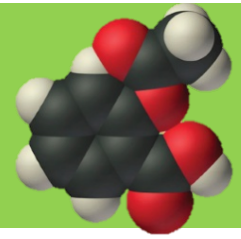


- A better name than “double displacement”
- Reactants are in aqueous (aq) solutions.
- A solid (s) product is formed.

$$AgNO_3\,(aq) + KCl\,(aq) \rightarrow AgCl\,(s) + KNO_3\,(aq)$$

$$Na_2SO_4\,(aq) + Pb(NO_3)_2\,(aq) \rightarrow PbSO_4\,(s) + 2NaNO_3\,(aq)$$

Combustion Reaction



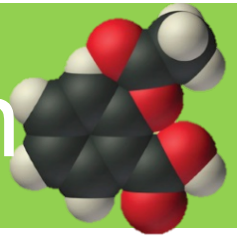
- Fuel and oxygen react
- Water and carbon dioxide are formed

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

$$C_3H_8\,(g) + 5O_2\,(g) \rightarrow 3CO_2\,(g) + 4H_2O\,(g)$$

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

Acids-Base (Neutralization) Reaction

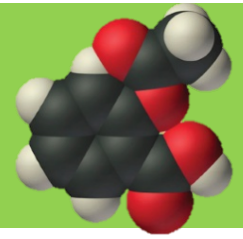


- Involves an acid and a base
- Reaction form water and a salt
- This type called *neutralization reactions*

acid + base → water + salt

$HCl + KOH \rightarrow H_2O + KCl$

Oxidation-Reduction Reactions

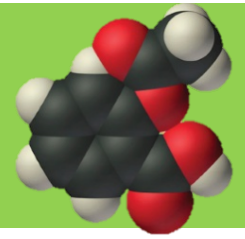


- The charge of an element on the reactant side is different than that on the product side.
- The element has gained or lost electrons during the reaction.
- Pure elements have a charge of zero.

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

$$2Cu\ (s) + O_2\ (g) \rightarrow 2CuO\ (g)$$

Combination Reaction, or…



- Combination reactions can be <u>combustion</u> or <u>oxidation-reduction</u>

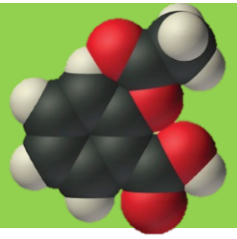
$2Na\,(s) + Cl_2\,(g) \rightarrow 2NaCl\,(g)$ *oxidation-reduction*

$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g)$ *combustion*

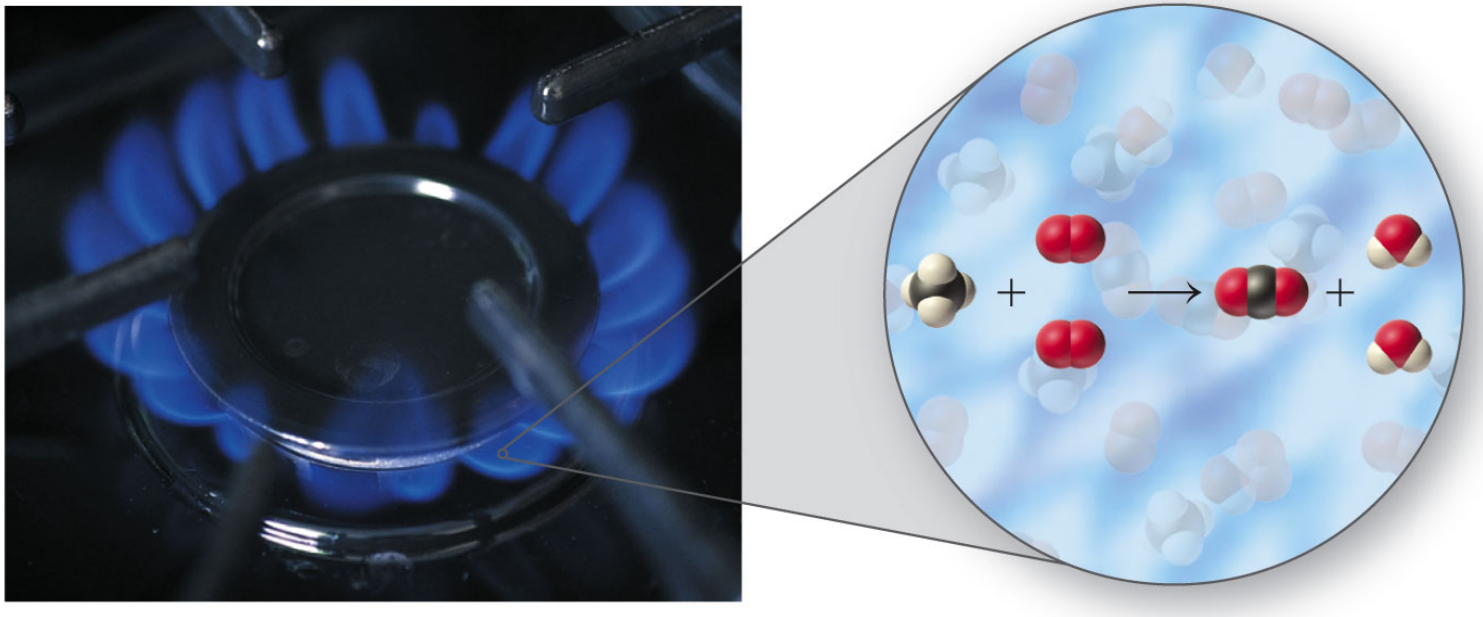
$N_2\,(g) + 3H_2\,(g) \rightarrow 2NH_3\,(g)$ *oxidation-reduction*

$CO_2(g) + CaO(s) \rightarrow CaCO_3(s)$ *oxidation-reduction*

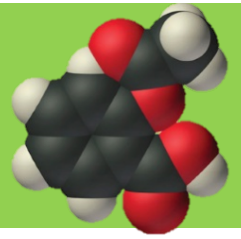
Chemical Reactions

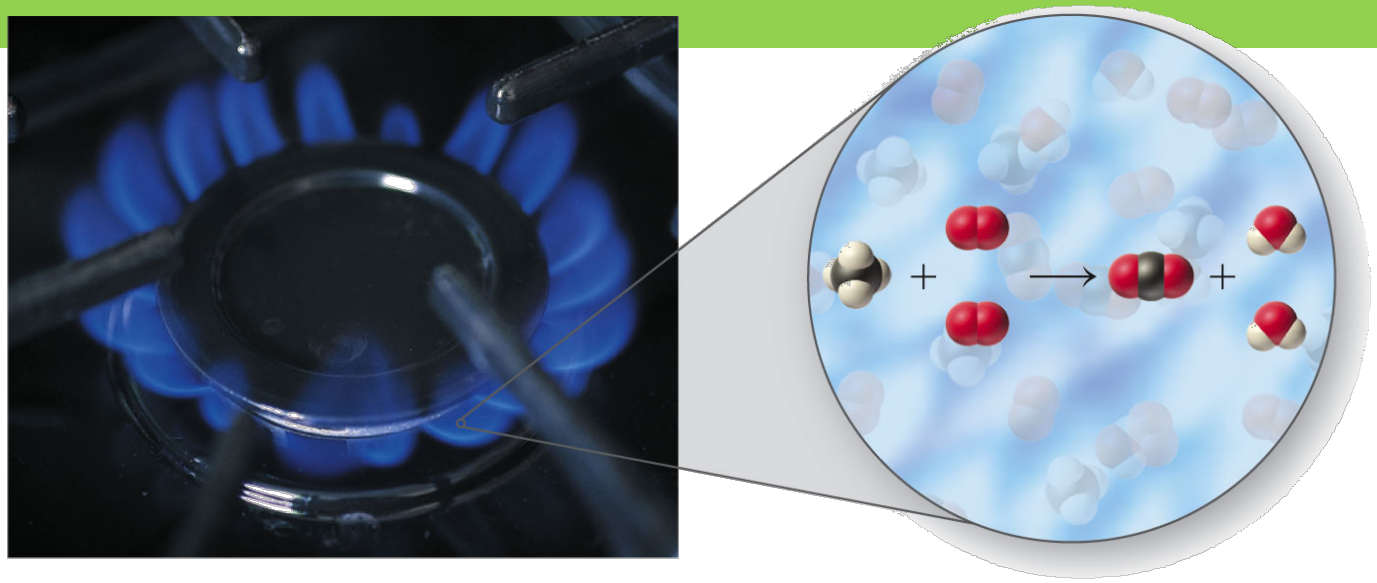


- Compounds exist as the result of chemical reactions.
- Compounds can also undergo chemical reactions
- Chemical reactions are represented by chemical equations.
- For example, *methane gas burns*.



Writing Chemical Equations



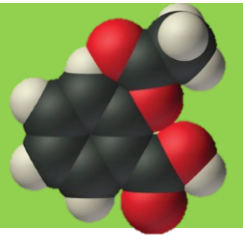


When oxygen gas is present, methane gas burns to produce carbon dioxide gas and water vapor.

methane (g) + oxygen (g) → carbon dioxide (g) + water (g)

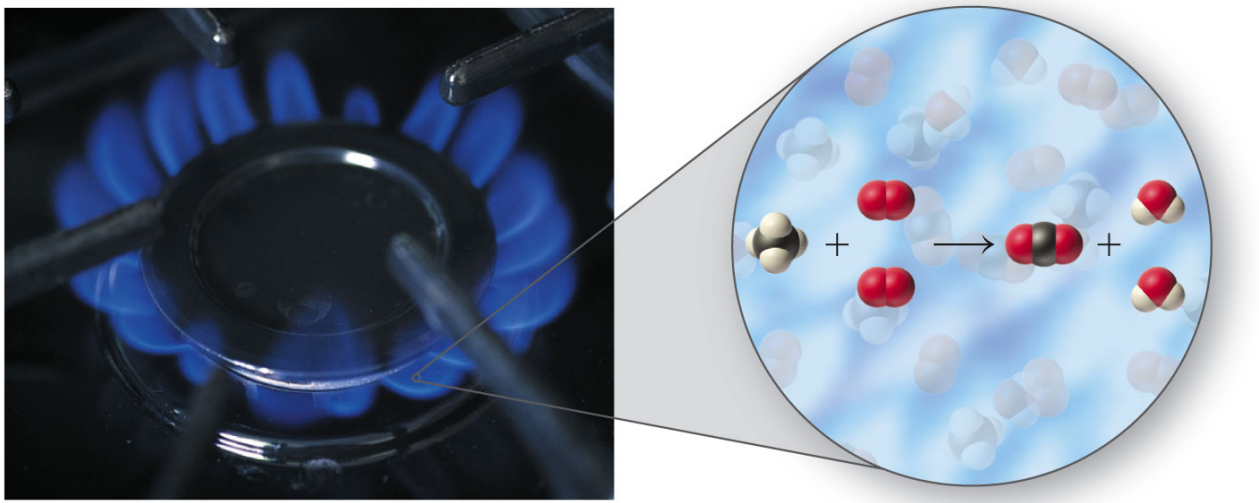
$$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (g)$$

Writing Chemical Equations

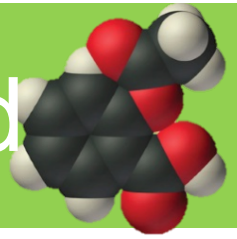


- Reactants are written on the left side of the equation.
- Products are written on the right side of the equation.
- The number and types of each atom must be the same on both sides (balanced) because matter is conserved.

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



Chemical Equations Must Be Balanced

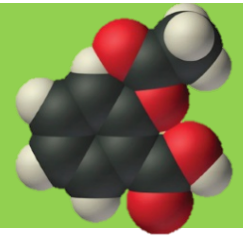


- Unbalanced:
  - $CH_4 + O_2 \rightarrow CO_2 + H_2O$

- Add coefficients to the reactants, and products make the number of atoms of each type of element on both sides of the equation equal.
- This changes the *number* of atoms and molecules involved in the reaction, but not the *types* of atoms and molecules.

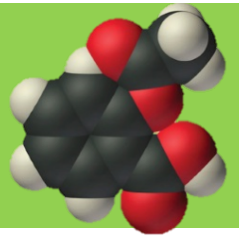
- Balanced:
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Balancing Guidelines



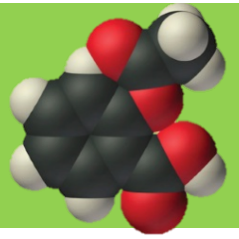
- If an element occurs in only one compound, balance that element first.
- If an element occurs as a free element, balance that element last.
- Change only coefficients, never subscripts.
- Eliminate fractions; use the lowest whole number ratio of coefficients.

Combustion Reactions



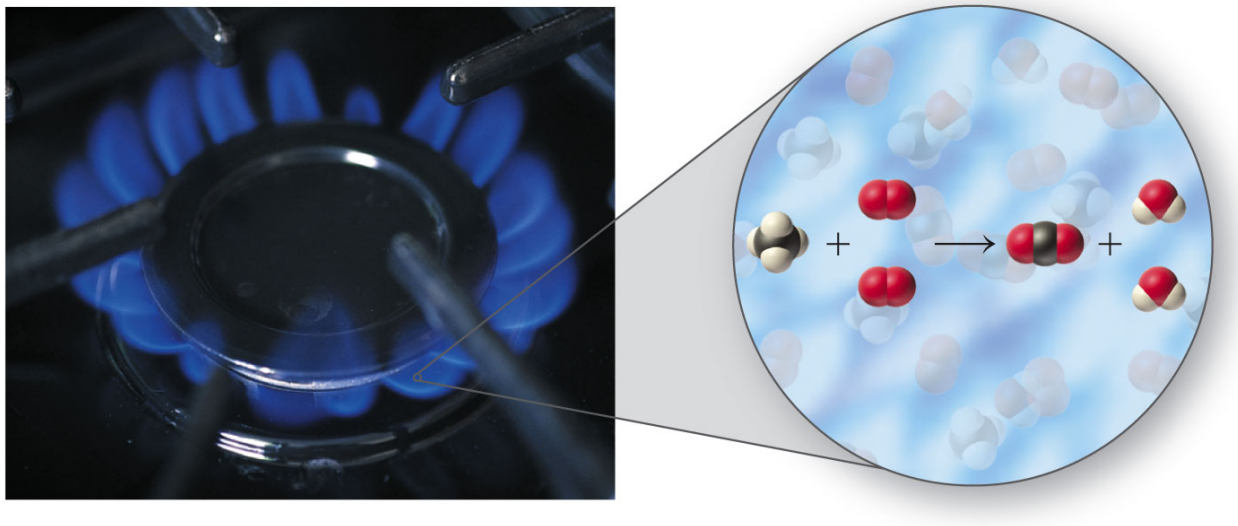
- A forest fire is a chemical reaction that's out of control.
  - Oxygen is needed.
  - Fuel is a reactant.
  - What are the products?

Combustion Reactions

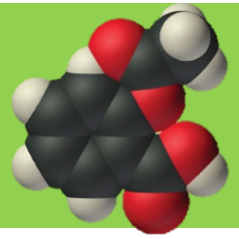


- The reaction of methane and oxygen is a combustion reaction.

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



Combustion Reactions

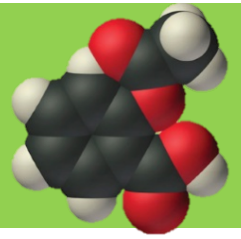


- Propane, C_3H_8, is often used as a fuel for home heating and cooking.
- Propane burns in oxygen to produce carbon dioxide (CO_2) and water (H_2O).

$$C_3H_8\,(g) + 5O_2\,(g) \rightarrow 3CO_2\,(g) + 4H_2O\,(g)$$

Propane (C_3H_8), used as a fuel

Practice



- The unbalanced equation:

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

- First, balance the elements present in only one compound on each side of the equation.

$$\mathbf{C_3}H_8 + O_2 \rightarrow \underline{\mathbf{3}}\mathbf{C}O_2 + H_2O \qquad \text{3 C's on each side}$$

$$C_3\mathbf{H_8} + O_2 \rightarrow 3CO_2 + \underline{\mathbf{4}}\mathbf{H_2}O \qquad \text{8 H's on each side}$$

- Balance the element present as a free element last.

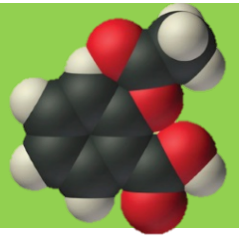
$$C_3H_8 + \underline{\mathbf{5}}\mathbf{O_2} \rightarrow \mathbf{3}CO_2 + \mathbf{4}H_2\mathbf{O} \qquad \text{10 O's on each side}$$

- Final balanced equation:

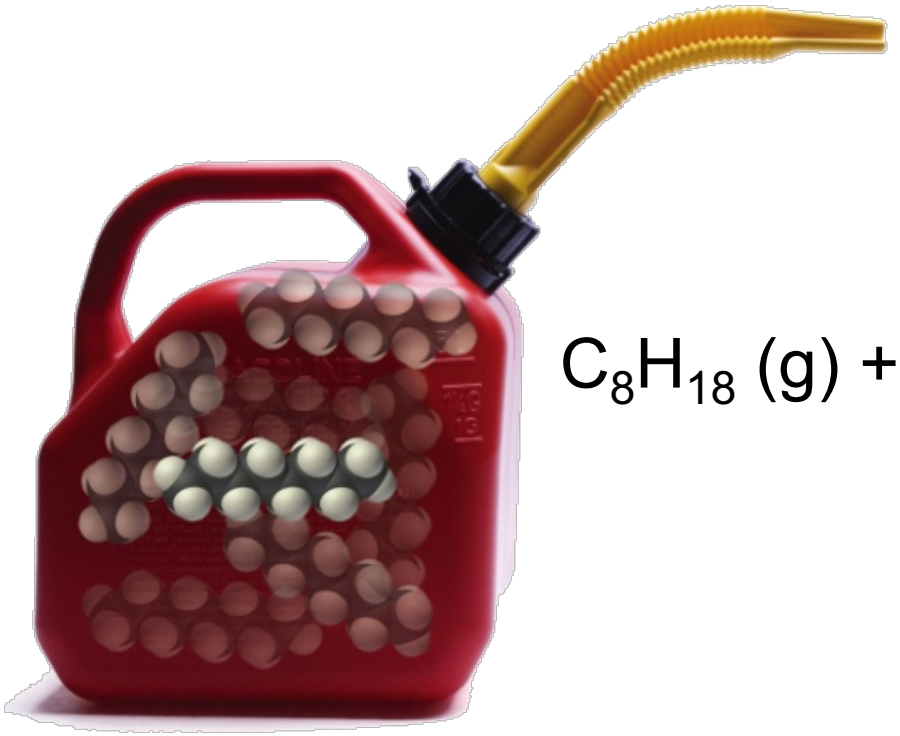
$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Note: The absence of coefficient in front of a reactant or product implies a "1".

Combustion Reactions



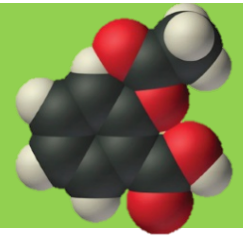
- Octane, C_8H_{18}, is called *gasoline* and is often used as a fuel for automobiles.
- Octane burns in oxygen to produce carbon dioxide (CO_2) and water (H_2O).



Octane (C_8H_{18}), a major component of gasoline

$$C_8H_{18}\,(g) + 12.5\,O_2\,(g) \rightarrow 8\,CO_2\,(g) + 9\,H_2O\,(g)$$

Combustion Reactions

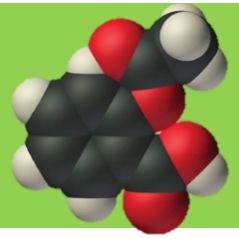


$$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (g)$$

$$C_3H_8\ (g) + 5O_2\ (g) \rightarrow 3CO_2\ (g) + 4H_2O\ (g)$$

$$C_8H_{18}\ (g) + 12.5\ O_2\ (g) \rightarrow 8\ CO_2\ (g) + 9\ H_2O\ (g)$$

Combustion Reactions



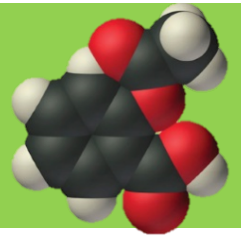
- It is acceptable to convert fractions to whole numbers.

$$C_8H_{18}\,(g) + 12.5\,O_2\,(g) \rightarrow 8\,CO_2\,(g) + 9\,H_2O\,(g)$$

$$2 \times (\; C_8H_{18}\,(g) + 12.5\,O_2\,(g) \rightarrow 8\,CO_2\,(g) + 9\,H_2O\,(g)\;)$$

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

Summary



- Chemical compounds
- Ionic and covalent compounds
- Chemical reactions
- Chemical equations
- Reactants and products