Chemistry, The Central Science, 10th edition
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Chapter 4
Aqueous Reactions and Solution Stoichiometry

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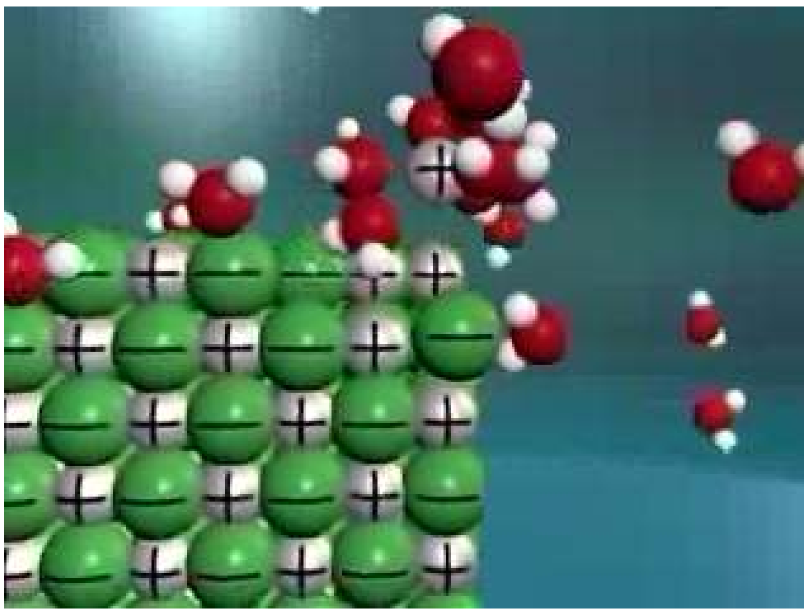
Solutions:

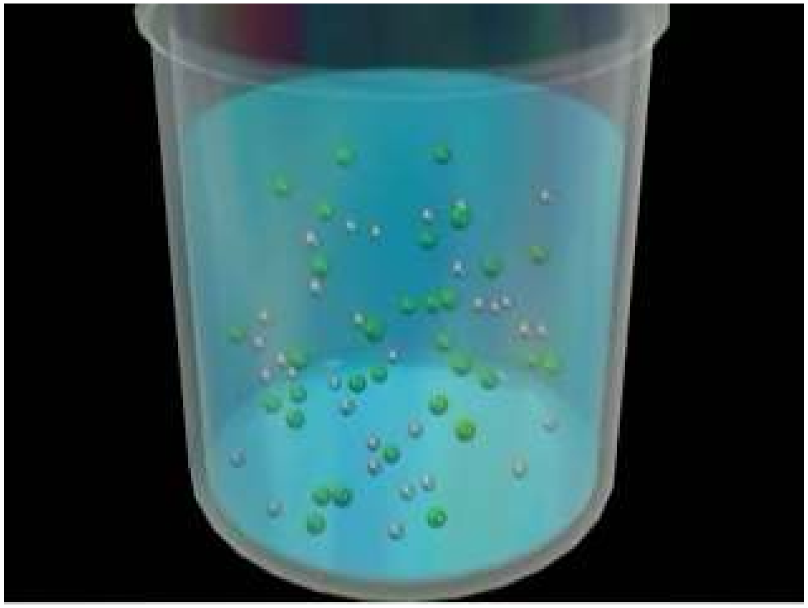
- Homogeneous mixtures of two or more pure substances.
- The solvent is present in greatest abundance.
- All other substances are solutes.

Dissociation



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

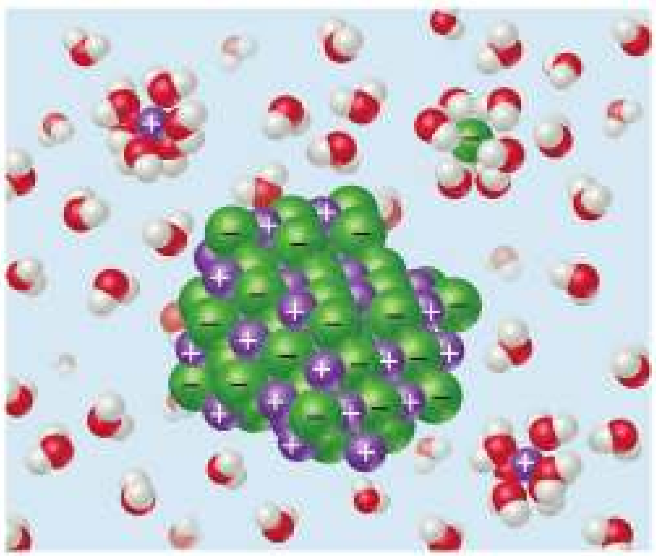
Electrolytes



- Substances that dissociate 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

	Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
Ionic	All	None	None
Molecular	Strong acids (see Table 4.2)	Weak acids (H . . .) Weak bases (NH_3)	All other compounds



Soluble ionic compounds tend to be electrolytes.

Electrolytes and Nonelectrolytes

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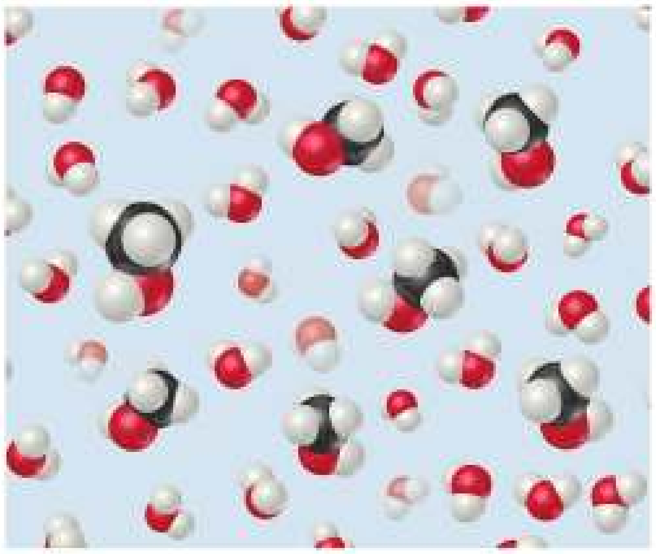
Molecular	Strong acids (see Table 4.2)	Weak acids (H . . .)	
		Weak bases (NH_3)	All other compounds



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

Electrolytes

- 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 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

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Sulfuric, H_2SO_4	

Strong Electrolytes Are…

- Strong acids
- Strong bases
- Soluble ionic salts

Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	$C_2H_3O_2^-$	None
	Cl^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	Br^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	I^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}
Insoluble Ionic Compounds		**Important Exceptions**
Compounds containing	S^{2-}	Compounds of NH_4^+, the alkali metal cations, and Ca^{2+}, Sr^{2+}, and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
	PO_4^{3-}	Compounds of NH_4^+ and the alkali metal cations
	OH^-	Compounds of the alkali metal cations, and NH_4^+, Ca^{2+}, Sr^{2+}, and Ba^{2+}

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”

$$AgNO_{3\,(aq)} + KCl_{\,(aq)} \longrightarrow$$

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Metathesis (Exchange) Reactions

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$$AgNO_{3\,(aq)} + KCl_{\,(aq)} \longrightarrow AgCl_{\,(s)} + KNO_{3\,(aq)}$$

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.

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

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.

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

$$AgCl\,(s) + \cancel{K^{+}(aq)} + \cancel{NO_3^{-}(aq)}$$

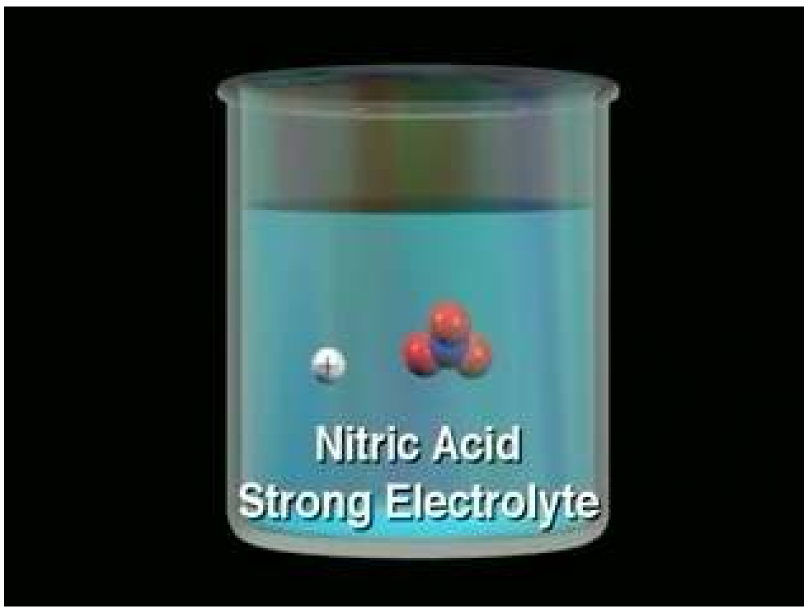
Writing Net Ionic Equations

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:

- Substances that increase the concentration of H^+ when dissolved in water (Arrhenius).
- Proton donors (Brønsted–Lowry).

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:

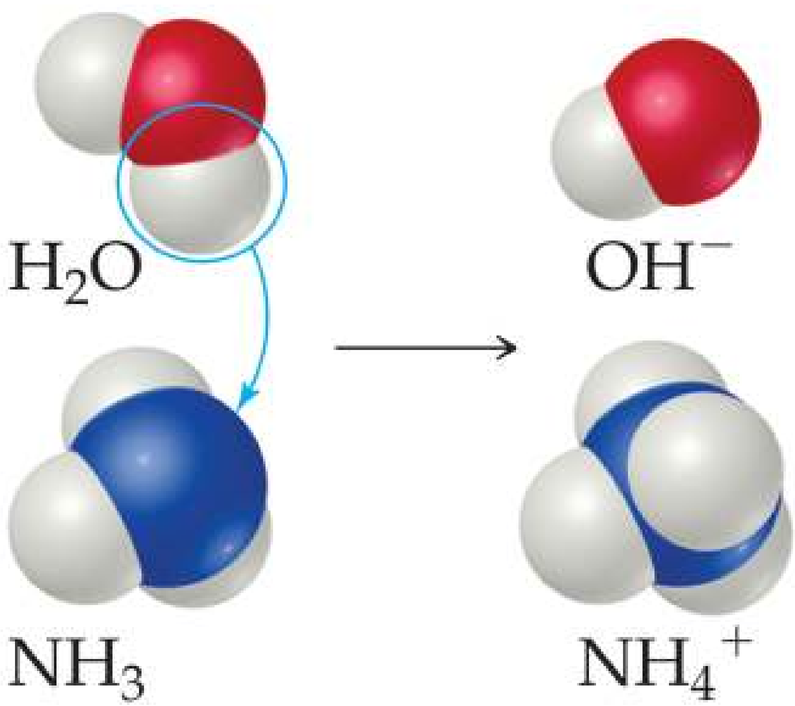
- Substances that increase the concentration of OH^- when dissolved in water (Arrhenius).
- Proton acceptors (Brønsted–Lowry).

Bases

The strong bases are the soluble 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.

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

Neutralization Reactions

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

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

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

Neutralization Reactions

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

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

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

Aqueous Reactions

Neutralization Reactions

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

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

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

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

Neutralization Reactions

Observe the reaction between Milk of Magnesia, $Mg(OH)_2$, and HCl.

Gas-Forming Reactions

- These metathesis reactions do not give the product expected.
- The expected product decomposes to give a gaseous product (CO_2 or SO_2).

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

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

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

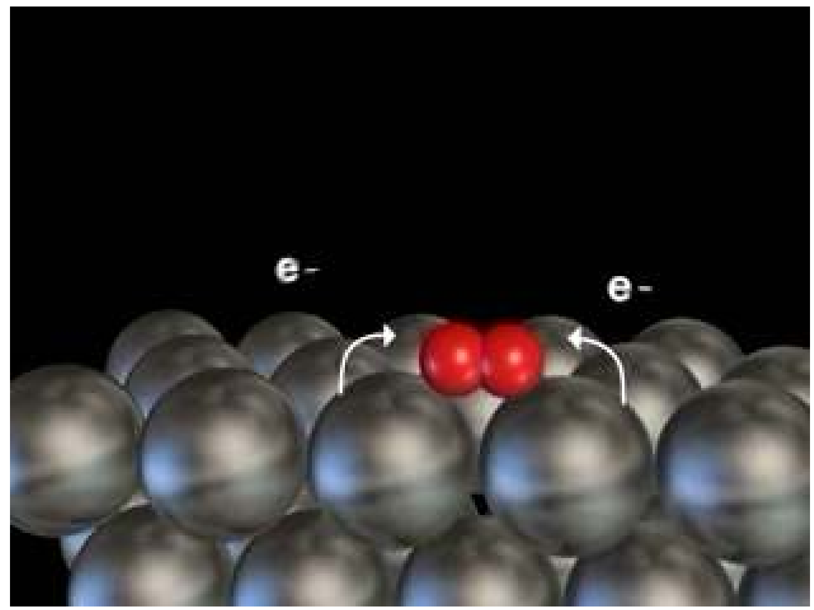
Gas-Forming Reactions

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

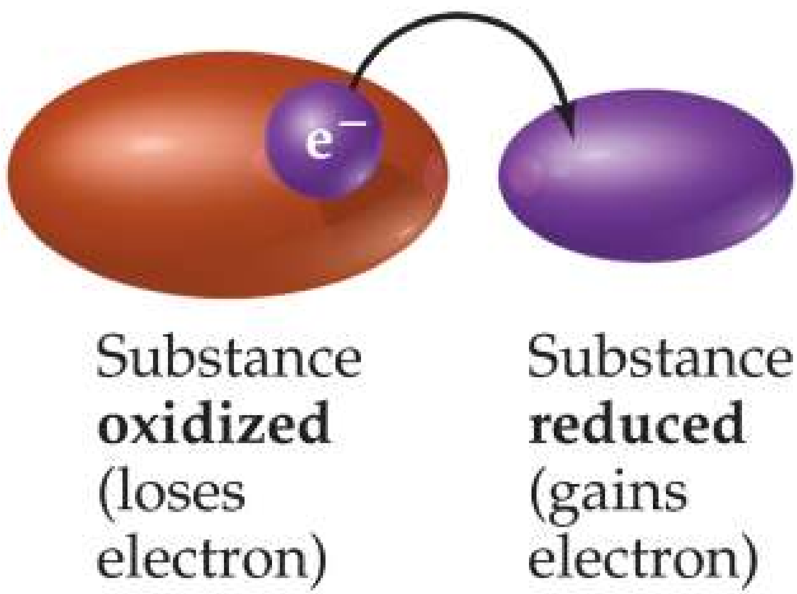
$$Na_2S\ (aq) + H_2SO_4\ (aq) \longrightarrow Na_2SO_4\ (aq) + H_2S\ (g)$$

Oxidation-Reduction Reactions

- An oxidation occurs when an atom or ion *loses* electrons.
- A reduction occurs when an atom or ion *gains* electrons.



Oxidation-Reduction Reactions



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.

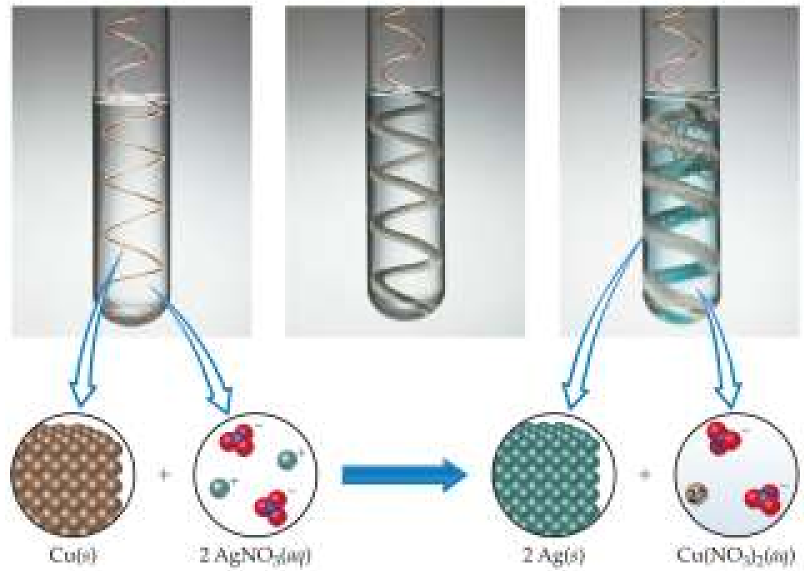
Oxidation Numbers

- 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.

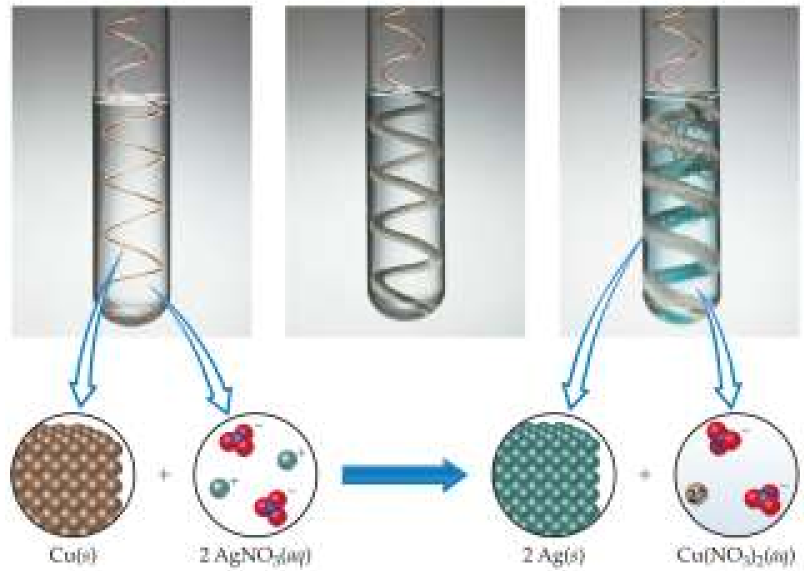
Displacement Reactions



In this reaction, silver ions oxidize copper metal.

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

Displacement Reactions

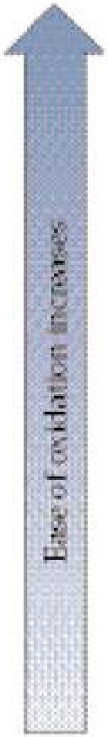


The reverse reaction, however, does not occur.

$$Cu^{2+}(aq) + 2\,Ag(s) \not\longrightarrow Cu(s) + 2\,Ag^{+}(aq)$$

Activity Series

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	$H_2(g) \longrightarrow 2H^{+}(aq) + 2e^{-}$
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	$Au(s) \longrightarrow Au^{3+}(aq) + 3e^{-}$



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.

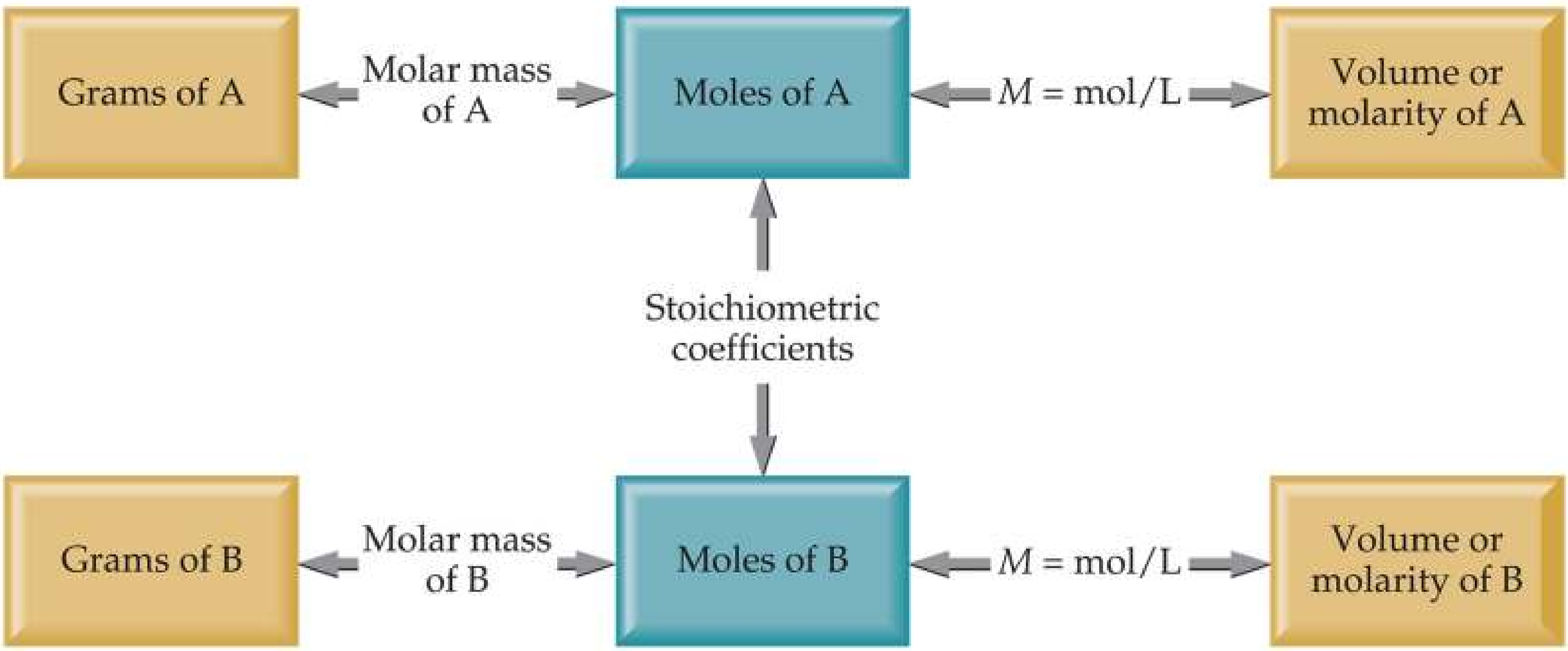
$$\text{Molarity } (M) = \frac{\text{moles of solute}}{\text{volume of solution in liters}}$$

Mixing a Solution

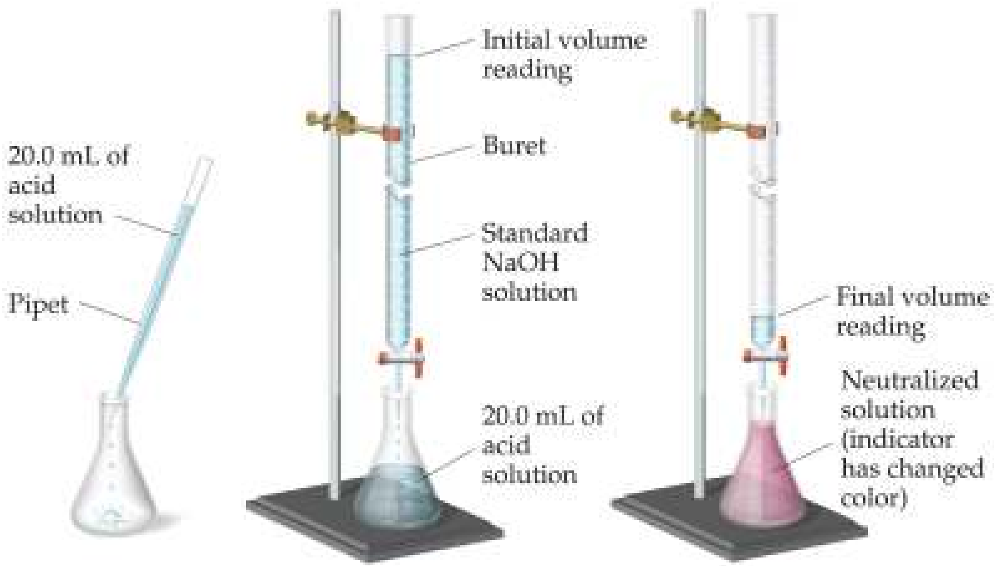
Dilution

Aqueous
Reactions

Using Molarities in Stoichiometric Calculations



Titration



The analytical technique in which one can calculate the concentration of a solute in a solution.

Titration