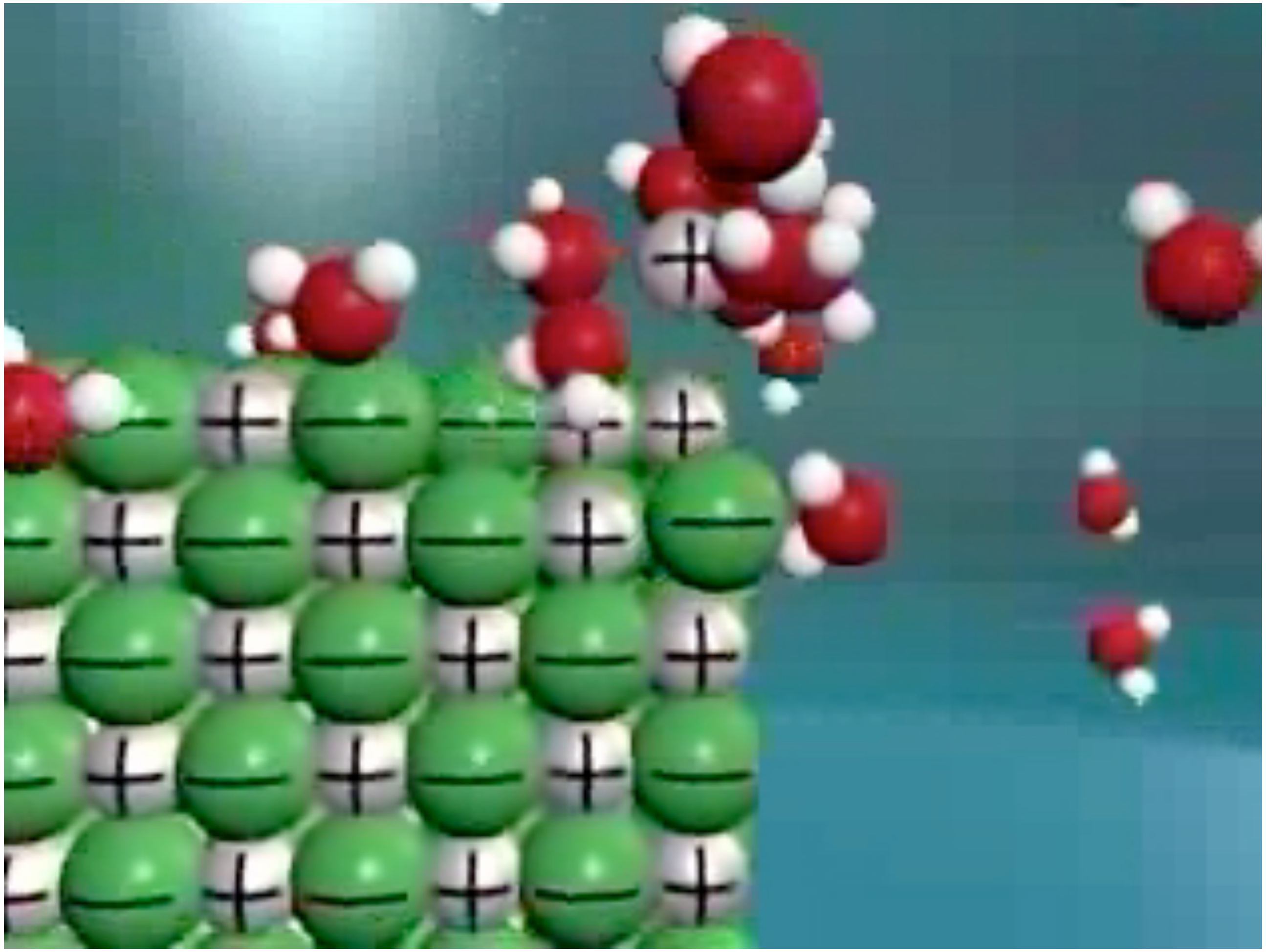
Chapter 4
Aqueous Reactions and Solution Stoichiometry

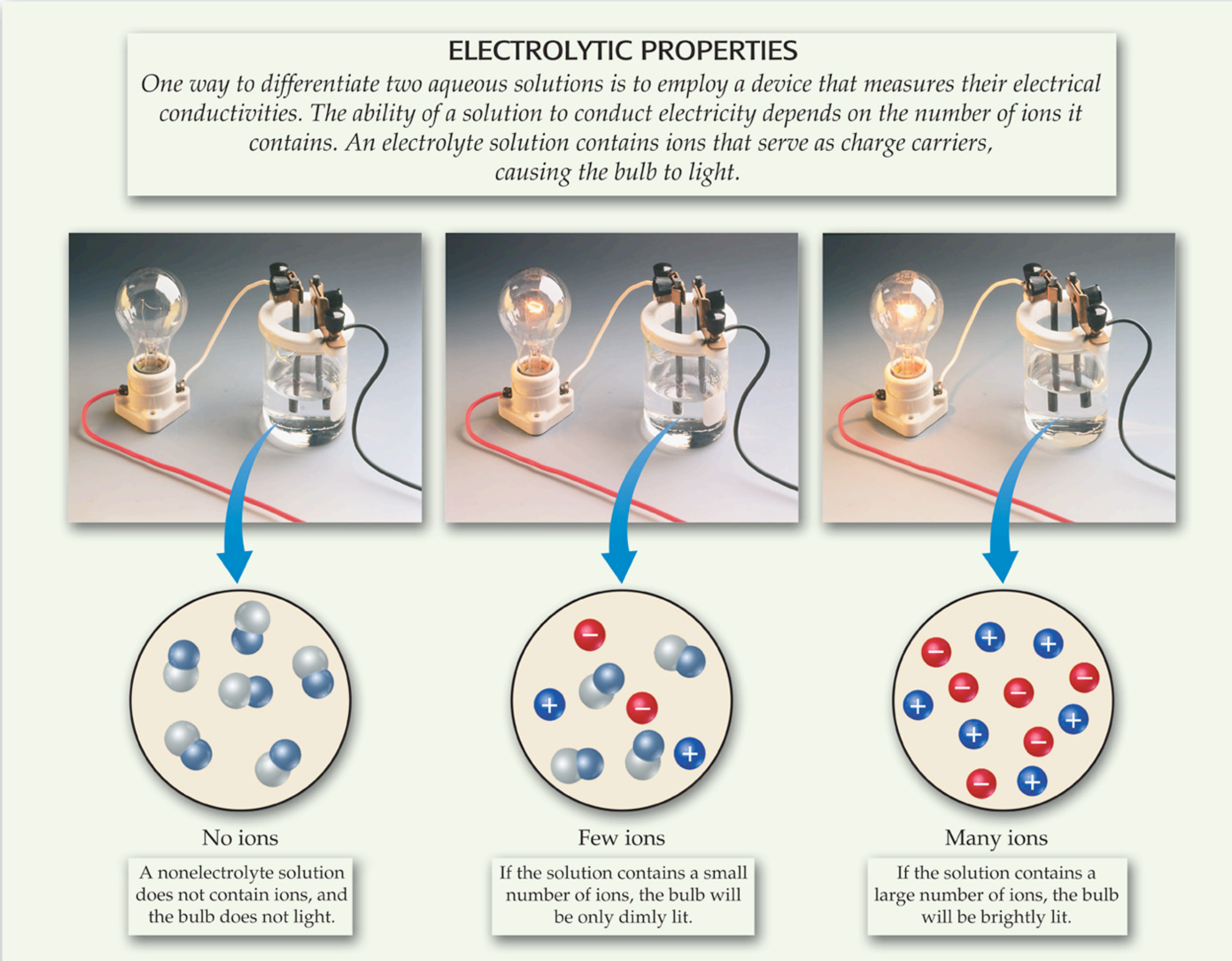
Solutions:

- Homogeneous mixtures of two or more pure substances.
- The solvent is usually present in greatest abundance.
- Or, the solvent is the liquid when a solid is dissolved
- All other substances are solutes.

Dissociation

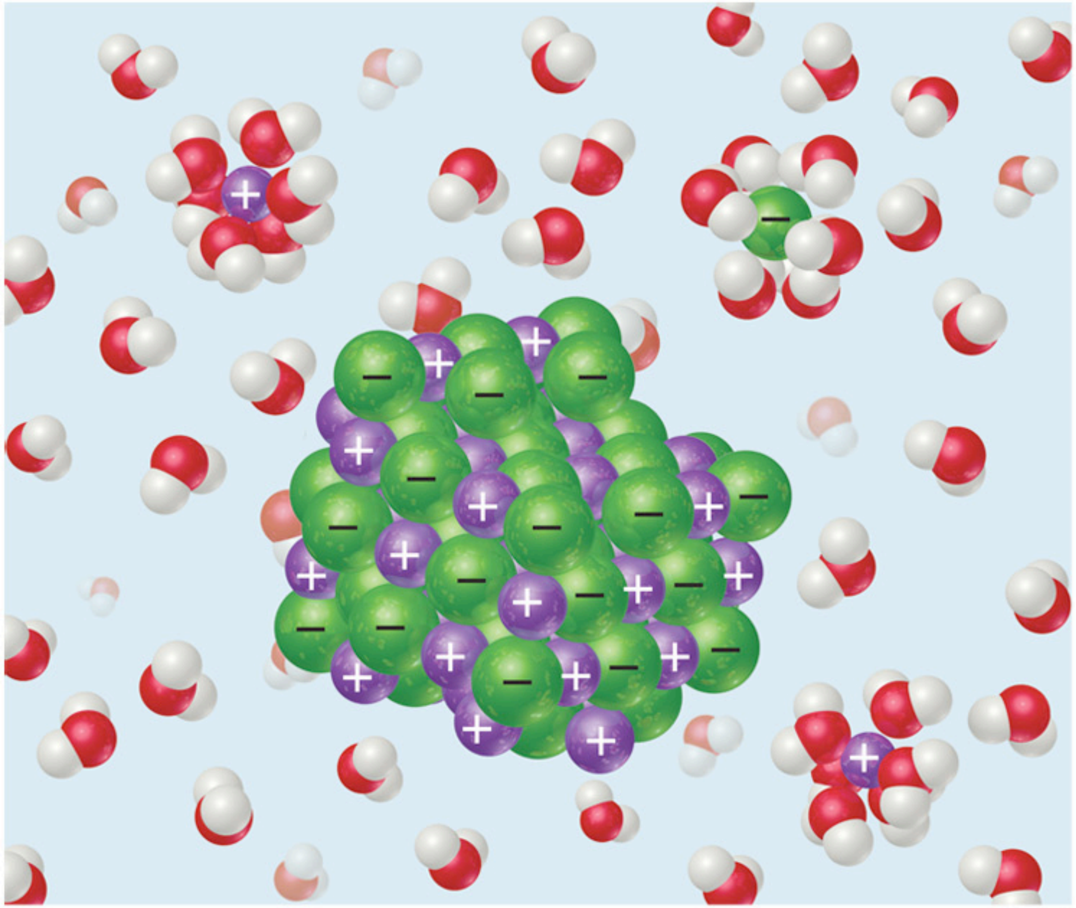


- ionic compound dissolves in water, the individual ions from the crystal are separated. This process is called dissociation.



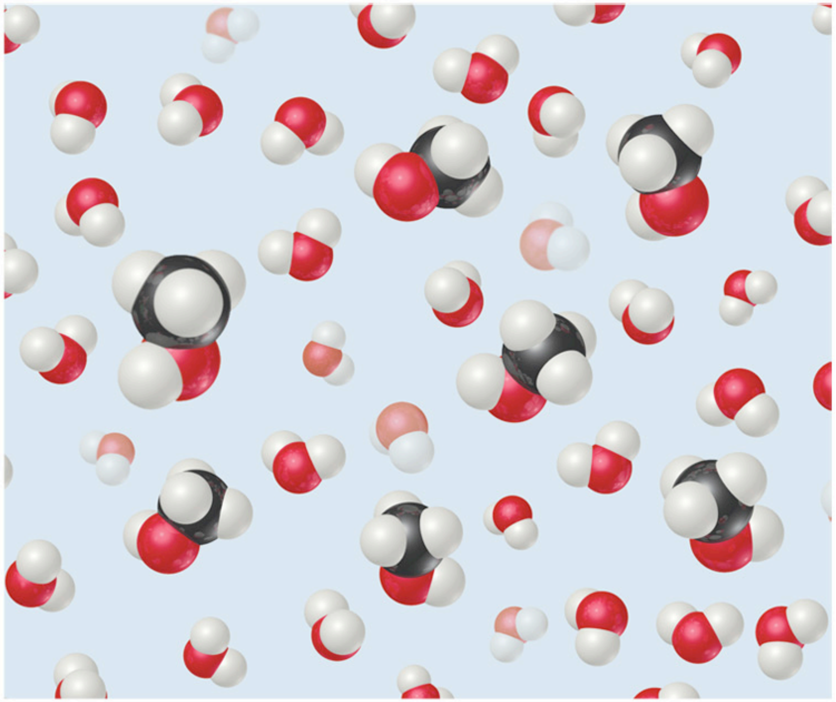
- Substances that dissociate into ions when dissolved in water are electrolytes.
- A nonelectrolyte may dissolve in water, but it does not dissociate into ions when it does so.

Electrolytes and Nonelectrolytes



Soluble ionic compounds tend to be electrolytes.

Electrolytes and Nonelectrolytes



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.
- A nonelectrolyte does not dissociate in water

	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

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	

The 7 common strong acids

KNOW THEM

Strong Electrolytes Are…

- Strong acids
- Strong bases

NOTE THIS IS MORE STUFF YOU NEED TO KNOW

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	

The strong bases

KNOW THEM!!!!

Strong Electrolytes Are…

- Strong acids
- Strong bases
- Soluble ionic salts
- If the salt doesn't dissolve, it can't conduct.

Solubility trends

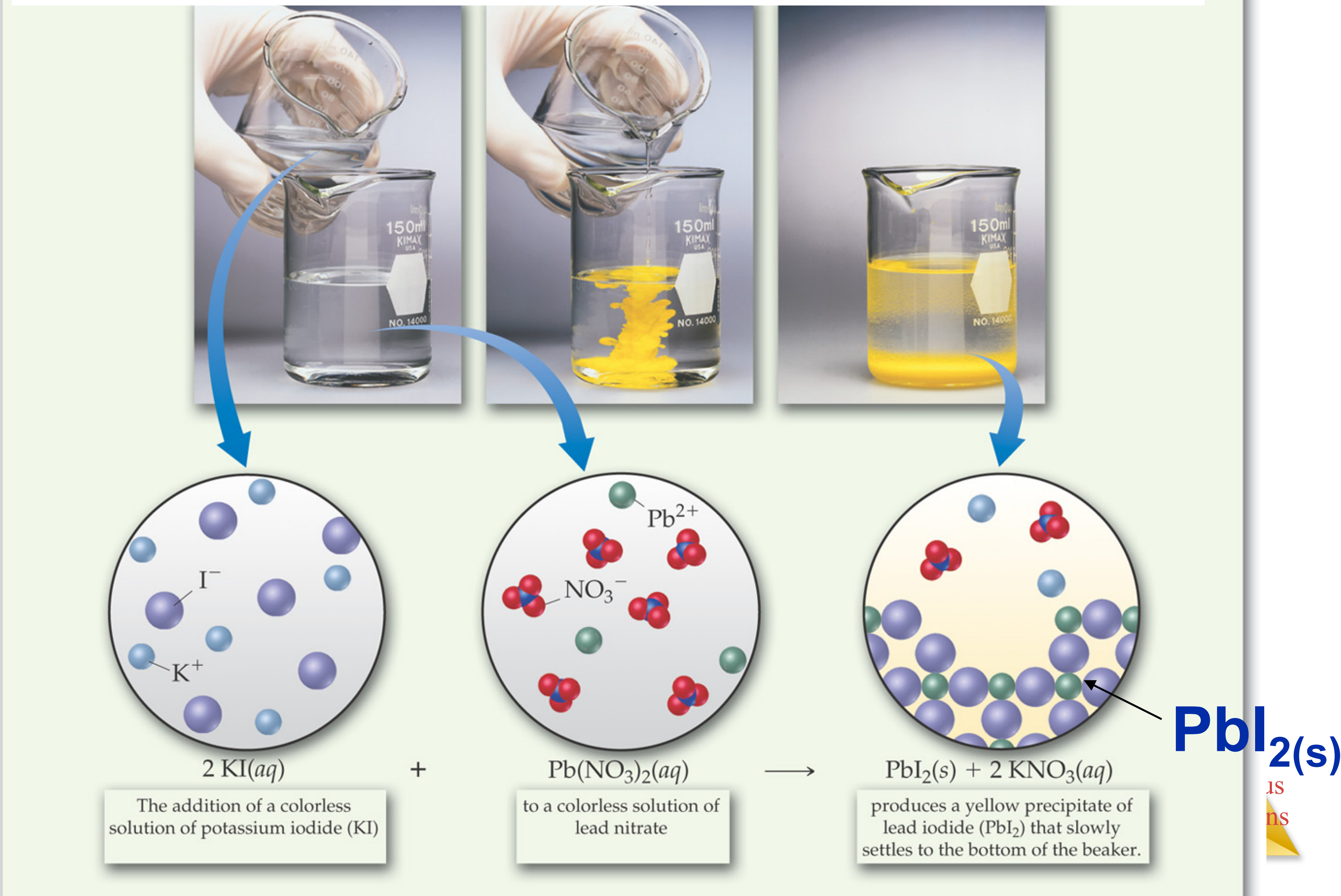
Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	$C_2H_3O_2^-$	None
	Cl^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	Br^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	I^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}

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+}

NH_4^+ salts are always soluble

Alkali metal salts are always soluble

Precipitation Reactions



Metathesis (Exchange) Reactions

- Metathesis comes from a Greek word that means "to transpose"
- It appears the ions in the reactant compounds exchange, or transpose, ions

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

Metathesis (Exchange) Reactions

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

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

This is a “reaction” because the AgCl precipitates. Otherwise, nothing would be happening.

$NaCl_{(aq)}$ + $KBr_{(aq)}$ -------> $KCl_{(aq)}$ + $NaBr_{(aq)}$

Nothing happens!

Solution Chemistry

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

Chemical Equation

The chemical equation lists the reactants and products, but some information must be assumed.

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

Ionic Equation

- In the ionic equation all strong electrolytes (strong acids, strong bases, and soluble ionic salts) are dissociated into their ions.
- reflects the species that are **actually 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 chemical 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.

Writing Net Ionic Equations

1. $NaCl_{(aq)} + AgNO_{3(aq)}$ ---------> $AgCl_{(s)} + NaNO_{3(aq)}$

$\cancel{Na^{+}} + Cl^{-} + Ag^{+} + \cancel{NO_3^{-}}$ ----> $AgCl_{(s)} + \cancel{Na^{+}} + \cancel{NO_3^{-}}$

$Ag^{+} + Cl^{-}$ -----> $AgCl_{(s)}$

2. $2NaBr_{(aq)} + MgCl_{2(aq)}$ -----> $2NaCl_{(aq)} + MgBr_{2(aq)}$

$\cancel{2Na^{+}} + \cancel{2Br^{-}} + \cancel{Mg^{2+}} + \cancel{2Cl^{-}}$ ----> $\cancel{2Na^{+}} + \cancel{2Cl^{-}} + \cancel{Mg^{2+}} + \cancel{2Br^{-}}$

Aqueous Reactions

Acids:

- Substances that **increase the concentration of H^+** when dissolved in water.

Aqueous Reactions

Acids

Strong: Fully dissociate into anion and H^+ (strong electrolytes)

Weak: Do not fully dissociate (weak electrolyte)

There are only seven strong acids:

- Hydrochloric (HCl)
- Hydrobromic (HBr)
- Hydroiodic (HI)
- Nitric (HNO_3)
- Sulfuric (H_2SO_4)
- Chloric ($HClO_3$)
- Perchloric ($HClO_4$)
- YOU MUST REMEMBER THESE.

Bases:

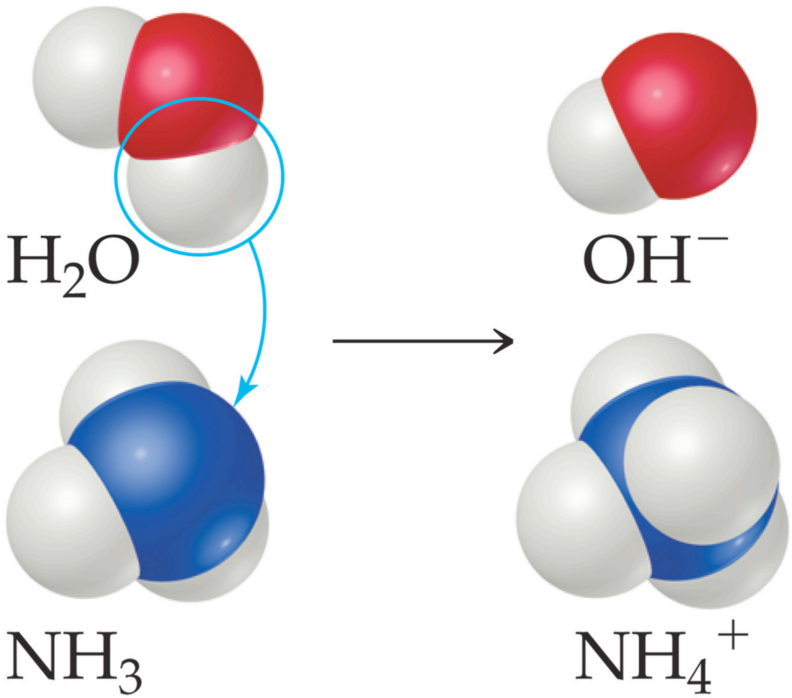
- Substances that increase the concentration of OH^- when dissolved in water.

Bases

The strong bases are the soluble salts of hydroxide ion:

- Alkali metals
- Calcium ($Ca(OH)_2$
- Strontium ($Sr(OH)_2$
- Barium ($Ba(OH)_2$

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…

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

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

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

$$H^+ + OH^- \text{ ---> } H_2O_{(l)}$$

Neutralization Reactions

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

$$Mg(OH)_{2(s)} + 2HCl_{(aq)} \text{ ----> } 2H_2O + MgCl_{2(aq)}$$

$$Mg(OH)_{2(s)} + 2H^+ + \cancel{2Cl^-} \text{ ----> } 2H_2O + Mg^{2+} + \cancel{2Cl^-}$$

$$Mg(OH)_{2(s)} + 2H^+ \text{ -----> } 2H_2O + Mg^{2+}$$

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).

$$CaCO_3\,(s) + 2HCl\,(aq) \longrightarrow CaCl_2\,(aq) + CO_2\,(g) + H_2O\,(l)$$

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

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

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:

$$Na_2S\ (aq) + 2HCl\ (aq) \longrightarrow 2NaCl\ (aq) + H_2S\ (g)$$

Stinky

Solution Stoichiometry

- Chemistry arithmetic in solution

Molarity

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

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

A unit of concentration.

Example

Make 300. mL of a 0.250 M solution of NaCl.

Needed: grams of NaCl.

Must find: moles NaCl (M = mol/L)

MW NaCl: 23 + 35.4 = 58.4 g/mol

300. mL = 0.300 L

0.250 mol/L(0.300 L)(58.4g/mol) = 4.38 g

Mixing a Solution

Aqueous
Reactions

Example

What is the molarity of a solution that contains 15 g of sodium acetate in 0.25 L

MW $NaC_2H_3O_2$: 82 g/mol

Needed: moles so you can calculate mol/L

$$\frac{15\text{g}(1\text{mol}/82\text{g})}{0.25\text{ L}} = 0.73\text{ mol/L}$$

Dilution

Example

You have a stock solution of 4.2 M $(NH_4)_2SO_4$. How much do you need to make 2.5 L of a 0.3 M $(NH_4)_2SO_4$ solution?

Needed, moles needed in final solution

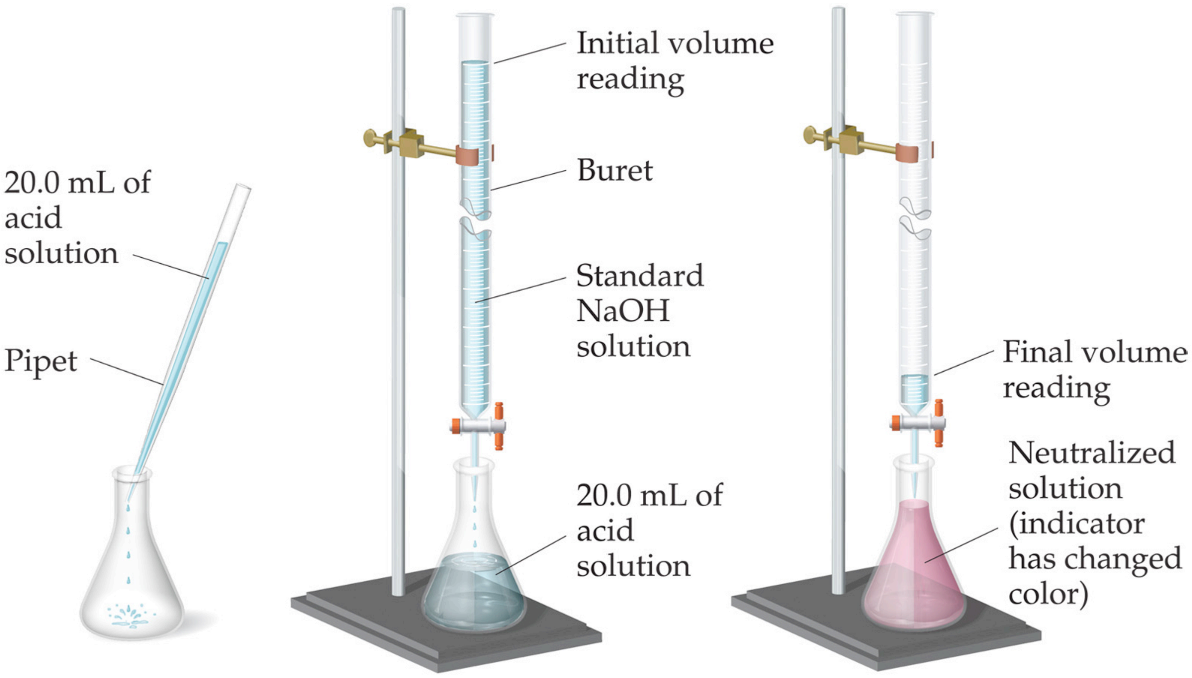
Need: volume of stock that contains the required # of moles

moles NH_4SO_4 needed: 2.5 L(0.3 mol/L)

Volume of stock: moles NH_4SO_4 needed(1/4.2 M $(NH_4)_2SO_4$)

Volume stock = 2.5L(0.3mol/L)(1L stock/4.2mol stock)=0.18 L

Titration

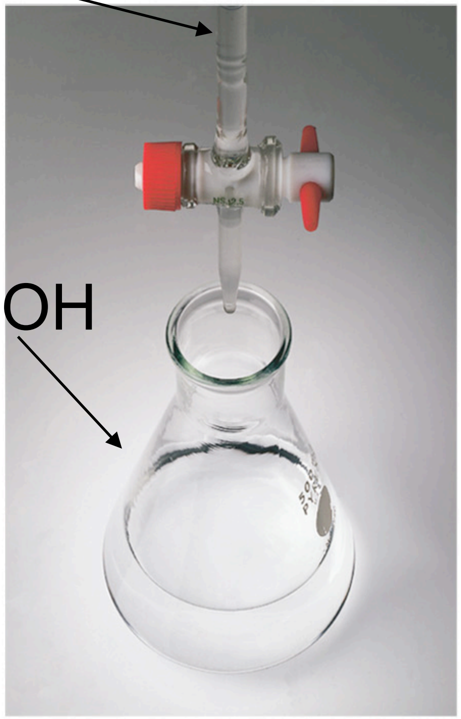


The analytical technique in which one can calculate the concentration of a solute in a solution.

Titration

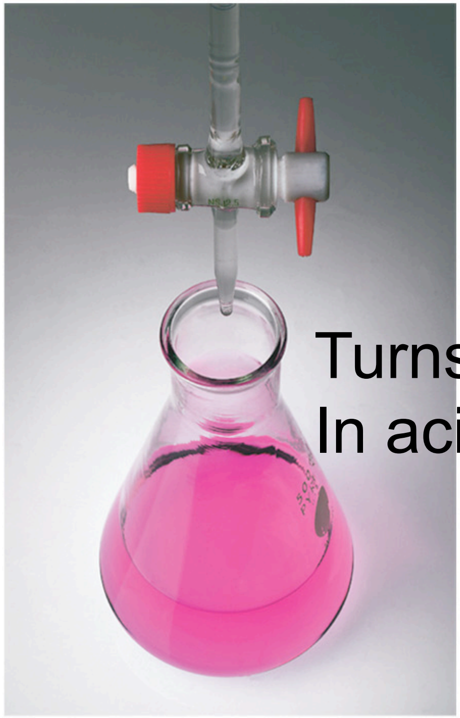
HCl

NaOH



[HCl] < [NaOH]

[HCl] = [NaOH]



Turns pink
In acid

[HCl] > [NaOH]

Add one reagent that reacts with another gradually, until the reagent is used up. Then determine amt. of reagent, if you know concentration of soln. added.

$HCl + NaOH \text{------>} NaCl + H_2O$

Aqueous Reactions

Example

0.172 L of an NaOH solution is titrated to its endpoint with 80.32 mL of a 0.0423 M solution of HCl. What was the concentration of the NaOH solution?

$HCl + NaOH \rightarrow NaCl + H_2O$

	HCl	NaOH
[M]	0.0423	?
V	0.08032 L	0.172L
moles	???	???

Need: moles HCl added = moles NaOH in unknown solution

moles HCl = 0.08032 L(0.0423 mol/L) = 0.00339 mole HCl

0.00339 mole HCl = 0.00339 mol NaOH in unknown solution.

[NaOH] = 0.00339 mol/0.172L=0.000585 mol/L (M).

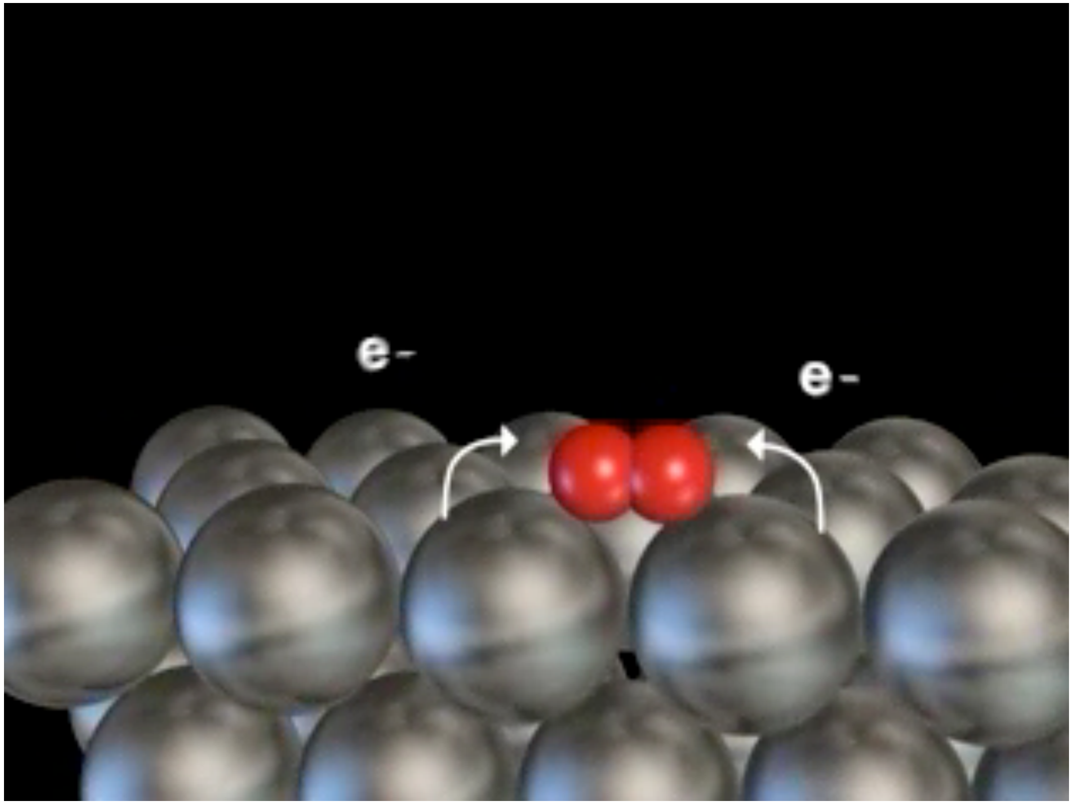
Demonstration:

$$2Mg + CO_2 \text{ ------> } 2MgO + C \text{ (charcoal)}$$

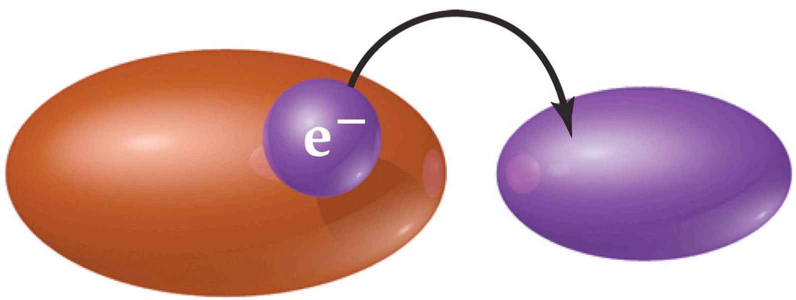
Aqueous Reactions

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



Substance **oxidized** (loses electron)

Substance **reduced** (gains electron)

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.

Book-keeping for electrons

Assigning 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.

Na oxidation number 0

Na^+ oxidation number +1

Assigning Oxidation Numbers

- Nonmetals tend to have negative oxidation numbers, although some are positive in certain compounds or ions (when they are bound to other nonmetals).
  - Oxygen has an oxidation number of −2, except in the peroxide ion (O_2^{2-}) in which it has an oxidation number of −1.
    - CO_2, H_2O, CaO etc. O has -2 oxidation number
  - Hydrogen is −1 when bonded to a metal, +1 when bonded to a nonmetal.
    - NaH H has -1 oxidation number
    - HCl H has +1 oxidation number
    - CH_4 H has +1 oxidation number

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 the oxidation number is negative;
  - they can have positive oxidation numbers, however, most notably in oxyanions.
    - CCl_4, HCl, Cl o.n. -1
    - ClO_4^- Cl o.n. +7 (must be because O is always negative)
    - HCOCl Cl o.n. -1

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.

CCl_4 Cl o.n. -1 -1(4) = -4. C o.n. +4

ClO_4^- O: -2(4) = -8 Cl: +7 (7-8=-1)

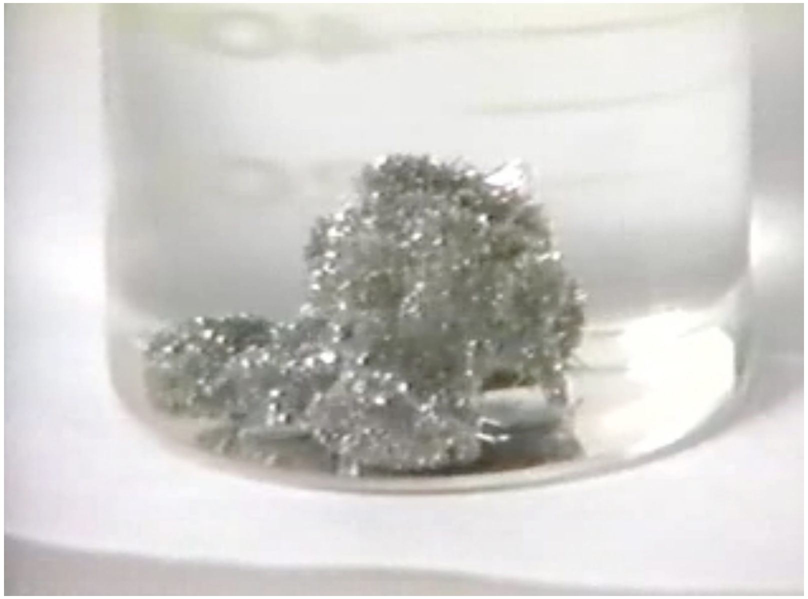
Oxidation Numbers

CO_3^{2-} NO_3^- $FeCl_3$ SF_6 H_2S

H_2SO_4 CaH_2 BBr_3 SO_3^- ClO^-

Aqueous
Reactions

Displacement Reactions



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

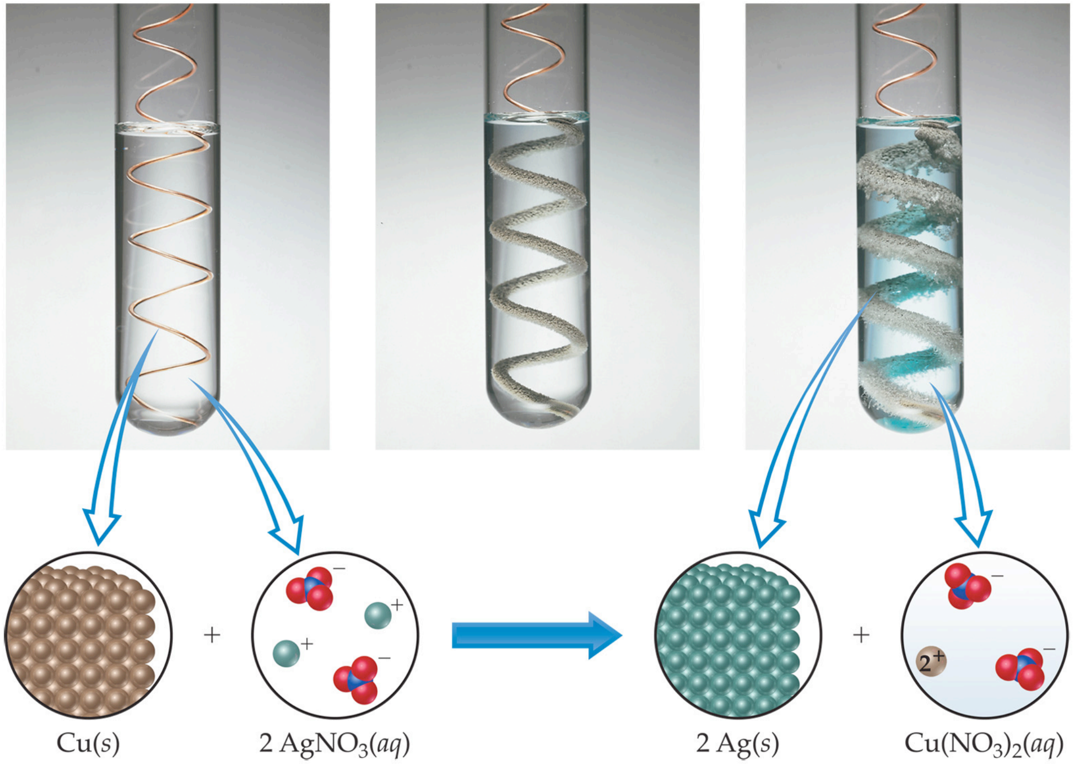
A + BX -------> AX + B

$2Li(s) + 2HBr$ ------> $LiBr + H_2$

$Na(s) + AgNO_3$ ------> $NaNO_3 + Ag(s)$

Aqueous Reactions

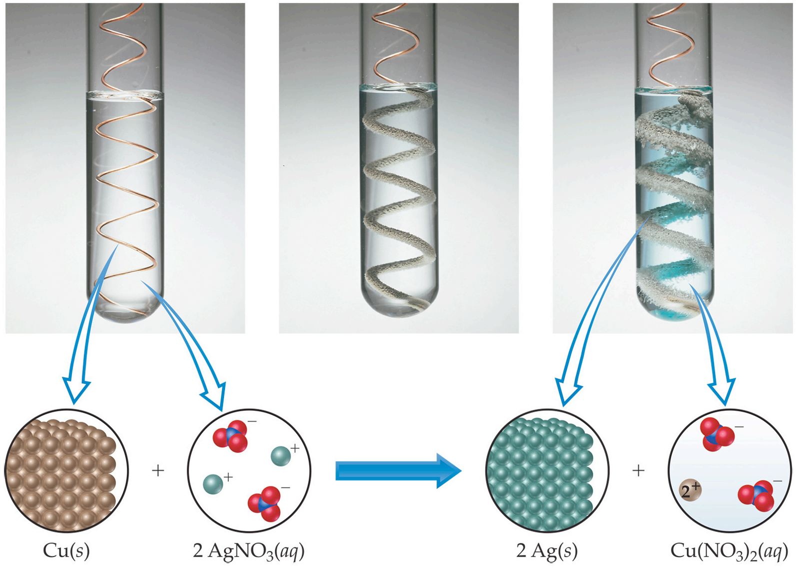
Displacement Reactions



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.

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

Why not??

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

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	$Au(s) \longrightarrow Au^{3+}(aq) + 3e^{-}$

What happens?

$Li + H_2$ ----> ??

$Li + H^{+}$ ------> ?

$Mn(s) + Fe^{2+}$ ---> ?

$Cr(s) + K^{+}$ -----> ?

$Ca(s) + Zn(s) + Mg^{2+}$?

Oxidation reduction reactions

A more complicated redox reaction:

$P_4 + 5O_2$ ---------> P_4O_{10}

O.N. 0 0 +5 -2

P **O**

+5(4) = 20 -2(10) = -20

electrons hop from P to O redox reaction

Acid/base reaction is next:

$P_4O_{10} + 6H_2O$ --------> $4H_3PO_4$ acidic solution

Aqueous Reactions