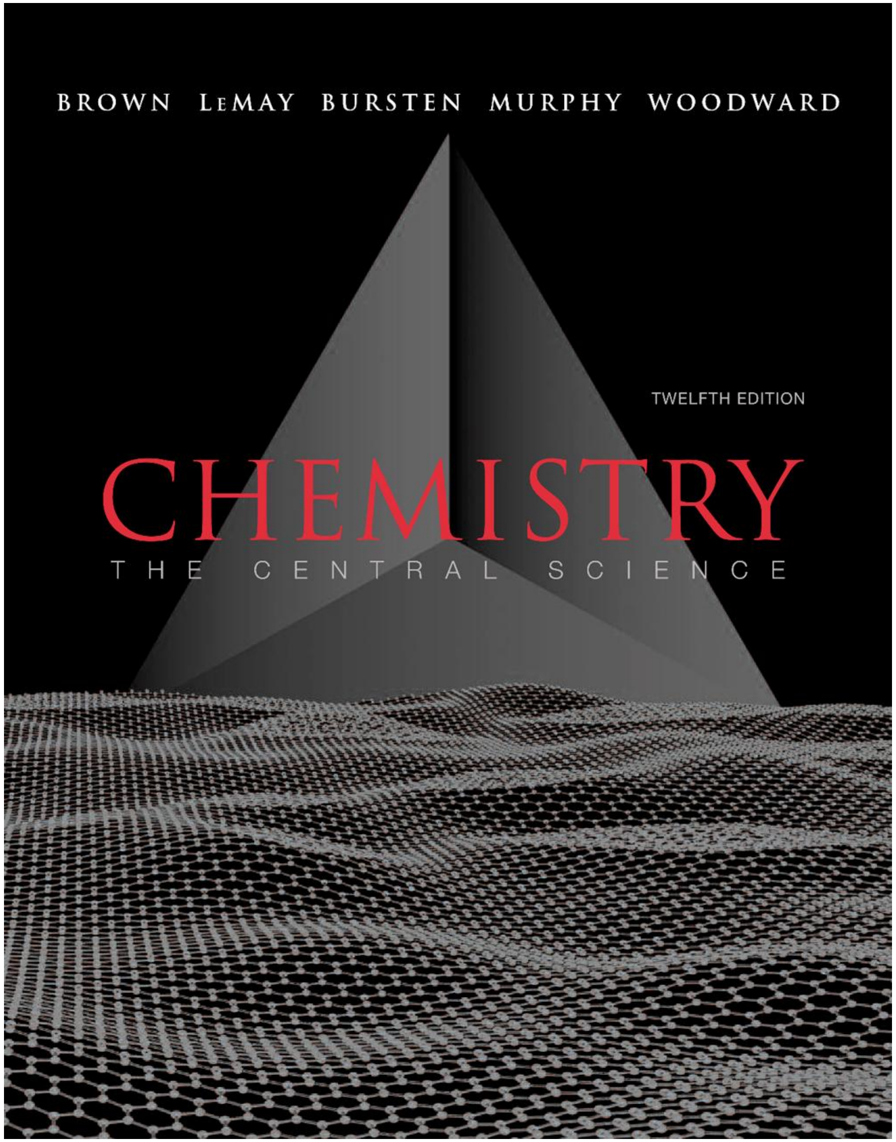

Lecture Presentation

Chapter 4

Reactions in Aqueous Solution

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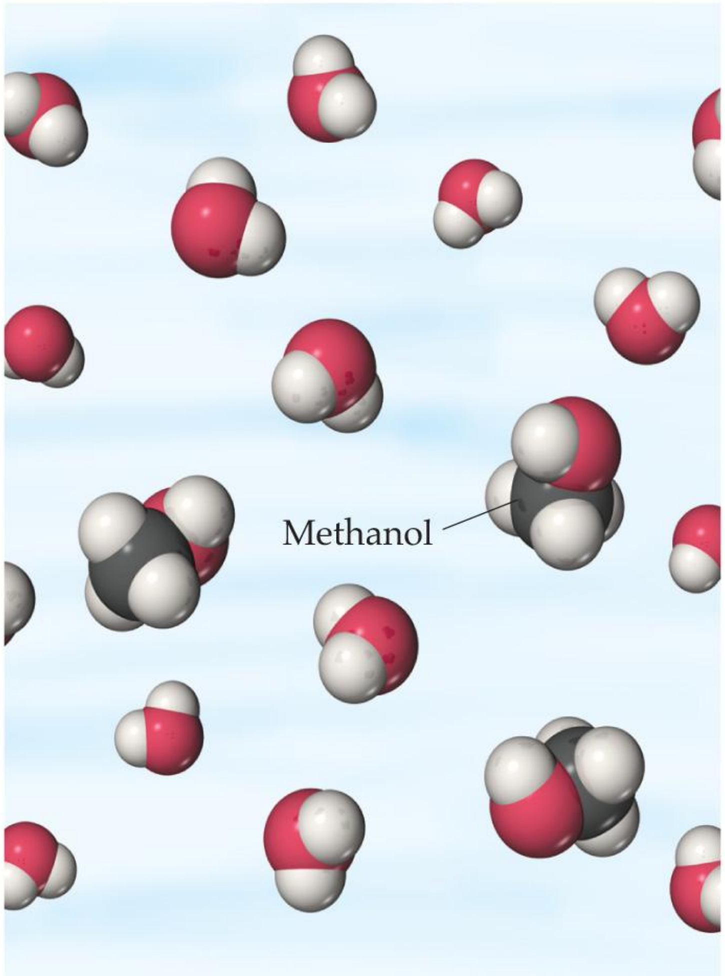
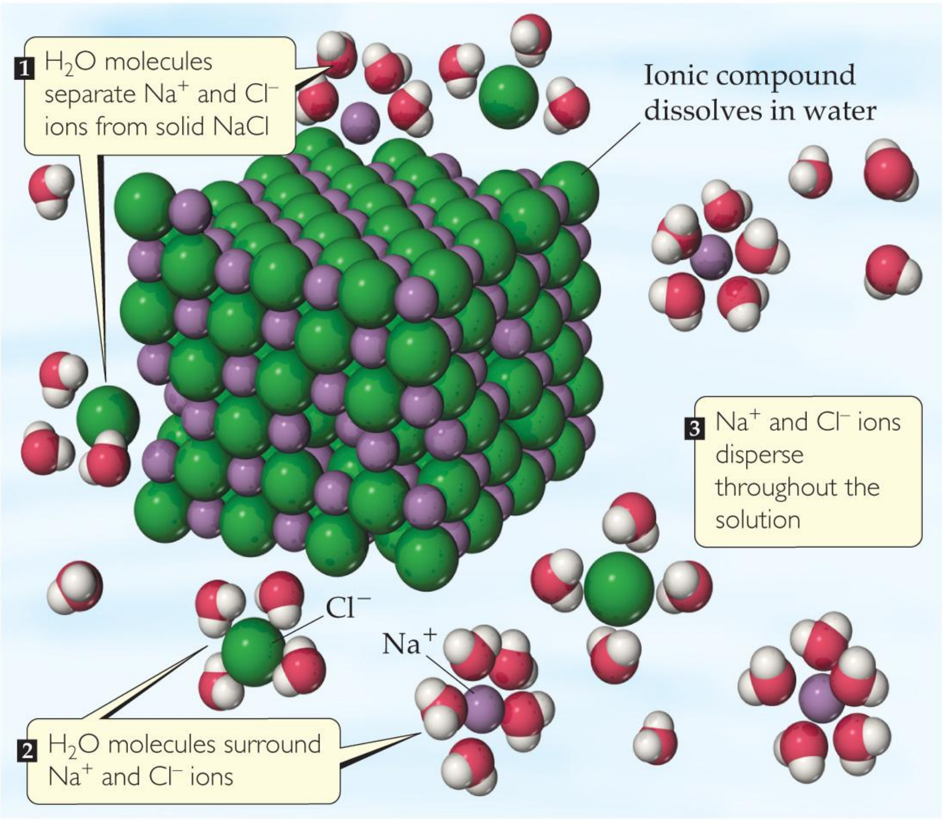
Solutions



(b) Molecular substances like methanol, CH_3OH, dissolve without forming ions

- **Solutions** are defined as homogeneous mixtures of two or more pure substances.
- The **solvent** is present in greatest abundance.
- All other substances are **solutes.**

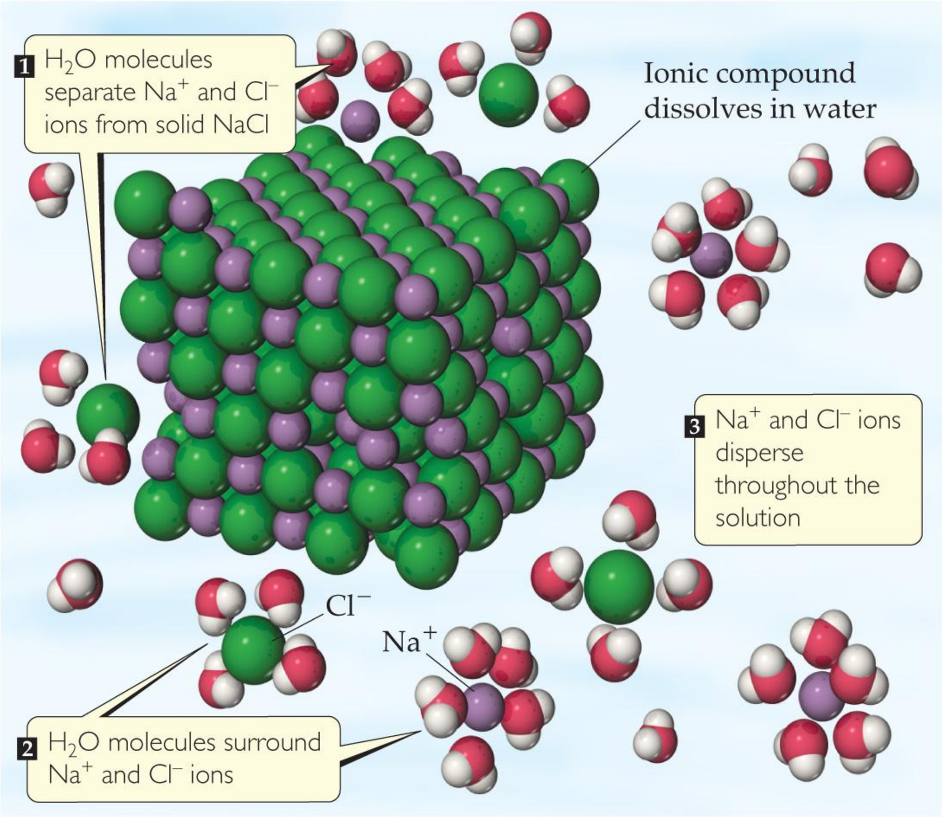
Dissociation



(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve

- When an ionic substance dissolves in water, the solvent pulls the individual ions from the crystal and solvates them.
- This process is called **dissociation**.

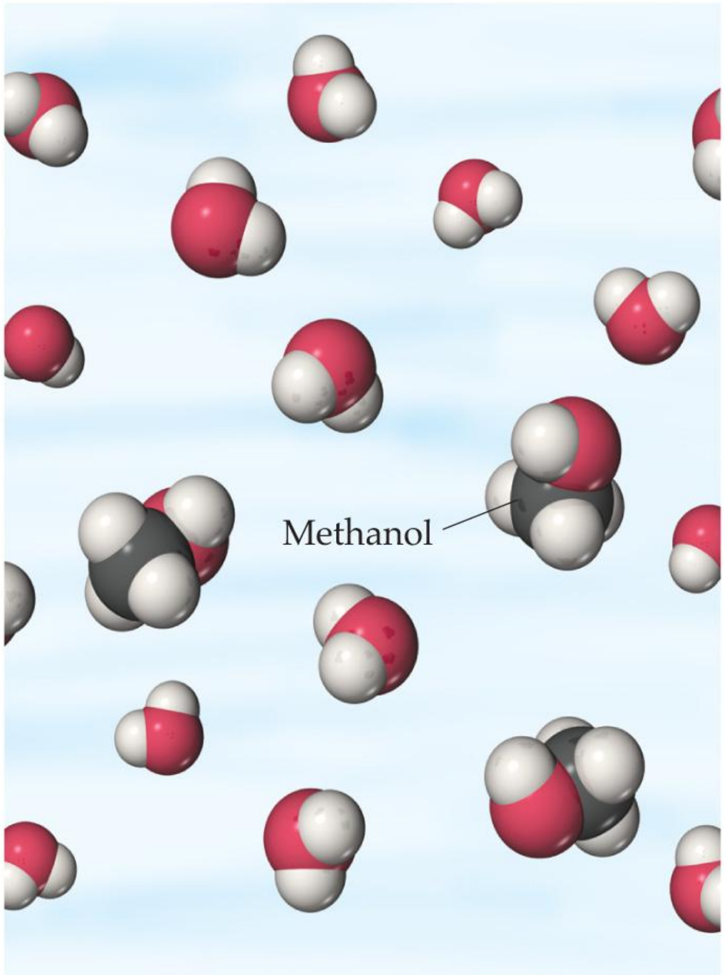
Dissociation



(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve

- An **electrolyte** is a substances that dissociates into ions when dissolved in water.

Solutions



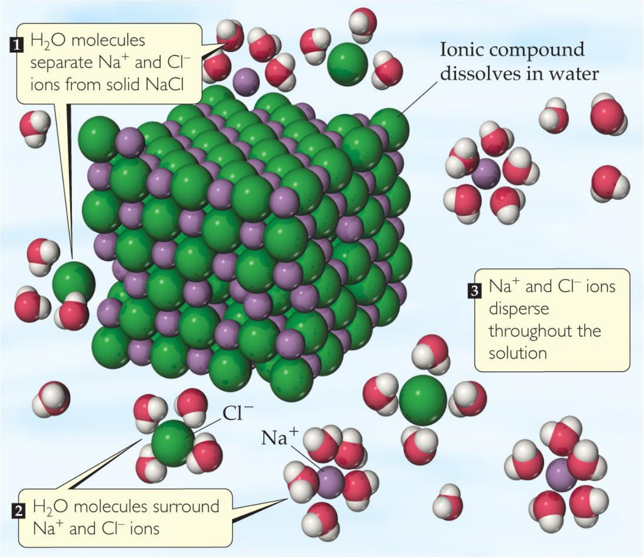
(b) Molecular substances like methanol, CH_3OH, dissolve without forming ions

- An **electrolyte** is a substance that dissociates into ions when dissolved in water.
- A **nonelectrolyte** may dissolve in water, but it does not dissociate into ions when it does so.

Electrolytes and Nonelectrolytes

TABLE 4.3 • Summary of the Electrolytic Behavior of Common Soluble Ionic and Molecular Compounds

	Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
Ionic	All	None	None
Molecular	Strong acids (see Table 4.2)	Weak acids, weak bases	All other compounds



(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve

Soluble ionic compounds tend to be electrolytes.

Electrolytes and Nonelectrolytes

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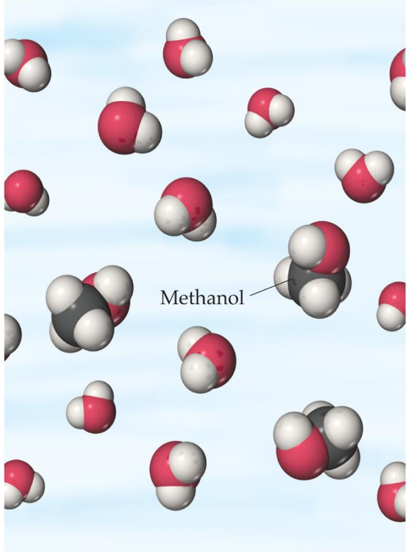


(b) Molecular substances like methanol, CH_3OH, dissolve without forming ions

Molecular compounds tend to be nonelectrolytes, except for acids and bases.

Electrolytes

Pure water,
$H_2O(l)$
does not conduct electricity

Sucrose solution,
$C_{12}H_{22}O_{11}(aq)$
Nonelectrolyte
does not conduct electricity

Sodium chloride solution,
$NaCl(aq)$
Electrolyte
conducts electricity

- A **strong electrolyte** dissociates completely when dissolved in water.
- A **weak electrolyte** only dissociates partially when dissolved in water.

Strong Electrolytes Are…

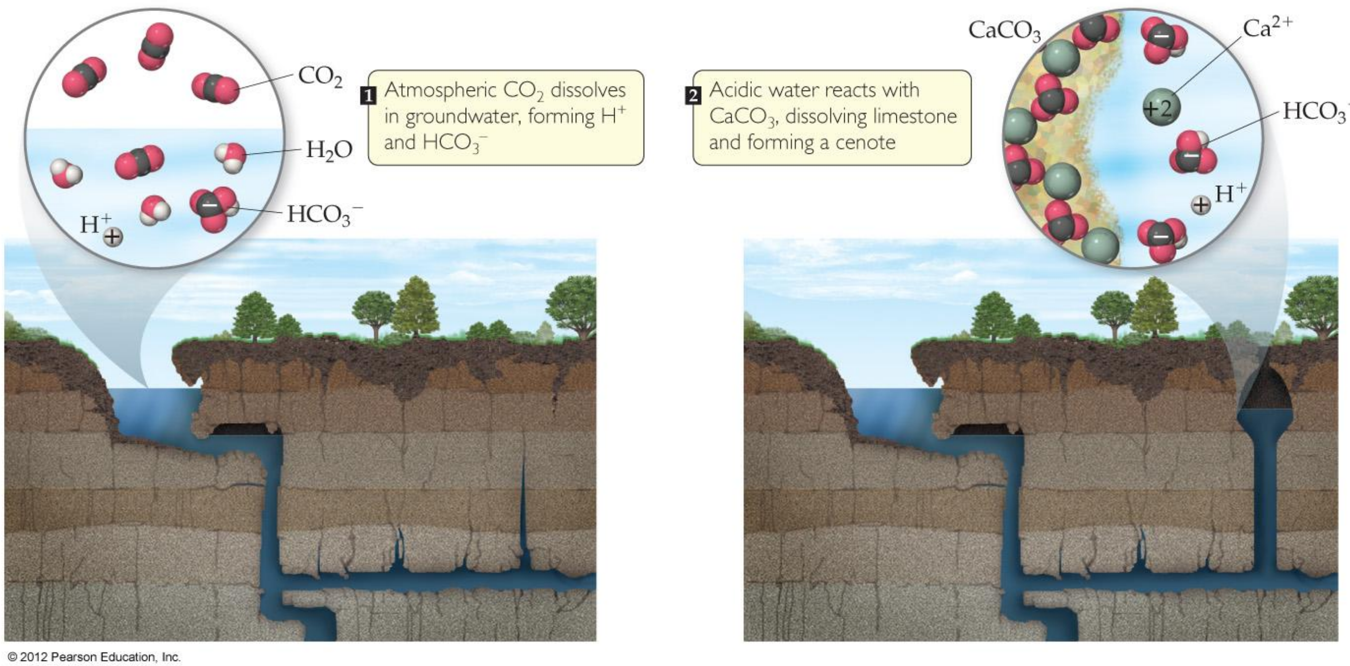
- Strong acids
- Strong bases

TABLE 4.2 • Common Strong Acids and Bases

Strong Acids	Strong Bases
Hydrochloric, HCl	Group 1A metal hydroxides [$LiOH$, $NaOH$, KOH, $RbOH$, $CsOH$]
Hydrobromic, HBr	Heavy group 2A metal hydroxides [$Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$]
Hydroiodic, HI	
Chloric, $HClO_3$	
Perchloric, $HClO_4$	
Nitric, HNO_3	
Sulfuric, H_2SO_4	

Strong Electrolytes Are…

- Strong acids
- Strong bases
- Soluble ionic salts



Precipitation Reactions

When one mixes ions that form compounds that are insoluble (as could be predicted by the solubility guidelines), a precipitate is formed.

Metathesis (Exchange) Reactions

- Metathesis comes from a Greek word that means "to transpose."

$$AgNO_3(aq) + KCl(aq) \longrightarrow$$

Metathesis (Exchange) Reactions

- Metathesis comes from a Greek word that means “to transpose.”
- It appears as though the ions in the reactant compounds exchange, or transpose, ions:

$$\mathbf{Ag}\mathrm{NO_3}(aq) + \mathrm{K}\mathbf{Cl}(aq) \longrightarrow \mathbf{AgCl}(s) + \mathrm{KNO_3}(aq)$$

Solution Chemistry

- It is helpful to pay attention to *exactly* what species are present in a reaction mixture (i.e., solid, liquid, gas, aqueous solution).
- If we are to understand reactivity, we must be aware of just what is changing during the course of a reaction.

Molecular Equation

The **molecular equation** lists the reactants and products in their molecular form:

$$AgNO_3(aq) + KCl(aq) \longrightarrow AgCl(s) + KNO_3(aq)$$

Ionic Equation

- In the **ionic equation** all strong electrolytes (strong acids, strong bases, and soluble ionic salts) are dissociated into their ions.
- This more accurately reflects the species that are found in the reaction mixture:

$$Ag^+(aq) + NO_3^-(aq) + K^+(aq) + Cl^-(aq) \longrightarrow$$
$$AgCl(s) + K^+(aq) + NO_3^-(aq)$$

Net Ionic Equation

- To form the net ionic equation, cross out anything that does not change from the left side of the equation to the right:

$$Ag^+(aq) + \cancel{NO_3^-(aq)} + \cancel{K^+(aq)} + Cl^-(aq) \longrightarrow$$
$$AgCl(s) + \cancel{K^+(aq)} + \cancel{NO_3^-(aq)}$$

Net Ionic Equation

- To form the net ionic equation, cross out anything that does not change from the left side of the equation to the right.
- The only things left in the equation are those things that change (i.e., react) during the course of the reaction:

$$\mathrm{Ag^{+}}(aq) + \mathrm{Cl^{-}}(aq) \longrightarrow \mathrm{AgCl}(s)$$

Net Ionic Equation

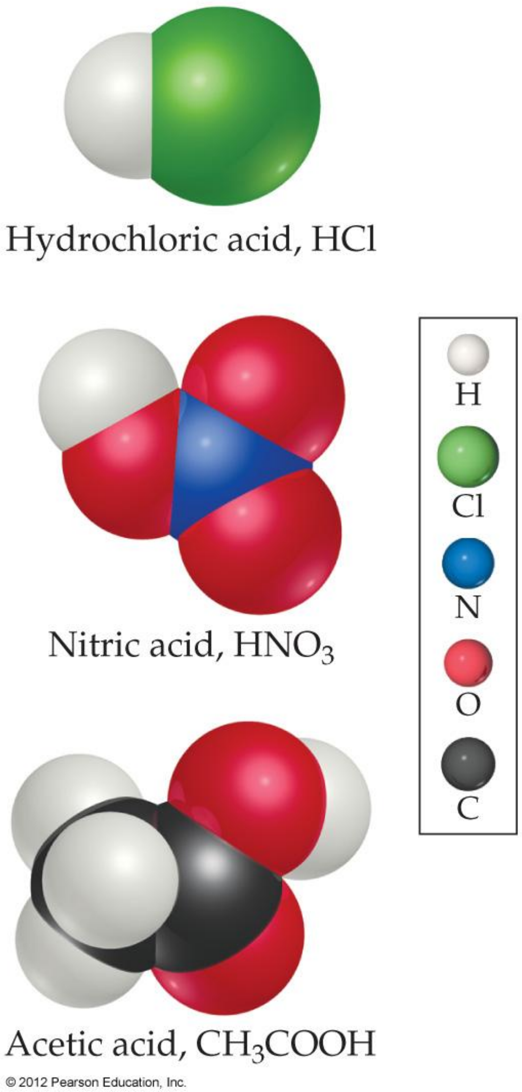
- To form the net ionic equation, cross out anything that does not change from the left side of the equation to the right.
- The only things left in the equation are those things that change (i.e., react) during the course of the reaction.
- Those things that didn't change (and were deleted from the net ionic equation) are called **spectator ions:**

$$Ag^+(aq) + \cancel{NO_3^-(aq)} + \cancel{K^+(aq)} + Cl^-(aq) \longrightarrow$$
$$AgCl(s) + \cancel{K^+(aq)} + \cancel{NO_3^-(aq)}$$

Writing Net Ionic Equations

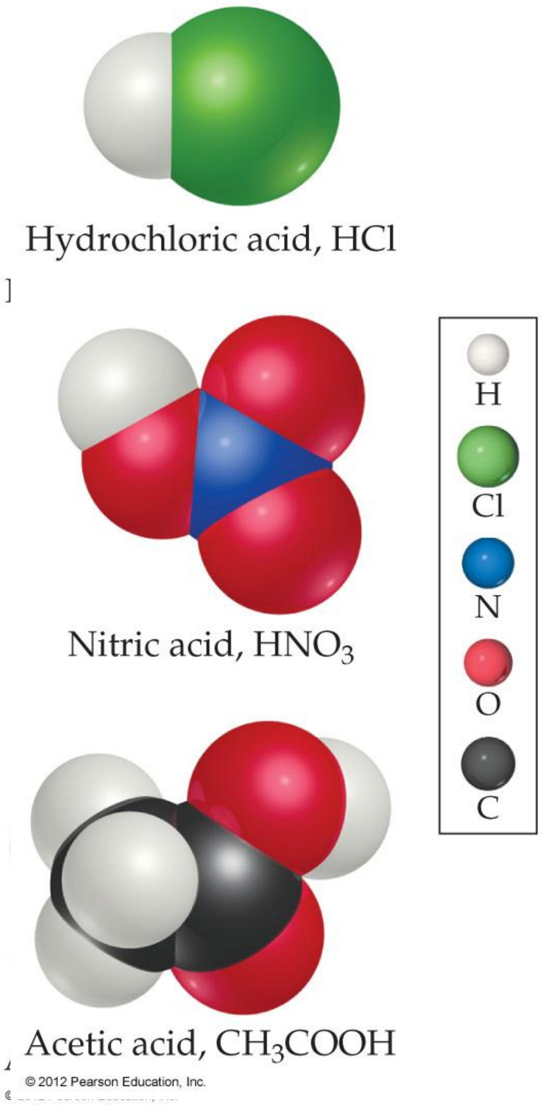
1. Write a balanced molecular equation.
2. Dissociate all strong electrolytes.
3. Cross out anything that remains unchanged from the left side to the right side of the equation.
4. Write the net ionic equation with the species that remain.

Acids



- The Swedish physicist and chemist S. A. Arrhenius defined acids as substances that increase the concentration of H^+ when dissolved in water.
- Both the Danish chemist J. N. Brønsted and the British chemist T. M. Lowry defined them as proton donors.

Acids

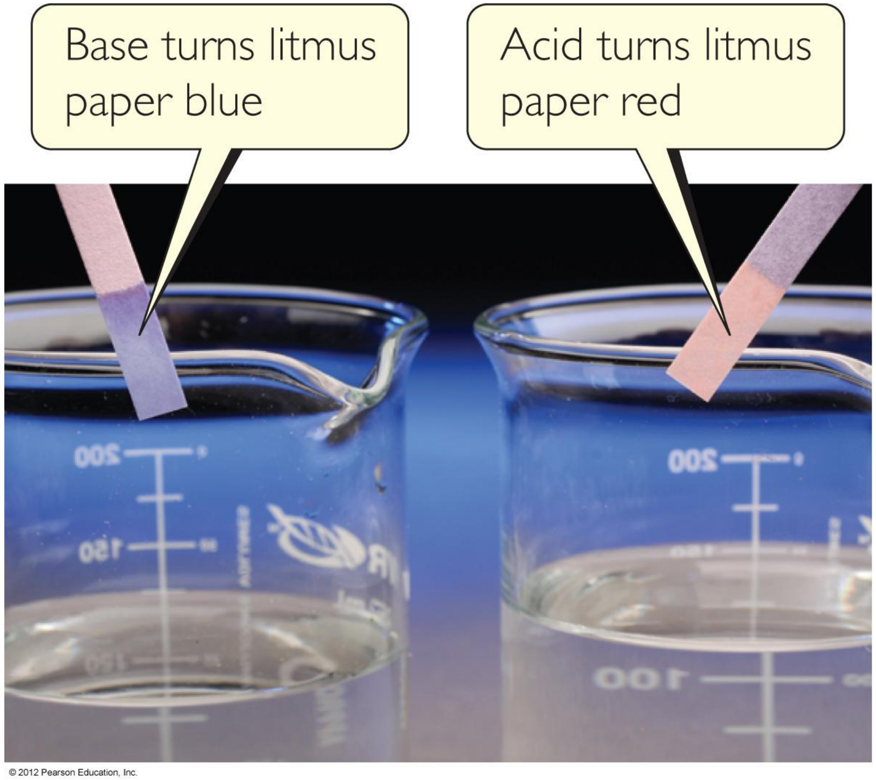


There are only seven strong acids:

- Hydrochloric (HCl)
- Hydrobromic (HBr)
- Hydroiodic (HI)
- Nitric (HNO_3)
- Sulfuric (H_2SO_4)
- Chloric ($HClO_3$)
- Perchloric ($HClO_4$)

Bases

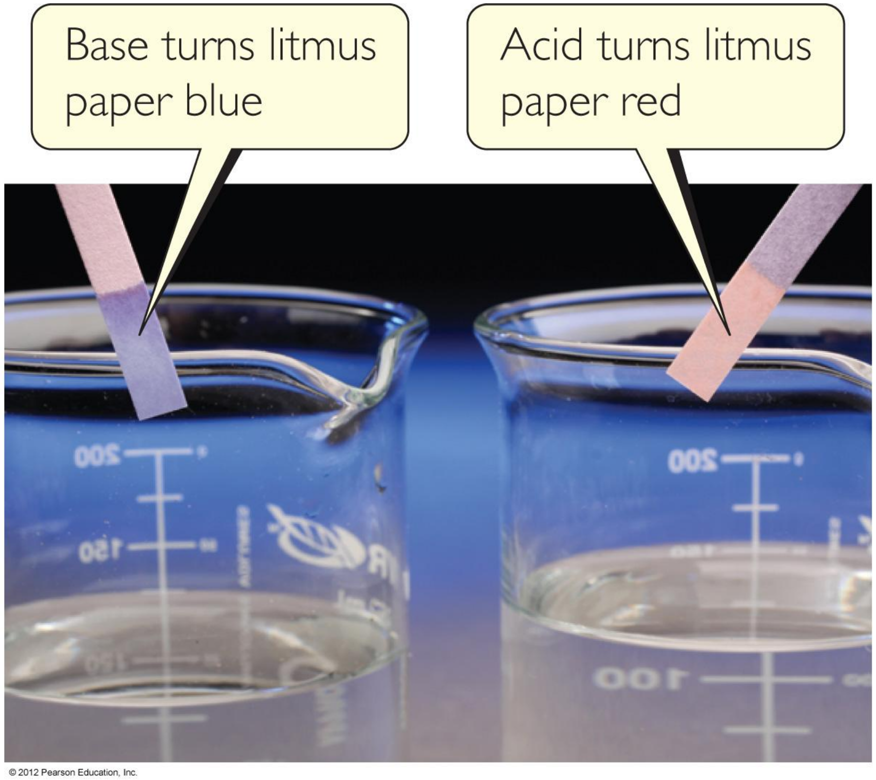
- Arrhenius defined bases as substances that increase the concentration of OH^- when dissolved in water.
- Brønsted and Lowry defined them as proton acceptors.



Bases

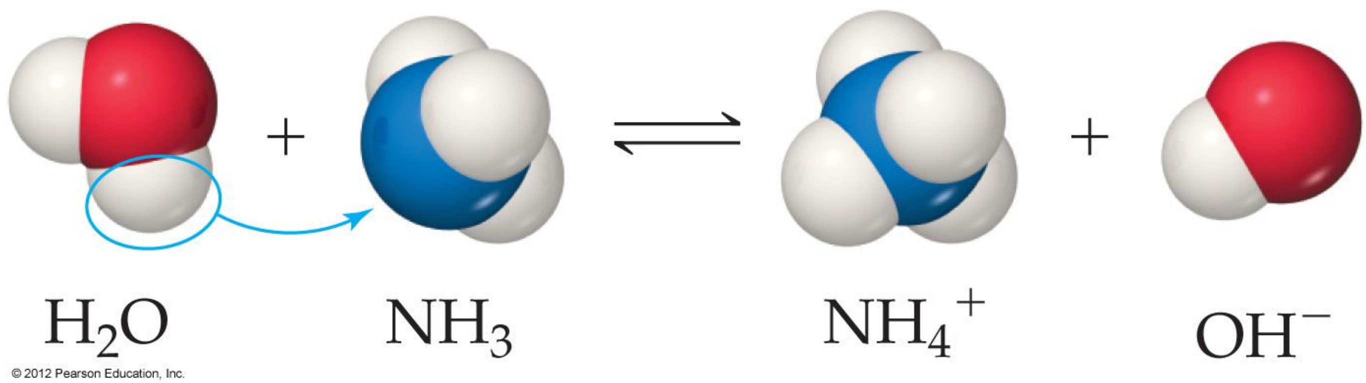
The strong bases are the soluble metal salts of hydroxide ion:

- Alkali metals
- Calcium
- Strontium
- Barium



Acid-Base Reactions

In an acid–base reaction, the acid donates a proton (H^+) to the base.



Neutralization Reactions

Generally, when solutions of an acid and a base are combined, the products are a salt and water:

$$CH_3COOH(aq) + NaOH(aq) \longrightarrow CH_3COONa(aq) + H_2O(l)$$

Neutralization Reactions

When a strong acid reacts with a strong base, the net ionic equation is

$$\text{HCl}(aq) + \text{NaOH}(aq) \longrightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l)$$

Neutralization Reactions

When a strong acid reacts with a strong base, the net ionic equation is

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

$$H^+(aq) + \cancel{Cl^-}(aq) + \cancel{Na^+}(aq) + OH^-(aq) \longrightarrow$$
$$\cancel{Na^+}(aq) + \cancel{Cl^-}(aq) + H_2O(l)$$

Neutralization Reactions

When a strong acid reacts with a strong base, the net ionic equation is

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

$$H^+(aq) + \cancel{Cl^-}(aq) + \cancel{Na^+}(aq) + OH^-(aq) \longrightarrow \cancel{Na^+}(aq) + \cancel{Cl^-}(aq) + H_2O(l)$$

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

Gas-Forming Reactions

- Some metathesis reactions do not give the product expected.
- In this reaction, the expected product (H_2CO_3) decomposes to give a gaseous product (CO_2):

$$CaCO_3(s) + HCl(aq) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

Gas-Forming Reactions

When a carbonate or bicarbonate reacts with an acid, the products are a salt, carbon dioxide, and water:

$$CaCO_3(s) + HCl(aq) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

$$NaHCO_3(aq) + HBr(aq) \longrightarrow NaBr(aq) + CO_2(g) + H_2O(l)$$

Gas-Forming Reactions

Similarly, when a sulfite reacts with an acid, the products are a salt, sulfur dioxide, and water:

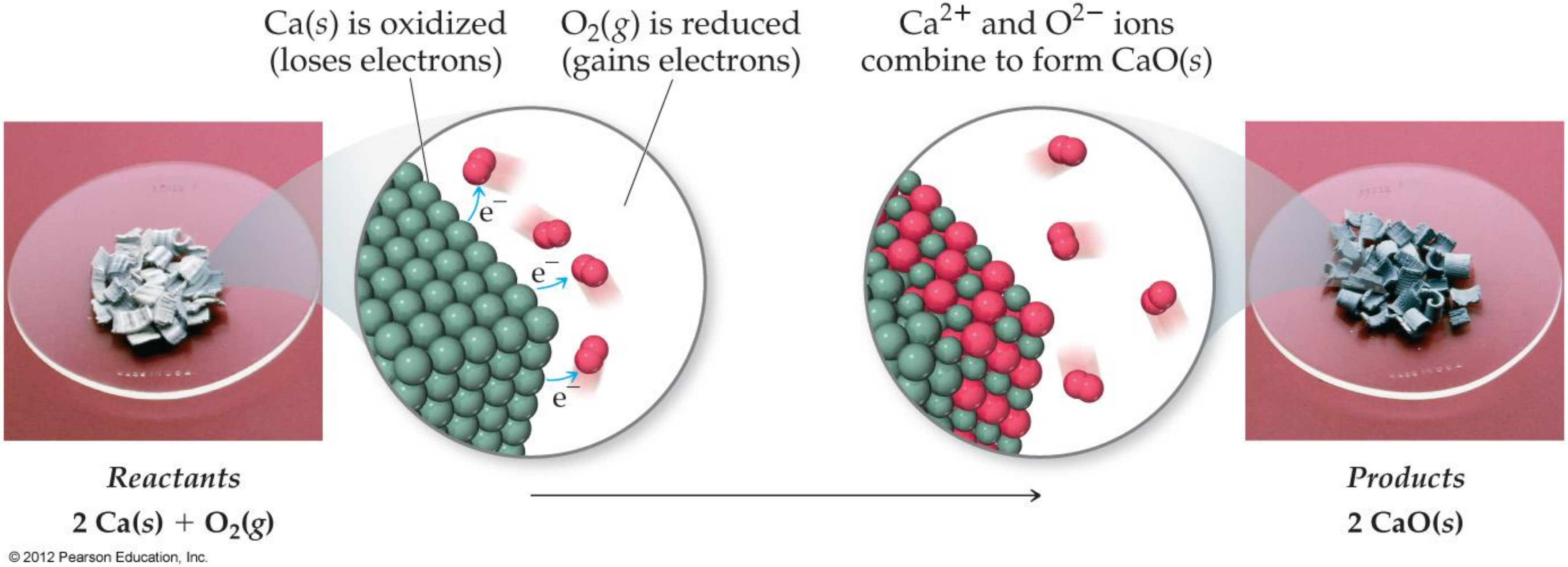
$$SrSO_3(s) + 2HI(aq) \longrightarrow SrI_2(aq) + SO_2(g) + H_2O(l)$$

Gas-Forming Reactions

- This reaction gives the predicted product, but you had better carry it out in the hood, or you will be *very* unpopular!
- But just as in the previous examples, a gas is formed as a product of this reaction:

$$Na_2S(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + H_2S(g)$$

Oxidation-Reduction Reactions



- An **oxidation** occurs when an atom or ion *loses* electrons.
- A **reduction** occurs when an atom or ion *gains* electrons.
- One cannot occur without the other.

Oxidation Numbers

To determine if an oxidation–reduction reaction has occurred, we assign an **oxidation number** to each element in a neutral compound or charged entity.

Oxidation Numbers

- Elements in their elemental form have an oxidation number of 0.
- The oxidation number of a monatomic ion is the same as its charge.

Oxidation Numbers

- Nonmetals tend to have negative oxidation numbers, although some are positive in certain compounds or ions.
  – Oxygen has an oxidation number of −2, except in the peroxide ion, in which it has an oxidation number of −1.
  – Hydrogen is −1 when bonded to a metal, +1 when bonded to a nonmetal.

Oxidation Numbers

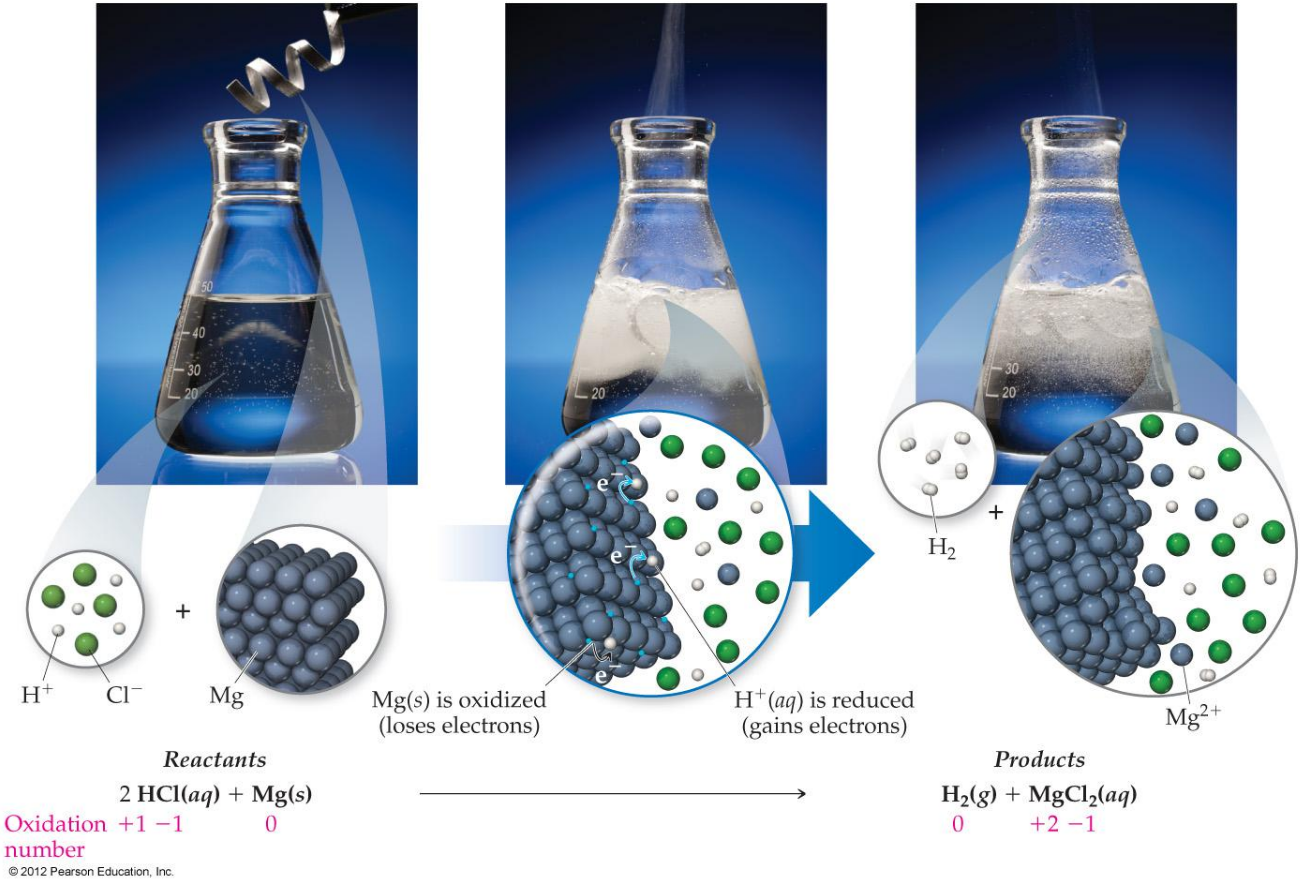
- Nonmetals tend to have negative oxidation numbers, although some are positive in certain compounds or ions.
  - Fluorine always has an oxidation number of −1.
  - The other halogens have an oxidation number of −1 when they are negative; they can have positive oxidation numbers, however, most notably in oxyanions.

Oxidation Numbers

- The sum of the oxidation numbers in a neutral compound is 0.
- The sum of the oxidation numbers in a polyatomic ion is the charge on the ion.

Displacement Reactions

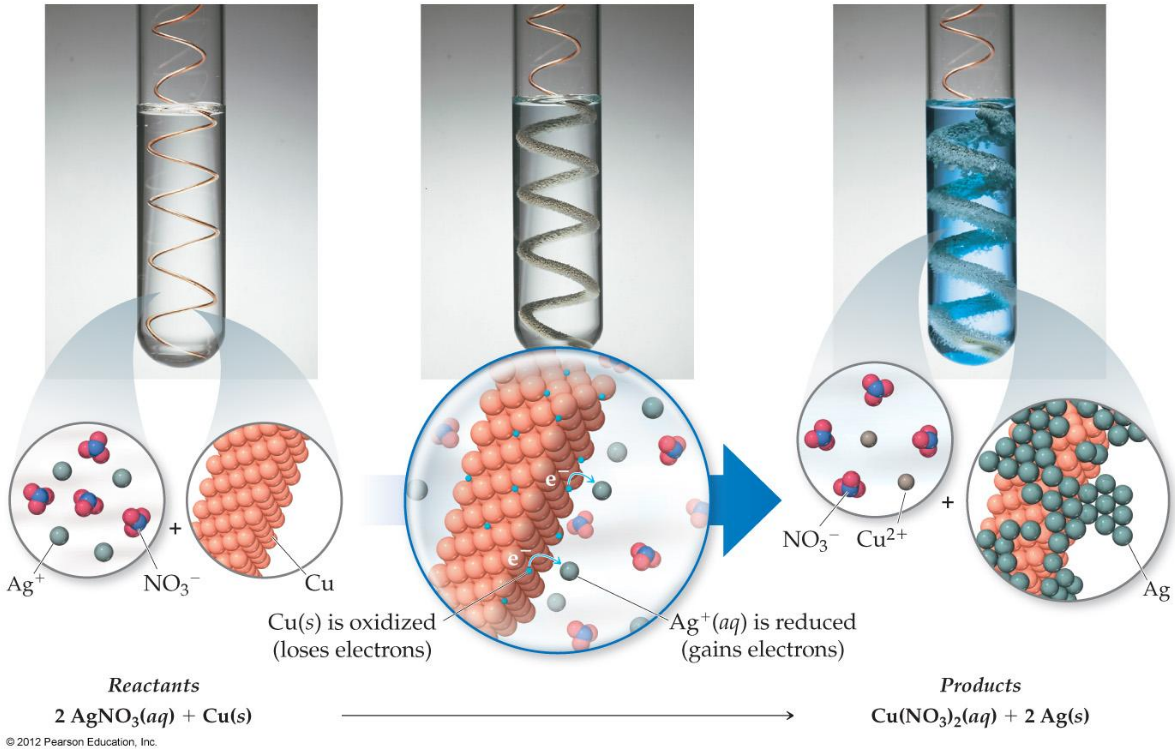
- In displacement reactions, ions oxidize an element.
- The ions, then, are reduced.



Aqueous Reactions

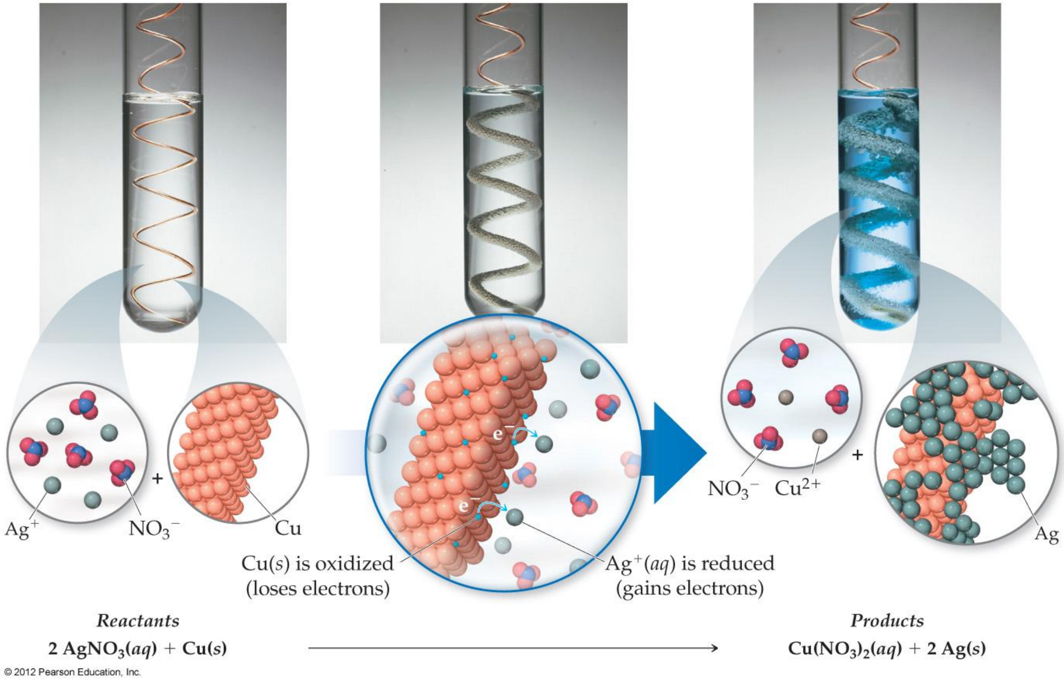
Displacement Reactions

In this reaction, silver ions oxidize copper metal:



$$Cu(s) + 2Ag^{+}(aq) \longrightarrow Cu^{2+}(aq) + 2Ag(s)$$

Displacement Reactions



The reverse reaction, however, does not occur:

$$Cu^{2+}(aq) + 2Ag(s) \xrightarrow{X} Cu(s) + 2Ag^{+}(aq)$$

Activity Series

TABLE 4.5 • Activity Series of Metals in Aqueous Solution

Metal	Oxidation Reaction
Lithium	$Li(s) \longrightarrow Li^{+}(aq) + e^{-}$
Potassium	$K(s) \longrightarrow K^{+}(aq) + e^{-}$
Barium	$Ba(s) \longrightarrow Ba^{2+}(aq) + 2e^{-}$
Calcium	$Ca(s) \longrightarrow Ca^{2+}(aq) + 2e^{-}$
Sodium	$Na(s) \longrightarrow Na^{+}(aq) + e^{-}$
Magnesium	$Mg(s) \longrightarrow Mg^{2+}(aq) + 2e^{-}$
Aluminum	$Al(s) \longrightarrow Al^{3+}(aq) + 3e^{-}$
Manganese	$Mn(s) \longrightarrow Mn^{2+}(aq) + 2e^{-}$
Zinc	$Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^{-}$
Chromium	$Cr(s) \longrightarrow Cr^{3+}(aq) + 3e^{-}$
Iron	$Fe(s) \longrightarrow Fe^{2+}(aq) + 2e^{-}$
Cobalt	$Co(s) \longrightarrow Co^{2+}(aq) + 2e^{-}$
Nickel	$Ni(s) \longrightarrow Ni^{2+}(aq) + 2e^{-}$
Tin	$Sn(s) \longrightarrow Sn^{2+}(aq) + 2e^{-}$
Lead	$Pb(s) \longrightarrow Pb^{2+}(aq) + 2e^{-}$
Hydrogen	$H_2(g) \longrightarrow 2\,H^{+}(aq) + 2e^{-}$
Copper	$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^{-}$
Silver	$Ag(s) \longrightarrow Ag^{+}(aq) + e^{-}$
Mercury	$Hg(l) \longrightarrow Hg^{2+}(aq) + 2e^{-}$
Platinum	$Pt(s) \longrightarrow Pt^{2+}(aq) + 2e^{-}$
Gold	$Au(s) \longrightarrow Au^{3+}(aq) + 3e^{-}$

Ease of oxidation increases

Molarity

- Two solutions can contain the same compounds but be quite different because the proportions of those compounds are different.
- Molarity is one way to measure the concentration of a solution:

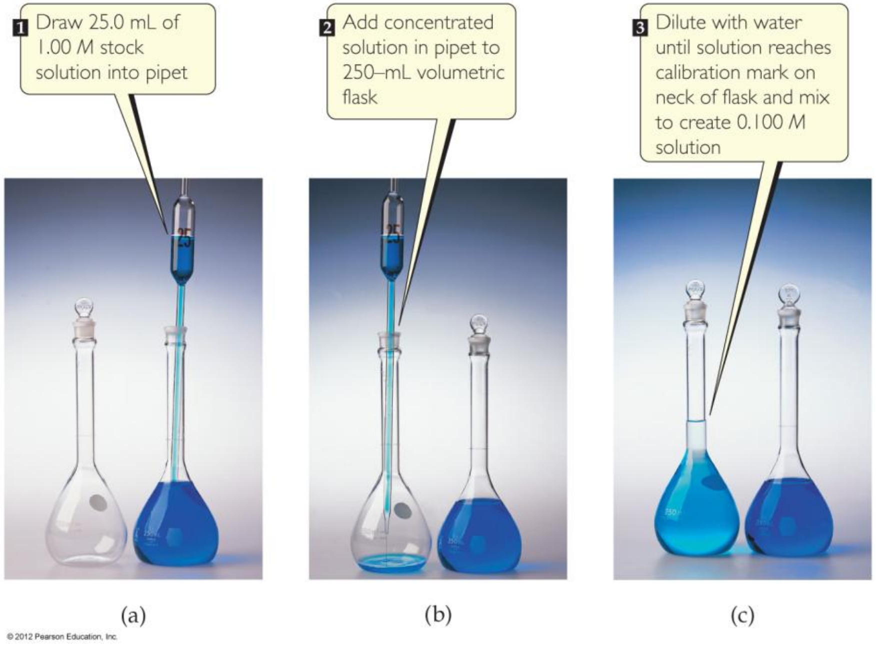
$$\text{Molarity } (M) = \frac{\text{moles of solute}}{\text{volume of solution in liters}}$$

Mixing a Solution

- To create a solution of a known molarity, one weighs out a known mass (and, therefore, number of moles) of the solute.
- The solute is added to a volumetric flask, and solvent is added to the line on the neck of the flask.

Dilution

- One can also dilute a more concentrated solution by
  - Using a pipet to deliver a volume of the solution to a new volumetric flask, and
  - Adding solvent to the line on the neck of the new flask.

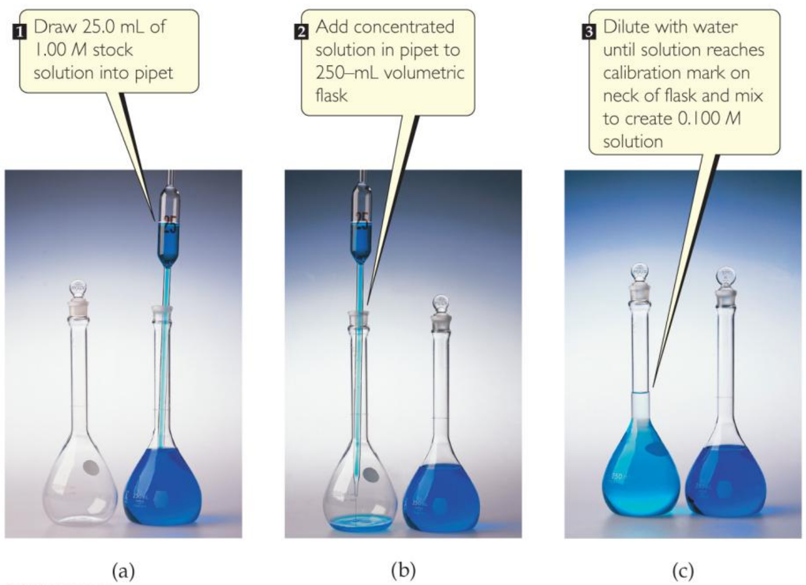


Dilution

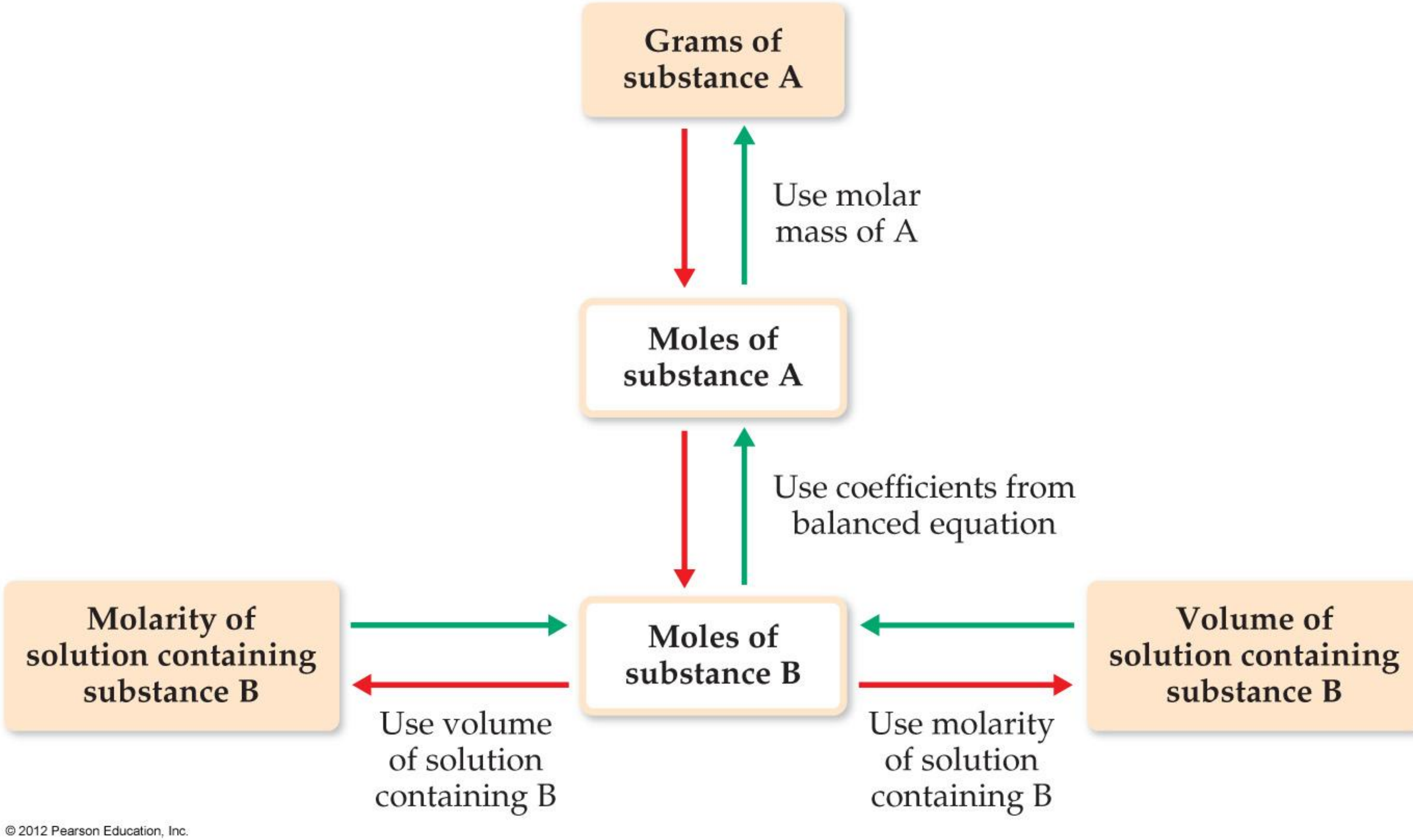
The molarity of the new solution can be determined from the equation

$$M_c \times V_c = M_d \times V_d,$$

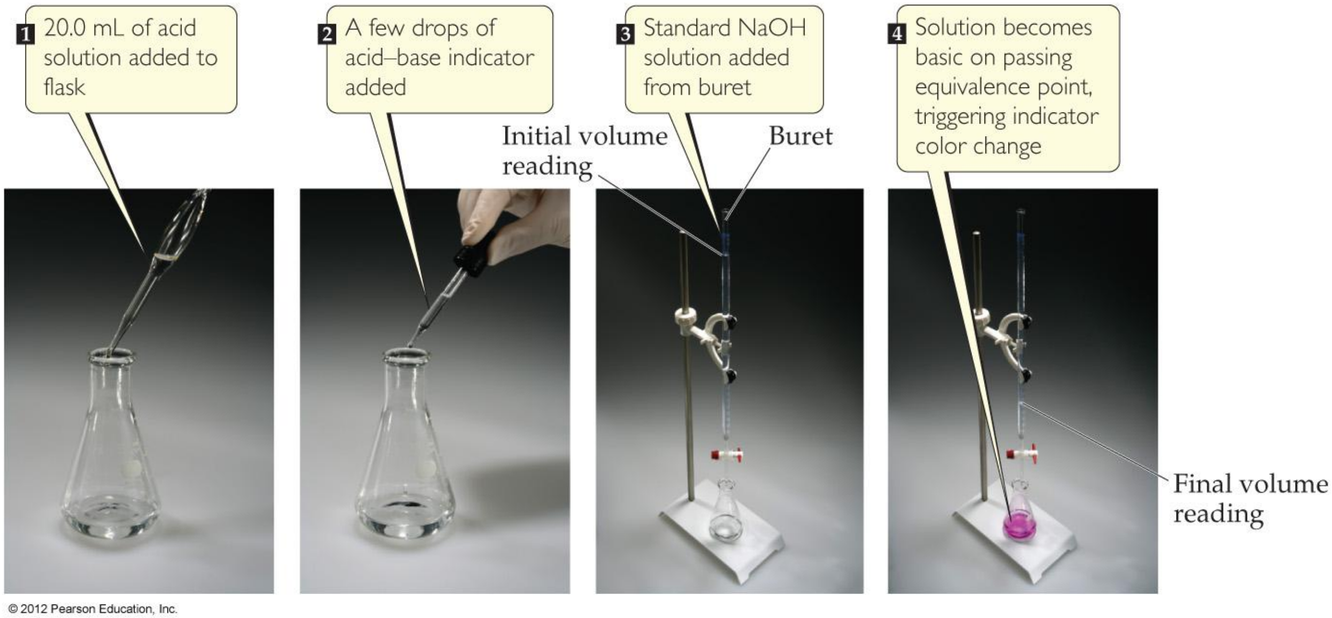
where M_c and M_d are the molarity of the concentrated and dilute solutions, respectively, and V_c and V_d are the volumes of the two solutions.

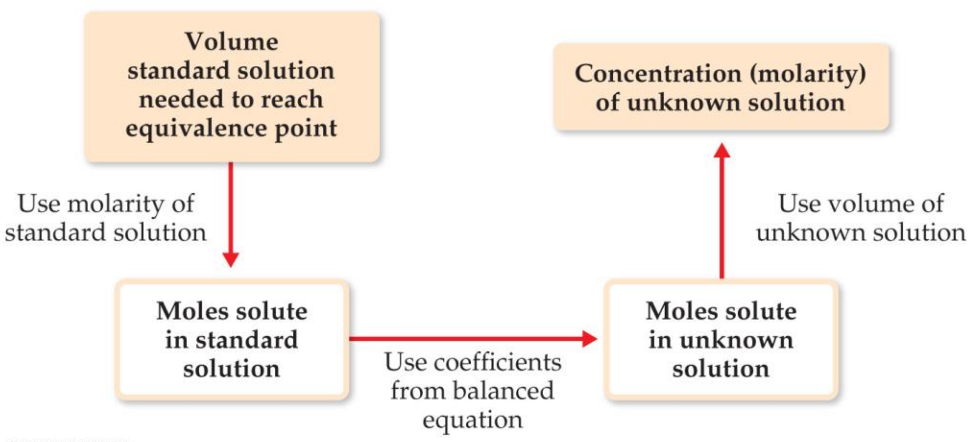


Using Molarities in Stoichiometric Calculations



Titration





Titration is an analytical technique in which one can calculate the concentration of a solute in a solution.