Chemical Reactions

Chemical Reactions

Chemical change = Chemical reaction

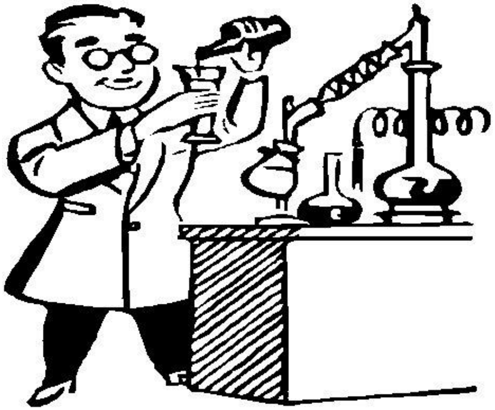
Substance(s) is used up (disappear)

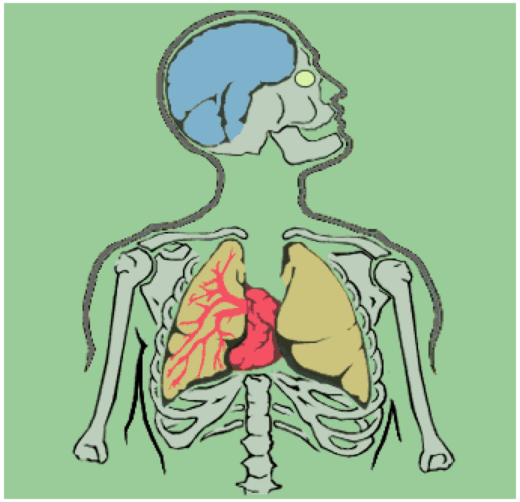
$\Downarrow$

New substance(s) is formed.

Different physical and chemical properties.

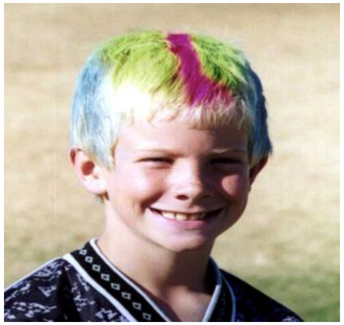
Chemical Reactions



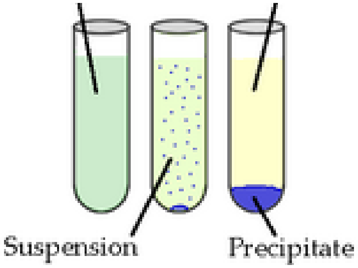


Evidence for chemical reactions

1. Color changes



2. A solid is formed (precipitation)



3. Bubbles form (gas)

4. Heat (and/or flame) is produced, or heat is absorbed

Chemical Reactions

$$A + B \rightarrow C + D$$

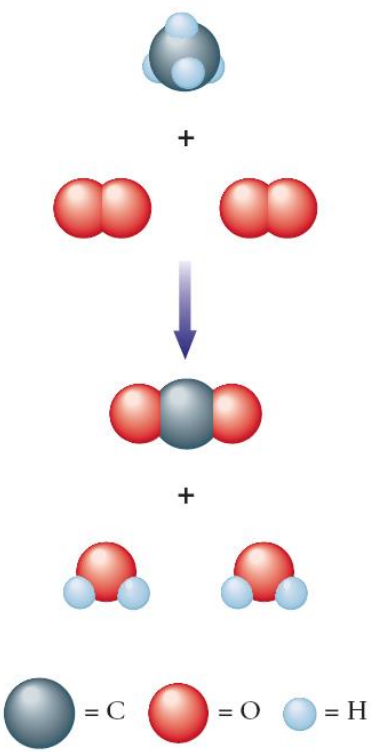
Reactants Products

Chemical Equation

Chemical Reactions

Methane		Oxygen		Carbon dioxide		Water
CH_4	$+$	O_2	$\rightarrow$	CO_2	$+$	H_2O

$$\underbrace{CH_4 + O_2}_{\text{Reactants}} \rightarrow \underbrace{CO_2 + H_2O}_{\text{Products}}$$



Products contain the same atoms as reactants.

Rearrangement of atoms

Chemical Equation

Physical States (forms)

Solid (s)
Liquid (l)
Gas (g)
Aqueous (aq)

$$Ca(OH)_2(s) + 2HCl(g) \rightarrow CaCl_2(s) + H_2O(l)$$

Chemical Equation

Chemical equation gives us some information:

1. Identities of the reactants and products.

2. Relative amounts of the reactants and products.

3. Physical states of the reactants and products.

4. Stoichiometry

Type of chemical reactions

1. $A + B \rightarrow AB$ **Synthesis reaction (combination)**

   $2H_2 + O_2 \rightarrow 2H_2O$

2. $AB \rightarrow A + B$ **Decomposition (analysis)**

   $2NaCl \rightarrow 2Na + Cl_2$

3. $A + BC \rightarrow AC + B$ **Single replacement reaction**

   $Fe + CuSO_4 \rightarrow FeSO_4 + Cu$

4. $AB + CD \rightarrow AD + CB$ **Double replacement reaction**

   $NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$

Type of chemical reactions

5. $AB + xO_2 \rightarrow yCO_2 + zH_2O$ + Heat (Energy) **Combustion**

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ + Heat

Balance a chemical equation

All chemical equations should be balanced.

Why balancing?

Balance a chemical equation

Law of conservation of mass

Atoms are neither destroyed nor created.

They shift from one substance to another.

Balance a chemical equation

1. Begin with atoms that appear in only one compound on the left and right.
2. If an atom occurs as a free element, balance it last.
3. Change only coefficients (not formulas).

$$C_3H_8(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

last

Always double check!

Balance a chemical equation

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

$\times 2$ $$2C_3H_8(g) + 10O_2(g) \rightarrow 6CO_2(g) + 8H_2O(g)$$

$\times 3$ $$3C_3H_8(g) + 15O_2(g) \rightarrow 9CO_2(g) + 12H_2O(g)$$

Lowest set of numbers

Examples for Balancing

$\underline{1}$ $C_2H_5OH(\mathit{l})$ + $\underline{3}$ $O_2(\mathit{g})$ → $\underline{2}$ $CO_2(\mathit{g})$ + $\underline{3}$ $H_2O(\mathit{g})$

$\underline{1}$ $PbCl_2(\mathit{aq})$ + $\underline{1}$ $K_2SO_4(\mathit{aq})$ → $\underline{1}$ $PbSO_4(\mathit{s})$ + $\underline{2}$ $KCl(\mathit{aq})$

$\underline{1}$ $CaC_2(\mathit{s})$ + $\underline{2}$ $H_2O(\mathit{l})$ → $\underline{1}$ $Ca(OH)_2(\mathit{s})$ + $\underline{1}$ $C_2H_2(\mathit{g})$

Examples for Balancing

$$\underline{\ 2\ }\ Fe(s) + \underline{\ 3/2\ }\ O_2(g) \rightarrow \underline{\ 1\ }\ Fe_2O_3(s)$$

$$\overset{4}{\cancel{2}}\ Fe(s) + \overset{3}{\cancel{3/2}}\ O_2(g) \rightarrow \overset{2}{\cancel{1}}\ Fe_2O_3(s)$$

Notes: *Always* use the lowest possible integer numbers.

If you get a fraction, multiply it out.

Examples for Balancing

$$\cancel{1}\ \underline{\quad} B_4H_{10}(g) + \cancel{11/2}\ \underline{\quad} O_2(g) \rightarrow \cancel{2}\ \underline{\quad} B_2O_3(g) + \cancel{5}\ \underline{\quad} H_2O(g)$$

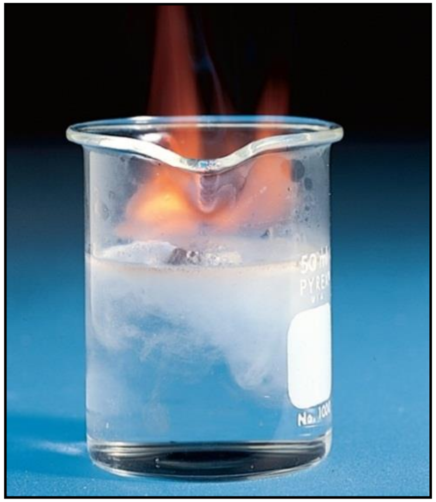
2 11 4 10

Examples for Balancing

- “Solid potassium reacts with water to form hydrogen gas and potassium hydroxide dissolved in solution.”

- Write and balance the chemical equation for this reaction.

$$\cancel{1}\,2\,K(s) + 2\,H_2O(l) \rightarrow \cancel{1}\,2\,KOH(aq) + 1\,H_2(g)$$



Why does a chemical reaction occur?

Several driving forces:

1. Formation of a solid

2. Formation of water

3. Transfer of electrons

4. Formation of a gas

Why does a chemical reaction occur?

Several driving forces:

1. Formation of a solid
2. Formation of water
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Reactions in Aqueous Solutions

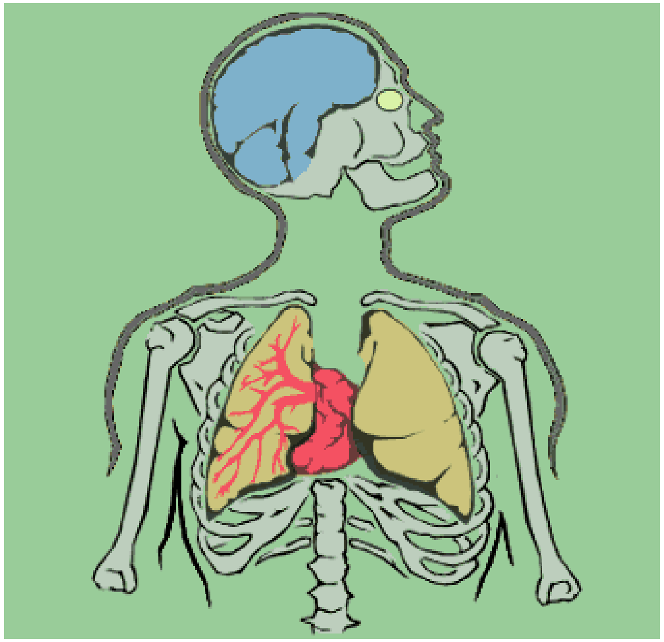
Ionic compounds (Salt)

Aqueous solution: solvent is water

Reactions in Aqueous Solutions

Chemical reactions that occur in water.

60% of our body is water.



In our body reactions occur in the aqueous solution.

Formation of a solid

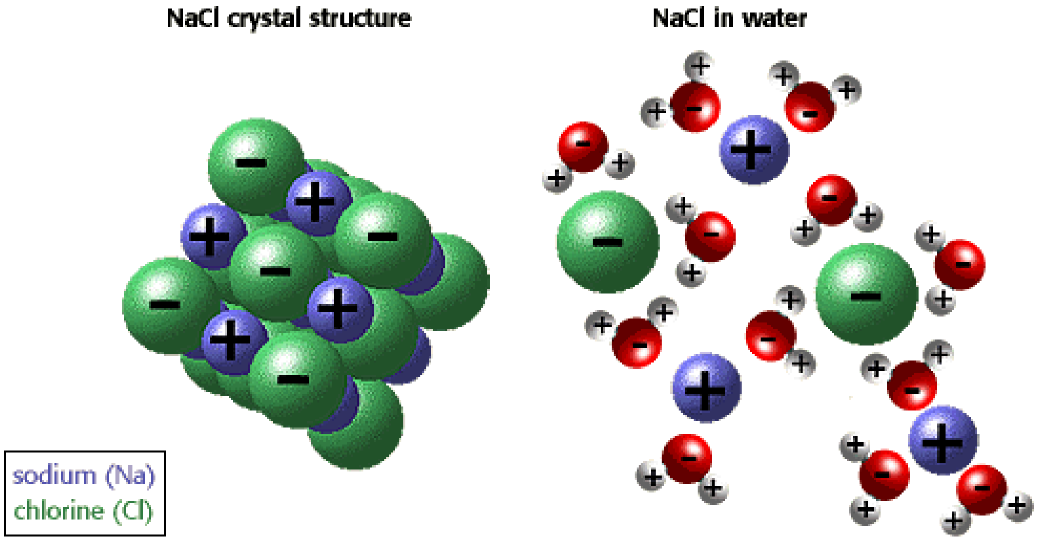
Precipitation reactions

Precipitate

$$KI + Pb(NO_3)_2 \rightarrow ?$$

Ionic Compounds

When an ionic compound dissolves in water, ions are produced.



Each ion is surrounded by water molecules.

Ions Hydrated by H_2O

Hydration

Ionic Compounds

1. Soluble ionic compound: it completely dissociates in water.
(ions are formed)

2. Slightly soluble ionic compound: it partially dissociates in water.

3. Insoluble ionic compound: it does not dissociate in water (almost).

- Note: the terms ***insoluble*** and ***slightly soluble*** mean such a miniscule amount dissolves that you can't see any decrease in the amount of solid present.

Solubility Rules

Table 7.1 General Rules for Solubility of Ionic Compounds (Salts) in Water at 25 °C

1. Most nitrate (NO_3^-) salts are soluble.
2. Most salts of Na^+, K^+, and NH_4^+ are soluble.
3. Most chloride salts are soluble. Notable exceptions are $AgCl$, $PbCl_2$, and Hg_2Cl_2.
4. Most sulfate salts are soluble. Notable exceptions are $BaSO_4$, $PbSO_4$, and $CaSO_4$.

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5. Most hydroxide compounds are only slightly soluble.* The important exceptions are NaOH and KOH. $Ba(OH)_2$ and $Ca(OH)_2$ are only moderately soluble.
6. Most sulfide (S^{2-}), carbonate (CO_3^{2-}), and phosphate (PO_4^{3-}) salts are only slightly soluble.*

Soluble

Insoluble

Preceding rules trump following rules.

Solubility Rules

- Another way of showing the same rules.

Soluble

NO_3^- salts	
Na^+, K^+, NH_4^+ salts	
Cl^-, Br^-, I^- salts	Except for those containing Ag^+, Hg_2^{2+}, Pb^{2+}
SO_4^{2-} salts	Except for those containing Ba^{2+}, Pb^{2+}, Ca^{2+}

Insoluble

S^{2-}, CO_3^{2-}, PO_4^{3-} salts	
OH^- salts	Except for those containing Na^+, K^+, Ca^{2+}, Ba^{2+}

Formation of a solid

Precipitation reactions

Precipitate

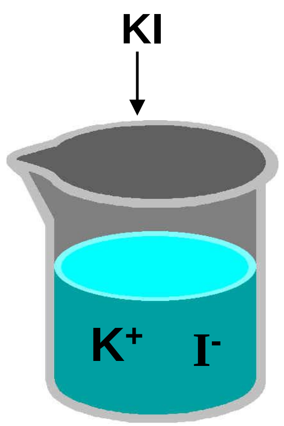
$$KI + Pb(NO_3)_2 \rightarrow ?$$

Aqueous Solution (ionic compounds)

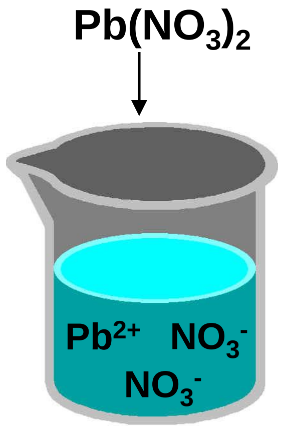
aqueous solution: solvent is water

$$KI(s) \xrightarrow{H_2O} K^+(aq) + I^-(aq)$$

Dissociation (Ionization)



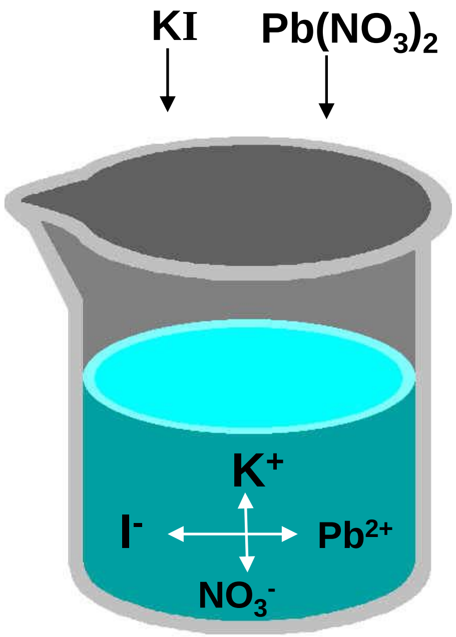
$$Pb(NO_3)_2(s) \xrightarrow{H_2O} Pb^{2+}(aq) + 2NO_3^-(aq)$$

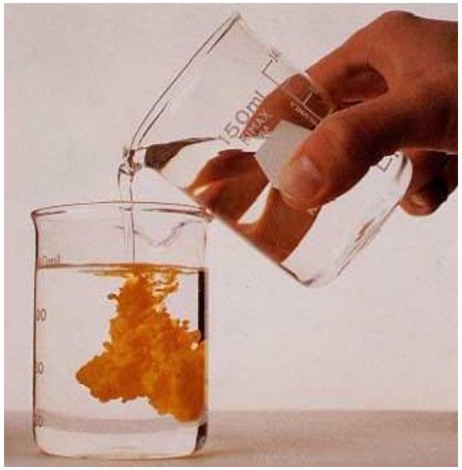


Aqueous Solution (ionic compounds)

Sometimes the ions react with each other.

Positive ions will interact with negative ions.





Sometimes ions stick together to form a solid (precipitate).

$$2KI(aq) + Pb(NO_3)_2(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

Molecular equation: $2KI(aq) + Pb(NO_3)_2(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$

Complete
Ionic equation: $2K^+(aq) + Pb^{2+}(aq) + 2I^-(aq) + 2NO_3^-(aq) \rightarrow PbI_2(s) + 2K^+(aq) + 2NO_3^-(aq)$

$\cancel{2K^+}(aq) + Pb^{2+}(aq) + 2I^-(aq) + \cancel{2NO_3^-}(aq) \rightarrow PbI_2(s) + \cancel{2K^+}(aq) + \cancel{2NO_3^-}(aq)$

Spectator ions

- The ions that ***do not react*** are called spectator ions.

Net ionic equation: $Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$

Ionic Equations

Net ionic equation: $Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$

Total charge on left side = Total charge on right side
balanced equation

$$2As^{3+}(aq) + 3s^{2-}(aq) \rightarrow As_2S_3(s)$$

Example

$Pb(NO_3)_2\textit{(aq)} + Na_2SO_4\textit{(aq)} \rightarrow ?$

$Pb(NO_3)_2\textit{(aq)} + Na_2SO_4\textit{(aq)} \rightarrow PbSO_4\textit{(s)} + NaNO_3\textit{(aq)}$

Balance it:

$Pb(NO_3)_2\textit{(aq)} + Na_2SO_4\textit{(aq)} \rightarrow PbSO_4\textit{(s)} + \mathbf{2}\ NaNO_3\textit{(aq)}$

$Pb^{2+}\textit{(aq)} + 2\ NO_3^-\textit{(aq)} + 2\ Na^+\textit{(aq)} + SO_4^{2-}\textit{(aq)} \rightarrow PbSO_4\textit{(s)} + 2\ Na^+\textit{(aq)} + 2\ NO_3^-\textit{(aq)}$

Complete ionic equation

Example

$$Pb^{2+}(aq) + \cancel{2\ NO_3^-}(aq) + \cancel{2\ Na^+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + \cancel{2\ Na^+}(aq) + \cancel{2\ NO_3^-}(aq)$$

Spectator ions

Net ionic equation: $\mathbf{Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s)}$

Practice

1. **Molecular equation**

   $KOH(aq) + Fe(NO_3)_3(aq) \rightarrow ?$

2. **Balancing**

3. **Complete ionic equation**

4. **Net ionic equation**

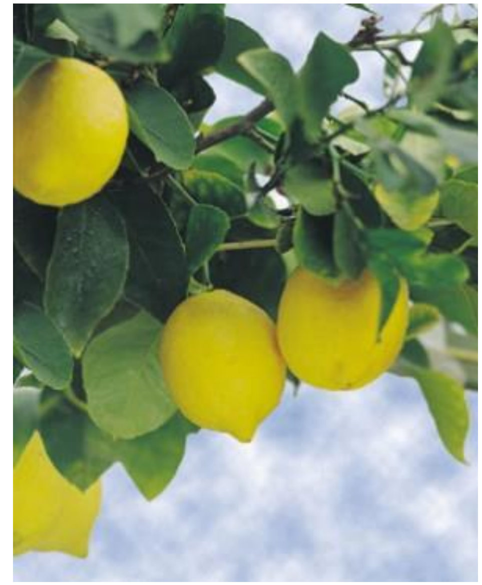
Why does a chemical reaction occur?

Several driving forces:

1. Formation of a solid
2. Formation of water
3. Transfer of electrons
4. Formation of a gas

Acids and Bases

Acids: sour



Bases: bitter or salty

Acid-Base Reactions

Neutralization

Strong acid + Strong base → Salt + H_2O

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

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

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

The only chemical change is the formation of water.

Why does a chemical reaction occur?

Several driving forces:

1. Formation of a solid
2. Formation of water
3. Transfer of electrons
4. Formation of a gas

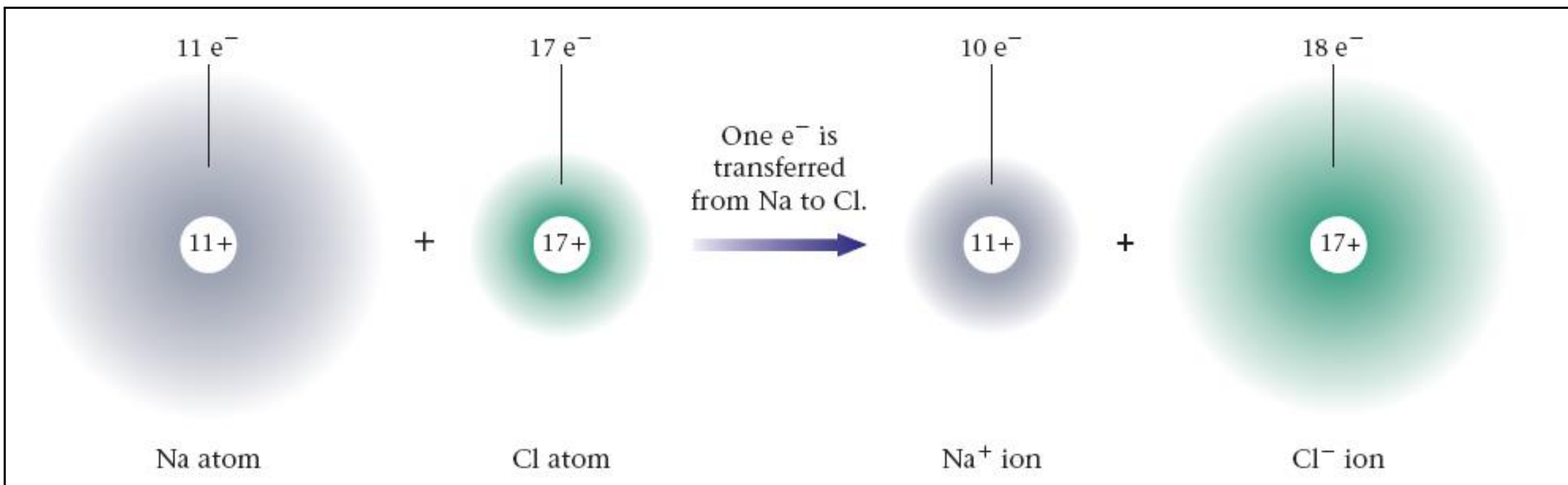
Oxidation and Reduction reactions (redox)

e^-

$$2Na(s) + Cl_2(g) \longrightarrow 2NaCl(s)$$

$$Na \rightarrow Na^+ + e^-$$

$$Cl + e^- \rightarrow Cl^-$$



Oxidation and Reduction reactions (redox)

oxidation: it is the loss of electrons.

$$Na \rightarrow Na^{+} + e^{-}$$

reduction: it is the gain of electrons.

$$Cl + e^{-} \rightarrow Cl^{-}$$

Remember – **LEO** says **GER**.
Loss of **E**lectrons is **O**xidation
Gain of **E**lectrons is **R**eduction.

Oxidation and Reduction reactions (redox)

Metal + Nonmetal : Transfer of electrons

Oxidation and Reduction reactions (redox)

Oxidation and reduction ***always*** occur together.

(The lost e^- must go somewhere!)

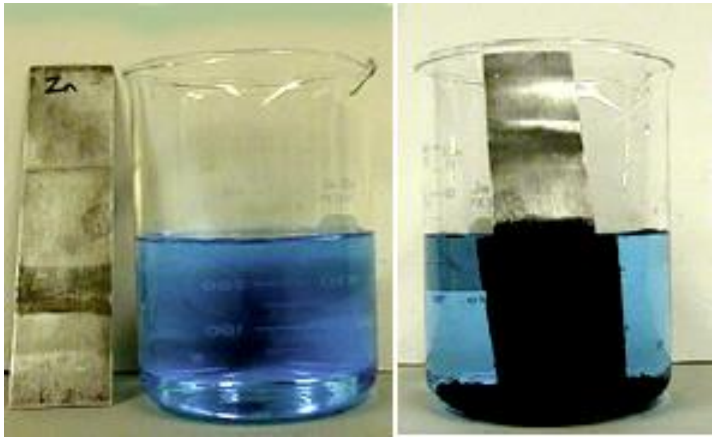
Oxidation and Reduction reactions (redox)

oxidation: it is the loss of electrons.
reduction: it is the gain of electrons.

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$ redox reaction

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ Zn is oxidized **(reducing agent)**

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ Cu^{2+} is reduced **(oxidizing agent)**



Oxidation and Reduction reactions (redox)

oxidation: is the gain of oxygen / loss of hydrogen.
reduction: is the loss of oxygen / gain of hydrogen.

$CH_4(s) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ redox reaction

C gains O and loses H
is oxidized
(reducing agent)

O gains H
Is reduced
(oxidizing agent)

single replacement reaction and combustion reactions $\rightarrow$ redox reactions

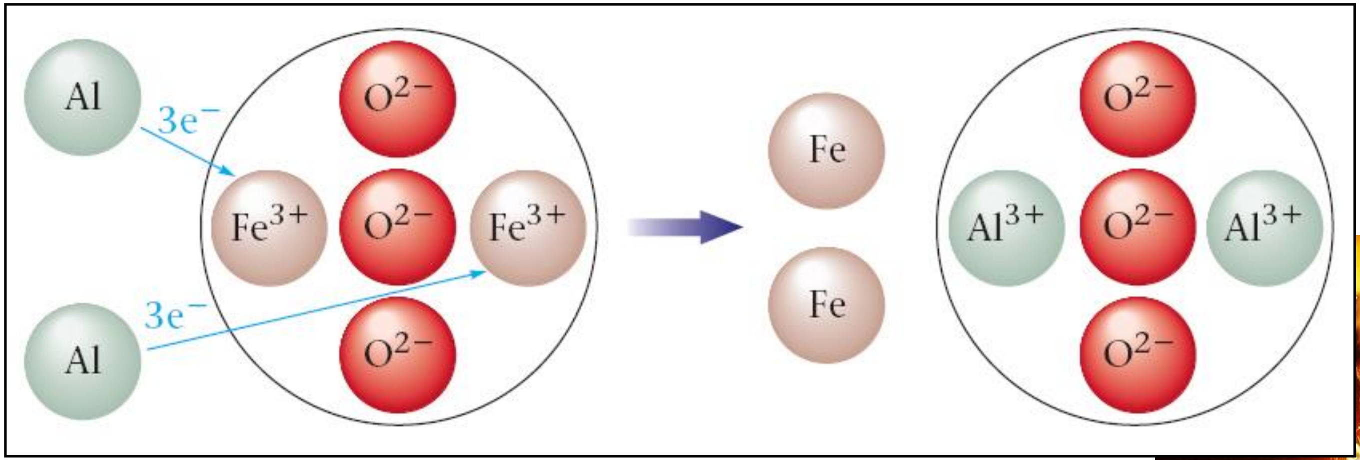
double replacement reactions $\rightarrow$ non redox

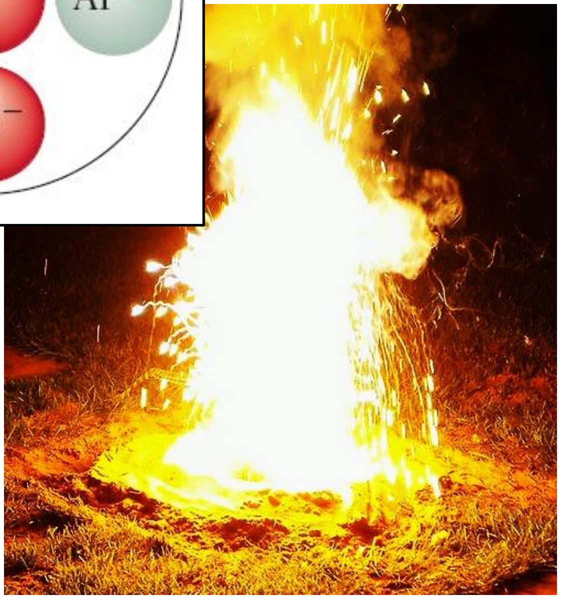
Oxidation and Reduction reactions (redox)

Example 2:

- $2\ Al(s) + Fe_2O_3(s) \rightarrow 2\ Fe(s) + Al_2O_3(s)$

  is oxidized   is reduced





- Called the *Thermite reaction*.
- Let's just say it's vigorous!

Oxidation and Reduction reactions (redox)

Example 3:

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

is oxidized   is reduced

Oxidation and Reduction reactions (redox)

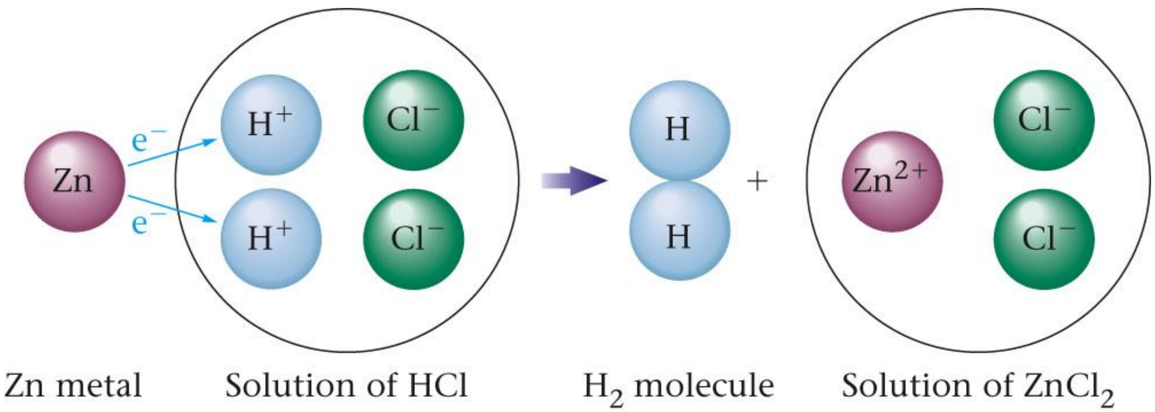
Example 4:

$$Zn(s) + 2\ HCl(aq) \rightarrow H_2(g) + ZnCl_2(aq)$$

$$Zn(s) + 2\ H^+(aq) + \cancel{2Cl^-}(aq) \rightarrow H_2(g) + Zn^{2+}(aq) + \cancel{2Cl^-}(aq)$$

$$Zn(s) + 2\ H^+(aq) \rightarrow H_2(g) + Zn^{2+}(aq)$$

is oxidized is reduced



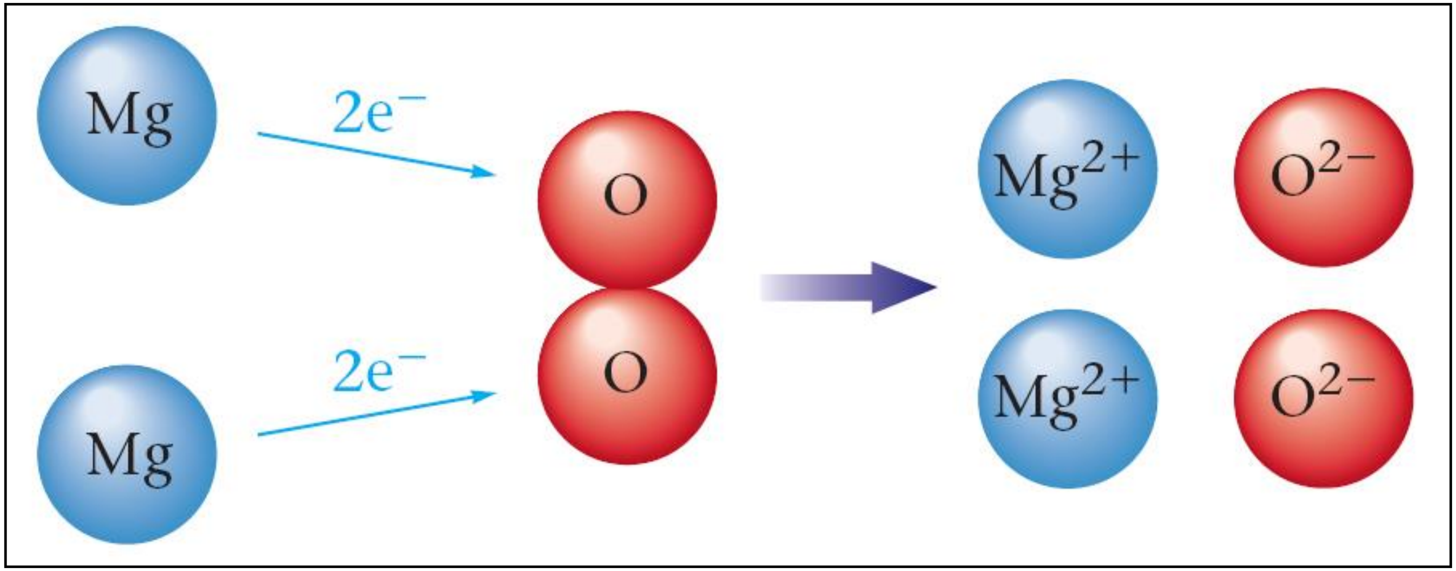
Note: this reaction also shows the fourth driving force of a reaction, namely, *the formation of a gas*.

Oxidation and Reduction reactions (redox)

Example 5:

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

is oxidized is reduced



Classification of chemical reactions