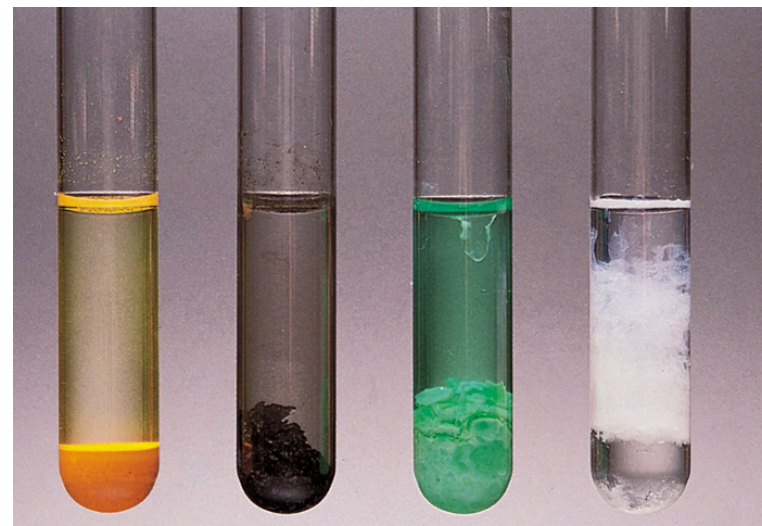




Reactions in Aqueous Solution

Chapter 4



A ***solution*** is a homogenous mixture of 2 or more substances

The ***solute*** is(are) the substance(s) present in the smaller amount(s)

The ***solvent*** is the substance present in the larger amount

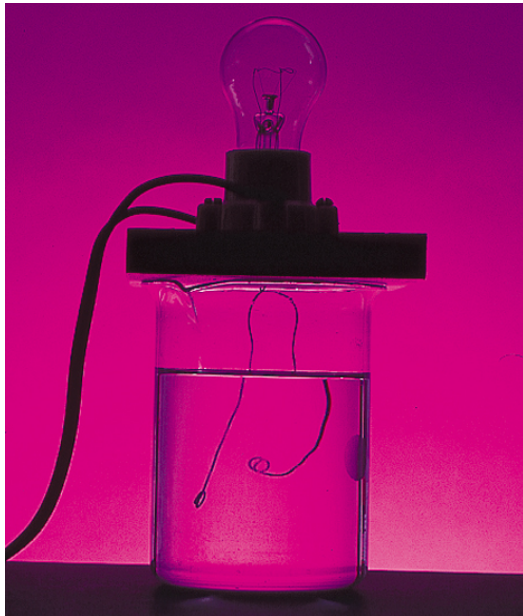
<u>Solution</u>	<u>Solvent</u>	<u>Solute</u>
Soft drink (<i>l</i>)	H ₂ O	Sugar, CO ₂
Air (<i>g</i>)	N ₂	O ₂ , Ar, CH ₄
Soft Solder (<i>s</i>)	Pb	Sn



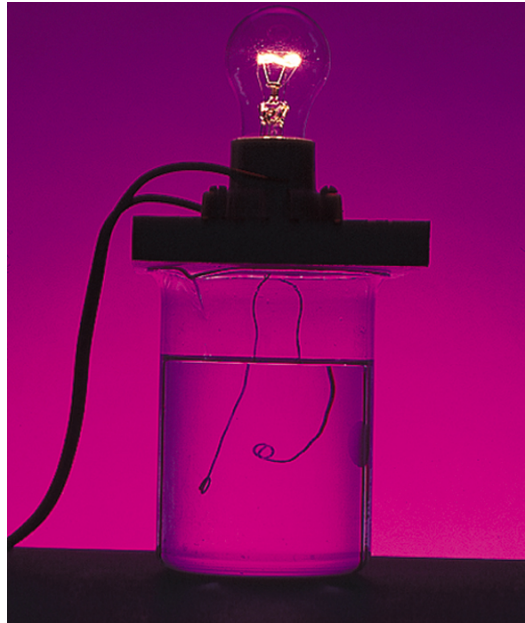
aqueous solutions
of KMnO₄

An *electrolyte* is a substance that, when dissolved in water, results in a solution that can conduct electricity.

A *nonelectrolyte* is a substance that, when dissolved, results in a solution that does not conduct electricity.



nonelectrolyte



weak electrolyte



strong electrolyte

Conduct electricity in solution?

Cations (+) and **Anions (-)**

Strong Electrolyte – 100% dissociation



Weak Electrolyte – not completely dissociated



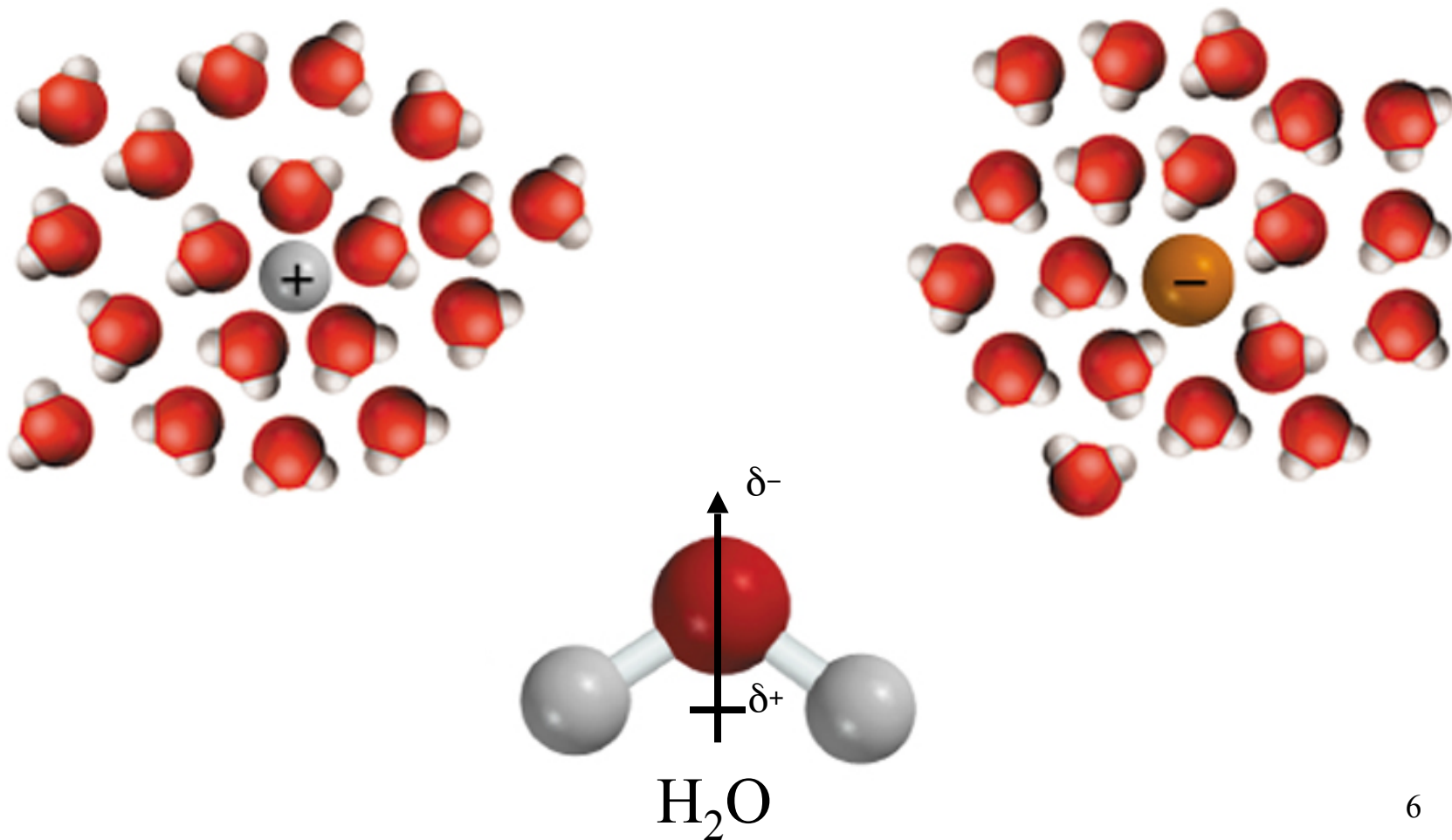
Ionization of acetic acid



A ***reversible*** reaction. The reaction can occur in both directions.

Acetic acid is a ***weak electrolyte*** because its ionization in water is incomplete.

Hydration is the process in which an ion is surrounded by water molecules arranged in a specific manner.



Nonelectrolyte does not conduct electricity?

No **cations (+)** and anions (-) in solution

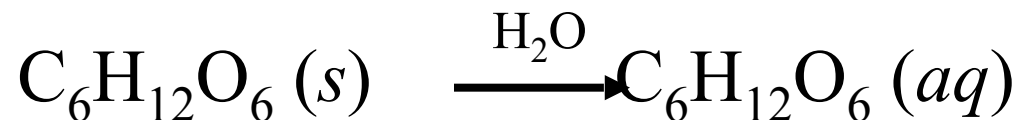


TABLE 4.1 Classification of Solutes in Aqueous Solution

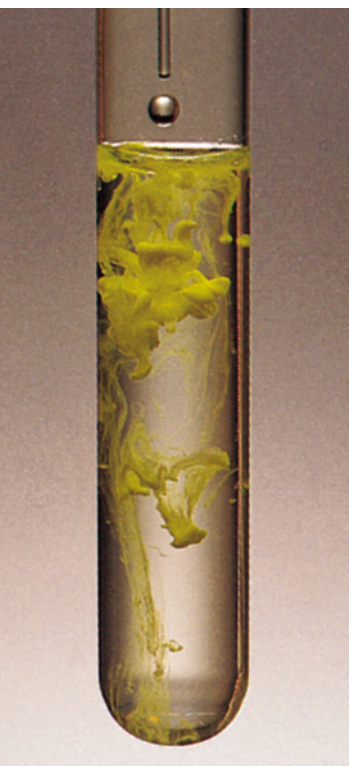
Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
HCl	CH ₃ COOH	(NH ₂) ₂ CO (urea)
HNO ₃	HF	CH ₃ OH (methanol)
HClO ₄	HNO ₂	C ₂ H ₅ OH (ethanol)
H ₂ SO ₄ [*]	NH ₃	C ₆ H ₁₂ O ₆ (glucose)
NaOH	H ₂ O [†]	C ₁₂ H ₂₂ O ₁₁ (sucrose)
Ba(OH) ₂		
Ionic compounds		

^{*}H₂SO₄ has two ionizable H⁺ ions.

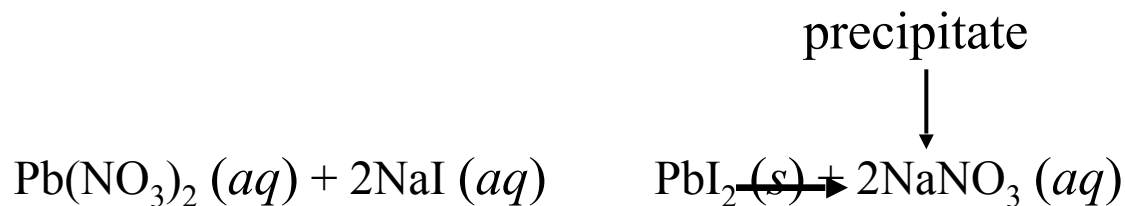
[†]Pure water is an extremely weak electrolyte.

Precipitation Reactions

Precipitate – insoluble solid that separates from solution



PbI_2



molecular equation



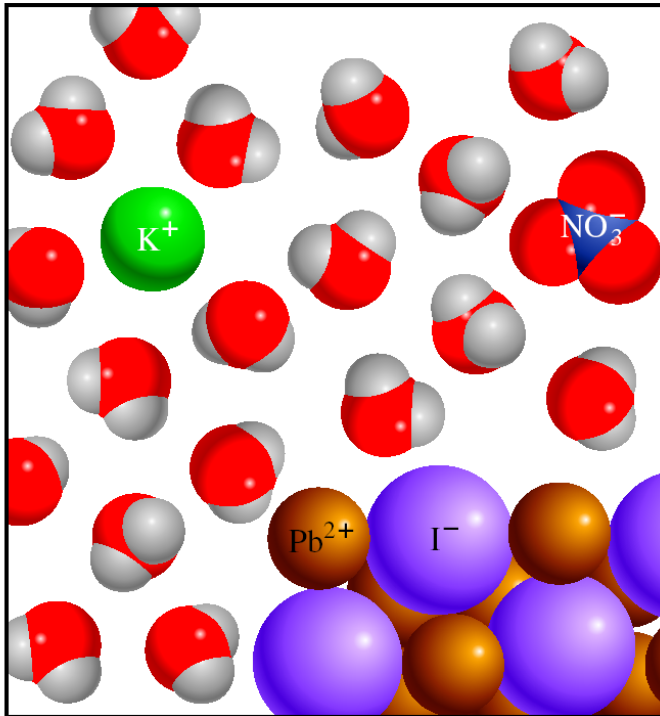
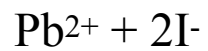
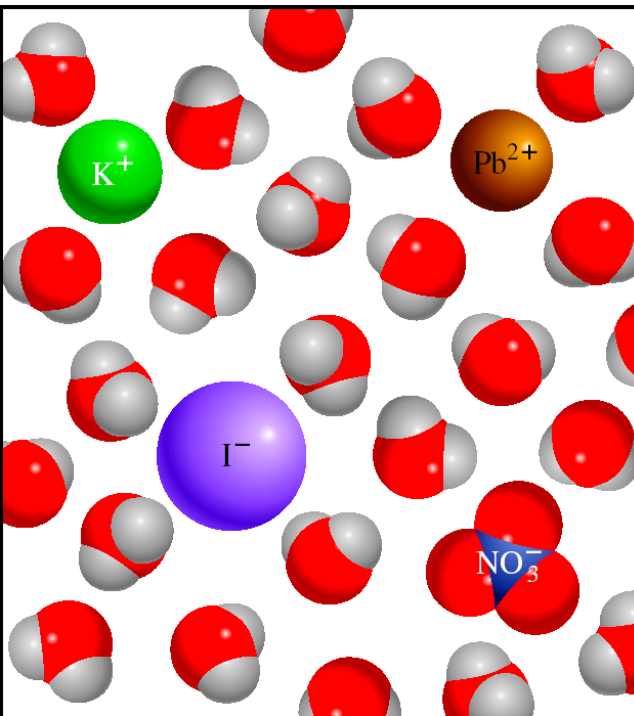
ionic equation



net ionic equation

Na^+ and NO_3^- are *spectator* ions

Precipitation of Lead Iodide



Solubility is the maximum amount of solute that will dissolve in a given quantity of solvent at a specific temperature.

TABLE 4.2 Solubility Rules for Common Ionic Compounds in Water at 25°C

Soluble Compounds

Compounds containing alkali metal ions (Li^+ , Na^+ , K^+ , Rb^+ , Cs^+) and the ammonium ion (NH_4^+)

Nitrates (NO_3^-), bicarbonates (HCO_3^-), and chlorates (ClO_3^-)

Halides (Cl^- , Br^- , I^-)

Sulfates (SO_4^{2-})

Insoluble Exceptions

Halides of Ag^+ , Hg_2^{2+} , and Pb^{2+}

Sulfates of Ag^+ , Ca^{2+} , Sr^{2+} , Ba^{2+} , Hg_2^{2+} , and Pb^{2+}

Insoluble Compounds

Carbonates (CO_3^{2-}), phosphates (PO_4^{3-}), chromates (CrO_4^{2-}), sulfides (S^{2-})

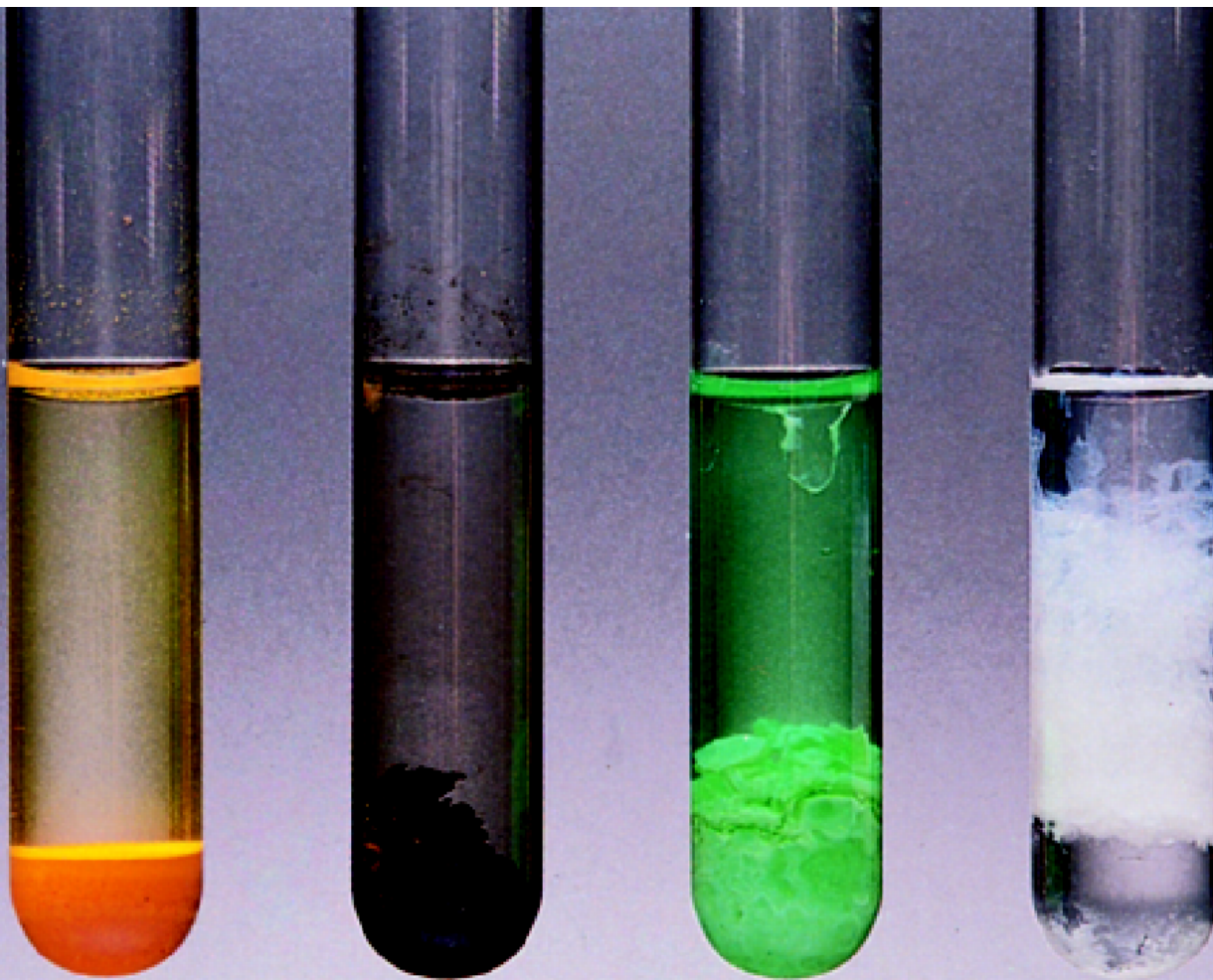
Hydroxides (OH^-)

Soluble Exceptions

Compounds containing alkali metal ions and the ammonium ion

Compounds containing alkali metal ions and the Ba^{2+} ion

Examples of Insoluble Compounds



CdS

PbS

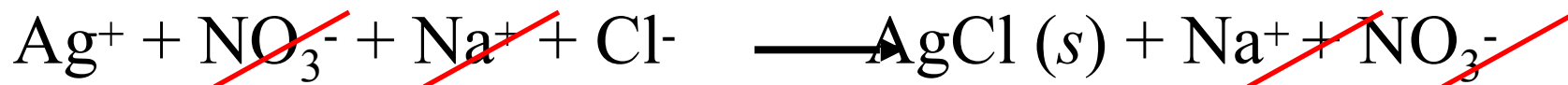
Ni(OH)₂

Al(OH)₃

Writing Net Ionic Equations

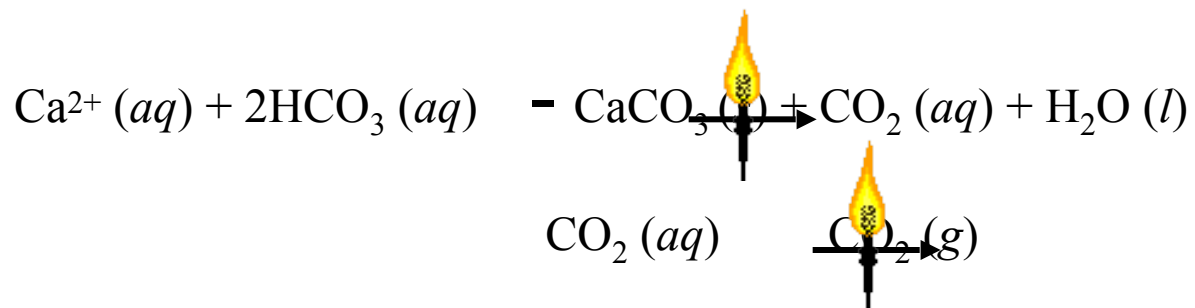
1. Write the balanced molecular equation.
2. Write the ionic equation showing the strong electrolytes completely dissociated into cations and anions.
3. Cancel the spectator ions on both sides of the ionic equation
4. Check that charges and number of atoms are balanced in the net ionic equation

Write the net ionic equation for the reaction of silver nitrate with sodium chloride.

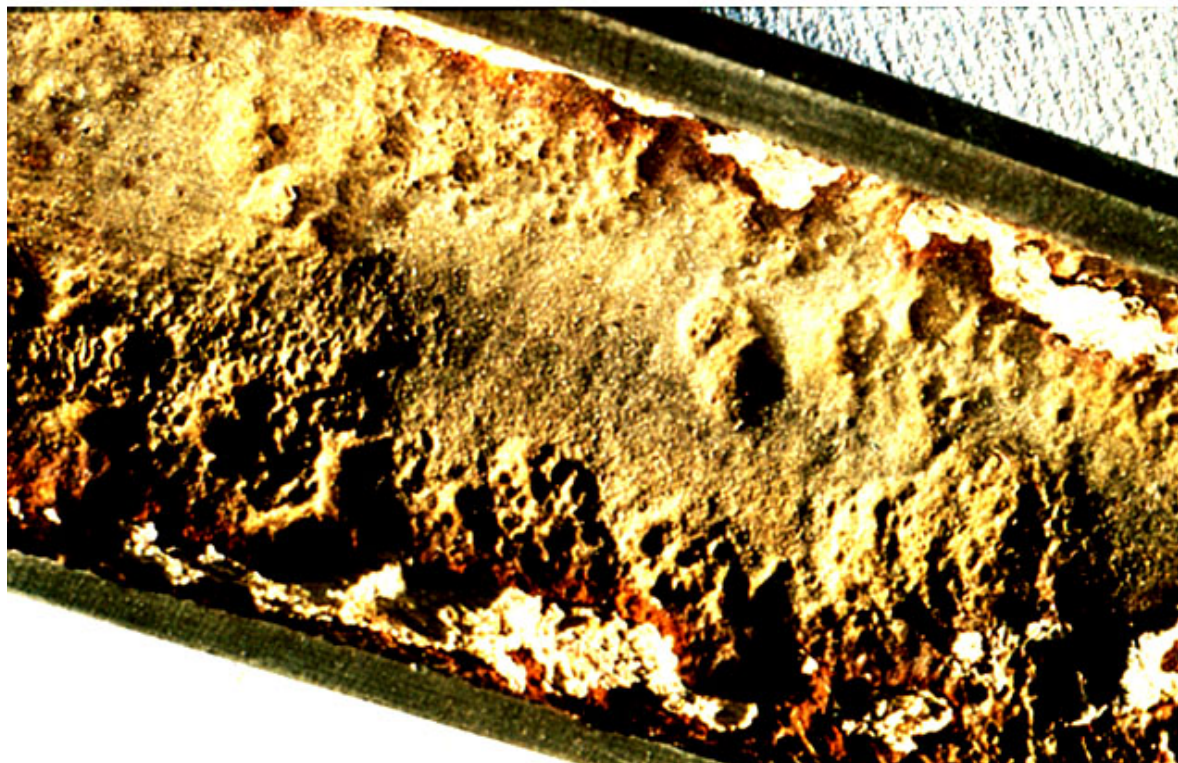


Chemistry In Action:

An Undesirable Precipitation Reaction



Boiler Scale Deposits



Properties of Acids

Have a sour taste. Vinegar owes its taste to acetic acid. Citrus fruits contain citric acid.

Cause color changes in plant dyes.

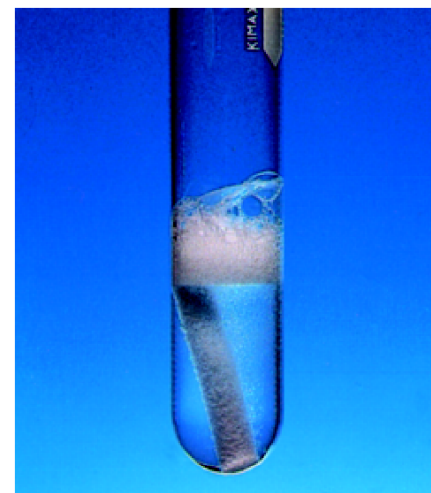
React with certain metals to produce hydrogen gas.



React with carbonates and bicarbonates to produce carbon dioxide gas



Aqueous acid solutions conduct electricity.



Properties of Bases

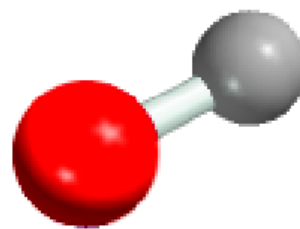
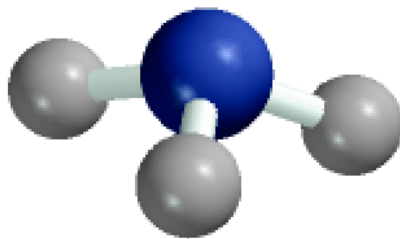
Have a bitter taste.

Feel slippery. Many soaps contain bases.

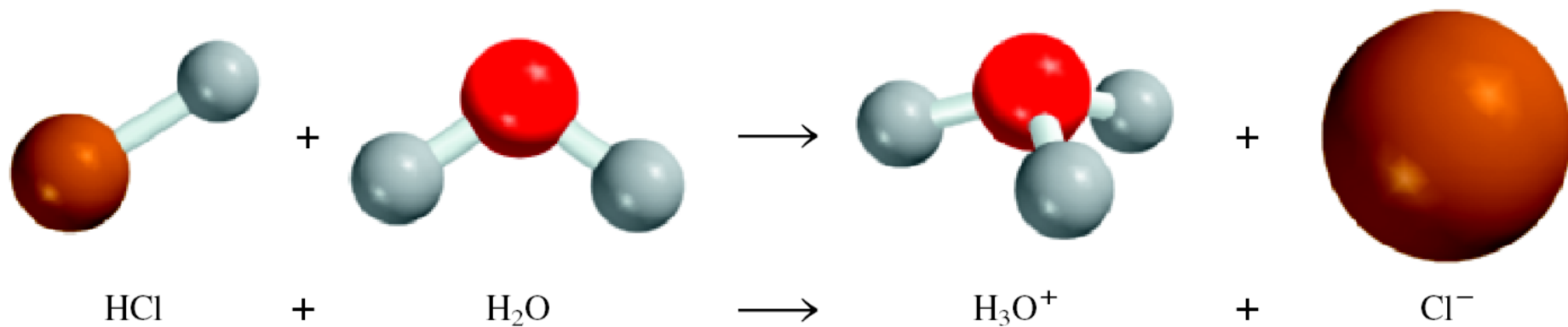
Cause color changes in plant dyes.

Aqueous base solutions conduct electricity.

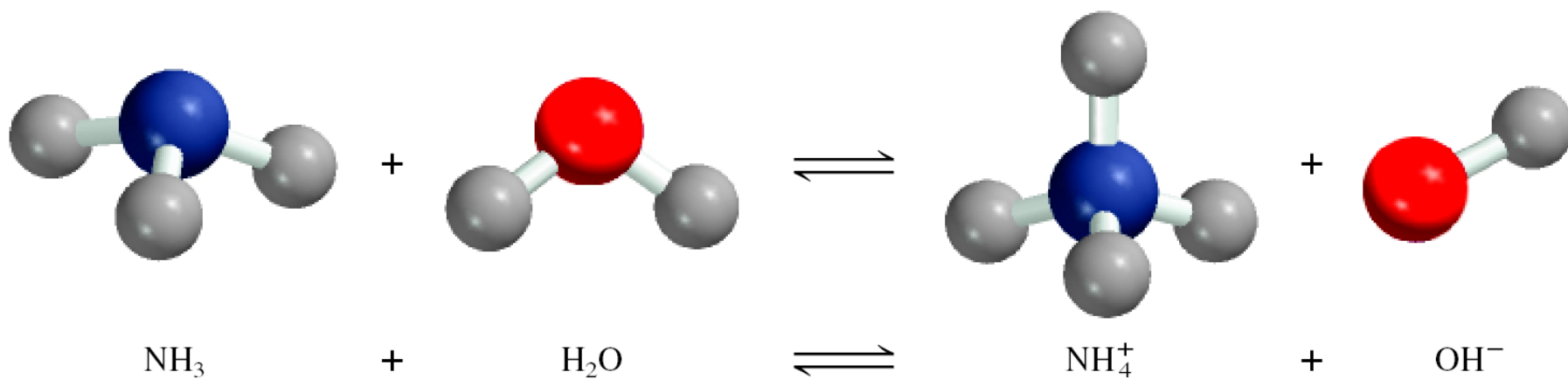
Examples:



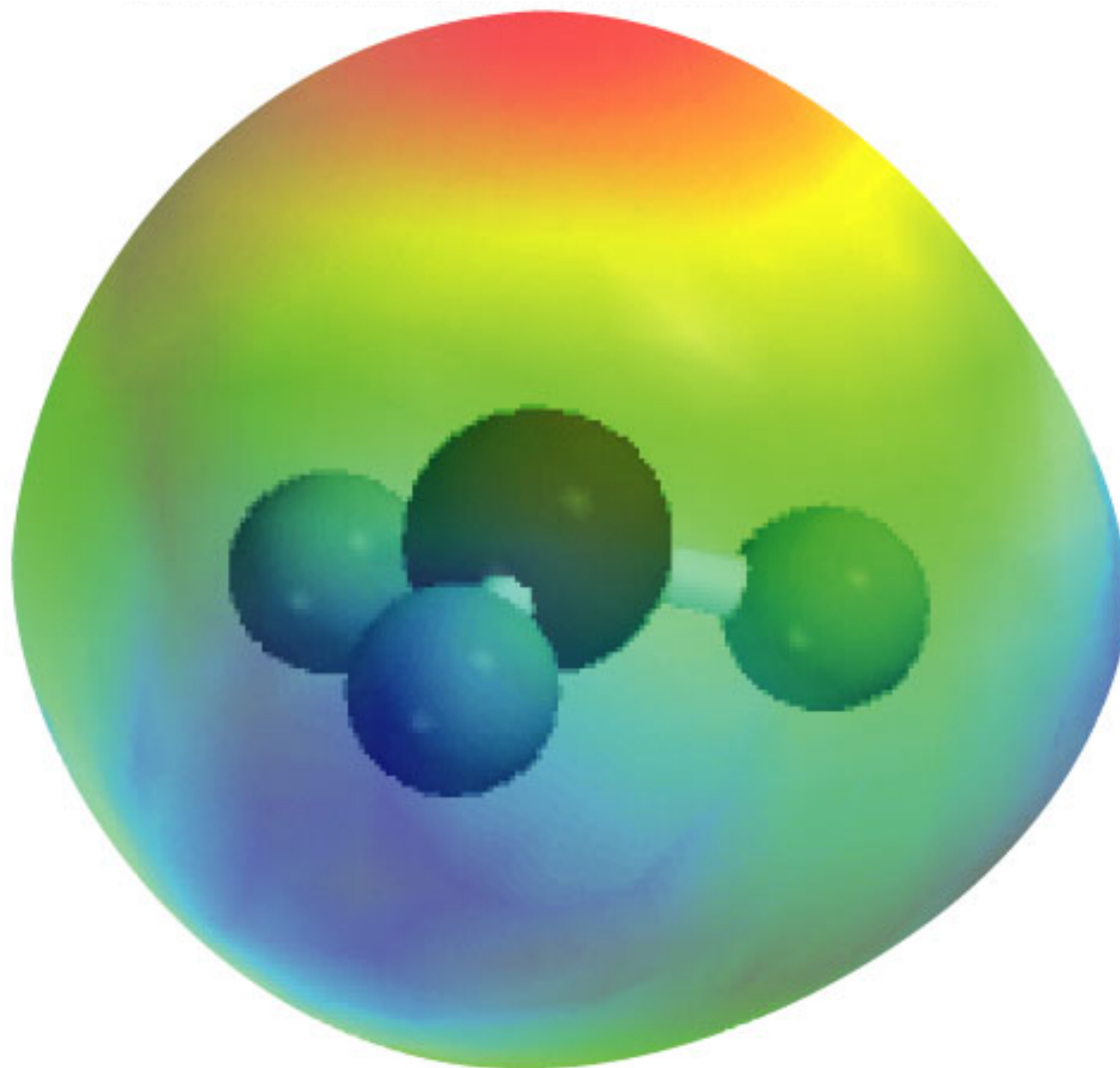
Arrhenius acid is a substance that produces H^+ (H_3O^+) in water



Arrhenius base is a substance that produces OH^- in water

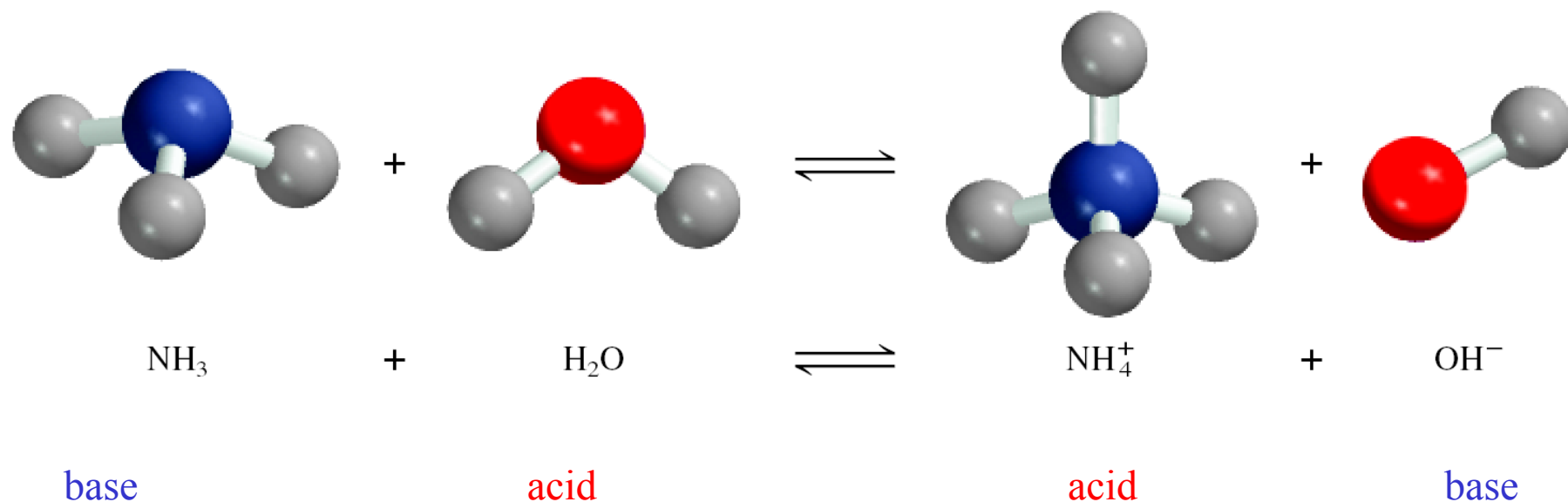


Hydronium ion, hydrated proton, H_3O^+



A *Brønsted acid* is a proton donor

A *Brønsted base* is a proton acceptor



A Brønsted *acid* must contain at least one ionizable proton!

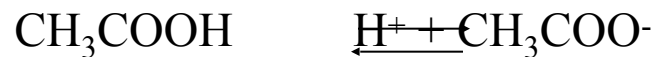
Monoprotic acids



Strong electrolyte, strong acid



Strong electrolyte, strong acid

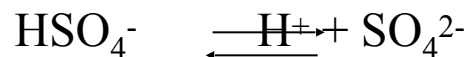


Weak electrolyte, weak acid

Diprotic acids

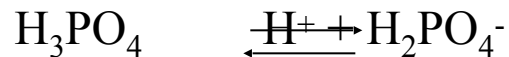


Strong electrolyte, strong acid

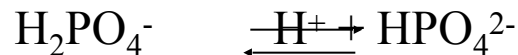


Weak electrolyte, weak acid

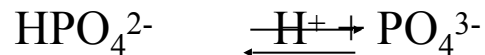
Triprotic acids



Weak electrolyte, weak acid



Weak electrolyte, weak acid



Weak electrolyte, weak acid

TABLE 4.3**Some Common Strong and Weak Acids****Strong Acids**

Hydrochloric acid HCl

Hydrobromic acid HBr

Hydroiodic acid HI

Nitric acid HNO_3

Sulfuric acid H_2SO_4

Perchloric acid HClO_4

Weak Acids

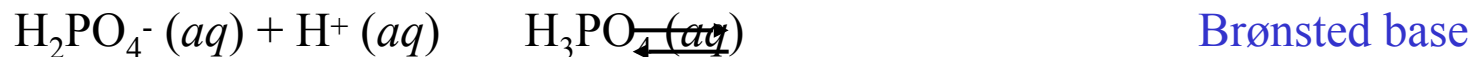
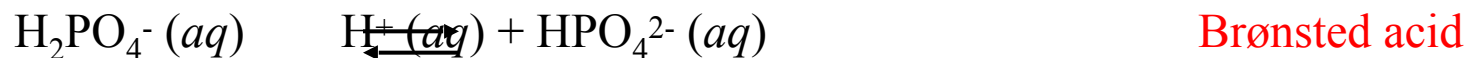
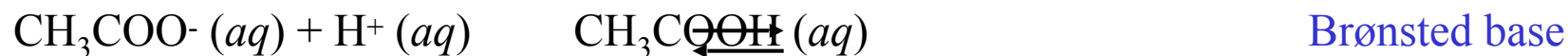
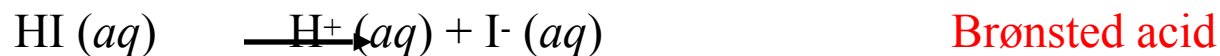
Hydrofluoric acid HF

Nitrous acid HNO_2

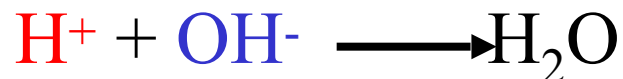
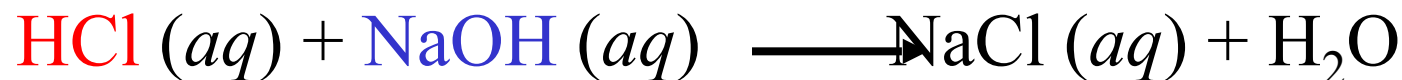
Phosphoric acid H_3PO_4

Acetic acid CH_3COOH

Identify each of the following species as a Brønsted acid, base, or both. (a) HI, (b) CH₃COO⁻, (c) H₂PO₄⁻



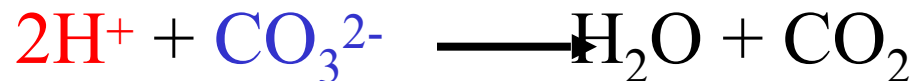
Neutralization Reaction



Neutralization Reaction Involving a Weak Electrolyte

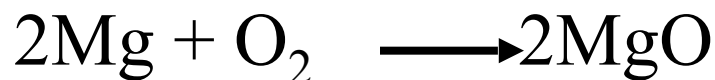
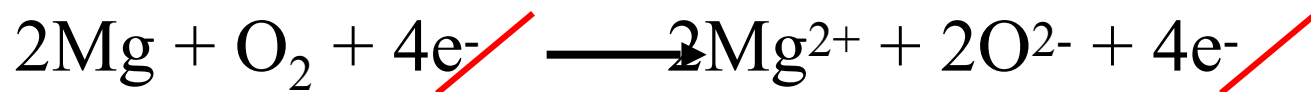
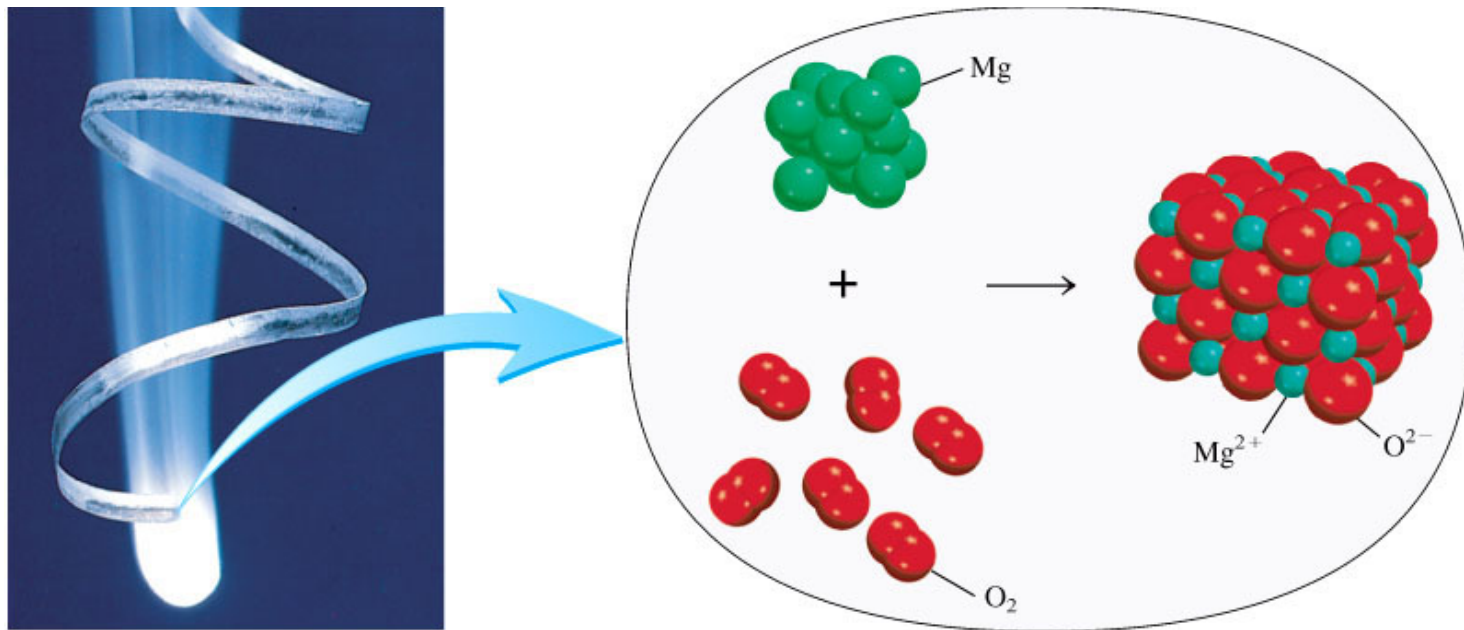


Neutralization Reaction Producing a Gas



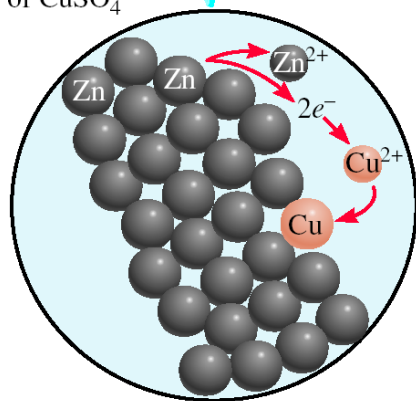
Oxidation-Reduction Reactions

(electron transfer reactions)

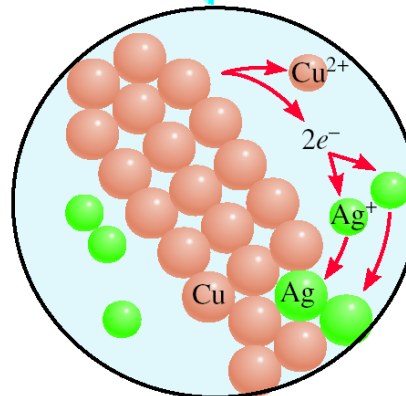
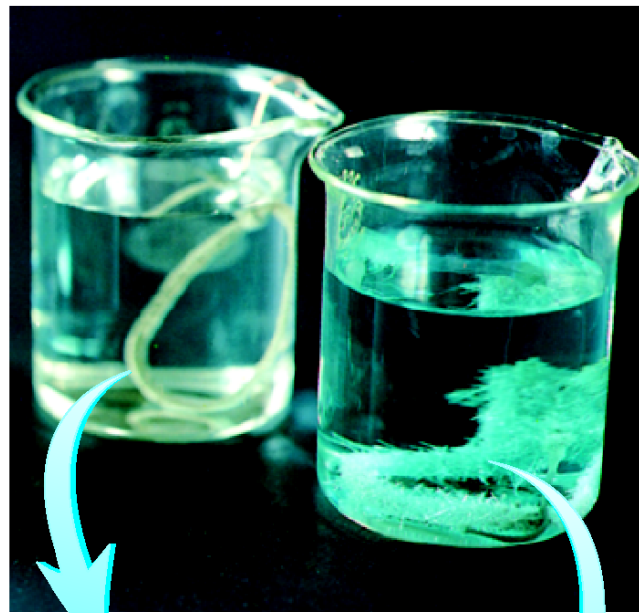




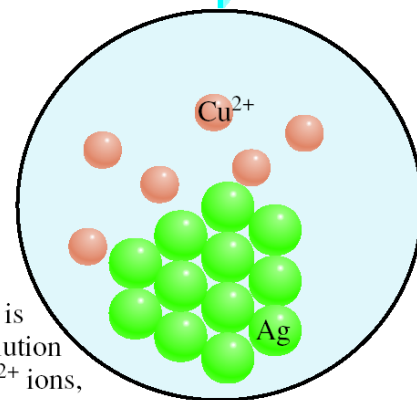
The Zn bar is in aqueous solution of CuSO_4



Cu^{2+} ions are converted to Cu atoms.
Zn atoms enter the solution as Zn^{2+} ions.



When a piece of copper wire is placed in an aqueous AgNO_3 solution Cu atoms enter the solution as Cu^{2+} ions, and Ag^+ ions are converted to solid Ag.





Zn is oxidized

Zn is the *reducing agent*



Cu²⁺ is reduced

Cu²⁺ is the *oxidizing agent*

Copper wire reacts with silver nitrate to form silver metal.

What is the oxidizing agent in the reaction?



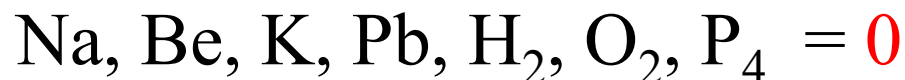
Ag⁺ is reduced

Ag⁺ is the oxidizing agent

Oxidation number

The charge the atom would have in a molecule (or an ionic compound) if electrons were completely transferred.

1. Free elements (uncombined state) have an oxidation number of zero.



2. In monatomic ions, the oxidation number is equal to the charge on the ion.



3. The oxidation number of oxygen is **usually** -2 . In H_2O_2 and O_2^{2-} it is -1 .

4. The oxidation number of hydrogen is $+1$ *except* when it is bonded to metals in binary compounds. In these cases, its oxidation number is -1 .
5. Group IA metals are $+1$, IIA metals are $+2$ and fluorine is always -1 .
6. The sum of the oxidation numbers of all the atoms in a molecule or ion is equal to the charge on the molecule or ion.
7. Oxidation numbers do not have to be integers. Oxidation number of oxygen in the superoxide ion, O_2^- , is $-1/2$.

What are the oxidation numbers of all the elements in HCO_3^- ?



$$\text{O} = -2 \quad \text{H} = +1$$

$$3 \times (-2) + 1 + ? = -1$$

$$\text{C} = +4$$

The Oxidation Numbers of Elements in their Compounds

1 1A																	18 8A
1 H +1 -1																	2 He
	2 2A											13 3A	14 4A	15 5A	16 6A	17 7A	
3 Li +1	4 Be +2											5 B +3	6 C +4 +2 -4	7 N +5 +4 +3 +2 +1 -3	8 O +2 +1 -2	9 F -1	10 Ne
11 Na +1	12 Mg +2											13 Al +3	14 Si +4 -4	15 P +5 +3 -3	16 S +6 +4 +2 -2	17 Cl +7 +6 +5 +4 +3 +1 -1	18 Ar
		3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B		10	11 1B	12 2B					
19 K +1	20 Ca +2	21 Sc +3	22 Ti +4 +3 +2	23 V +5 +4 +3 +2	24 Cr +6 +5 +4 +3 +2	25 Mn +7 +6 +4 +3 +2	26 Fe +3 +2	27 Co +3 +2	28 Ni +2	29 Cu +2 +1	30 Zn +2	31 Ga +3	32 Ge +4 -4	33 As +5 +3 -3	34 Se +6 +4 -2	35 Br +5 +3 +1 -1	36 Kr +4 +2
37 Rb +1	38 Sr +2	39 Y +3	40 Zr +4	41 Nb +5 +4	42 Mo +6 +4 +3	43 Tc +7 +6 +4	44 Ru +8 +6 +4 +3	45 Rh +4 +3 +2	46 Pd +4 +2	47 Ag +1	48 Cd +2	49 In +3	50 Sn +4 +2	51 Sb +5 +3 -3	52 Te +6 +4 -2	53 I +7 +5 +1 -1	54 Xe +6 +4 +2
55 Cs +1	56 Ba +2	57 La +3	72 Hf +4	73 Ta +5	74 W +6 +4	75 Re +7 +6 +4	76 Os +8 +4	77 Ir +4 +3	78 Pt +4 +2	79 Au +3 +1	80 Hg +2 +1	81 Tl +3 +1	82 Pb +4 +2	83 Bi +5 +3	84 Po +2	85 At -1	86 Rn

What are the oxidation numbers of all the elements in each of these compounds?



$$\text{Na} = +1 \quad \text{O} = -2$$

$$3x(-2) + 1 + ? = 0$$

$$\text{I} = +5$$



$$\text{F} = -1$$

$$7x(-1) + ? = 0$$

$$\text{I} = +7$$



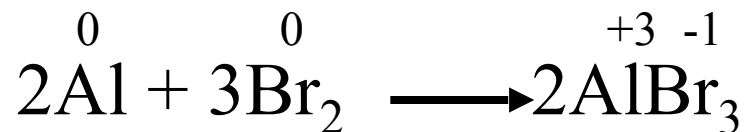
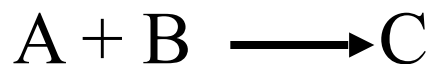
$$\text{O} = -2 \quad \text{K} = +1$$

$$7x(-2) + 2x(+1) + 2x(?) = 0$$

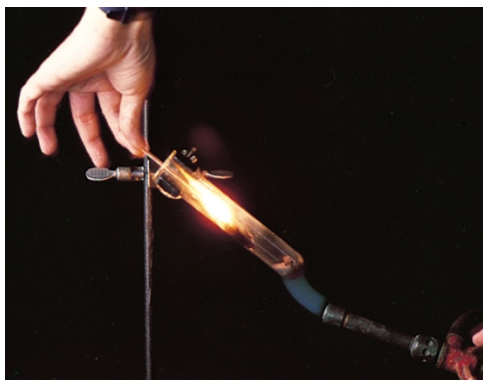
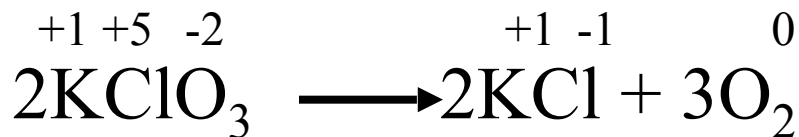
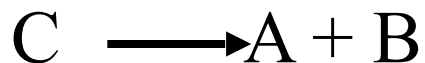
$$\text{Cr} = +6$$

Types of Oxidation-Reduction Reactions

Combination Reaction

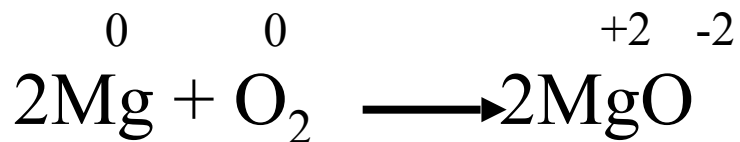
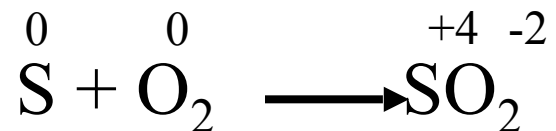
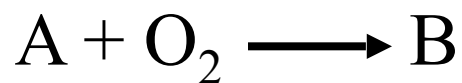


Decomposition Reaction



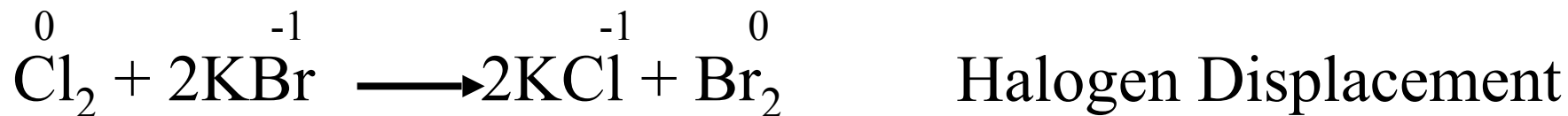
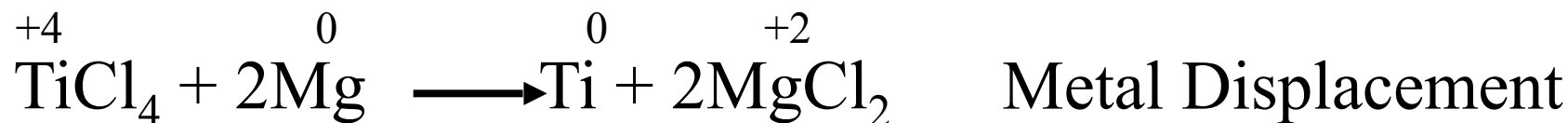
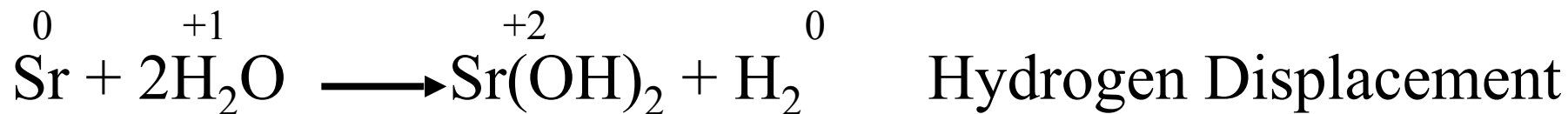
Types of Oxidation-Reduction Reactions

Combustion Reaction




Types of Oxidation-Reduction Reactions

Displacement Reaction



The Activity Series for Metals



$\text{Li} \rightarrow \text{Li}^+ + e^-$	
$\text{K} \rightarrow \text{K}^+ + e^-$	
$\text{Ba} \rightarrow \text{Ba}^{2+} + 2e^-$	React with cold water to produce H_2
$\text{Ca} \rightarrow \text{Ca}^{2+} + 2e^-$	
$\text{Na} \rightarrow \text{Na}^+ + e^-$	
$\text{Mg} \rightarrow \text{Mg}^{2+} + 2e^-$	
$\text{Al} \rightarrow \text{Al}^{3+} + 3e^-$	
$\text{Zn} \rightarrow \text{Zn}^{2+} + 2e^-$	React with steam to produce H_2
$\text{Cr} \rightarrow \text{Cr}^{3+} + 3e^-$	
$\text{Fe} \rightarrow \text{Fe}^{2+} + 2e^-$	
$\text{Cd} \rightarrow \text{Cd}^{2+} + 2e^-$	
$\text{Co} \rightarrow \text{Co}^{2+} + 2e^-$	
$\text{Ni} \rightarrow \text{Ni}^{2+} + 2e^-$	React with acids to produce H_2
$\text{Sn} \rightarrow \text{Sn}^{2+} + 2e^-$	
$\text{Pb} \rightarrow \text{Pb}^{2+} + 2e^-$	
$\text{H}_2 \rightarrow 2\text{H}^+ + 2e^-$	
$\text{Cu} \rightarrow \text{Cu}^{2+} + 2e^-$	
$\text{Ag} \rightarrow \text{Ag}^+ + e^-$	
$\text{Hg} \rightarrow \text{Hg}^{2+} + 2e^-$	Do not react with water or acids to produce H_2
$\text{Pt} \rightarrow \text{Pt}^{2+} + 2e^-$	
$\text{Au} \rightarrow \text{Au}^{3+} + 3e^-$	

Hydrogen Displacement Reaction



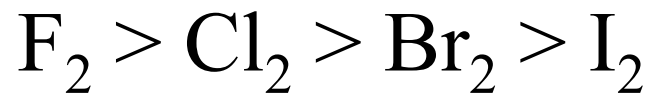
M is metal

BC is acid or H_2O

B is H_2



The Activity Series for Halogens



Halogen Displacement Reaction

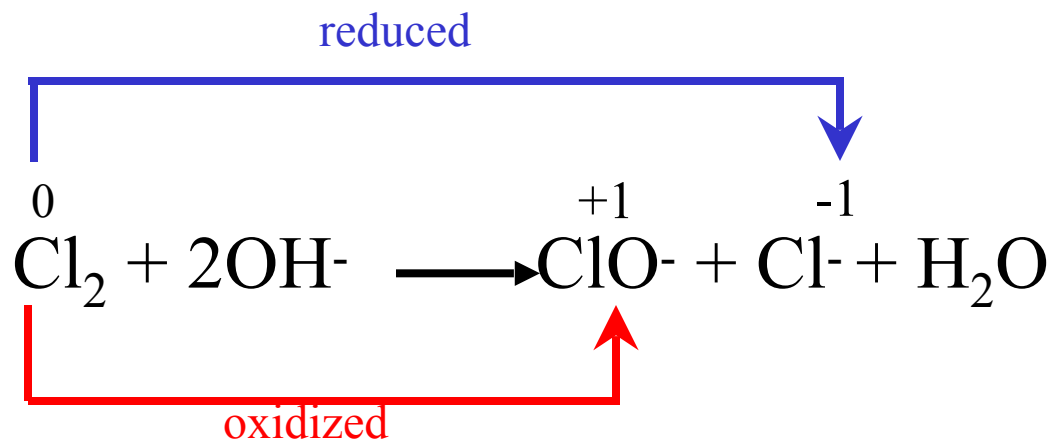


Types of Oxidation-Reduction Reactions

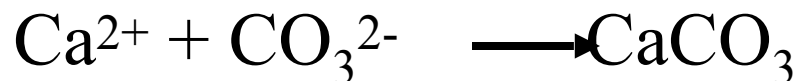
Disproportionation Reaction

The same element is simultaneously oxidized and reduced.

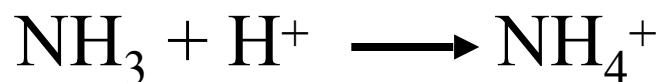
Example:



Classify each of the following reactions.



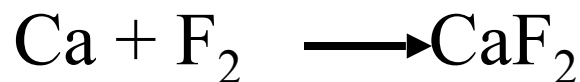
Precipitation



Acid-Base

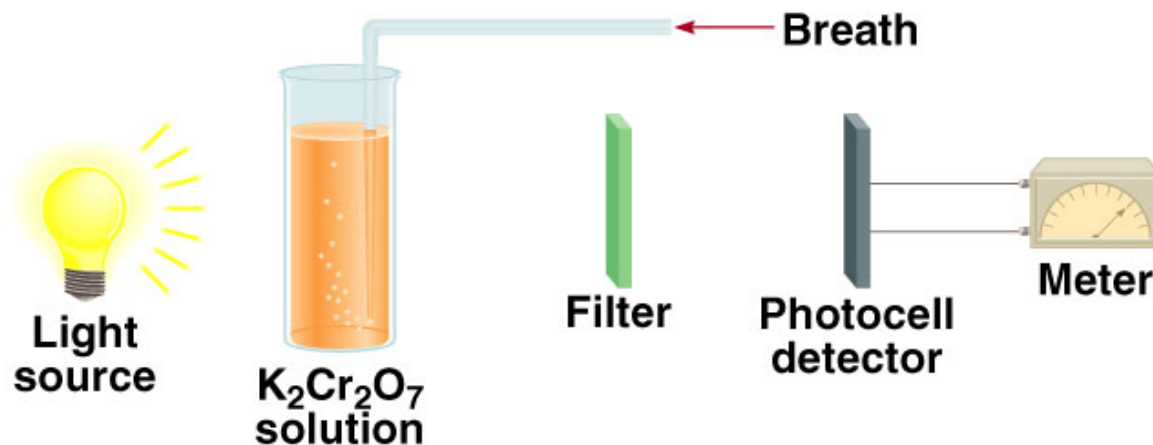
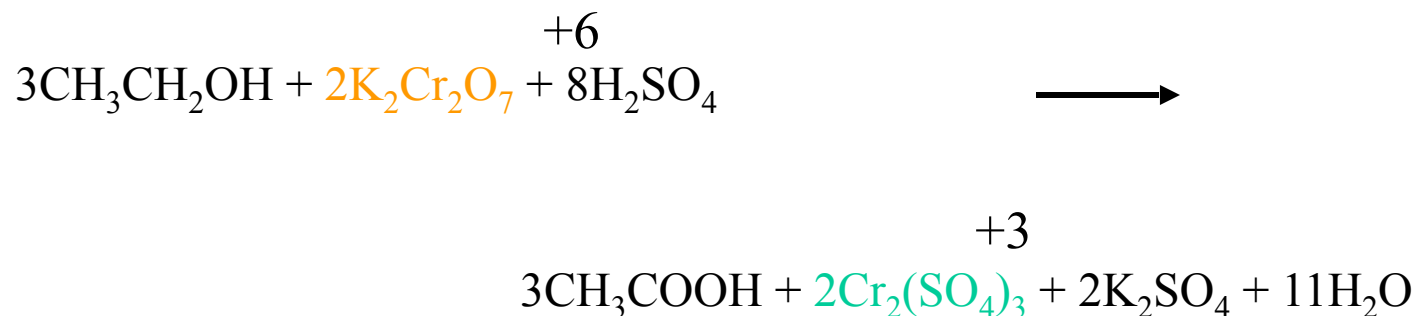


Redox (H_2 Displacement)



Redox (Combination)

Chemistry in Action: Breath Analyzer



Solution Stoichiometry

The ***concentration*** of a solution is the amount of solute present in a given quantity of solvent or solution.

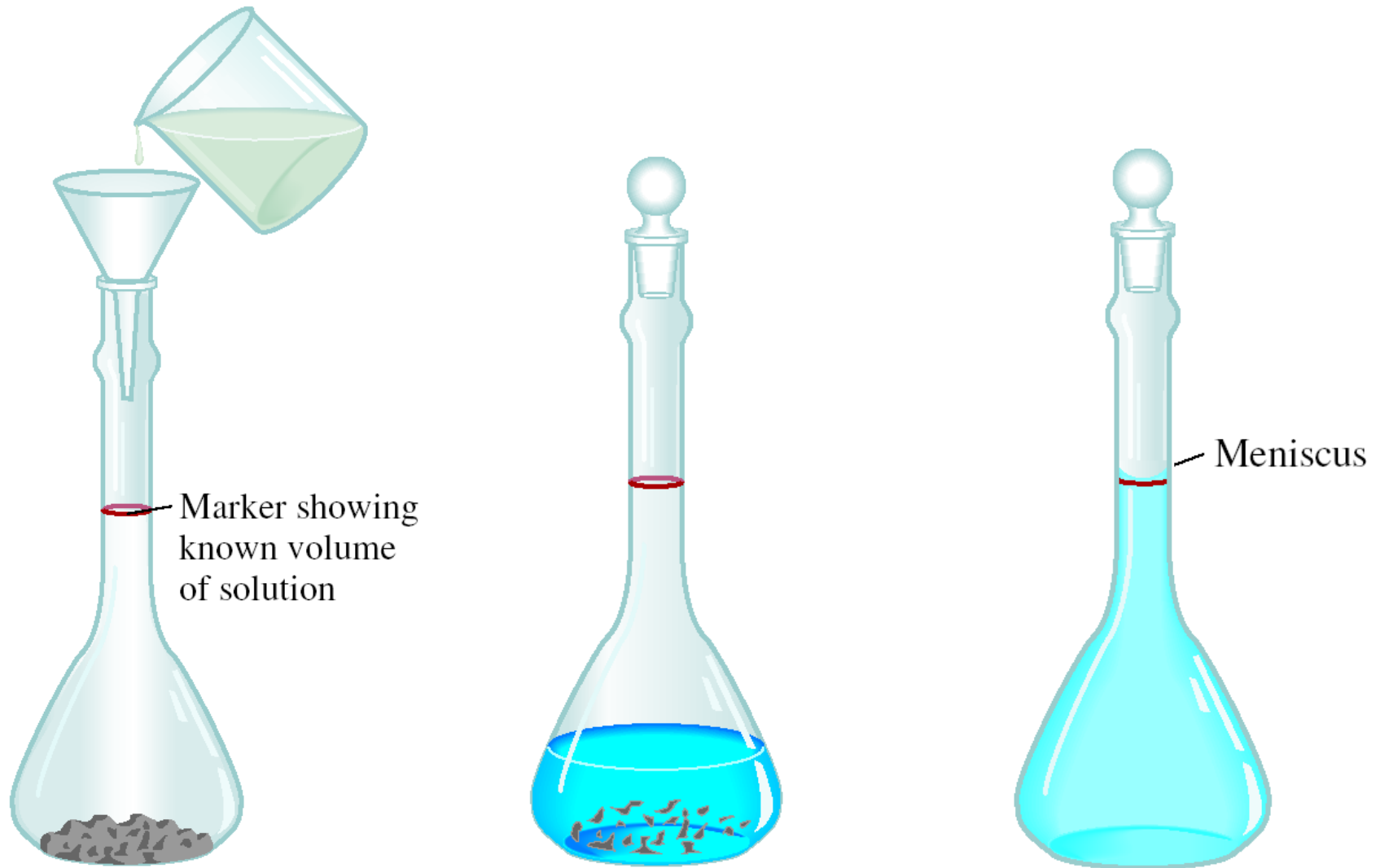
$$M = \text{molarity} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

What mass of KI is required to make 500. mL of a 2.80 M KI solution?

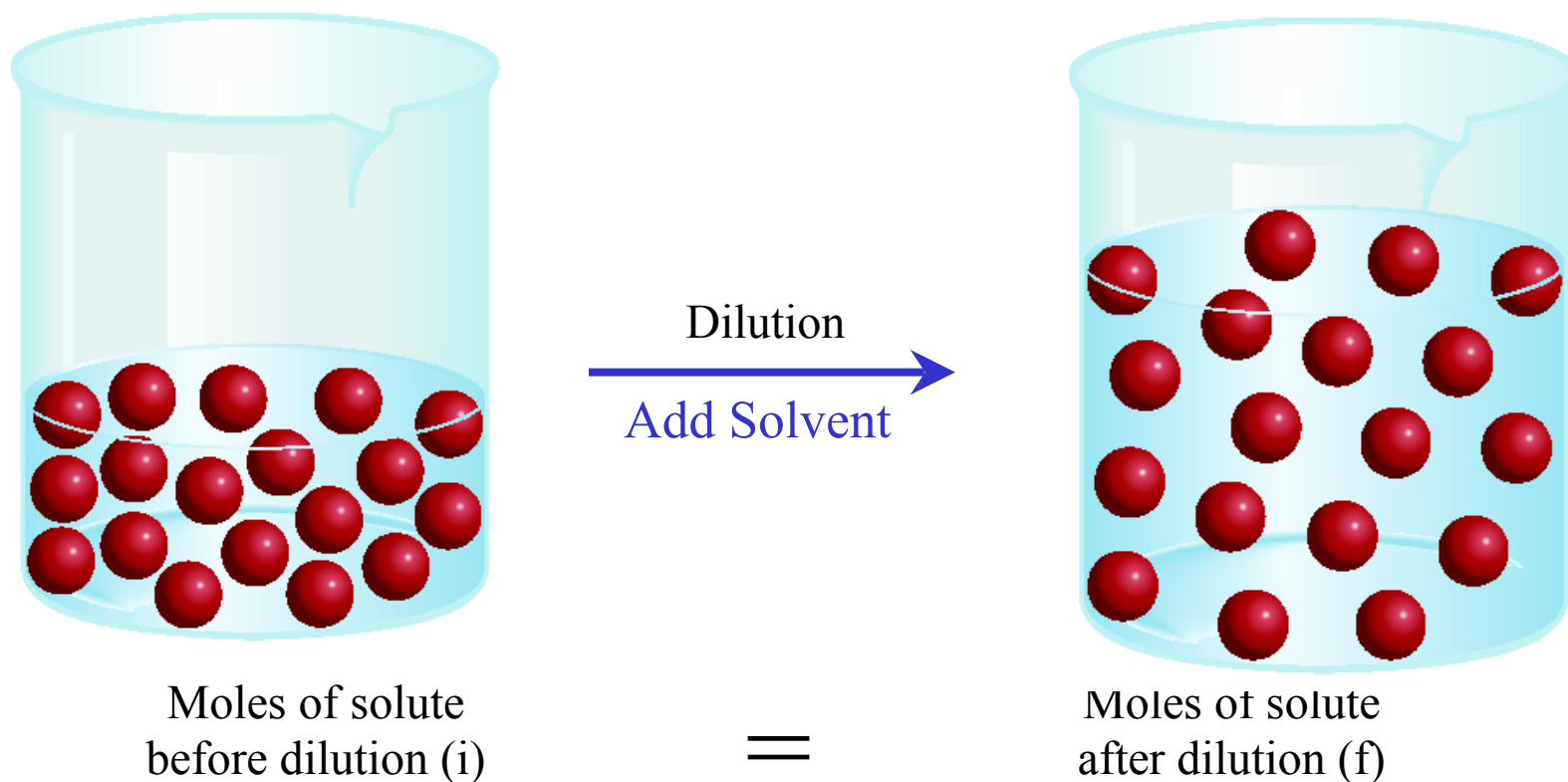
volume of KI solution $\xrightarrow{M \text{ KI}}$ moles KI $\xrightarrow{M \text{ KI}}$ grams KI

$$500. \cancel{\text{mL}} \times \frac{1 \cancel{\text{L}}}{1000 \cancel{\text{mL}}} \times \frac{2.80 \cancel{\text{mol KI}}}{1 \cancel{\text{L soln}}} \times \frac{166 \text{ g KI}}{1 \cancel{\text{mol KI}}} = 232 \text{ g KI}$$

Preparing a Solution of Known Concentration



Dilution is the procedure for preparing a less concentrated solution from a more concentrated solution.



$$M_i V_i$$

$$=$$

$$M_f V_f$$

How would you prepare 60.0 mL of 0.200 *M* HNO₃ from a stock solution of 4.00 *M* HNO₃?

$$M_i V_i = M_f V_f$$

$$M_i = 4.00 \text{ M} \quad M_f = 0.200 \text{ M} \quad V_f = 0.0600 \text{ L} \quad V_i = ? \text{ L}$$

$$V_i = \frac{M_f V_f}{M_i} = \frac{0.200 \text{ M} \times 0.0600 \text{ L}}{4.00 \text{ M}} = 0.00300 \text{ L} = 3.00 \text{ mL}$$

Dilute 3.00 mL of acid with water to a total volume of 60.0 mL.

Gravimetric Analysis

1. Dissolve unknown substance in water
2. React unknown with known substance to form a precipitate
3. Filter and dry precipitate
4. Weigh precipitate
5. Use chemical formula and mass of precipitate to determine amount of unknown ion

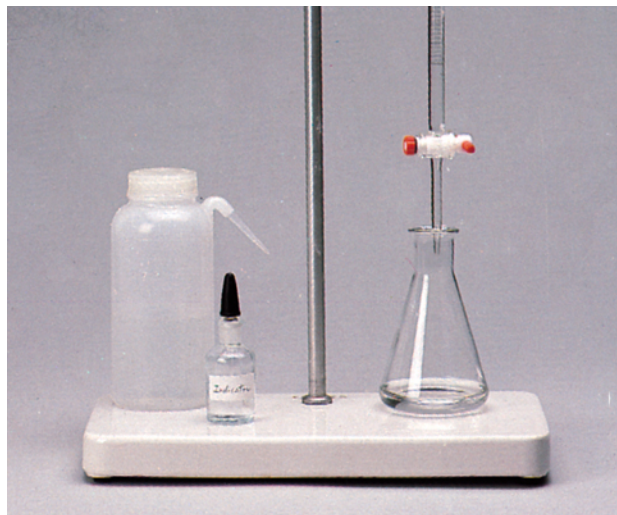


Titrations

In a ***titration*** a solution of accurately known concentration is added gradually to another solution of unknown concentration until the chemical reaction between the two solutions is complete.

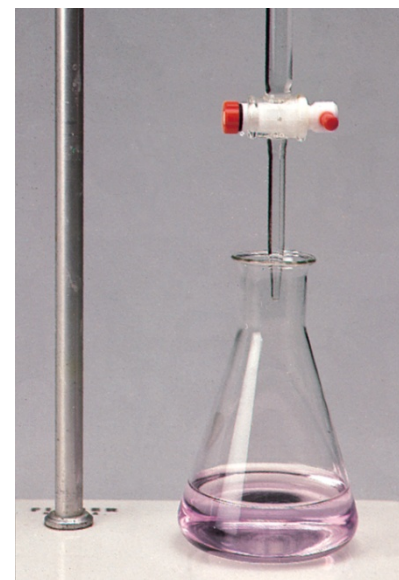
Equivalence point – the point at which the reaction is complete

Indicator – substance that changes color at (or near) the equivalence point



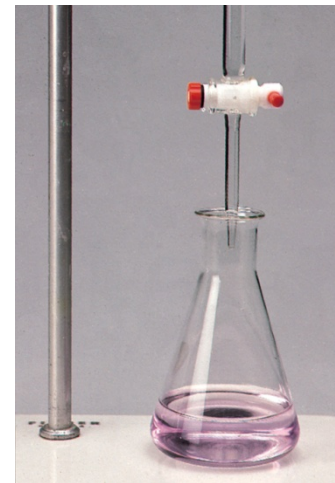
Slowly add base
to unknown acid
UNTIL

the indicator
changes color



Titration can be used in the analysis of

Acid-base reactions



Redox reactions



What volume of a 1.420 *M* NaOH solution is required to titrate 25.00 mL of a 4.50 *M* H₂SO₄ solution?

WRITE THE CHEMICAL EQUATION!



Diagram illustrating the relationship between volume, molarity (*M*), moles, and the reaction coefficient (rxn coef.) for the titration:

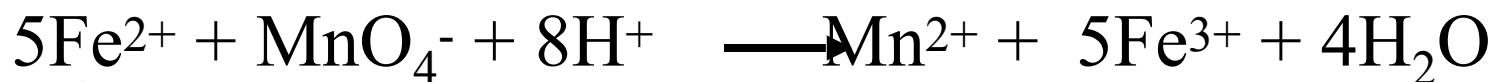
volume acid $\xrightarrow[\text{acid}]{M}$ moles acid $\xrightarrow[\text{coef.}]{\text{rxn}}$ moles base $\xrightarrow[\text{base}]{M}$ volume base

Red arrows point from the *M* and rxn labels to the coefficients in the chemical equation above.

$$25.00 \text{ mL} \times \frac{4.50 \text{ mol H}_2\text{SO}_4}{1000 \text{ mL soln}} \times \frac{2 \text{ mol NaOH}}{1 \text{ mol H}_2\text{SO}_4} \times \frac{1000 \text{ mL soln}}{1.420 \text{ mol NaOH}} = 158 \text{ mL}$$

16.42 mL of 0.1327 *M* KMnO₄ solution is needed to oxidize 25.00 mL of an acidic FeSO₄ solution. What is the molarity of the iron solution?

WRITE THE CHEMICAL EQUATION!



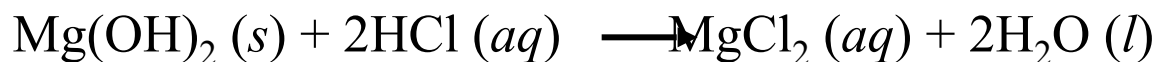
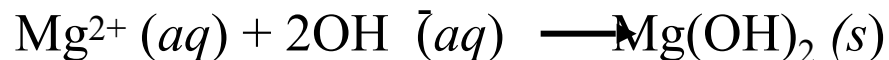
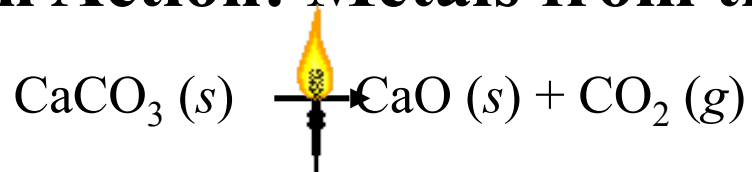
$\text{volume red} \xrightarrow[\text{red}]{M} \text{moles red} \xrightarrow[\text{coef.}]{\text{rxn}} \text{moles oxid} \xrightarrow[\text{oxid}]{V} M \text{ oxid}$

$$16.42 \text{ mL} = 0.01642 \text{ L}$$

$$25.00 \text{ mL} = 0.02500 \text{ L}$$

$$0.01642 \text{ L} \times \frac{0.1327 \text{ mol KMnO}_4}{1 \text{ L}} \times \frac{5 \text{ mol Fe}^{2+}}{1 \text{ mol KMnO}_4} \times \frac{1}{0.02500 \text{ L Fe}^{2+}} = 0.4358 \text{ M}$$

Chemistry in Action: Metals from the Sea



Magnesium Hydroxide

