



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)

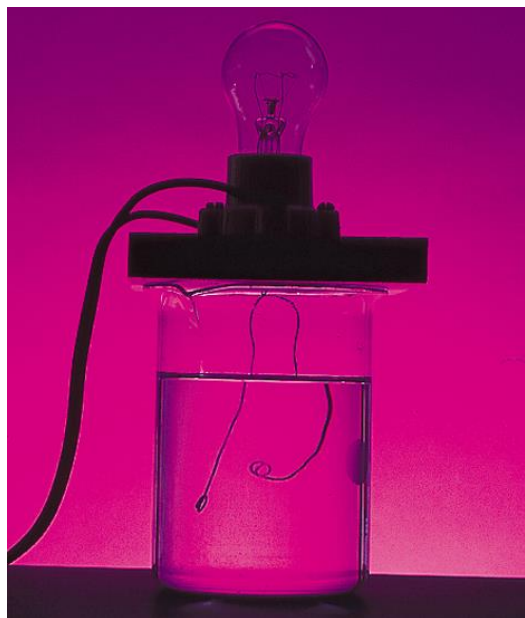
The **solvent** is the substance present in the larger amount

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

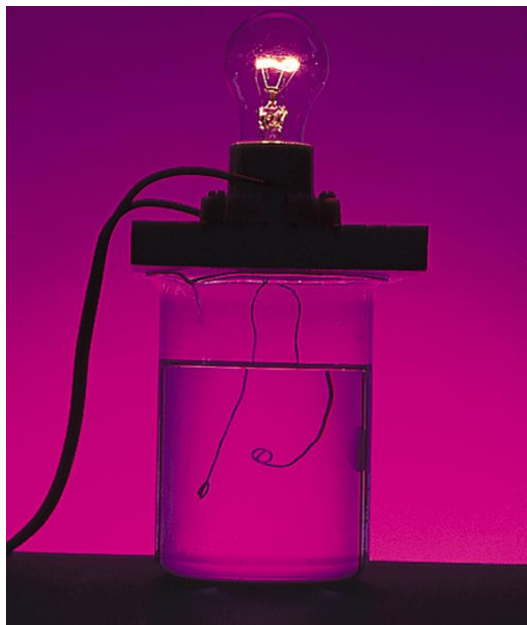


An ***electrolyte*** is a substance that, when dissolved in water, results in a solution that can conduct electricity.

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



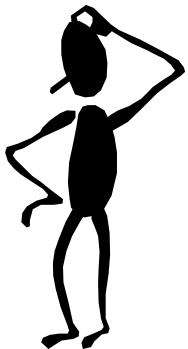
nonelectrolyte



weak electrolyte



strong electrolyte



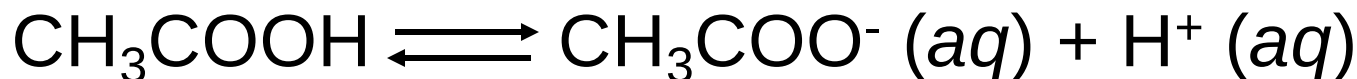
Conduct electricity in solution?

Cations (+) and Anions (-)

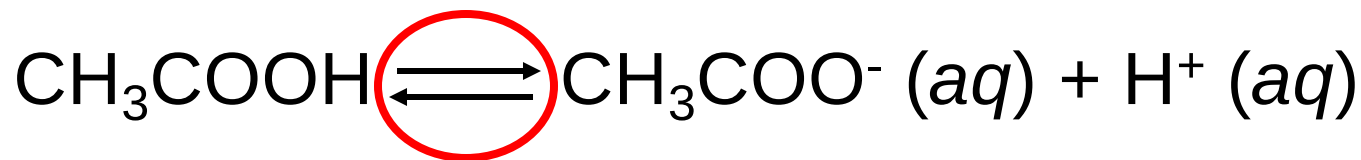
Strong Electrolyte – 100% dissociation



Weak Electrolyte – not completely dissociated



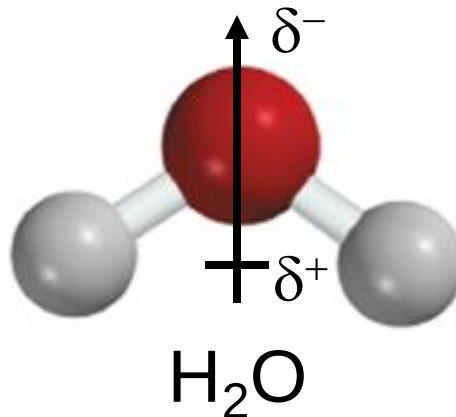
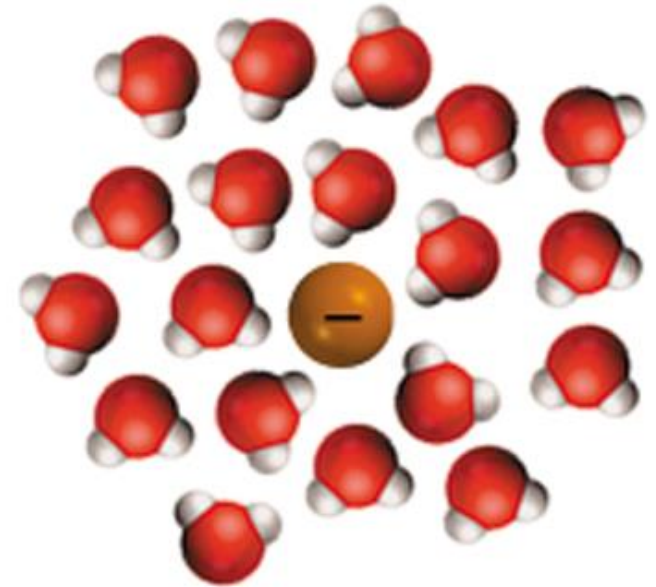
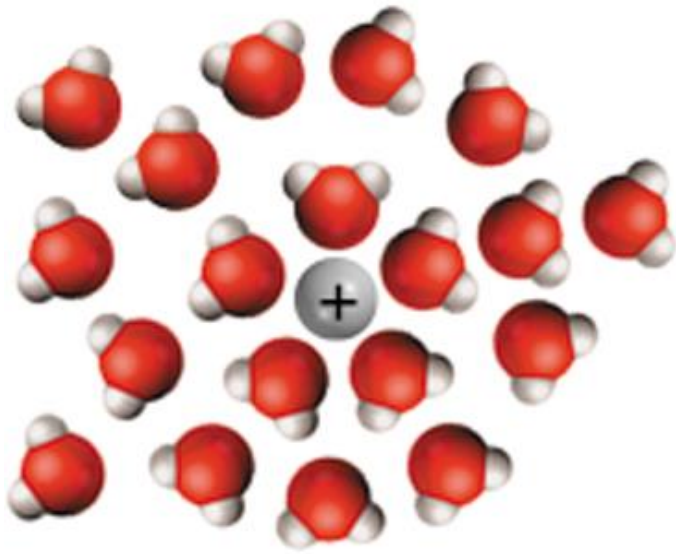
Ionization of acetic acid

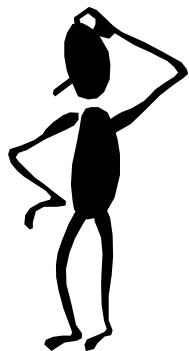


A ***reversible*** reaction. The reaction can occur in both directions.

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

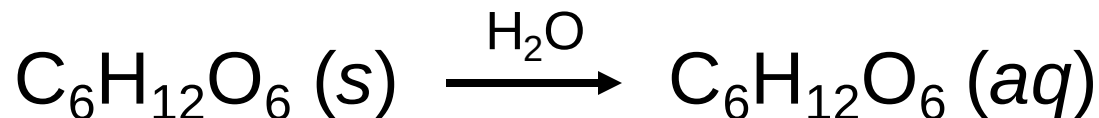


TABLE 4.1 Classification of Solutes in Aqueous Solution

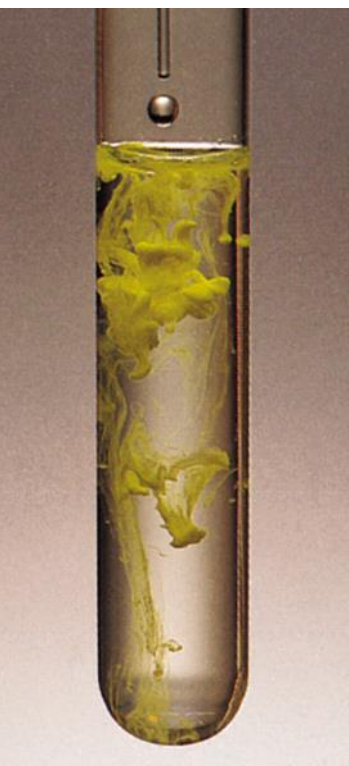
Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
HCl	CH ₃ COOH	(NH ₂) ₂ CO (urea)
HNO ₃	HF	CH ₃ OH (methanol)
HClO ₄	HNO ₂	C ₂ H ₅ OH (ethanol)
H ₂ SO ₄ [*]	NH ₃	C ₆ H ₁₂ O ₆ (glucose)
NaOH	H ₂ O [†]	C ₁₂ H ₂₂ O ₁₁ (sucrose)
Ba(OH) ₂		
Ionic compounds		

^{*}H₂SO₄ has two ionizable H⁺ ions.

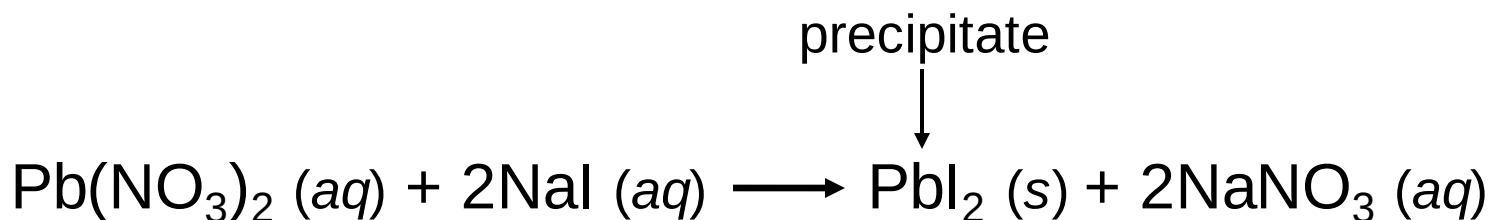
[†]Pure water is an extremely weak electrolyte.

Precipitation Reactions

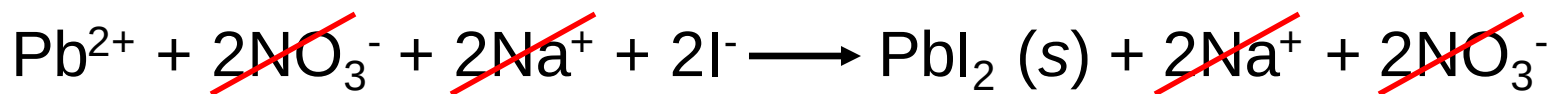
Precipitate – insoluble solid that separates from solution



PbI₂



molecular equation



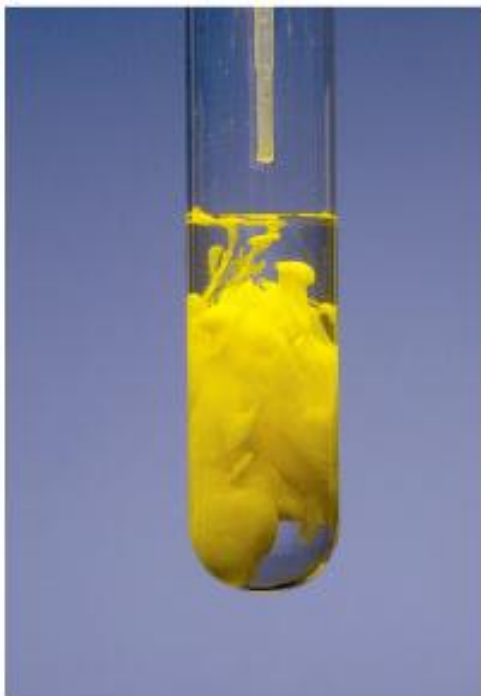
ionic equation



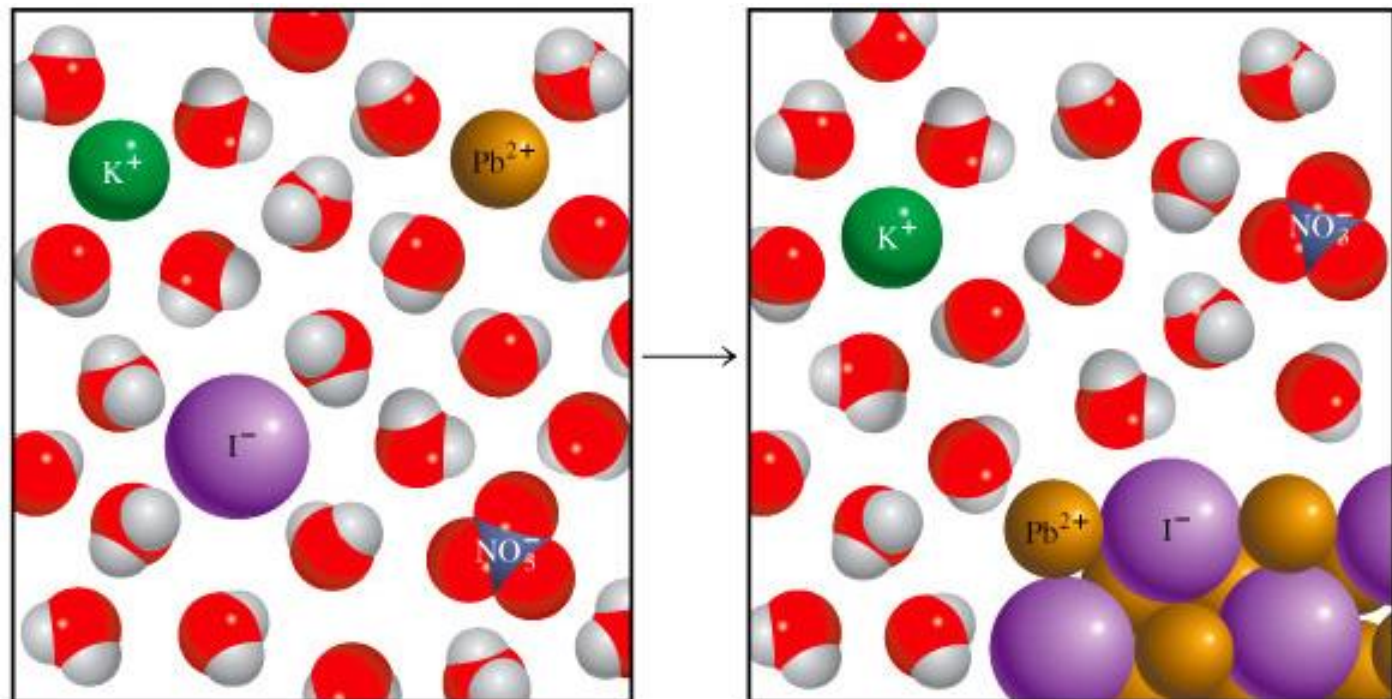
net ionic equation

Na⁺ and NO₃⁻ are *spectator* ions

Precipitation of Lead Iodide



PbI_2



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

Exceptions

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-})

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

Exceptions

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

Hydroxides (OH^-)

Compounds containing alkali metal ions and the ammonium ion

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

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

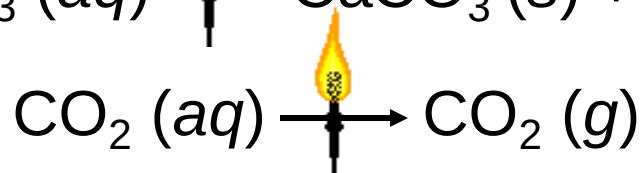
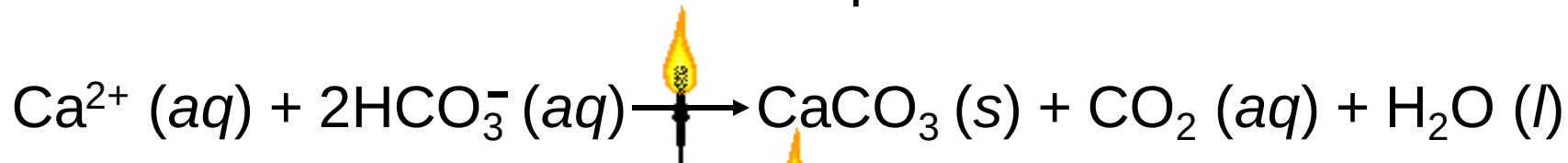


Write the net ionic equation for the reaction of silver nitrate with sodium chloride.

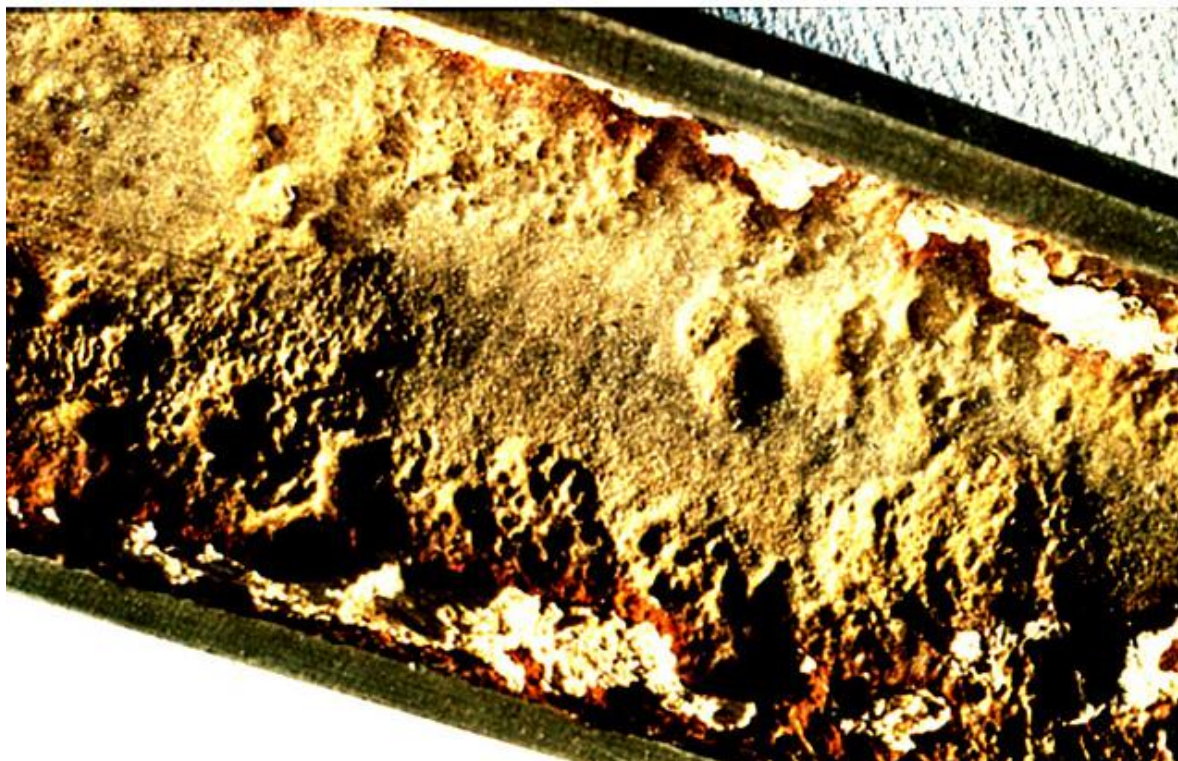


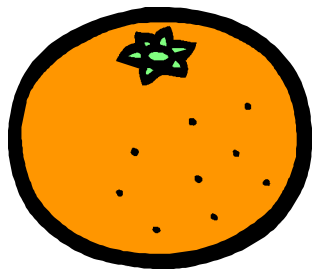
Chemistry In Action:

An Undesirable Precipitation Reaction



Boiler Scale Deposits





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.

Bases

Have a bitter taste.

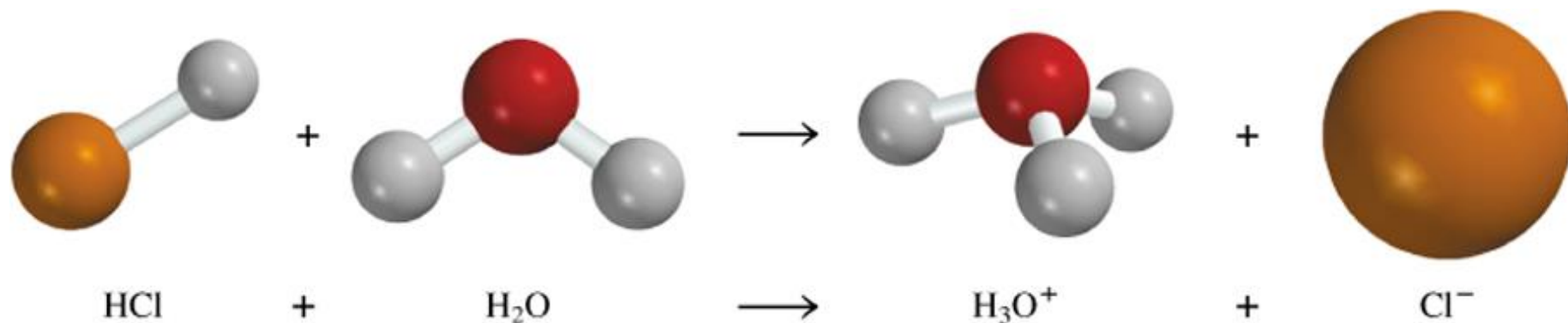
Feel slippery. Many soaps contain bases.

Cause color changes in plant dyes.

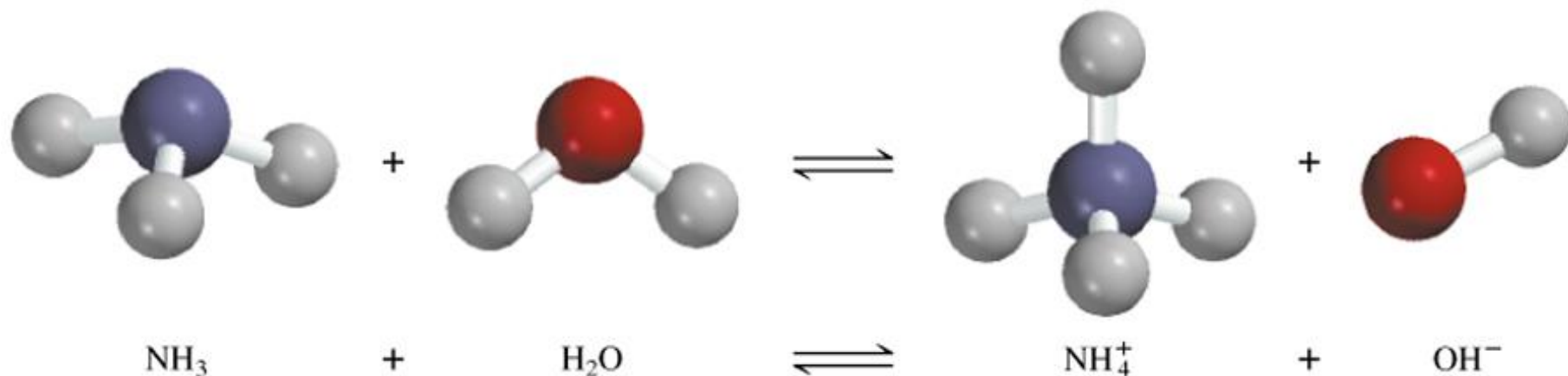
Aqueous base solutions conduct electricity.



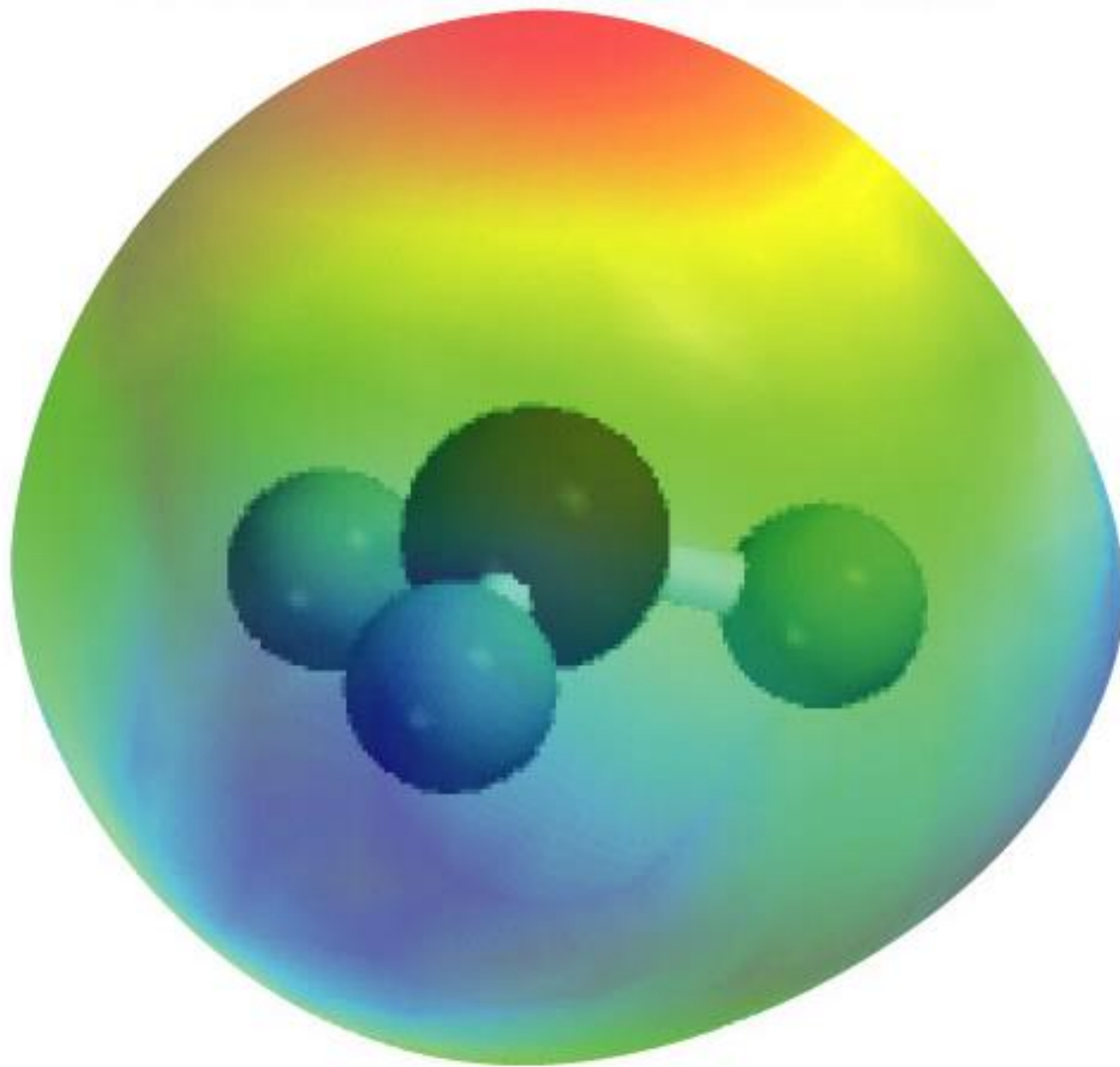
Arrhenius acid is a substance that produces H^+ (H_3O^+) in water



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

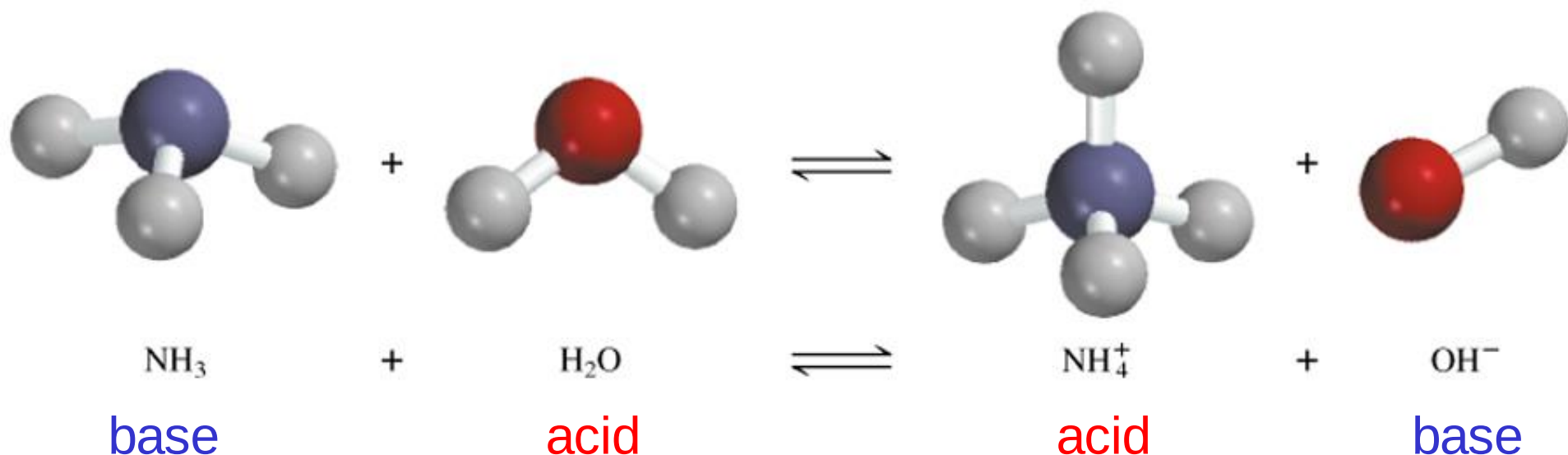


Hydronium ion, hydrated proton, H_3O^+



A **Brønsted acid** is a proton donor

A **Brønsted base** is a proton acceptor



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

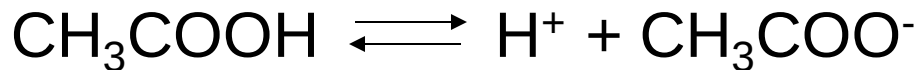
Monoprotic acids



Strong electrolyte, strong acid



Strong electrolyte, strong acid

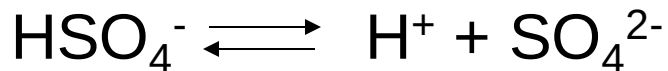


Weak electrolyte, weak acid

Diprotic acids

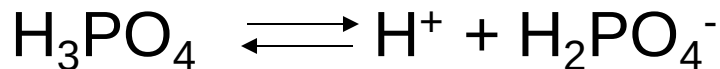


Strong electrolyte, strong acid

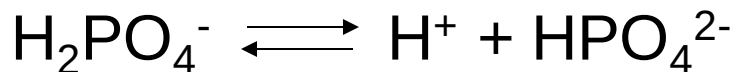


Weak electrolyte, weak acid

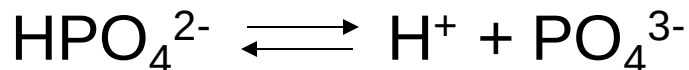
Triprotic acids



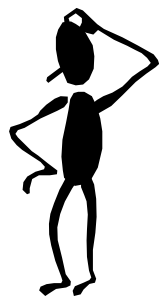
Weak electrolyte, weak acid



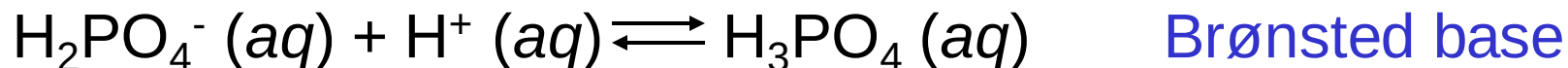
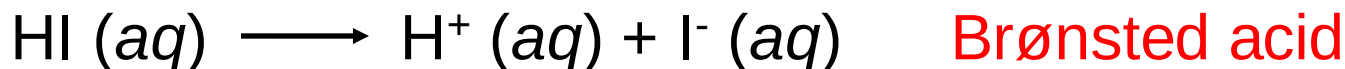
Weak electrolyte, weak acid



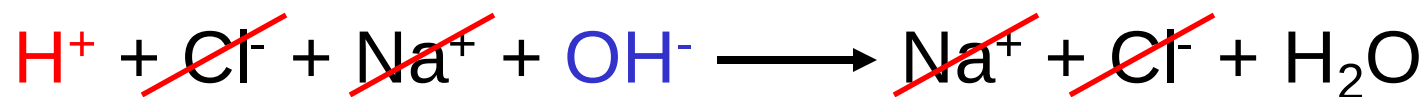
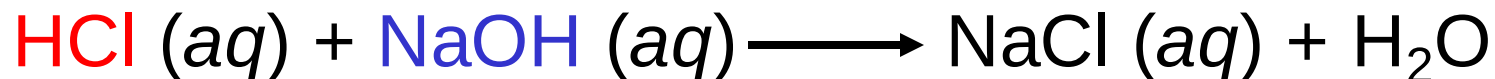
Weak electrolyte, weak acid



Identify each of the following species as a Brønsted acid, base, or both. (a) HI, (b) CH_3COO^- , (c) H_2PO_4^-

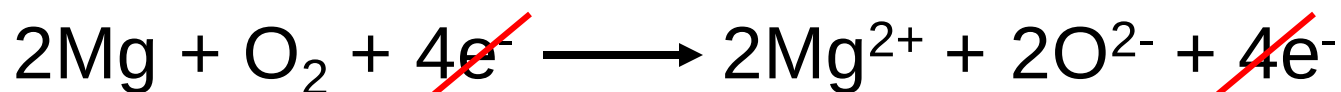
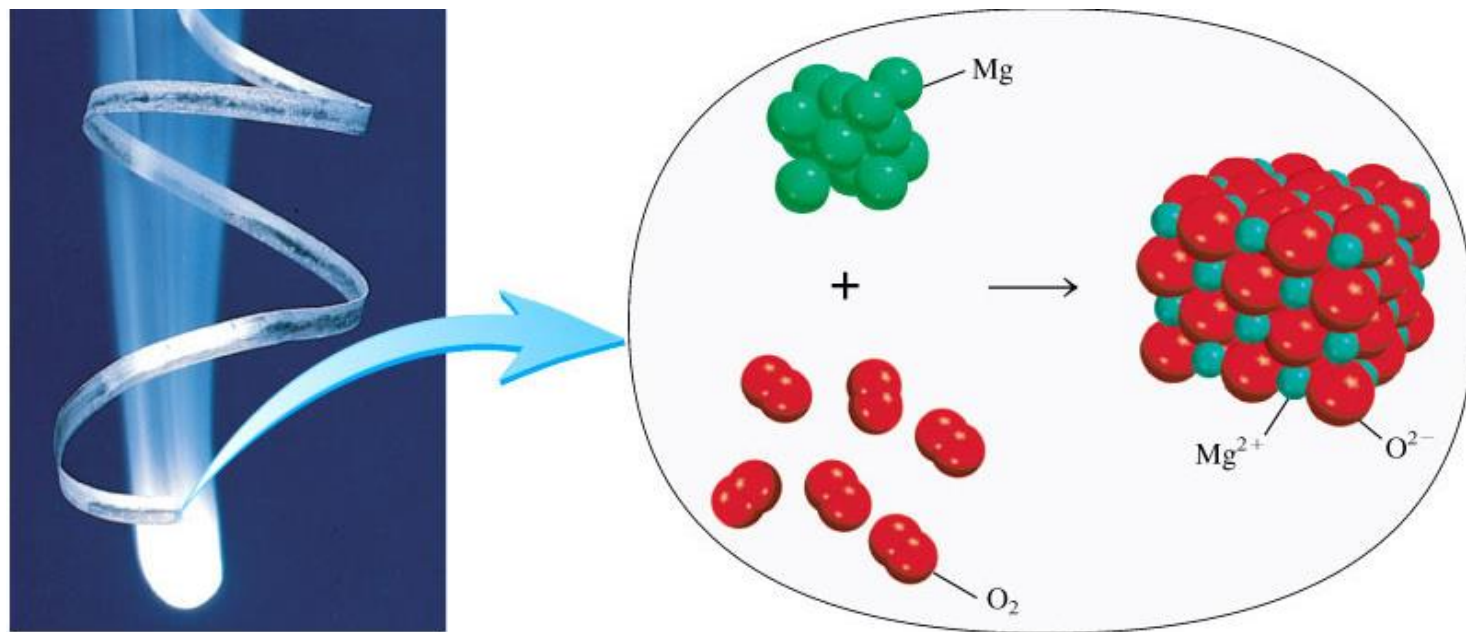


Neutralization Reaction



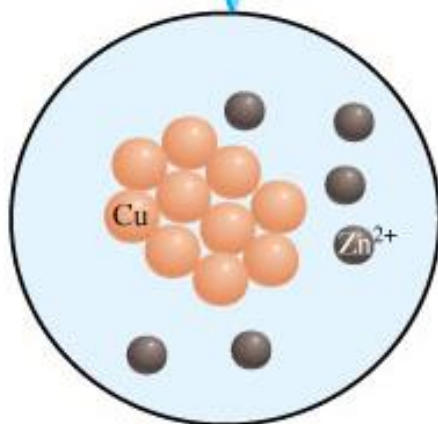
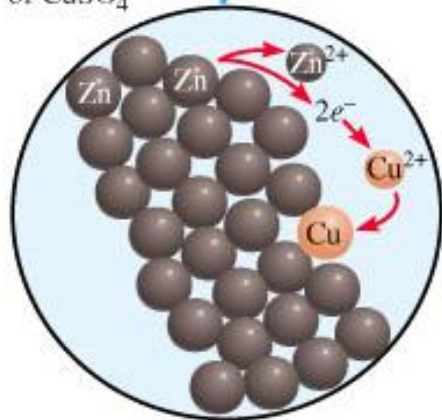
Oxidation-Reduction Reactions

(electron transfer reactions)



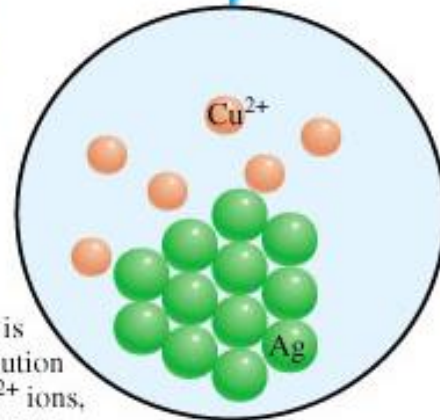
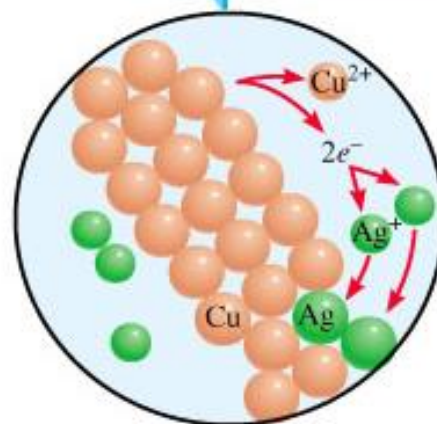


The Zn bar is in aqueous solution of CuSO_4



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

(a)



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.

(b)



$\text{Zn} \longrightarrow \text{Zn}^{2+} + 2\text{e}^-$ Zn is oxidized Zn is the **reducing agent**

$\text{Cu}^{2+} + 2\text{e}^- \longrightarrow \text{Cu}$ Cu^{2+} is reduced Cu^{2+} is the **oxidizing agent**



Copper wire reacts with silver nitrate to form silver metal.
What is the oxidizing agent in the reaction?



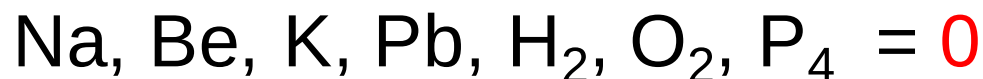
$\text{Cu} \longrightarrow \text{Cu}^{2+} + 2\text{e}^-$

$\text{Ag}^+ + 1\text{e}^- \longrightarrow \text{Ag}$ 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.

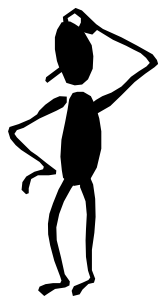


2. In monatomic ions, the oxidation number is equal to the charge on the ion.



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 **$-1/2$** .



Oxidation numbers of all
the elements in HCO_3^- ?



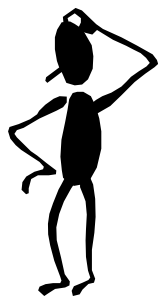
$$\text{O} = \textbf{-2} \quad \text{H} = \textbf{+1}$$

$$3\text{x}(\textbf{-2}) + \textbf{1} + \textbf{?} = -1$$

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

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	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				



Oxidation numbers of all
the elements in the
following ?



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

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

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



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

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

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



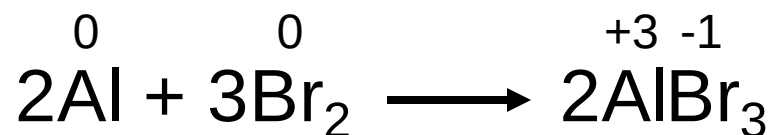
$$\text{O} = -2 \quad \text{K} = +1$$

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

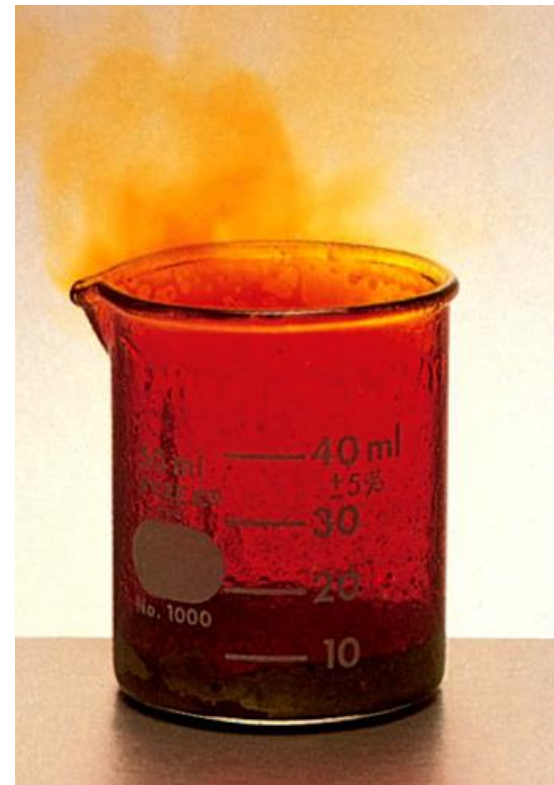
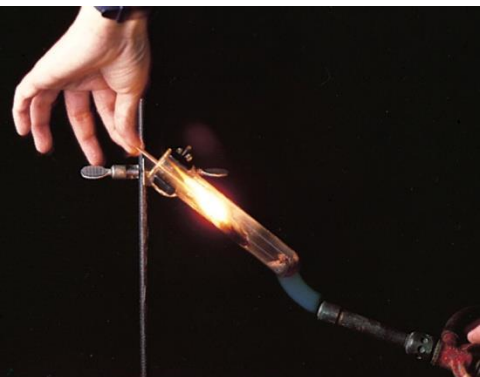
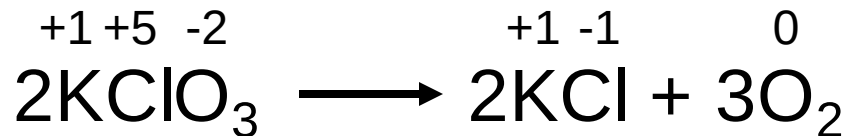
$$\text{Cr} = +6$$

Types of Oxidation-Reduction Reactions

Combination Reaction

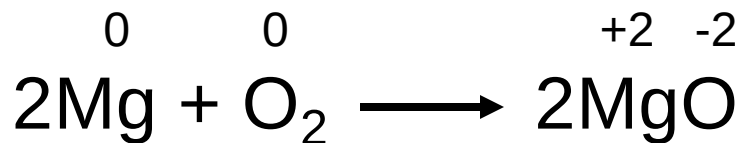
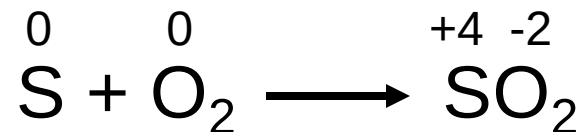
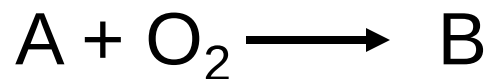


Decomposition Reaction



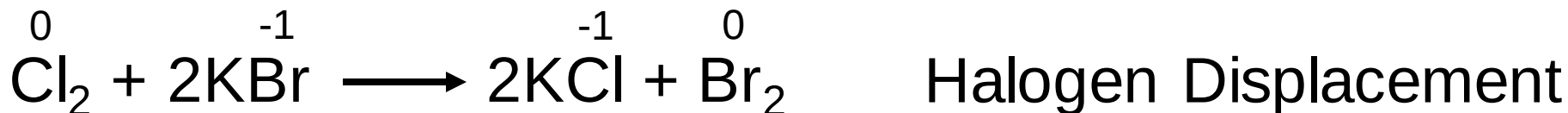
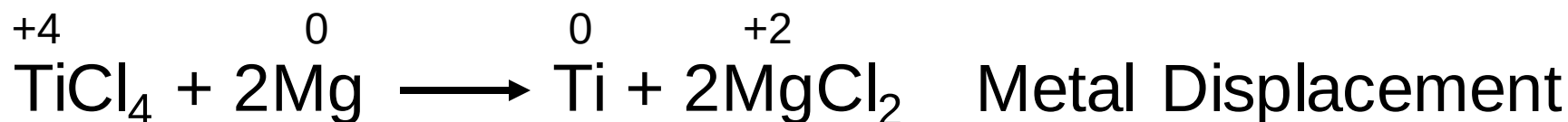
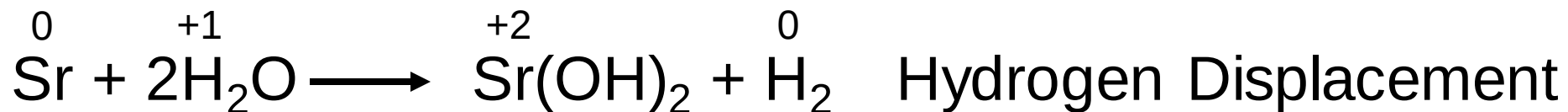
Types of Oxidation-Reduction Reactions

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
$\text{Pt} \rightarrow \text{Pt}^{2+} + 2e^-$	
$\text{Au} \rightarrow \text{Au}^{3+} + 3e^-$	

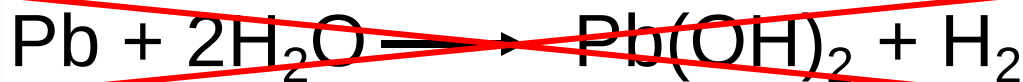
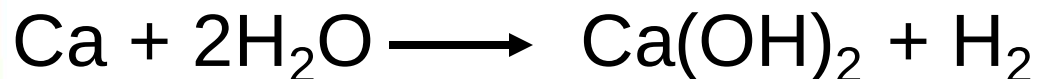
Hydrogen Displacement Reaction



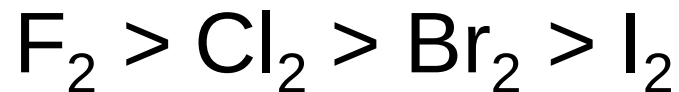
M is metal

BC is acid or H_2O

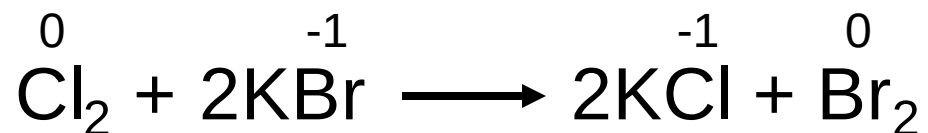
B is H_2



The Activity Series for Halogens



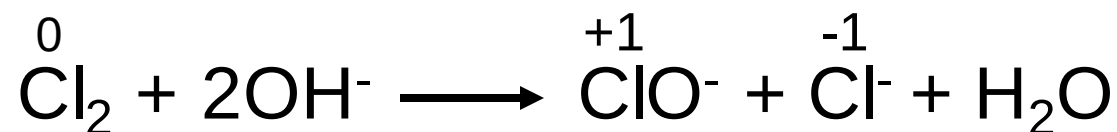
Halogen Displacement Reaction



Types of Oxidation-Reduction Reactions

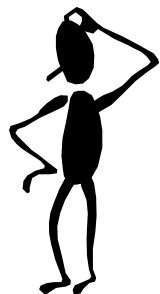
Disproportionation Reaction

Element is simultaneously oxidized and reduced.

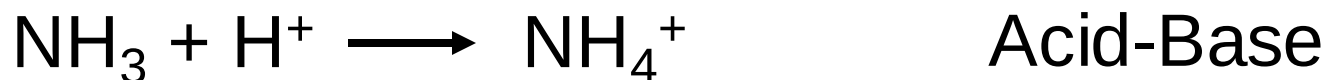


Chlorine Chemistry

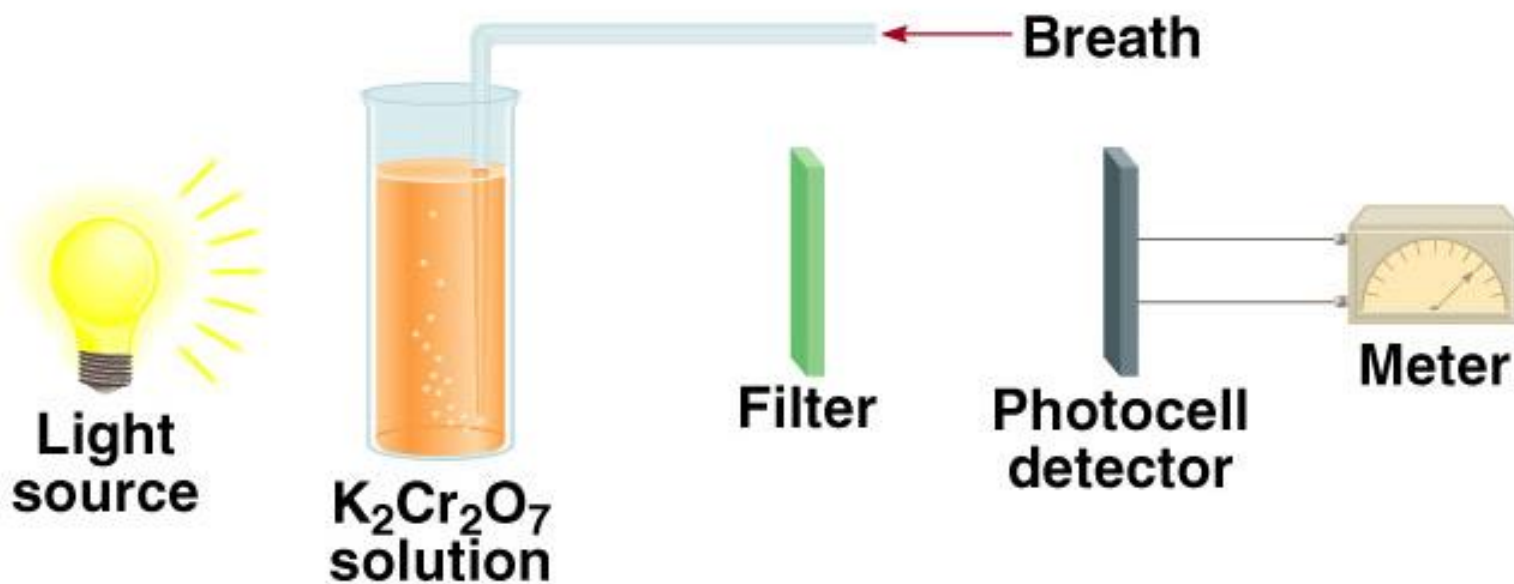
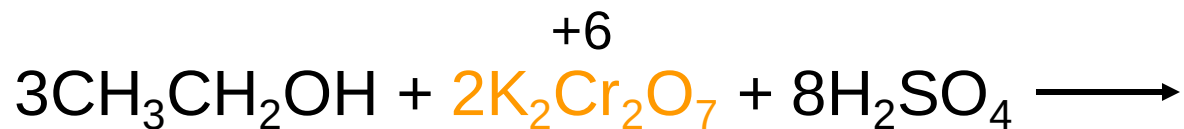




Classify the following reactions.



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.

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

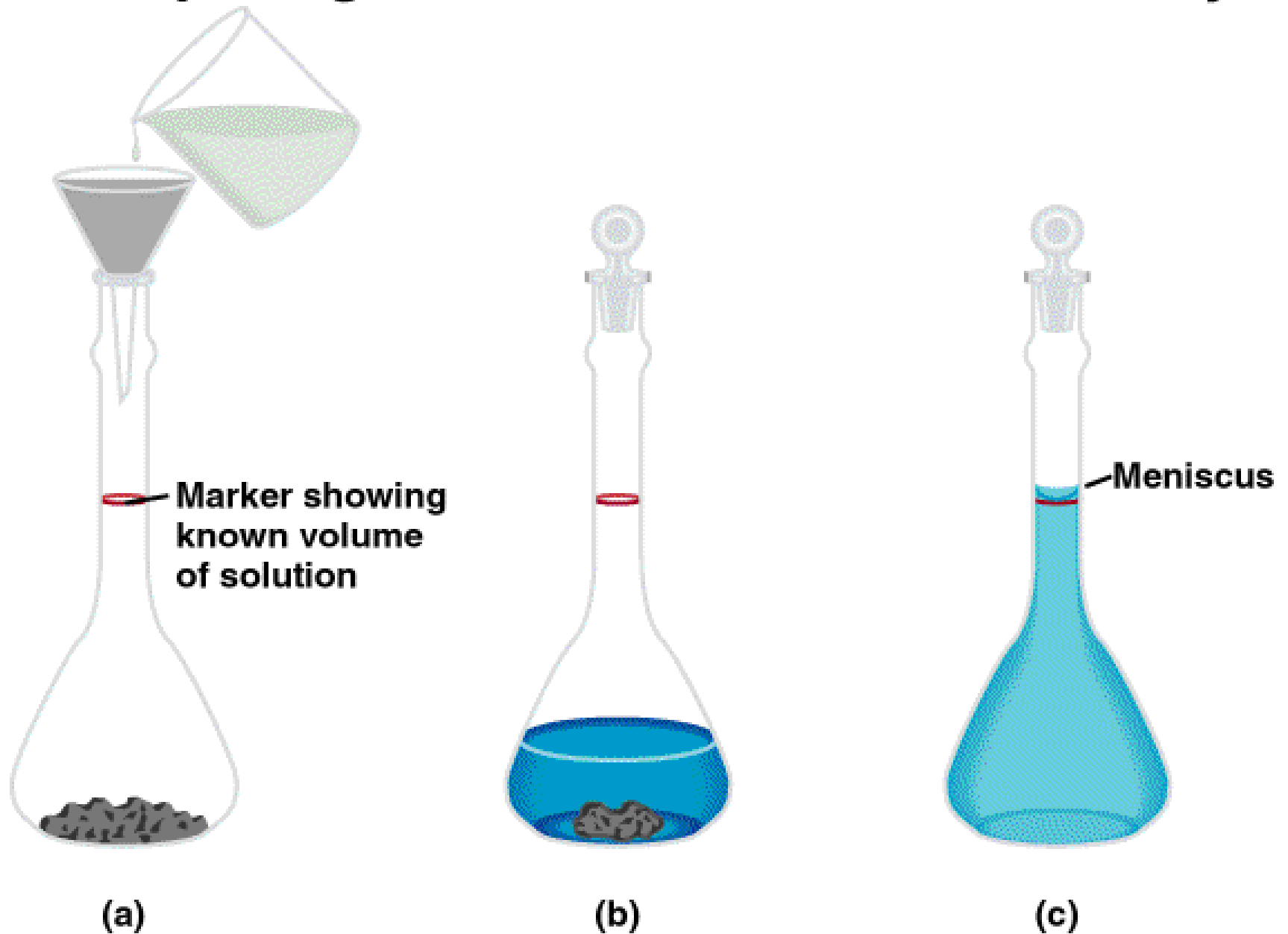


What mass of KI is required to make 500. mL of a 2.80 M KI solution?

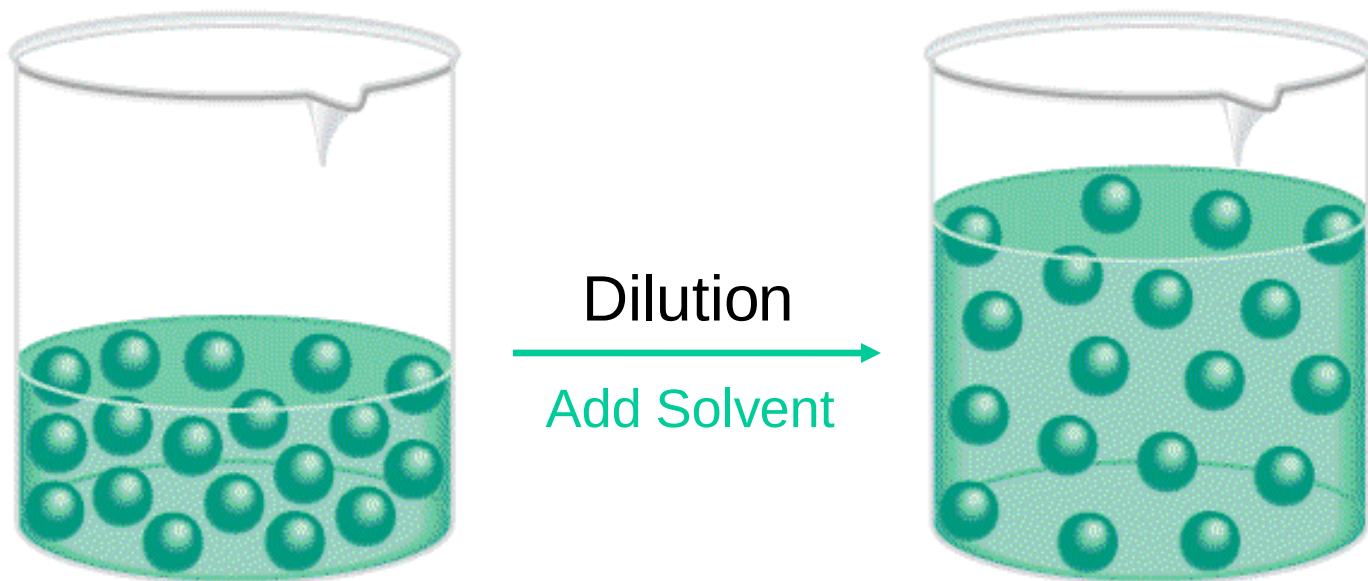
volume of KI solution $\xrightarrow{M \text{ KI}}$ moles KI $\xrightarrow{M \text{ KI}}$ grams KI

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

Preparing a Solution of Known Molarity



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



Moles of solute
before dilution (i)

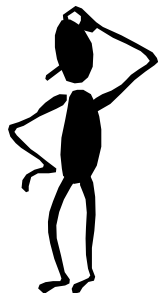
=

Moles of solute
after dilution (f)

$$M_i V_i$$

=

$$M_f V_f$$



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

$$M_i V_i = M_f V_f$$

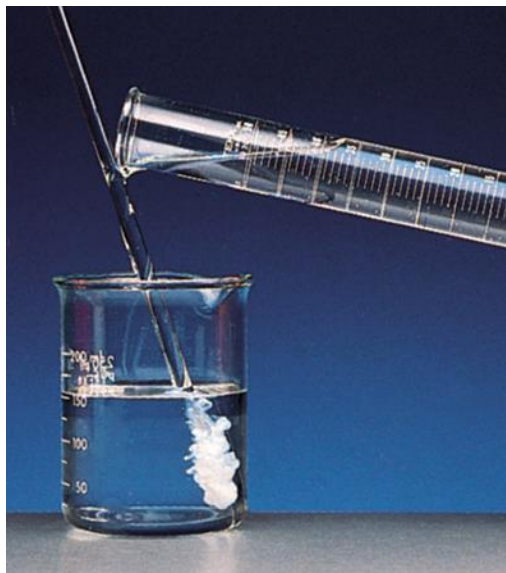
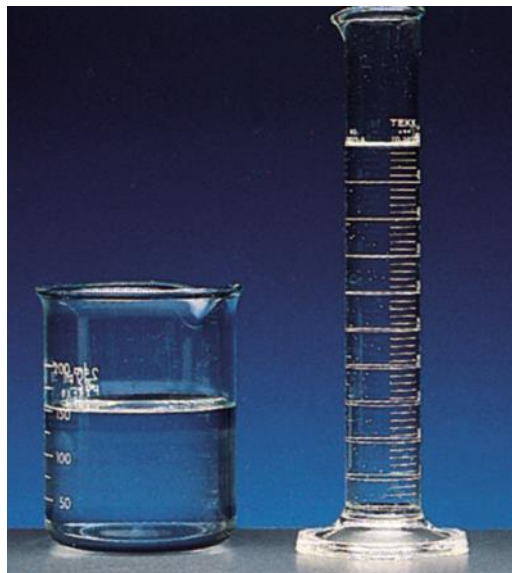
$$M_i = 4.00 \quad M_f = 0.200 \quad V_f = 0.06 \text{ L} \quad V_i = ? \text{ L}$$

$$V_i = \frac{M_f V_f}{M_i} = \frac{0.200 \times 0.06}{4.00} = 0.003 \text{ L} = 3 \text{ mL}$$

3 mL of acid + 57 mL of water = 60 mL of solution

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

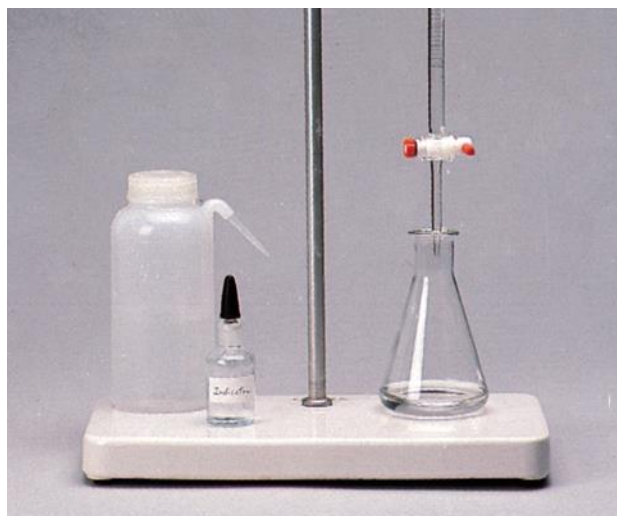


Titrations

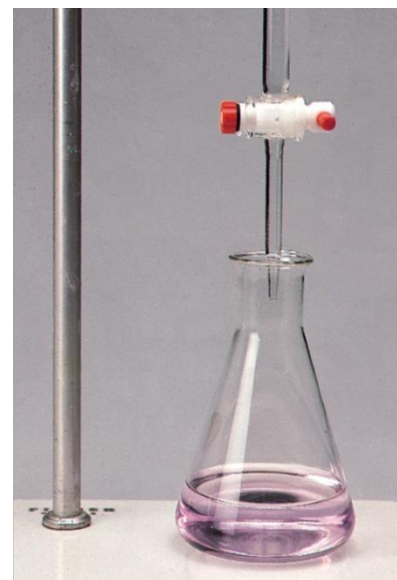
In a ***titration*** a solution of accurately known concentration is added gradually to another solution of unknown concentration until the chemical reaction between the two solutions is complete.

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





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



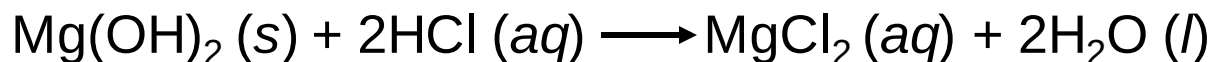
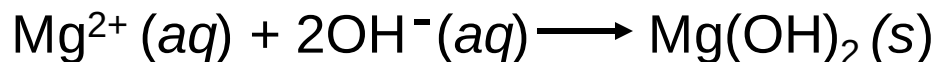
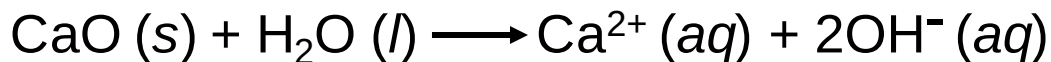
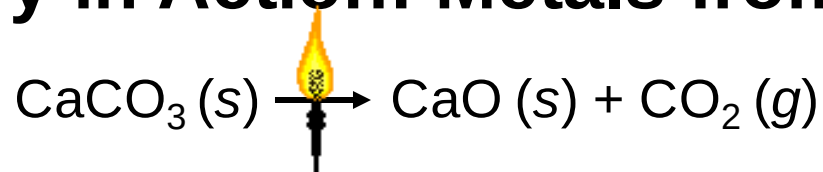
WRITE THE CHEMICAL EQUATION!



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

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

Chemistry in Action: Metals from the Sea



Magnesium Hydroxide

