

Lecture Presentation

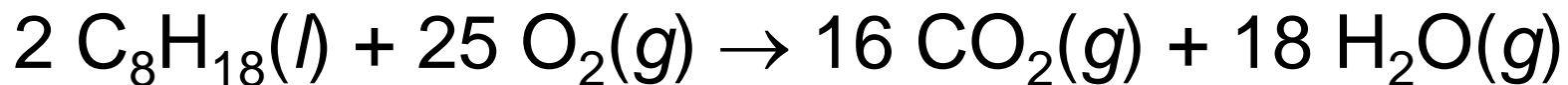
Chemical Quantities and Aqueous Reactions

Quantities in Chemical Reactions

- The amount of every substance used and made in a chemical reaction is related to the amounts of all the other substances in the reaction.
 - Law of conservation of mass
 - Balancing equations by balancing atoms
- The study of the numerical relationship between chemical quantities in a chemical reaction is called **stoichiometry**.

Reaction Stoichiometry

- **The coefficients in a chemical reaction specify the relative amounts in moles of each of the substances involved in the reaction.**



– 2 molecules of C_8H_{18} react with 25 molecules of O_2 to form 16 molecules of CO_2 and 18 molecules of H_2O .

– 2 moles of C_8H_{18} react with 25 moles of O_2 to form 16 moles of CO_2 and 18 moles of H_2O .

2 mol C_8H_{18} : 25 mol O_2 : 16 mol CO_2 : 18 mol H_2O

Making Pizza

- The number of pizzas you can make depends on the amount of the ingredients you use.

1 crust + 5 oz tomato sauce + 2 cups cheese → 1 pizza

This relationship can be expressed mathematically.

1 crust : 5 oz sauce : 2 cups cheese : 1 pizza

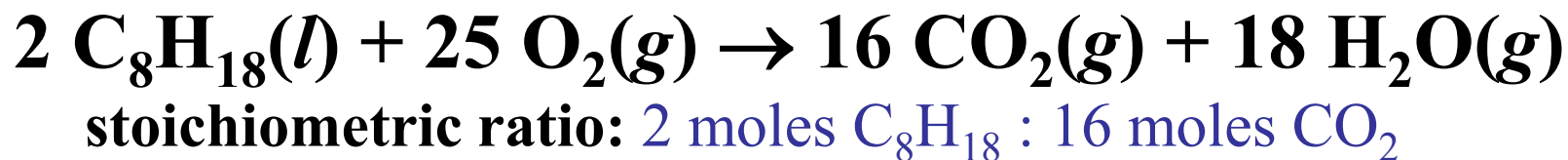
- We can compare the amount of pizza that can be made from 10 cups of cheese:
 - Since 2 cups cheese : 1 pizza, then,

$$10 \text{ cups cheese} \times \frac{1 \text{ pizza}}{2 \text{ cups cheese}} = 5 \text{ pizzas}$$

Making Molecules: Mole-to-Mole Conversions

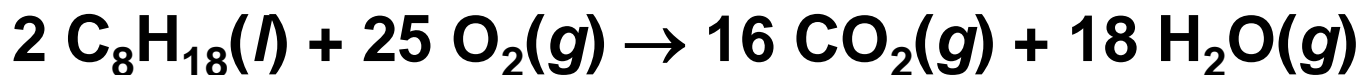
- We use the ratio from the balanced chemical equation in the same way that we used the ratio from the pizza recipe.

The ratio of the coefficients acts as a conversion factor between the amount in moles of the reactants and products.



The ratio acts as a conversion factor between the amount in moles of the reactant C_8H_{18} and the amount in moles of the product CO_2 .

Suppose That We Burn 22.0 Moles of C_8H_{18} ; How Many Moles of CO_2 Form?



stoichiometric ratio: 2 moles C_8H_{18} : 16 moles CO_2

$$22.0 \text{ mol } \cancel{C_8H_{18}} \times \frac{16 \text{ mol } CO_2}{2 \cancel{\text{ mol } C_8H_{18}}} = 176 \text{ mol } CO_2$$

The combustion of 22 moles of C_8H_{18} adds 176 moles of CO_2 to the atmosphere.

Limiting Reactant, Theoretical Yield

- Recall our pizza recipe:

1 crust + 5 oz tomato sauce + 2 cups cheese → 1 pizza

- If we have 4 crusts, 10 cups of cheese, and 15 oz tomato sauce. How many pizzas can we make?

We have enough crusts to make $4 \text{ crusts} \times \frac{1 \text{ pizza}}{1 \text{ crust}} = 4 \text{ pizzas}$

We have enough cheese to make $10 \text{ cups cheese} \times \frac{1 \text{ pizza}}{2 \text{ cups cheese}} = 5 \text{ pizzas}$

We have enough tomato sauce to make

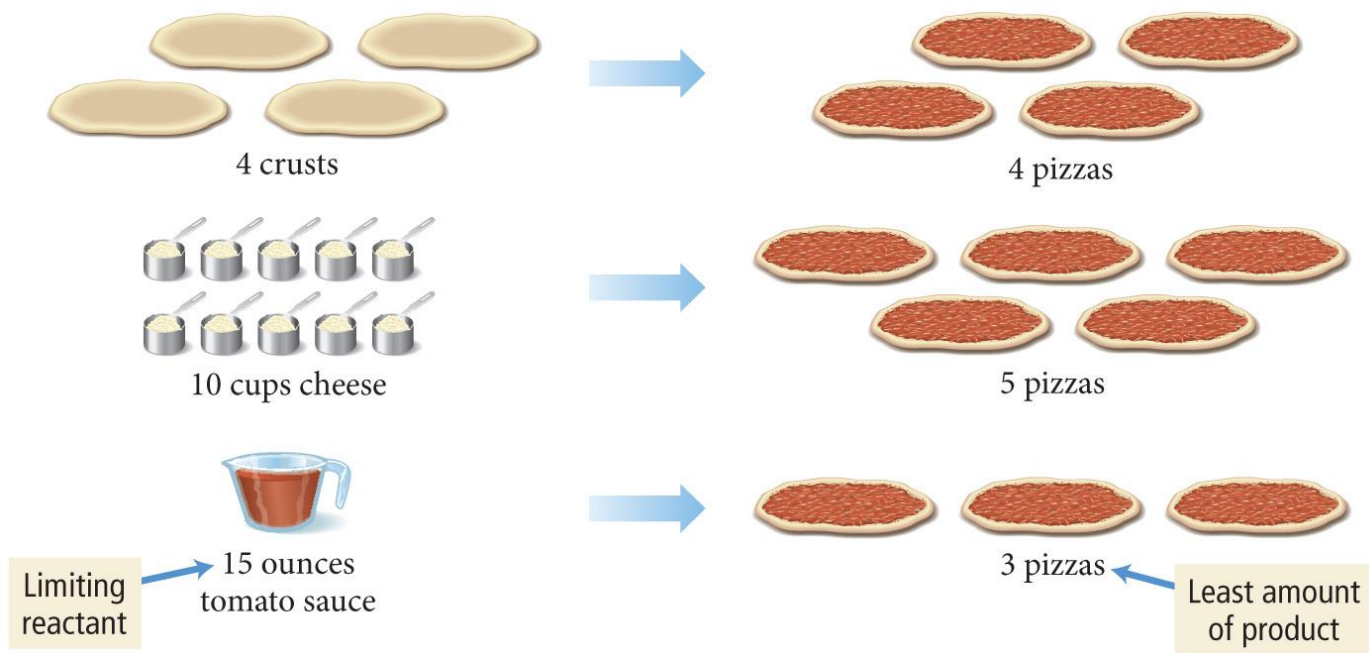
$$15 \text{ ounces tomato sauce} \times \frac{1 \text{ pizza}}{5 \text{ ounces tomato sauce}} = 3 \text{ pizzas}$$

Limiting reactant

Smallest number of pizzas

Limiting Reactant

- We have enough crusts for four pizzas, enough cheese for five pizzas, but enough tomato sauce for only three pizzas.
 - We can make only three pizzas. The tomato sauce *limits* how many pizzas we can make.



Theoretical Yield

- Tomato sauce is the **limiting reactant**, the reactant that makes *the least amount of product*.
 - The limiting reactant is also known as the *limiting reagent*.
- The maximum number of pizzas we can make depends on this ingredient. In chemical reactions, we call this the **theoretical yield**.
 - This is the amount of product that can be made in a chemical reaction based on the amount of limiting reactant.
 - The ingredient that makes the least amount of pizza determines how many pizzas you can make (**theoretical yield**).

In a Chemical Reaction

- For reactions with multiple reactants, it is likely that one of the reactants will be completely used before the others.
- When this reactant is used up, the reaction stops and no more product is made.
- The reactant that limits the amount of product is called the **limiting reactant**.
 - It is sometimes called the limiting reagent.
 - The limiting reactant gets completely consumed.
- Reactants not completely consumed are called **excess reactants**.
- The amount of product that can be made from the limiting reactant is called the **theoretical yield**.

More Making Pizzas

Assume that while making pizzas, we burn a pizza, drop one on the floor, or other uncontrollable events happen so that we only make two pizzas. The actual amount of product made in a chemical reaction is called the **actual yield**.

We can determine the efficiency of making pizzas by calculating the percentage of the maximum number of pizzas we actually make. In chemical reactions, we call this the **percent yield**.

$$\% \text{ yield} = \frac{2 \text{ pizzas}}{3 \text{ pizzas}} \times 100\% = 67\%$$

Summarizing Limiting Reactant and Yield

- **The limiting reactant (or limiting reagent)** is the reactant that is completely consumed in a chemical reaction and limits the amount of product.
- **The reactant in excess** is any reactant that occurs in a quantity greater than is required to completely react with the limiting reactant.

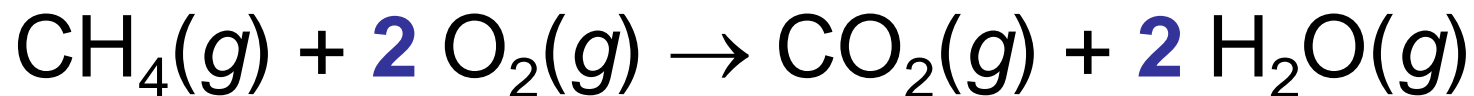
Summarizing Limiting Reactant and Yield

- **The theoretical yield** is the amount of product that can be made in a chemical reaction based on the amount of limiting reactant.
- **The actual yield** is the amount of product actually produced by a chemical reaction.
- **The percent yield** is calculated as follows:

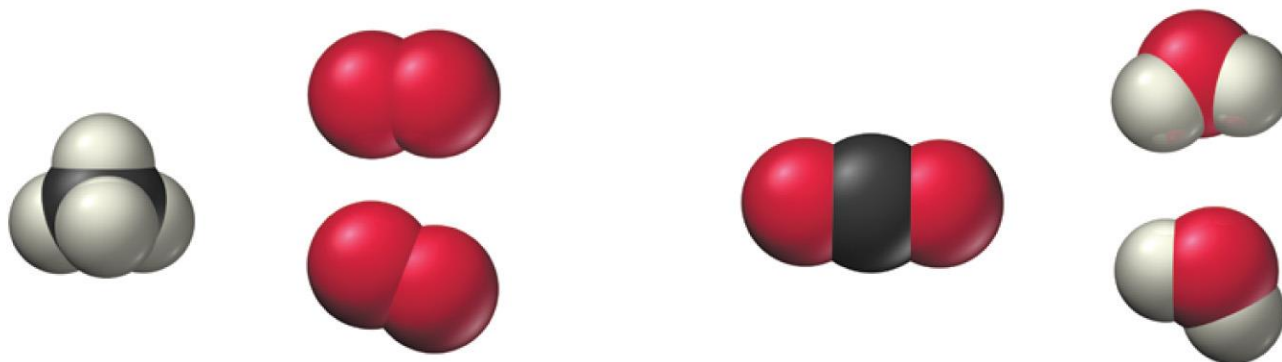
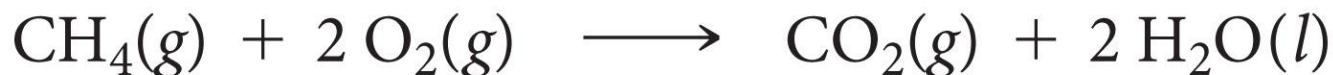
$$\frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

Apply These Concepts to a Chemical Reaction

- Recall our balanced equation for the combustion of methane:

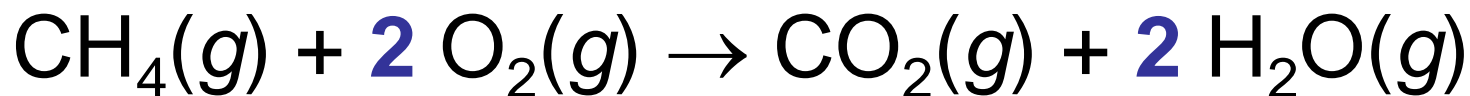


- Our balanced equation for the combustion of methane implies that every one molecule of CH_4 reacts with two molecules of O_2 .

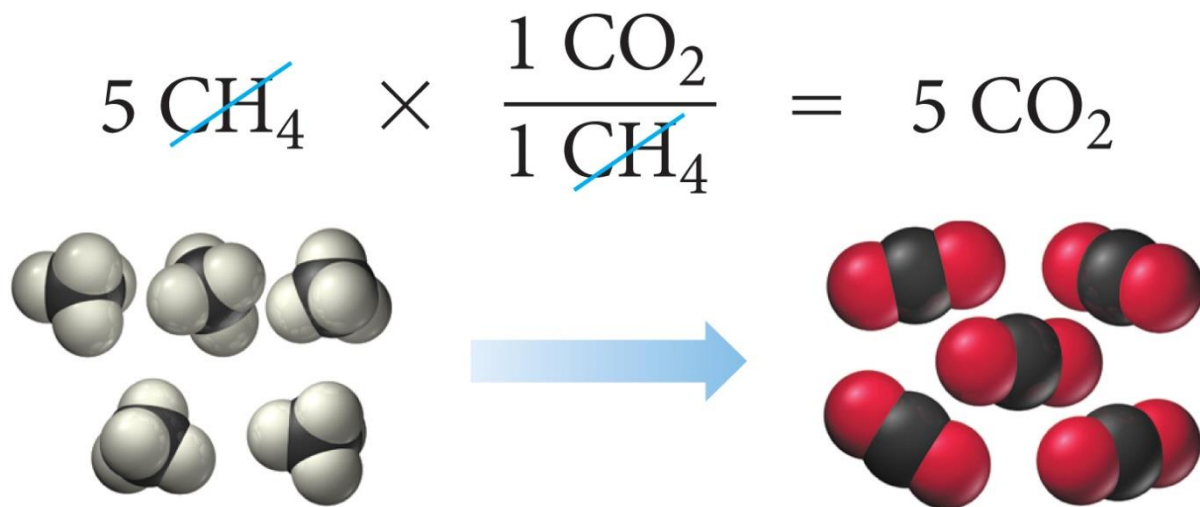


Combustion of Methane

- If we have five molecules of CH_4 and eight molecules of O_2 , which is the limiting reactant?

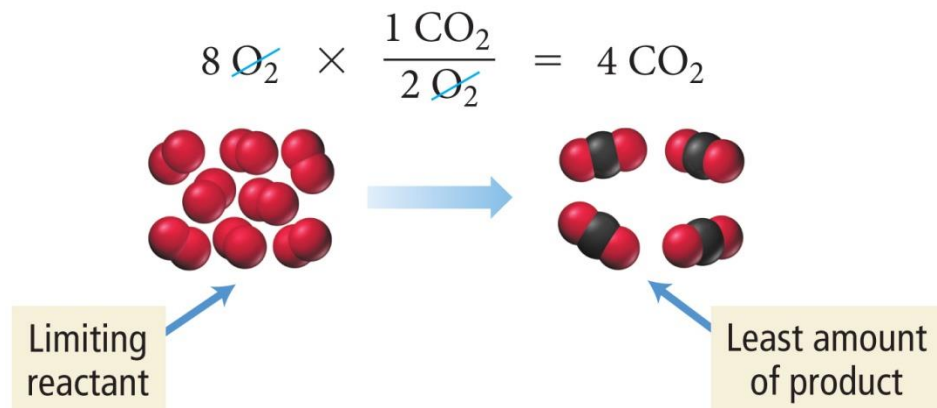


- First we calculate the number of CO_2 molecules that can be made from 5 CH_4 molecules.



Combustion of Methane

- Then we calculate the number of CO₂ molecules that can be made from 8 O₂ molecules.



- We have enough CH₄ to make 5 CO₂ molecules and 4 CO₂ molecules.
- Therefore, O₂ is the limiting reactant, and 4 CO₂ molecules is the theoretical yield.
- CH₄ is in excess.

Solution Concentration and Solution Stoichiometry

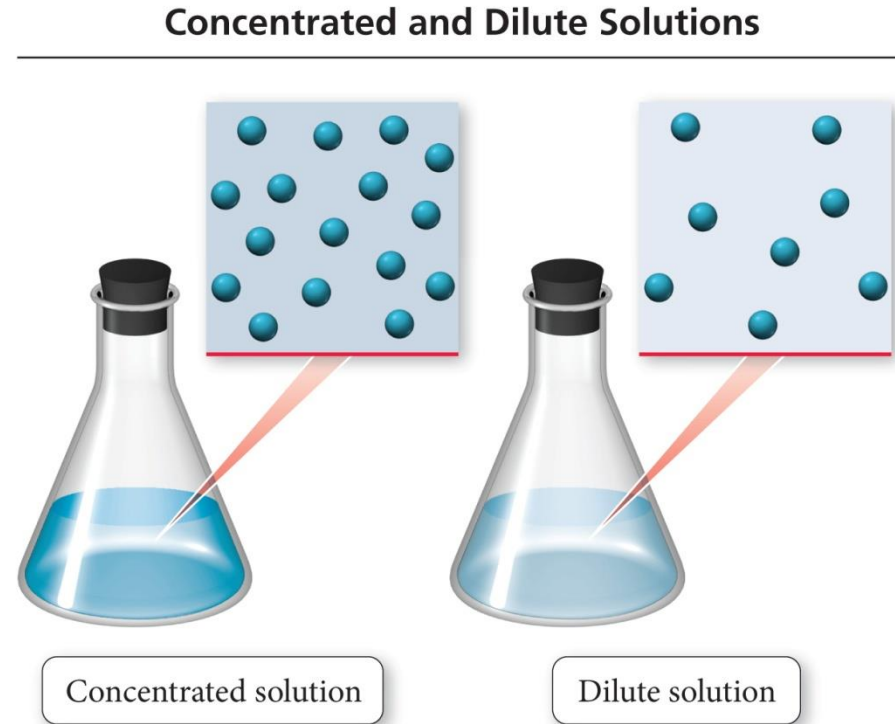
- When table salt is mixed with water, it seems to disappear or become a liquid, the mixture is homogeneous.
 - The salt is still there, as you can tell from the taste or simply boiling away the water.
- Homogeneous mixtures are called **solutions**.
- The component of the solution that changes state is called the **solute**.
- The component that keeps its state is called the **solvent**.
 - If both components start in the same state, the major component is the solvent.

Solution Concentration

- Because solutions are mixtures, the composition can vary from one sample to another.
 - Pure substances have constant composition.
 - Saltwater samples from different seas or lakes have different amounts of salt.
- So to describe solutions accurately, we must describe how much of each component is present.
 - We saw that with pure substances, we can describe them with a single name because all samples are identical.

Solution Concentration

- Solutions are often described quantitatively, as dilute or concentrated.
- **Dilute solutions** have a small amount of solute compared to solvent.
- **Concentrated solutions** have a large amount of solute compared to solvent.



Solution Concentration: Molarity

- A common way to express solution concentration is **molarity (M)**.
 - Molarity is the amount of solute (in moles) divided by the volume of solution (in liters).

$$\text{Molarity (M)} = \frac{\text{amount of solute (in mol)}}{\text{volume of solution (in L)}}$$

Preparing 1 L of a 1.00 M NaCl Solution

Preparing a Solution of Specified Concentration

The diagram illustrates the process of preparing a 1.00 M NaCl solution in three stages:

- Step 1:** Weighing and adding 1.00 mol of NaCl. A vial labeled "2.5g" pours white crystals into a funnel, which is placed over a volumetric flask. The flask contains "1.00 mol NaCl (58.44 g)".
- Step 2:** Adding water. A beaker pours water into the flask. A red arrow points to the water level with the text: "Add water until solid is dissolved. Then add additional water until the 1-liter mark is reached." The flask is labeled "Water".
- Step 3:** Mixing. An arrow labeled "Mix" points to the final volumetric flask, which contains a clear blue liquid. A yellow box below it says: "A 1.00 molar NaCl solution".

Using Molarity in Calculations

- We can use the molarity of a solution as a conversion factor between moles of the solute and liters of the solution.
 - For example, a 0.500 M NaCl solution contains 0.500 mol NaCl for every liter of solution.

$$\frac{0.500 \text{ mol NaCl}}{\text{L solution}}$$

converts

L solution



mol NaCl

$$\frac{\text{L solution}}{0.500 \text{ mol NaCl}}$$

converts

mol NaCl



L solution

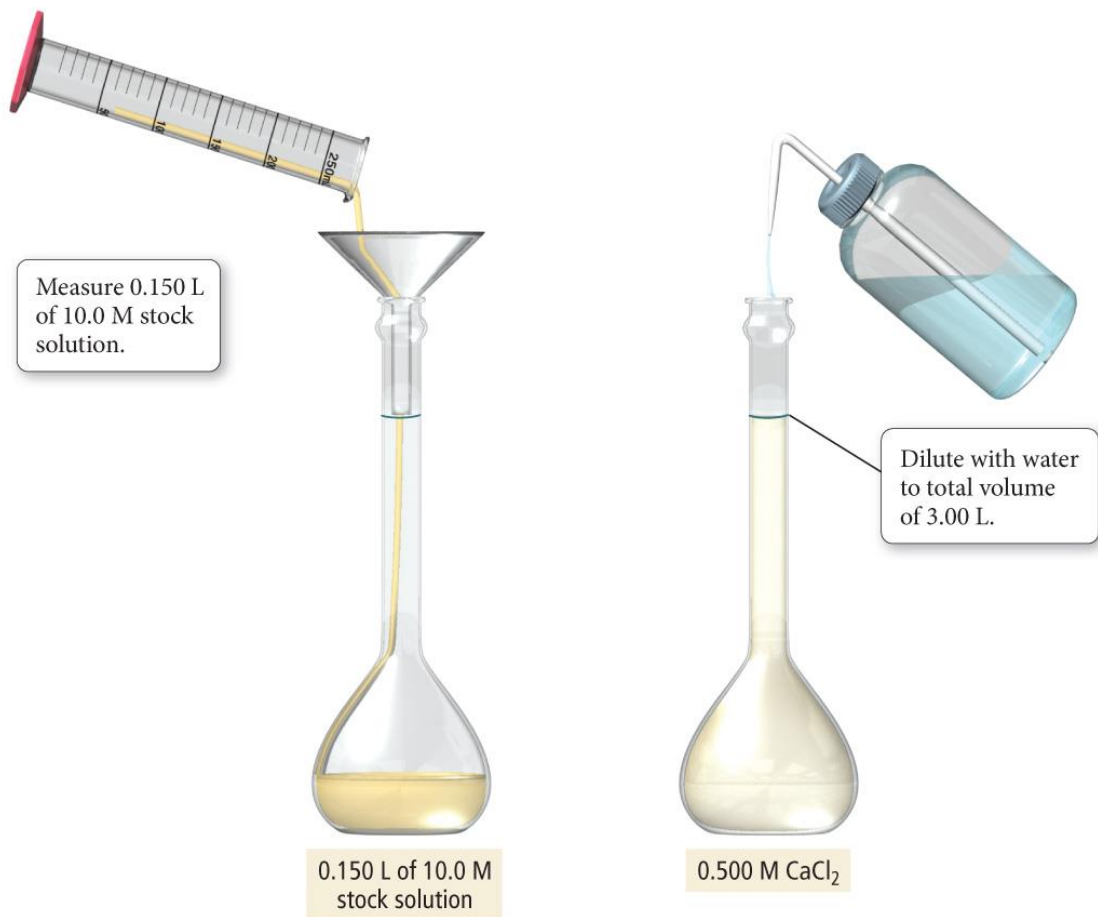
Solution Dilution

- Often, solutions are stored as concentrated **stock solutions**.
- To make solutions of lower concentrations from these stock solutions, more solvent is added.
 - The amount of solute doesn't change, just the volume of solution:
moles solute in solution 1 = moles solute in solution 2
- The concentrations and volumes of the stock and new solutions are inversely proportional:

$$M_1 \cdot V_1 = M_2 \cdot V_2$$

Preparing 3.00 L of 0.500 M CaCl₂ from a 10.0 M Stock Solution

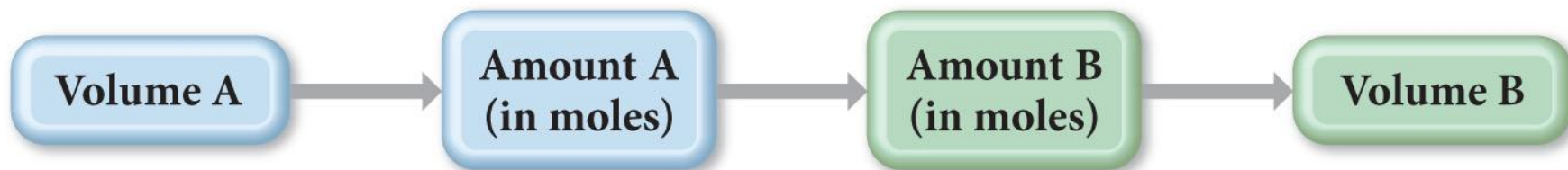
Diluting a Solution



$$M_1V_1 = M_2V_2$$
$$\frac{10.0 \text{ mol}}{\cancel{\text{L}}} \times 0.150\cancel{\text{L}} = \frac{0.500 \text{ mol}}{\cancel{\text{L}}} \times 3.00\cancel{\text{L}}$$
$$1.50 \text{ mol} = 1.50 \text{ mol}$$

Solution Stoichiometry

- Because molarity relates the moles of solute to the liters of solution, it can be used to convert between amount of reactants and/or products in a chemical reaction.
 - The general conceptual plan for these kinds of calculations begins with the volume of a reactant or product.



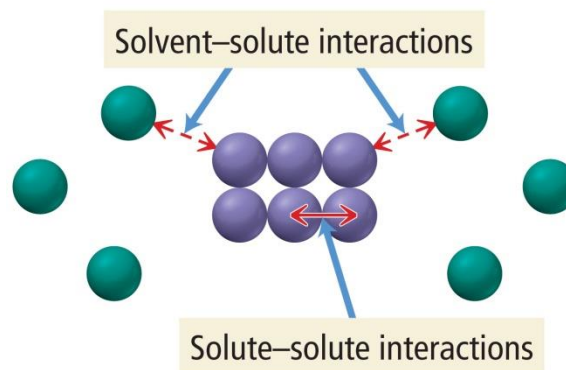
Types of Aqueous Solutions and Solubility

- Consider two familiar aqueous solutions: salt water and sugar water.
 - Salt water is a homogeneous mixture of NaCl and H₂O.
 - Sugar water is a homogeneous mixture of C₁₂H₂₂O₁₁ and H₂O.
- As you stir either of these two substances into the water, it seems to disappear.
 - How do solids such as salt and sugar dissolve in water?

What Happens When a Solute Dissolves?

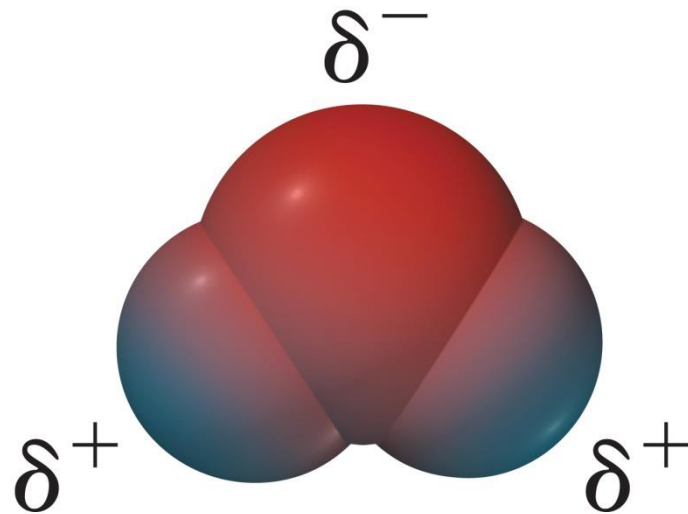
- There are attractive forces between the solute particles holding them together.
- There are also attractive forces between the solvent molecules.
- When we mix the solute with the solvent, there are attractive forces between the solute particles and the solvent molecules.
- If the attractions between solute and solvent are strong enough, the solute will dissolve.

Solute and Solvent Interactions



Charge Distribution in a Water Molecule

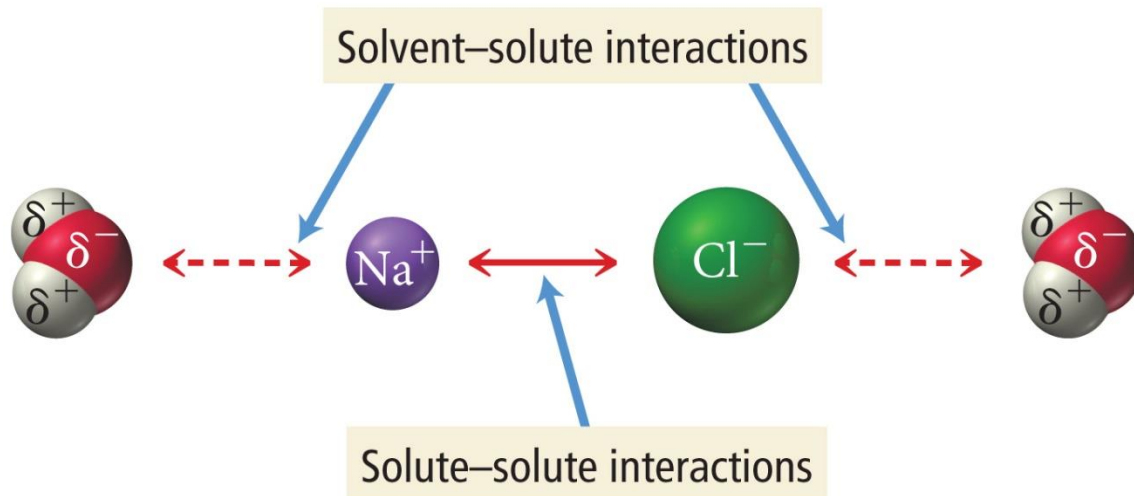
- There is an uneven distribution of electrons within the water molecule.
 - This causes the oxygen side of the molecule to have a partial negative charge (δ^-) and the hydrogen side to have a partial positive charge (δ^+).



Solute and Solvent Interactions in a Sodium Chloride Solution

- When sodium chloride is put into water, the attraction of Na^+ and Cl^- ions to water molecules competes with the attraction among the oppositely charged ions themselves.

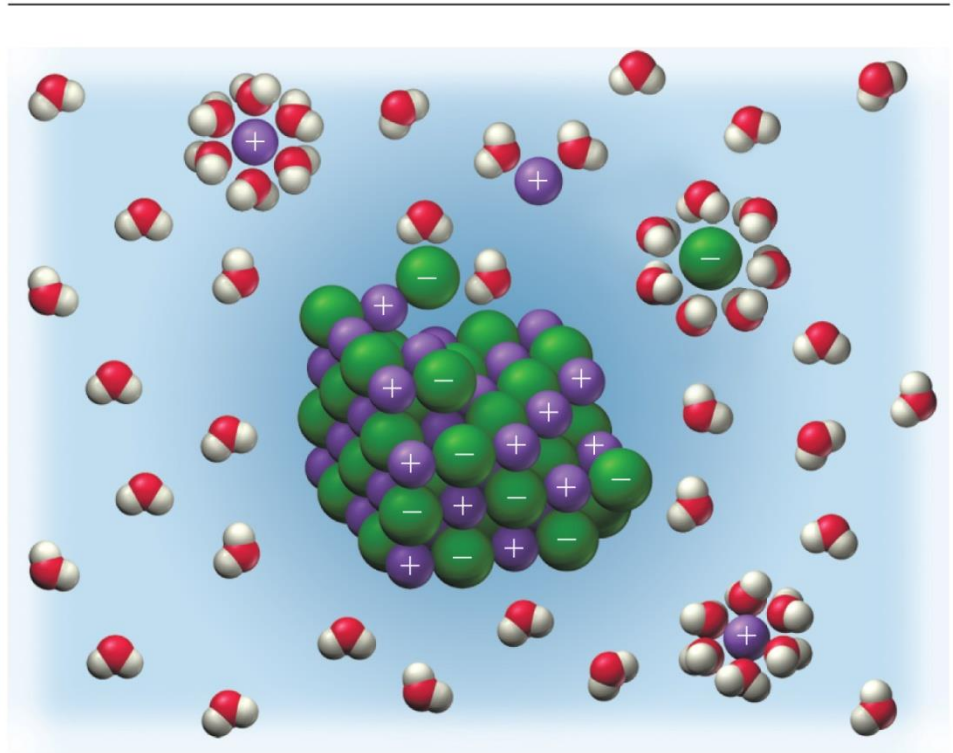
Interactions in a Sodium Chloride Solution



Sodium Chloride Dissolving in Water

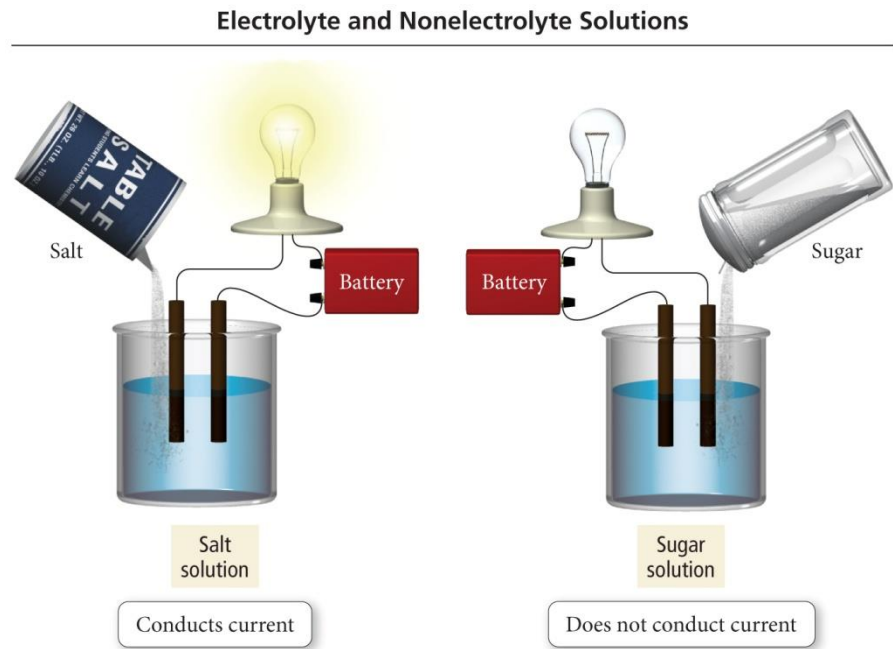
- Each ion is attracted to the surrounding water molecules and pulled off and away from the crystal.
- When it enters the solution, the ion is surrounded by water molecules, insulating it from other ions.
- The result is a solution with free moving charged particles able to conduct electricity.

Dissolution of an Ionic Compound



Electrolyte and Nonelectrolyte Solutions

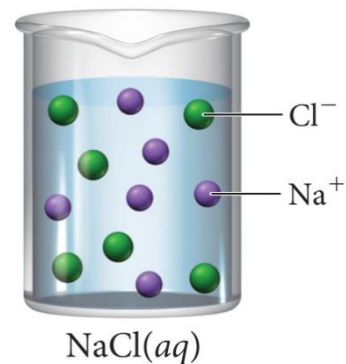
- Materials that dissolve in water to form a solution that will conduct electricity are called **electrolytes**.
- Materials that dissolve in water to form a solution that will not conduct electricity are called **nonelectrolytes**.



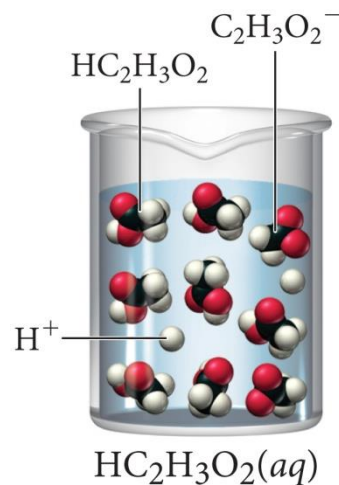
- A solution of salt (an electrolyte) conducts electrical current. A solution of sugar (a nonelectrolyte) does not.

Electrolyte and Nonelectrolyte Solutions

- Ionic substances such as sodium chloride that completely dissociate into ions when they dissolve in water are **strong electrolytes**.
- In contrast to sodium chloride, sugar is a molecular compound.
- Most molecular compounds (except for acids), dissolve in water as intact molecules.



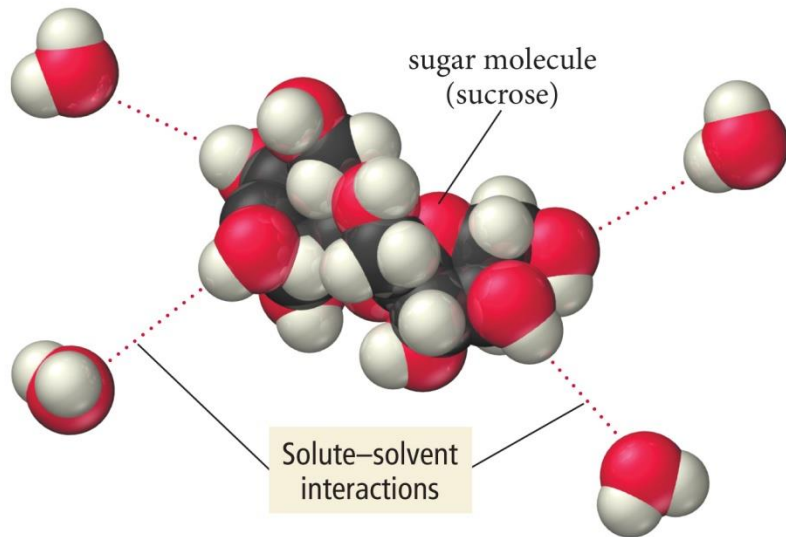
Strong
electrolyte



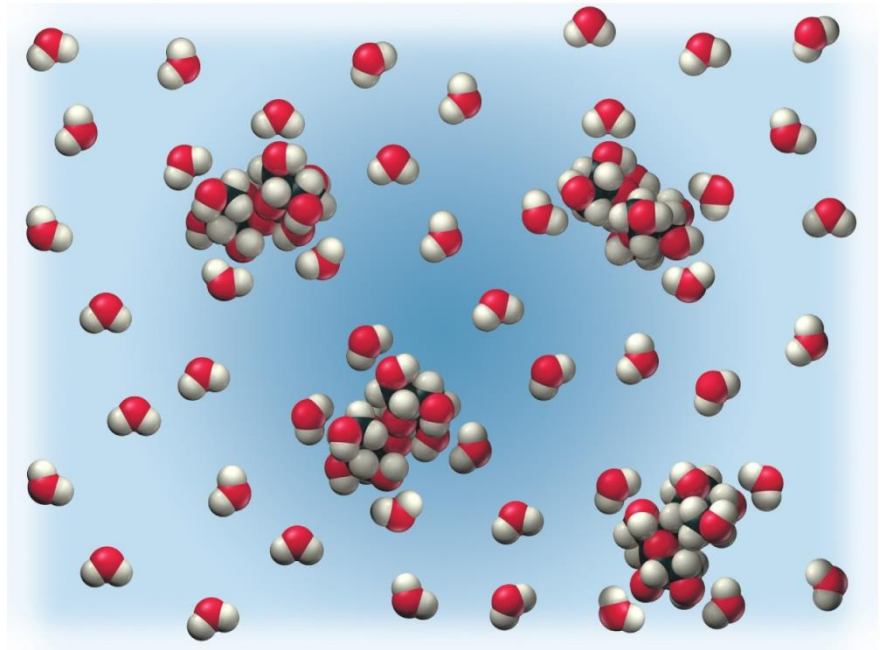
Weak acid

Salt versus Sugar Dissolved in Water

Interactions between Sugar and Water Molecules

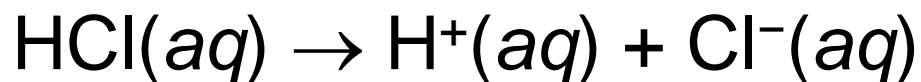


Sugar Solution

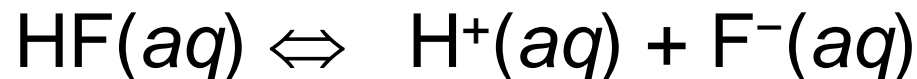


Binary Acids

- Acids are molecular compounds that **ionize** when they dissolve in water.
 - The molecules are pulled apart by their attraction for the water.
 - When acids ionize, they form H^+ cations and also anions.
- The percentage of molecules that ionize varies from one acid to another.
- Acids that ionize virtually 100% are called **strong acids**.

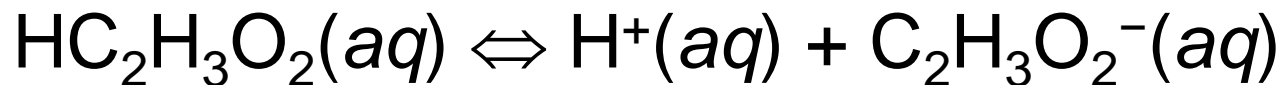


- Acids that only ionize a small percentage are called **weak acids**.



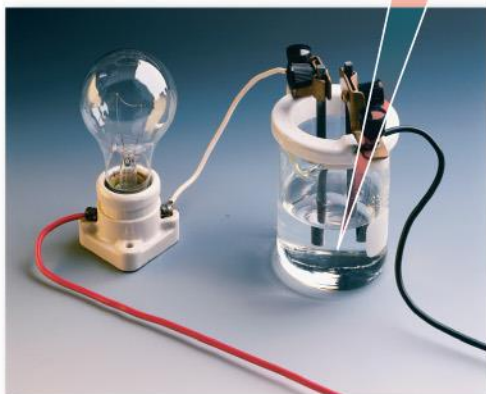
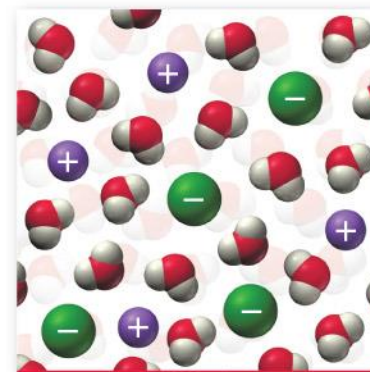
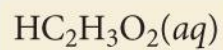
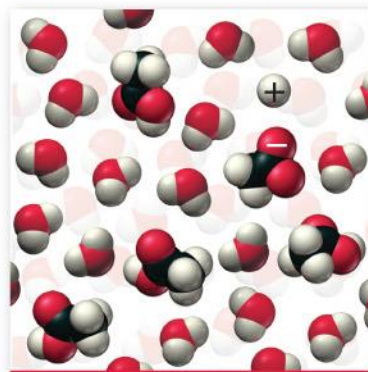
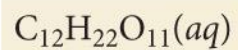
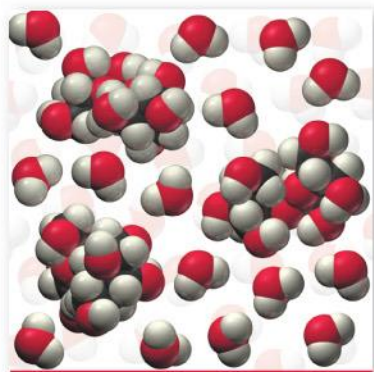
Strong and Weak Electrolytes

- **Strong electrolytes** are materials that dissolve completely as ions.
 - Ionic compounds and strong acids
 - Solutions conduct electricity well
- **Weak electrolytes** are materials that dissolve mostly as molecules, but partially as ions.
 - Weak acids
 - Solutions conduct electricity, but not well
- When compounds containing a polyatomic ion dissolve, the polyatomic ion stays together.



Classes of Dissolved Materials

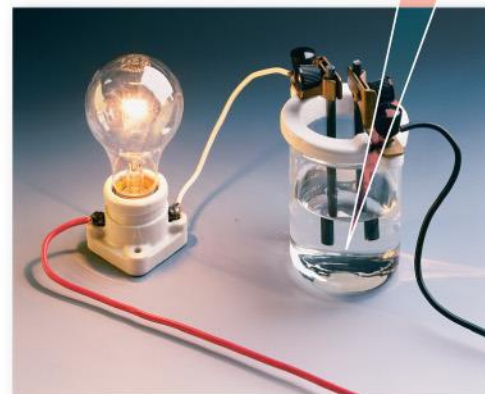
Electrolytic Properties of Solutions



Nonelectrolyte



Weak electrolyte



Strong electrolyte

Dissociation and Ionization

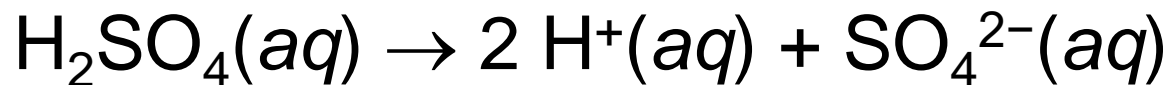
- When ionic compounds dissolve in water, the anions and cations are separated from each other. This is called **dissociation**.



- When compounds containing polyatomic ions dissociate, the polyatomic group stays together as one ion.



- When strong acids dissolve in water, the molecule **ionizes** into H^+ and anions.

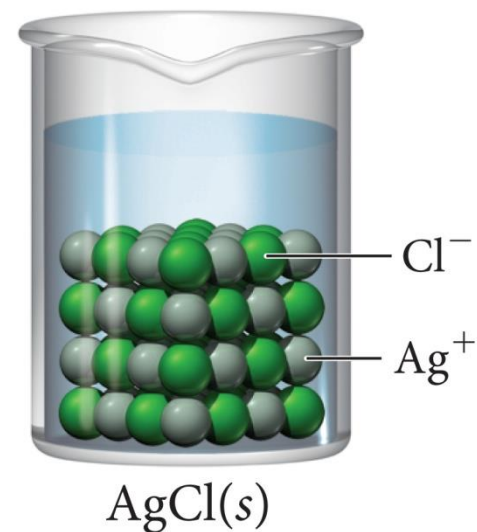


The Solubility of Ionic Compounds

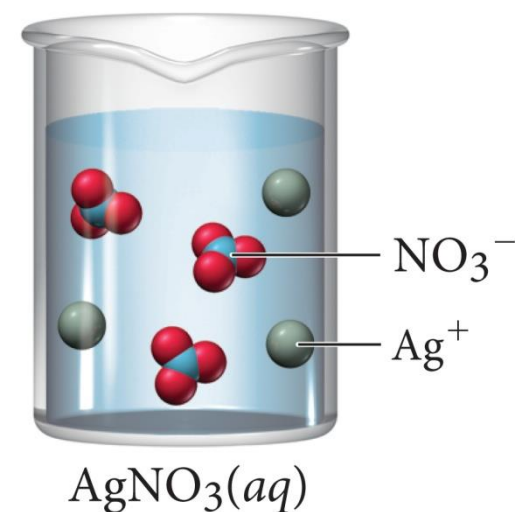
- When an ionic compound dissolves in water, the resulting solution contains
 - not the intact ionic compound itself,
 - but its component ions dissolved in water.
- However, not all ionic compounds dissolve in water.
 - If we add AgCl to water, for example, it remains solid and appears as a white powder at the bottom of the water.
- In general, a compound is termed **soluble** if it dissolves in water and **insoluble** if it does not.

Solubility of Salts

- If we mix solid AgNO_3 with water, it dissolves and forms a strong electrolyte solution.
- Silver chloride, on the other hand, is almost completely insoluble.
 - If we mix solid AgCl with water, virtually all of it remains as a solid within the liquid water.



Insoluble



Soluble

When Will a Salt Dissolve?

- Whether a particular compound is soluble or insoluble depends on several factors.
- 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, and then develop some rules based on those experimental results.
 - We call this method the **empirical method**.

Solubility Rules

TABLE 4.1 Solubility Rules for Ionic Compounds in Water

Compounds Containing the Following Ions Are Generally Soluble	Exceptions
Li^+ , Na^+ , K^+ , and NH_4^+	None
NO_3^- and $\text{C}_2\text{H}_3\text{O}_2^-$	None
Cl^- , Br^- , and I^-	When these ions pair with Ag^+ , Hg_2^{2+} , or Pb^{2+} , the resulting compounds are insoluble.
SO_4^{2-}	When SO_4^{2-} pairs with Sr^{2+} , Ba^{2+} , Pb^{2+} , Ag^+ , or Ca^{2+} , the resulting compound is insoluble.
Compounds Containing the Following Ions Are Generally Insoluble	Exceptions
OH^- and S^{2-}	When these ions pair with Li^+ , Na^+ , K^+ , or NH_4^+ , the resulting compounds are soluble.
	When S^{2-} pairs with Ca^{2+} , Sr^{2+} , or Ba^{2+} , the resulting compound is soluble.
	When OH^- pairs with Ca^{2+} , Sr^{2+} , or Ba^{2+} , the resulting compound is slightly soluble.
CO_3^{2-} and PO_4^{3-}	When these ions pair with Li^+ , Na^+ , K^+ , or NH_4^+ , the resulting compounds are soluble.

Precipitation Reactions

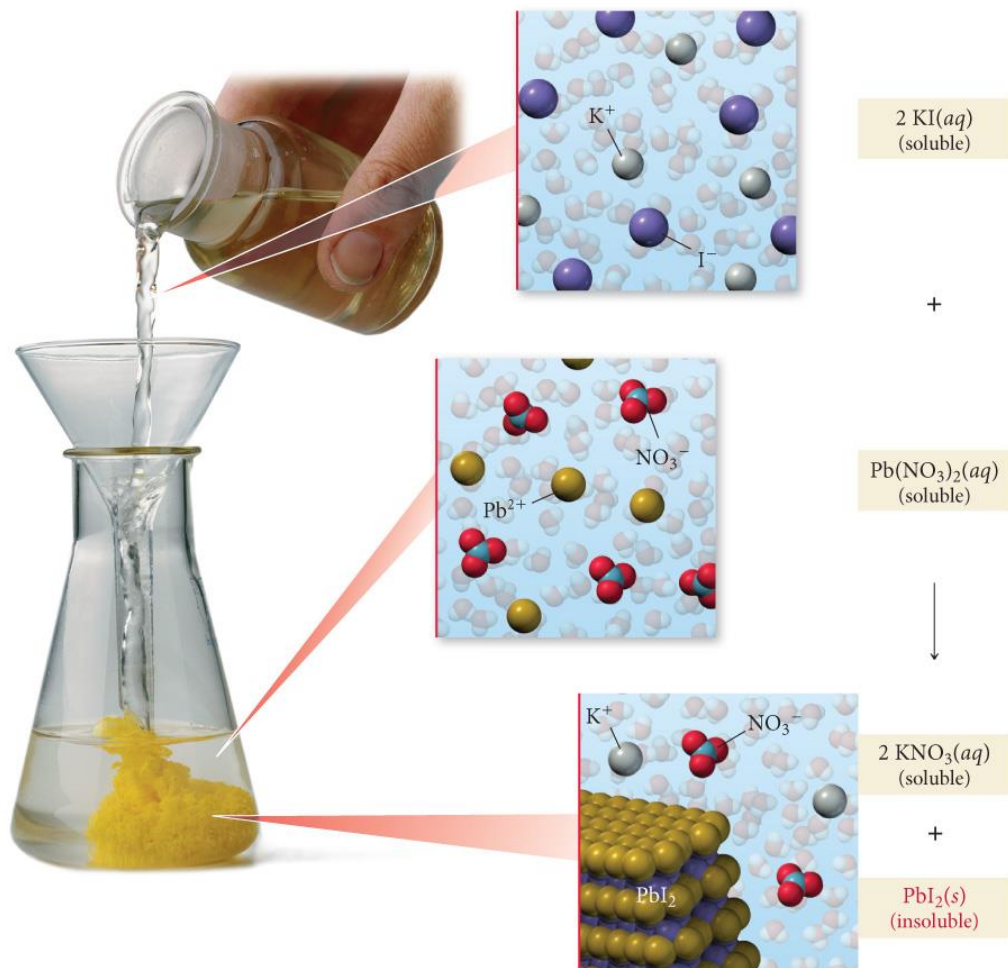
- **Precipitation reactions** are reactions in which a solid forms when we mix two solutions.
 - Reactions between aqueous solutions of ionic compounds produce an ionic compound that is insoluble in water.
 - The insoluble product is called a **precipitate**.

Precipitation of Lead(II) Iodide

Precipitation Reaction

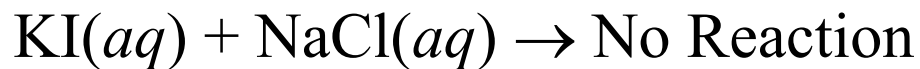
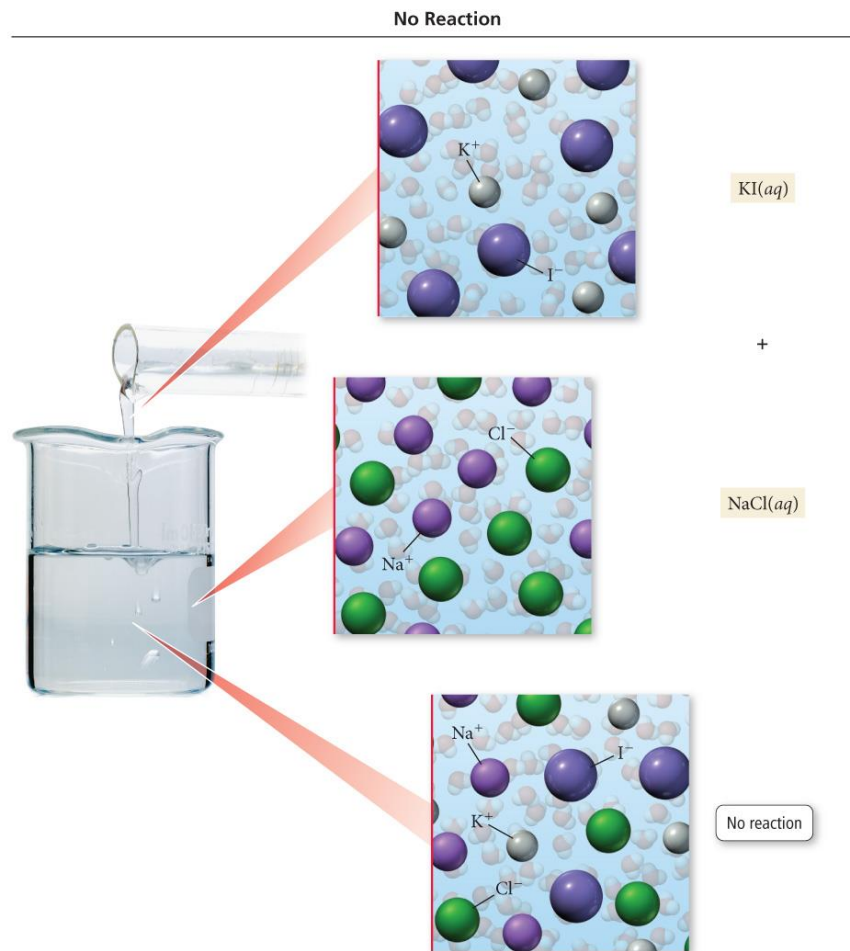


When a potassium iodide solution is mixed with a lead(II) nitrate solution, a yellow lead(II) iodide precipitate forms.



No Precipitation Means No Reaction

- Precipitation reactions do not always occur when two aqueous solutions are mixed.
 - Combine solutions of KI and NaCl and nothing happens.



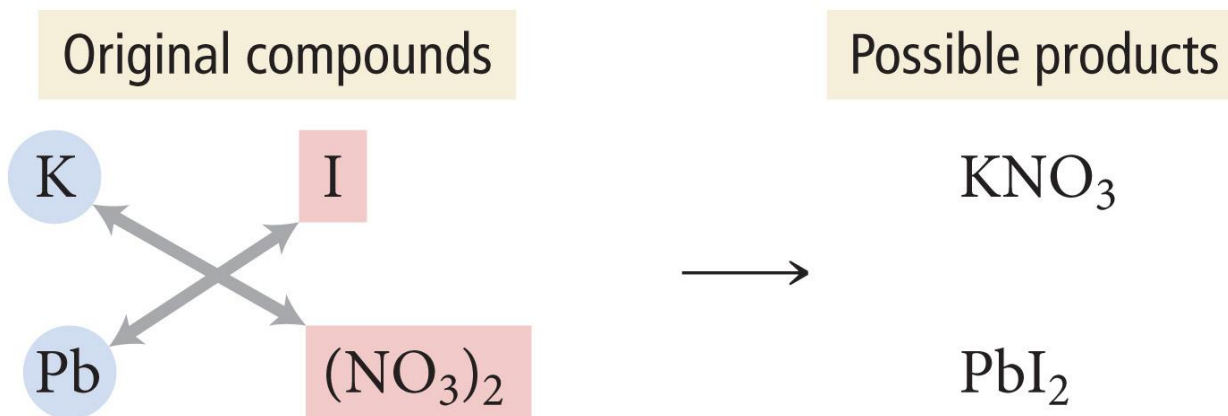
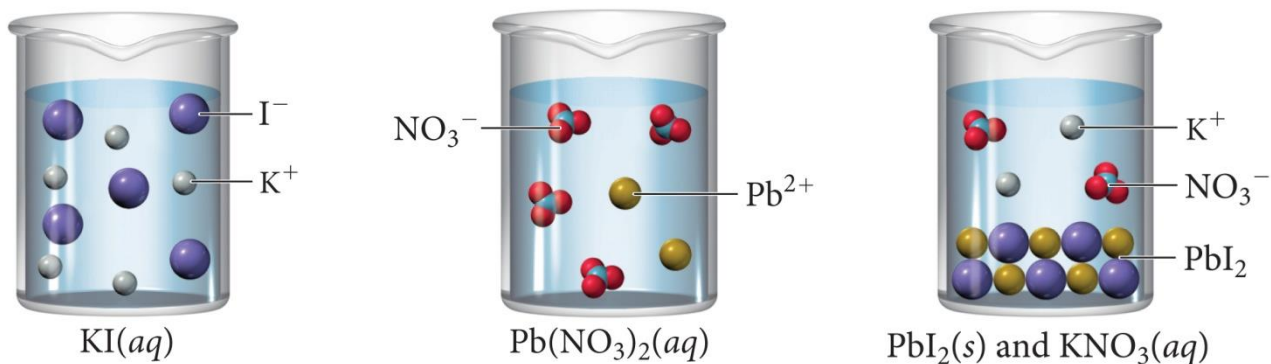
Predicting Precipitation Reactions

1. Determine what ions each aqueous reactant has.
2. Determine formulas of possible products.
 - Exchange ions.
 - (+) ion from one reactant with (–) ion from other
 - Balance charges of combined ions to get the formula of each product.
3. Determine solubility of each product in water.
 - Use the solubility rules.
 - If product is insoluble or slightly soluble, it will precipitate.
4. If neither product will precipitate, write **no reaction** after the arrow.

Predicting Precipitation Reactions

5. If any of the possible products are insoluble, write their formulas as the products of the reaction using **(s)** after the formula to indicate **solid**. Write any soluble products with **(aq)** after the formula to indicate **aqueous**.
6. Balance the equation.
 - Remember to only change coefficients, not subscripts.

Predicting Precipitation Reactions



Representing Aqueous Reactions

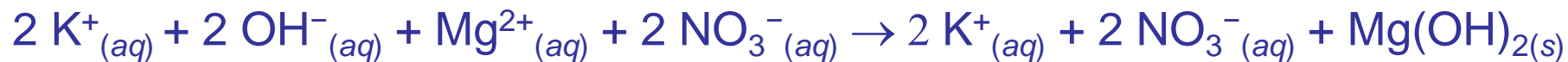
- An equation showing the complete neutral formulas for each compound in the aqueous reaction as if they existed as molecules is called a **molecular equation**.



- In actual solutions of soluble ionic compounds, dissolved substances are present as ions. Equations that describe the material's structure when dissolved are called **complete ionic equations**.

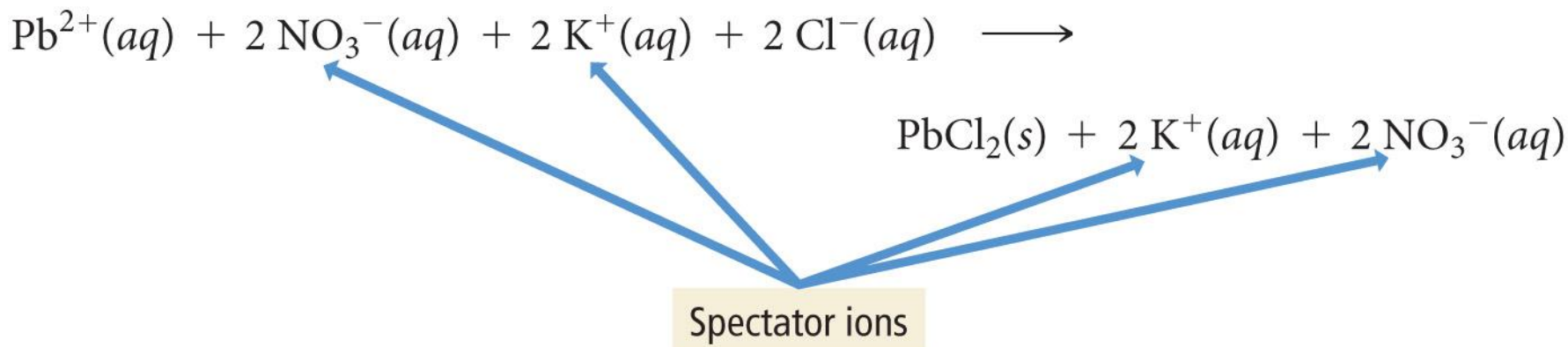
Ionic Equation

- Rules of writing the complete ionic equation:
 - Aqueous strong electrolytes are written as ions.
 - Soluble salts, strong acids, strong bases
 - Insoluble substances, weak electrolytes, and nonelectrolytes are written in molecule form.
 - Solids, liquids, and gases are not dissolved, hence molecule form

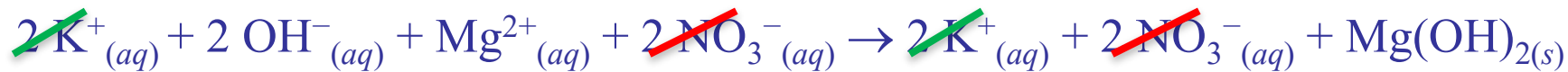


Ionic Equation

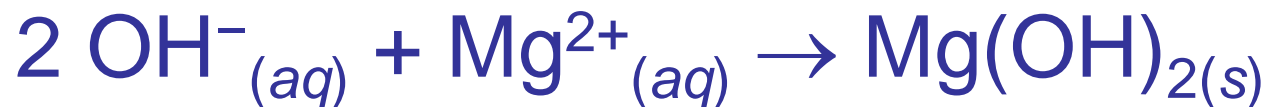
- Notice that in the complete ionic equation, some of the ions in solution appear unchanged on both sides of the equation.
- These ions are called **spectator ions** because they do not participate in the reaction.



Net Ionic Equation

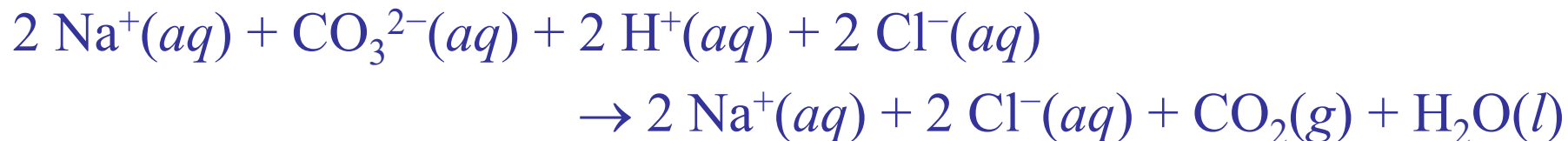
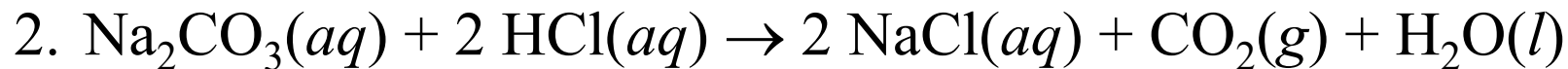
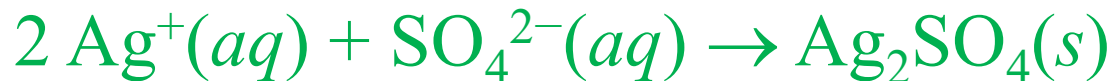
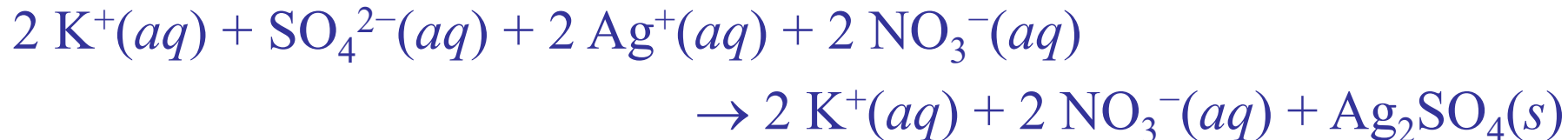
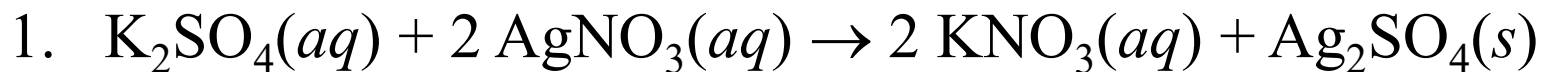


- An ionic equation in which the spectator ions are removed is called a **net ionic equation**.



Examples

- Write the ionic and net ionic equation for each of the following:



Acid–Base and Gas-Evolution Reactions

- Two other important classes of reactions that occur in aqueous solution are
 1. acid–base reactions
 2. and gas-evolution reactions.
- Acid–base Reaction:
 - An **acid–base reaction** is also called a **neutralization reaction**.
 - An acid reacts with a base and the two neutralize each other, producing water (or in some cases a weak electrolyte).

Acid–Base and Gas-Evolution Reactions

- Gas-evolution reactions
 - In a **gas-evolution reaction**, a gas forms, resulting in bubbling.
- In both acid–base and gas-evolution reactions, as in precipitation reactions, the reactions occur when the anion from one reactant combines with the cation of the other.
 - Many gas-evolution reactions are also acid–base reactions.

Acid–Base Reactions

Arrhenius Definitions:

- Acid: Substance that produces H^+



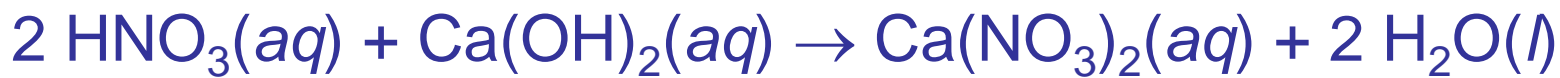
- Some acids—called **polyprotic acids**

- These acids contain more than one ionizable proton and release them sequentially.
 - For example, sulfuric acid, H_2SO_4 is a **diprotic acid**.
 - It is strong in its first ionizable proton, but weak in its second.
- Base: Substance that produces OH^- ions in aqueous solution



Acid–Base Reactions

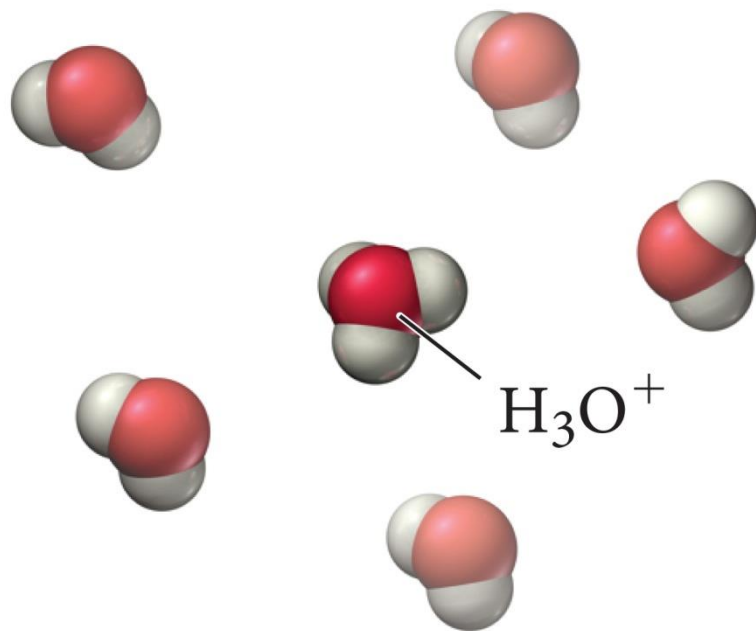
- Also called **neutralization reactions** because the acid and base neutralize each other's properties



- The net ionic equation for an acid–base reaction is

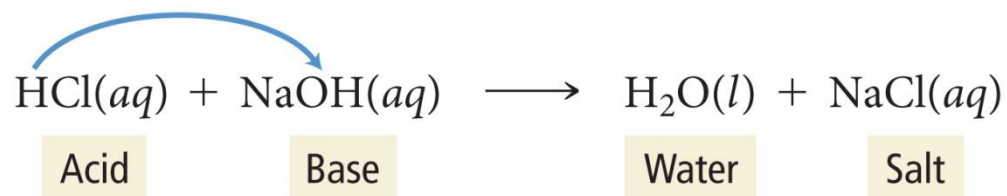


– as long as the salt that forms is soluble in water.

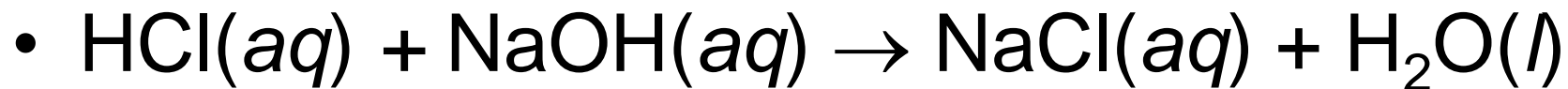


Acids and Bases in Solution

- Acids ionize in water to form H^+ ions.
 - More precisely, the H from the acid molecule is donated to a water molecule to form **hydronium ion, H_3O^+** .
 - Most chemists use H^+ and H_3O^+ interchangeably.
- Bases dissociate in water to form OH^- ions.
 - Bases, such as NH_3 , that do not contain OH^- ions, produce OH^- by pulling H off water molecules.
- In the reaction of an acid with a base, the H^+ from the acid combines with the OH^- from the base to make water.
- The cation from the base combines with the anion from the acid to make the salt.



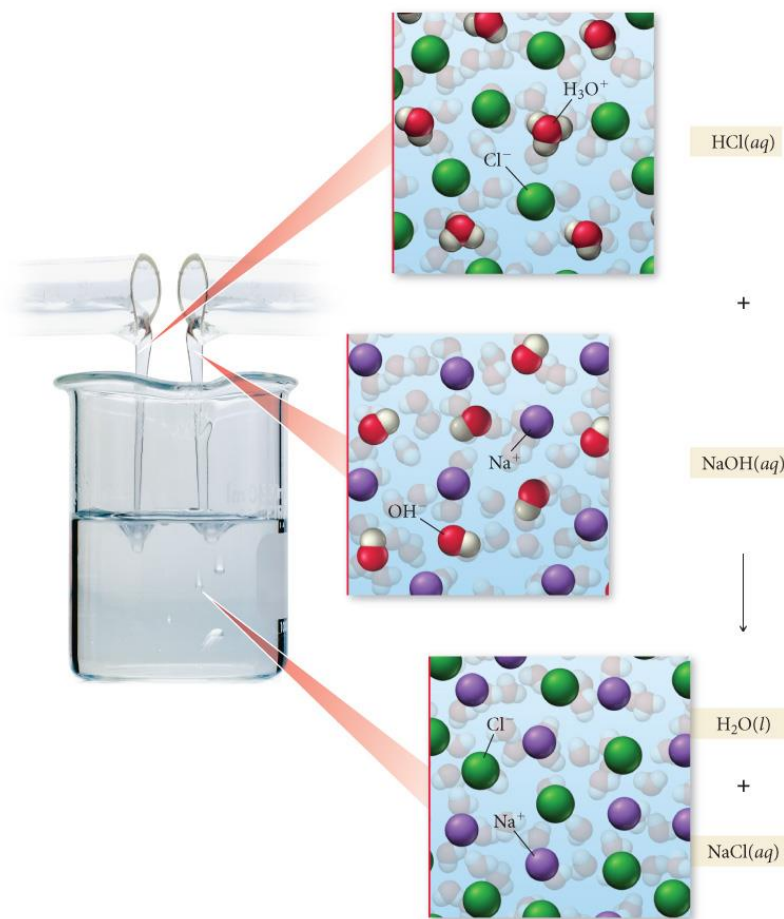
Acid–Base Reaction



Acid–Base Reaction



The reaction between hydrochloric acid and sodium hydroxide forms water and a salt, sodium chloride, which remains dissolved in the solution.



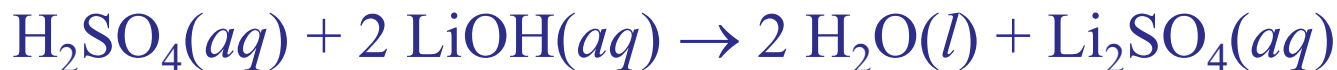
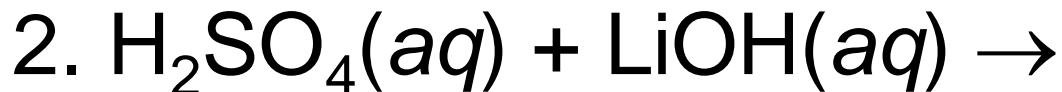
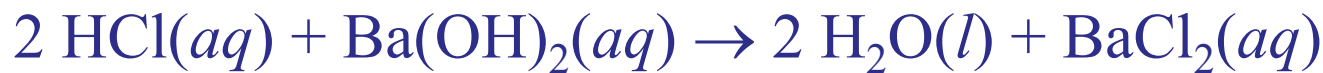
Some Common Acids and Bases

TABLE 4.2 Some Common Acids and Bases

Name of Acid	Formula	Name of Base	Formula
Hydrochloric acid	HCl	Sodium hydroxide	NaOH
Hydrobromic acid	HBr	Lithium hydroxide	LiOH
Hydroiodic acid	HI	Potassium hydroxide	KOH
Nitric acid	HNO ₃	Calcium hydroxide	Ca(OH) ₂
Sulfuric acid	H ₂ SO ₄	Barium hydroxide	Ba(OH) ₂
Perchloric acid	HClO ₄	Ammonia*	NH ₃ (weak base)
Acetic acid	HC ₂ H ₃ O ₂ (weak acid)		
Hydrofluoric acid	HF (weak acid)		

*Ammonia does not contain OH⁻, but it produces OH⁻ in a reaction with water that occurs only to a small extent: $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$.

Predict the Product of the Reactions



Acid–Base Titrations

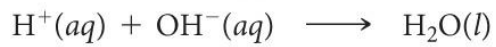
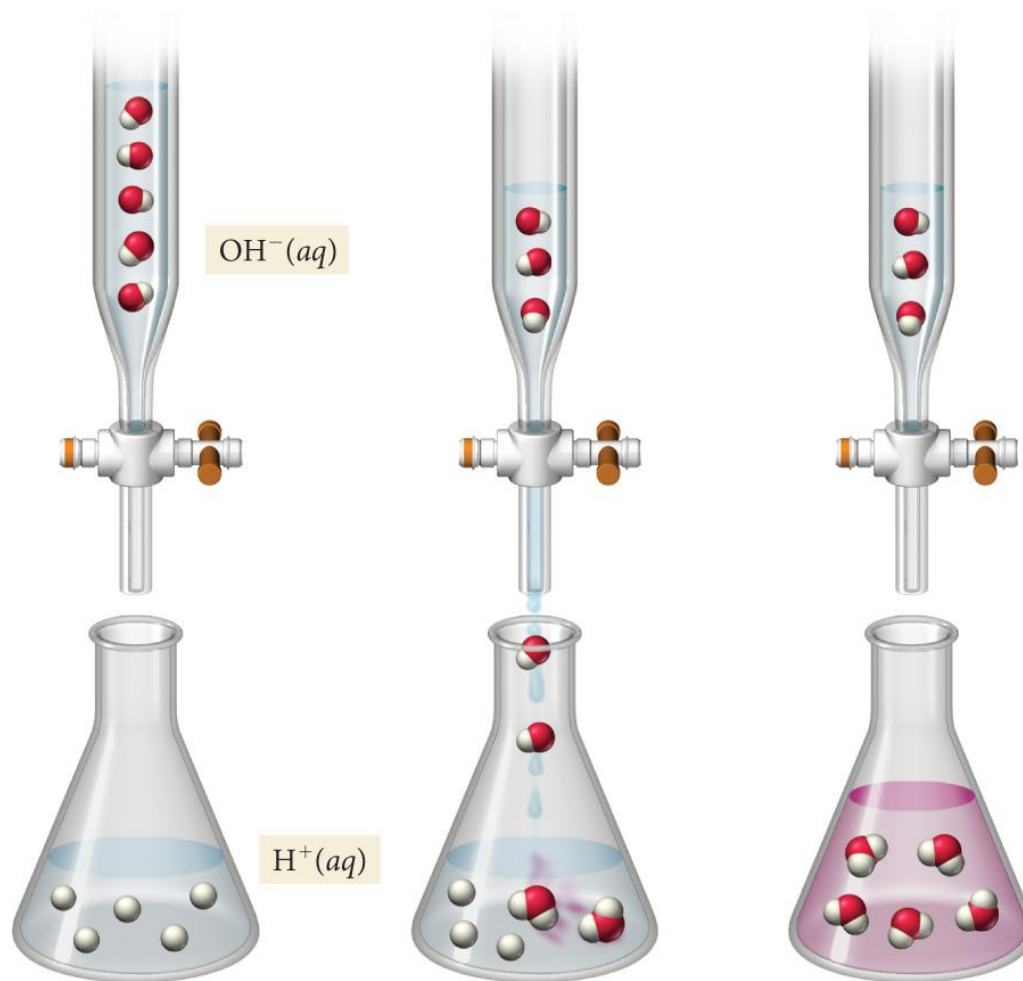
- In a **titration**, a substance in a solution of known concentration is reacted with another substance in a solution of unknown concentration.
- At this point, called the **endpoint**, the reactants are in their stoichiometric ratio.
 - The unknown solution is added slowly from an instrument called a **burette**.
 - A long glass tube with precise volume markings that allows small additions of solution
 - The titrant is the solution in the burette.

Acid–Base Titrations

- In acid–base titrations, because both the reactant and product solutions are colorless, a chemical is added that changes color when the solution undergoes large changes in acidity/alkalinity.
 - The chemical is called an **indicator**.
- At the endpoint of an acid–base titration, the number of moles of H^+ equals the number of moles of OH^- .
 - This is also known as the **equivalence point**.

Acid–Base Titration

Acid–Base Titration

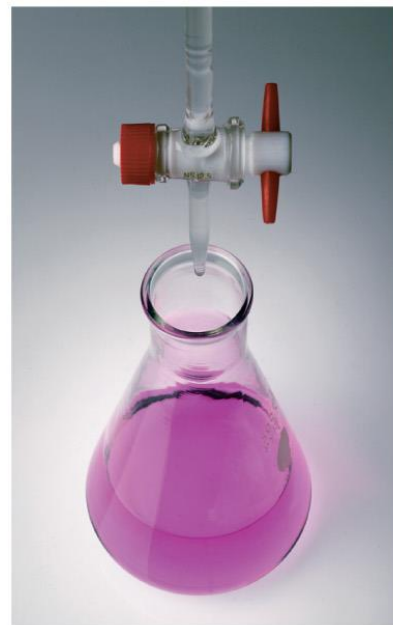
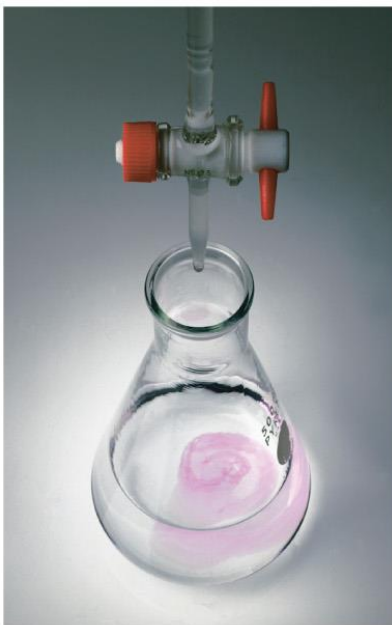


Beginning of titration

Equivalence point

Titration

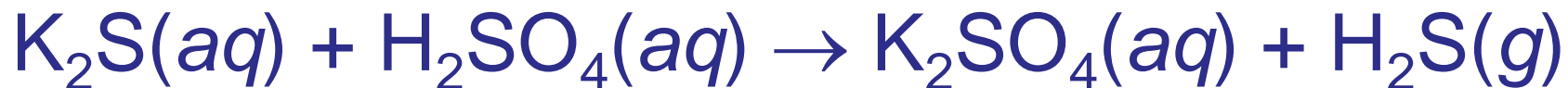
Indicator in Titration



- In this titration, NaOH is added to a dilute HCl solution. When the NaOH and HCl reach stoichiometric proportions (the equivalence point), the phenolphthalein indicator changes color to pink.

Gas-Evolving 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.

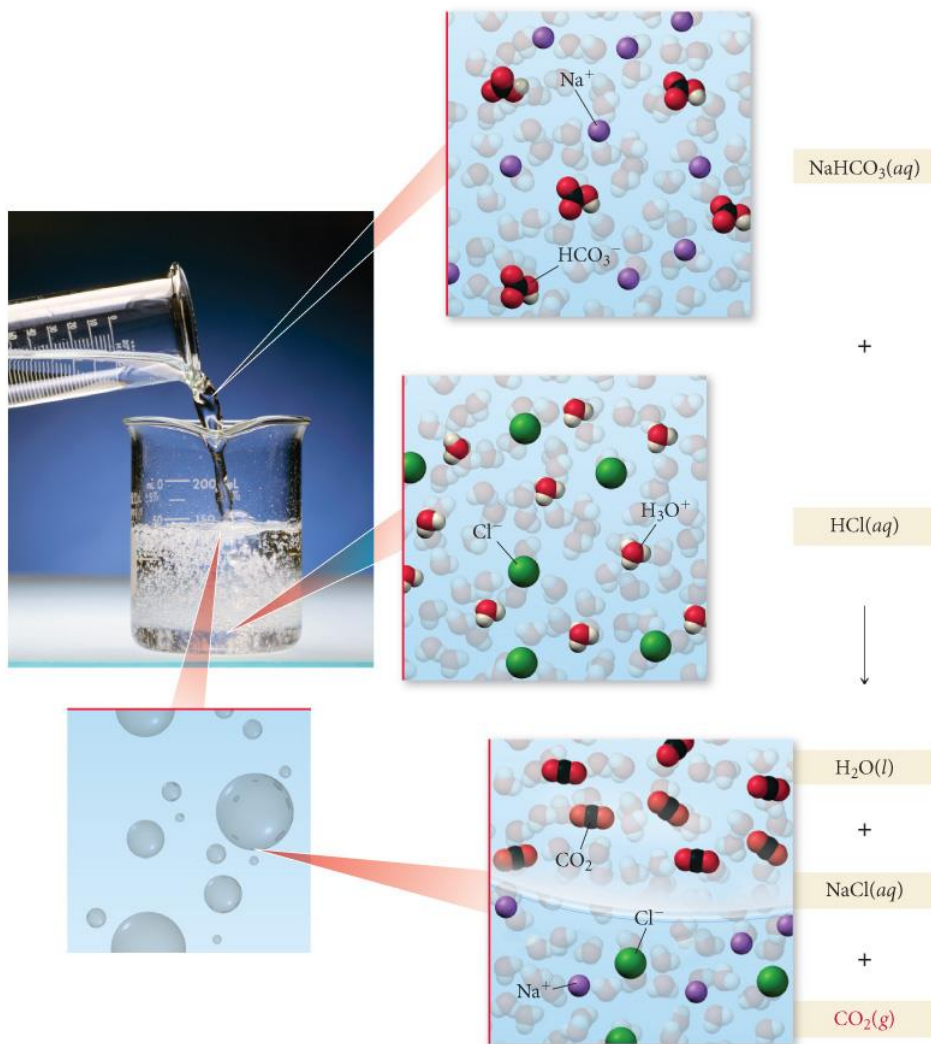


Gas-Evolution Reaction

Gas-Evolution Reaction



When aqueous sodium bicarbonate is mixed with aqueous hydrochloric acid, gaseous CO_2 bubbles are the result of the reaction.



Types of Compounds That Undergo Gas-Evolution Reactions

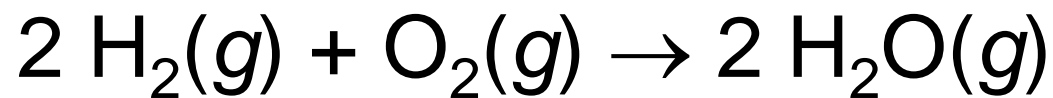
TABLE 4.3 Types of Compounds That Undergo Gas-Evolution Reactions

Reactant Type	Intermediate Product	Gas Evolved	Example
Sulfides	None	H ₂ S	$2 \text{HCl}(aq) + \text{K}_2\text{S}(aq) \rightarrow \text{H}_2\text{S}(g) + 2 \text{KCl}(aq)$
Carbonates and bicarbonates	H ₂ CO ₃	CO ₂	$2 \text{HCl}(aq) + \text{K}_2\text{CO}_3(aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2(g) + 2 \text{KCl}(aq)$
Sulfites and bisulfites	H ₂ SO ₃	SO ₂	$2 \text{HCl}(aq) + \text{K}_2\text{SO}_3(aq) \rightarrow \text{H}_2\text{O}(l) + \text{SO}_2(g) + 2 \text{KCl}(aq)$
Ammonium	NH ₄ OH	NH ₃	$\text{NH}_4\text{Cl}(aq) + \text{KOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{NH}_3(g) + \text{KCl}(aq)$

Oxidation–Reduction Reactions

- The reactions in which electrons are transferred from one reactant to the other are called **oxidation-reduction reactions**.
 - These are also called **redox reactions**.
 - Many redox reactions involve the reaction of a substance with oxygen.
 - $4 \text{ Fe}(s) + 3 \text{ O}_2(g) \rightarrow 2 \text{ Fe}_2\text{O}_3(s)$ (rusting)
 - $2 \text{ C}_8\text{H}_{18}(l) + 25 \text{ O}_2(g) \longrightarrow 16 \text{ CO}_2(g) + 18 \text{ H}_2\text{O}(g)$ (combustion)
 - $2 \text{ H}_2(g) + \text{ O}_2(g) \longrightarrow 2 \text{ H}_2\text{O}(g)$

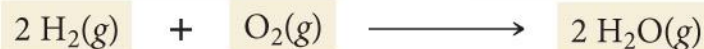
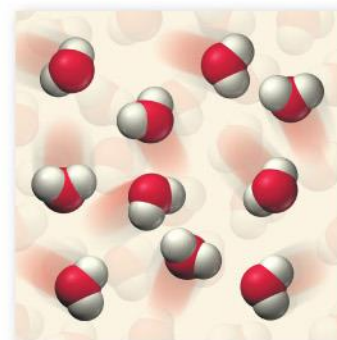
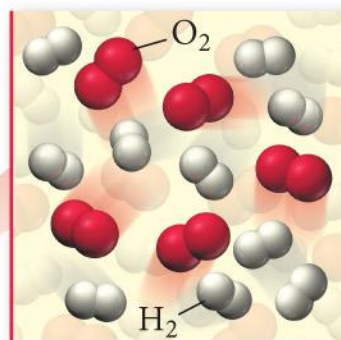
Combustion as Redox



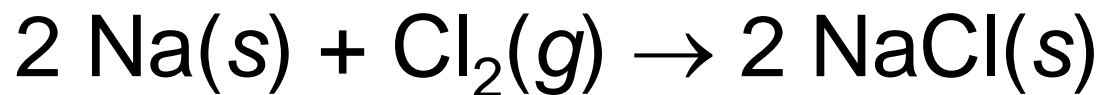
Oxidation–Reduction Reaction



Hydrogen and oxygen react to form gaseous water.



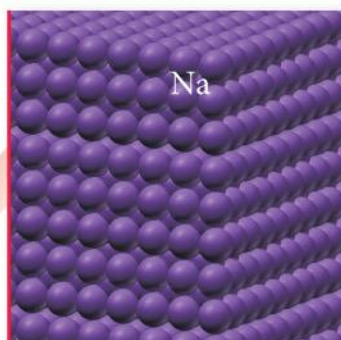
Redox without Combustion



Oxidation–Reduction Reaction without Oxygen

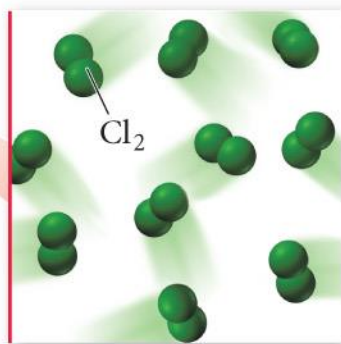


Electrons are transferred from sodium to chlorine, forming sodium chloride.
Sodium is oxidized and chlorine is reduced.



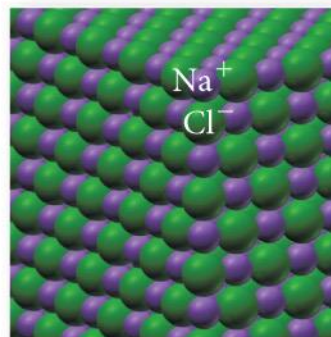
Na(s)

+



Cl₂(g)

Electron
transfer
→



NaCl(s)



Reactions of Metals with Nonmetals

- Consider the following reactions:



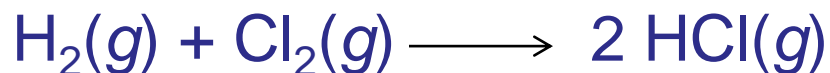
- The reactions involve a metal reacting with a nonmetal.
- In addition, both reactions involve the conversion of free elements into ions.



Redox Reaction

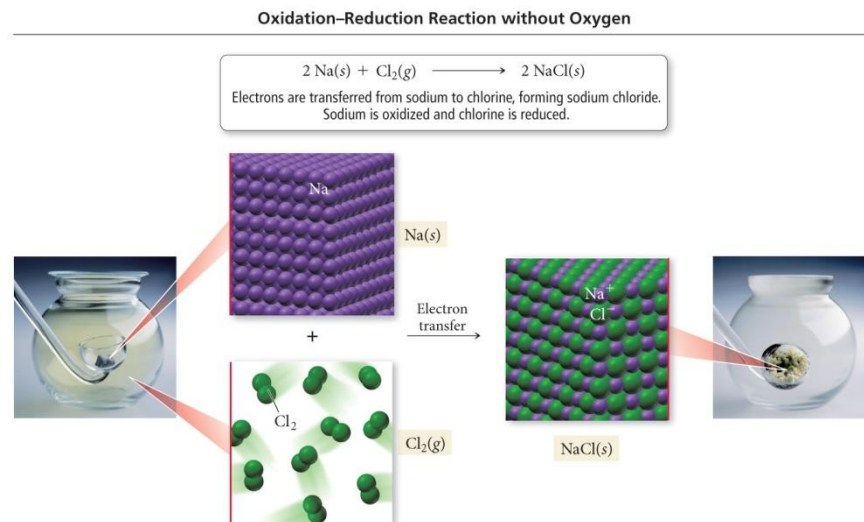
- The transfer of electrons does not need to be a *complete* transfer (as occurs in the formation of an ionic compound) for the reaction to qualify as oxidation–reduction.

– For example, consider the reaction between hydrogen gas and chlorine gas:



- When hydrogen bonds to chlorine, the electrons are unevenly shared, resulting in

- an increase of electron density (reduction) for chlorine and
- a decrease in electron density (oxidation) for hydrogen.



Oxidation and Reduction

- To convert a free element into an ion, the atoms must gain or lose electrons.
 - Of course, if one atom loses electrons, another must accept them.
- Reactions where electrons are transferred from one atom to another are redox reactions.
- Atoms that lose electrons are being **oxidized**, while atoms that gain electrons are being **reduced**.



Oxidation States

- For reactions that are not metal + nonmetal, or do not involve O_2 , we need a method for determining how the electrons are transferred.
- Chemists assign a number to each element in a reaction called an **oxidation state** that allows them to determine the electron flow in the reaction.
 - Even though they look like them, **oxidation states are not ion charges!**
 - Oxidation states are imaginary charges assigned based on a set of rules.
 - Ion charges are real, measurable charges.

Rules for Assigning Oxidation States

The following rules are in order of priority:

1. Free elements have an oxidation state = 0.
 - Na = 0 and Cl₂ = 0 in 2 Na(s) + Cl₂(g)
2. Monatomic ions have an oxidation state equal to their charge.
 - Na = +1 and Cl = -1 in NaCl
3. (a) The sum of the oxidation states of all the atoms in a compound is 0.
 - Na = +1 and Cl = -1 in NaCl, (+1) + (-1) = 0

Rules for Assigning Oxidation States

3. (b) The sum of the oxidation states of all the atoms in a polyatomic ion equals the charge on the ion.
 - N = +5 and O = -2 in NO_3^- , $(+5) + 3(-2) = -1$
4. (a) Group I metals have an oxidation state of +1 in all their compounds.
 - Na = +1 in NaCl
4. (b) Group II metals have an oxidation state of +2 in all their compounds.
 - Mg = +2 in MgCl_2

Rules for Assigning Oxidation States

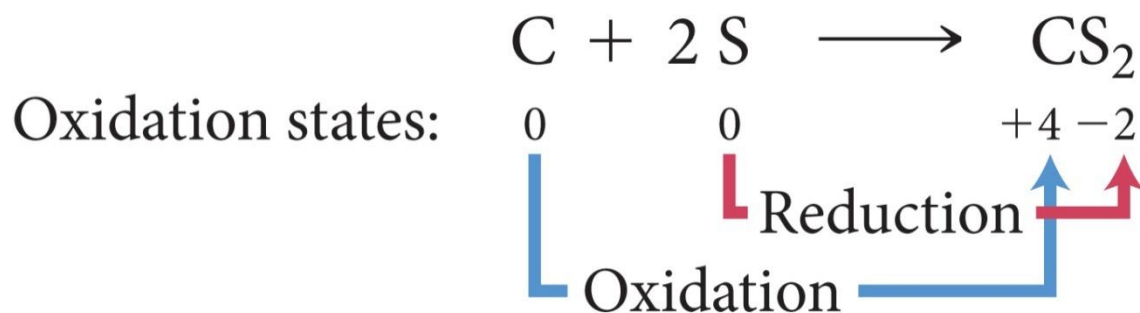
5. In their compounds, nonmetals have oxidation states according to the table below.

- Nonmetals higher on the table take priority.

Nonmetal	Oxidation State	Example
Fluorine	-1	MgF ₂ -1 ox state
Hydrogen	+1	H ₂ O +1 ox state
Oxygen	-2	CO ₂ -2 ox state
Group 7A	-1	CCl ₄ -1 ox state
Group 6A	-2	H ₂ S -2 ox state
Group 5A	-3	NH ₃ -3 ox state

Identifying Redox Reactions

- Oxidation: An increase in oxidation state
- Reduction: A decrease in oxidation state



- Carbon changes from an oxidation state of 0 to an oxidation state of +4.
 - Carbon *loses electrons* and is *oxidized*.
- Sulfur changes from an oxidation state of 0 to an oxidation state of –2.
 - Sulfur *gains electrons* and is *reduced*.

Redox Reactions

- Oxidation and reduction must occur simultaneously.
 - If an atom loses electrons another atom must take them.
- The reactant that reduces an element in another reactant is called the **reducing agent**.
 - The reducing agent contains the element that is oxidized.
- The reactant that oxidizes an element in another reactant is called the **oxidizing agent**.
 - The oxidizing agent contains the element that is reduced.

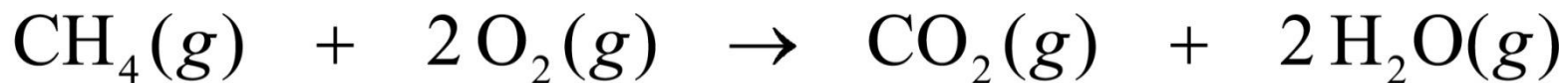


Na is oxidized, while Cl is reduced.

Na is the reducing agent, and Cl_2 is the oxidizing agent.

Combustion Reactions

- *Combustion reactions* are characterized by the reaction of a substance with to form one or more oxygen-containing compounds, often including water.
 - Combustion reactions also emit heat.
- For example, as you saw earlier in this chapter, natural gas (CH₄) reacts with oxygen to form carbon dioxide and water:



Oxidation state: -4 +1

0

+4 -2

+1 -2

Combustion

- Ethanol, the alcohol in alcoholic beverages, also reacts with oxygen in a combustion reaction to form carbon dioxide and water.

