Chapter 6
Chemical reactions
Classification
And Mass Relationships

- Chemical reactions and Chemical Equations
- Balancing Chemical Equations
- Mole, Avogadro’s Number
- Stoichiometric Problems
- Percent Yield
- Types of Chemical Reactions
- Oxidation Numbers

Chemical reactions

A chemical change always involves a rearrangement of atoms and the expression of the atomic rearrangement like this is called a chemical reaction.

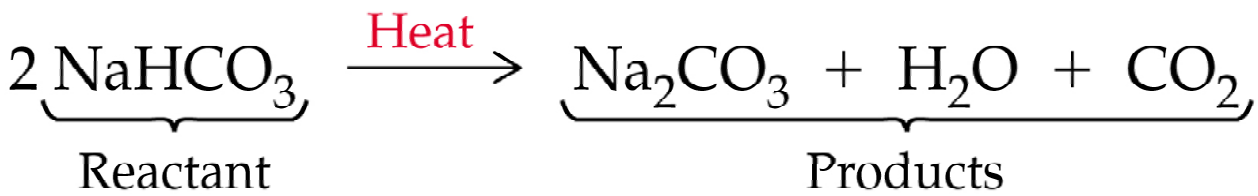
The chemical reaction is represented by a chemical equation in which the chemicals present before the reaction (reactants) are written on the left and the chemicals formed after the reaction (products) are written on the right of an arrow that represents the direction of the chemical reaction.

Reactants → Products

The burning of methane in the presence of oxygen can be represented by the following reaction-

Reactants				Products		
CH_4	+	O_2	→	CO_2	+	H_2O
Methane		oxygen		carbon dioxide		water

The products contain the same atoms as the reactants but they are rearranged as different molecules

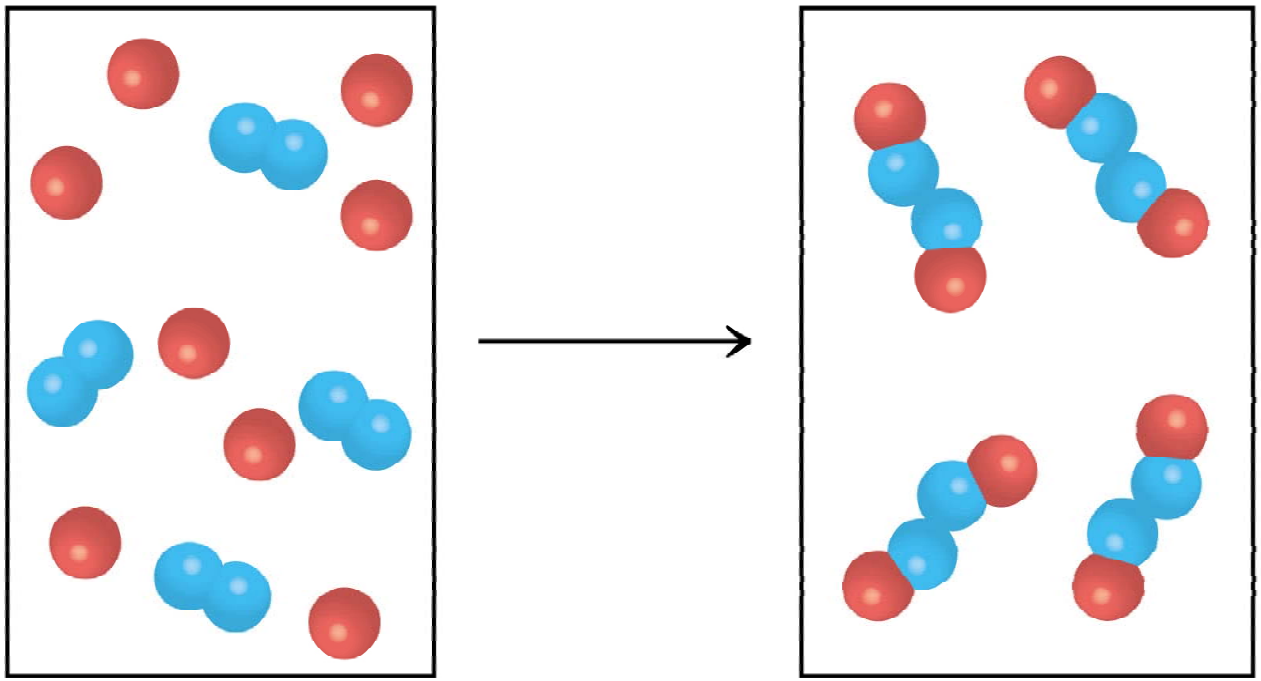

Heat
2 NaHCO3
Reactant
Na2CO3 + H2O + CO2
Products

Law of Conservation of Mass:

Matter can not be created or destroyed in any physical or chemical reaction

Making sure that the equation of a reaction obeys this rule is called the balancing the chemical equation.

$$FeCl_3 + 3\ KOH \rightarrow Fe(OH)_3 + 3\ KCl$$



Physical state

Besides the compounds involved we often write the physical state in the formula

Symbol	state
(s)	solid
(l)	liquid
(g)	gas
(aq)	dissolved in water

For example

Solid potassium reacts with water (liquid) to form hydrogen gas and an aqueous solution of potassium hydroxide.

This reaction is written as

K **(s)** + H_2O **(l)** → H_2 **(g)** + KOH (aq)

This is an unbalanced reaction.

It can be balanced as

$2K$ **(s)** + $2\ H_2O$ **(l)** → H_2 **(g)** +2 KOH (aq)

Writing chemical reactions and recognizing reactants and products

Write the *unbalanced* chemical reaction

Solid sodium metal reacts with liquid water to form solid magnesium hydroxide and hydrogen gas.

$Mg\ (s) + H_2O\ (l) \rightarrow Mg(OH)_2\ (s) + H_2\ (g)$

(The reaction is not balanced)

Write the *unbalanced* chemical reaction

Solid ammonium dichromate decomposes to solid chromium (III) oxide , gaseous nitrogen and gaseous water.

$(NH_4)_2\ Kr_2O_7(s) \rightarrow Cr_2O_3\,(s)+N_2(g)+\ H_2O(g)$

(The reaction is not balanced.)

Balancing Chemical Reactions

There are certain things that we should keep in mind while balancing a chemical reaction.

1. Atoms are conserved in a chemical reaction.

2. The formulas of the compounds must never be changed while balancing a chemical reaction - i.e. the subscripts can never be changed nor atoms can be added or subtracted in a chemical formula.

3. Chemical reactions are balanced with the smallest integers (whole numbers). These integers are called coefficients for the balanced reactions

Chemical reactions are balanced by trial and error.

Balance the following reactions

- $Li_2O\ (s) + H_2O\ (l) \rightarrow LiOH\ (aq)$
- $CH_4\ (g) + H_2O\ (g) \rightarrow CO\ (g) + H_2\ (g)$
- $FeS\ (s) + HCl\ (aq) \rightarrow FeCl_2(aq) + H_2S\ (g)$
- $C_2H_5OH\ (l) + O_2\ (g) \rightarrow CO_2(g) + H_2O\ (g)$

The Mole

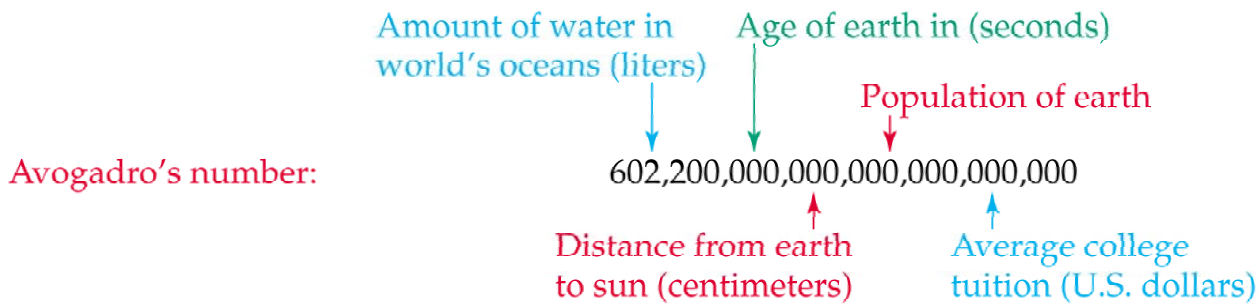
- When two things have different sizes you can't get equal numbers by taking equal weights. For example since one grape weighs less than one cabbage, one pound of each will have different numbers.

- The same is true for atoms or molecules of different substances.

  Equal numbers hydrogen and glucose molecules always have a mass ratio equal to the ratio of their molecular weights, 2:180.

- The concept of moles accounts for the number of atoms in a sample.
- One gram molecular mass of any substance is known as one mole.
- One mole of any element contains 6.02×10^{23} atoms of that substance.

- This number was first determined by an Italian scientist by the name Avogadro and therefore it is known as the Avogadro’s number.


Amount of water in world's oceans (liters)
Age of earth in (seconds)
Population of earth
Avogadro's number:
602,200,000,000,000,000,000,000
Distance from earth to sun (centimeters)
Average college tuition (U.S. dollars)

Mass to moles

Calculate the number of moles in a 27 g sample of Copper.

To do a calculation like this we need to remember the concept of Dimensional analysis.

Copper has an atomic mass of 58.9332 amu.

Therefore one mole of copper is 58.9332 g.

$$1\text{mol} = 58.9332\ \text{g}$$

$$\frac{1\ \text{mol}}{58.9332\ \text{g}} = \frac{58.9332}{1\ \text{mol}}$$

$$27\ \text{g} \times \frac{1\ \text{mol}}{58.9322\ \text{g}} = 0.4581\ \text{mol}$$

Molar Mass

So far we talked about atoms

Now we have to look at molecules

The molar mass of any substance is the mass (in grams) of one mol of the substance

Calculate the molar mass of a compound CO_2

1 mol of carbon = 12.01 g

1 mol of oxygen = 15.9994 g x 2 (for the 2 atom spresent)

= 31.9988 g

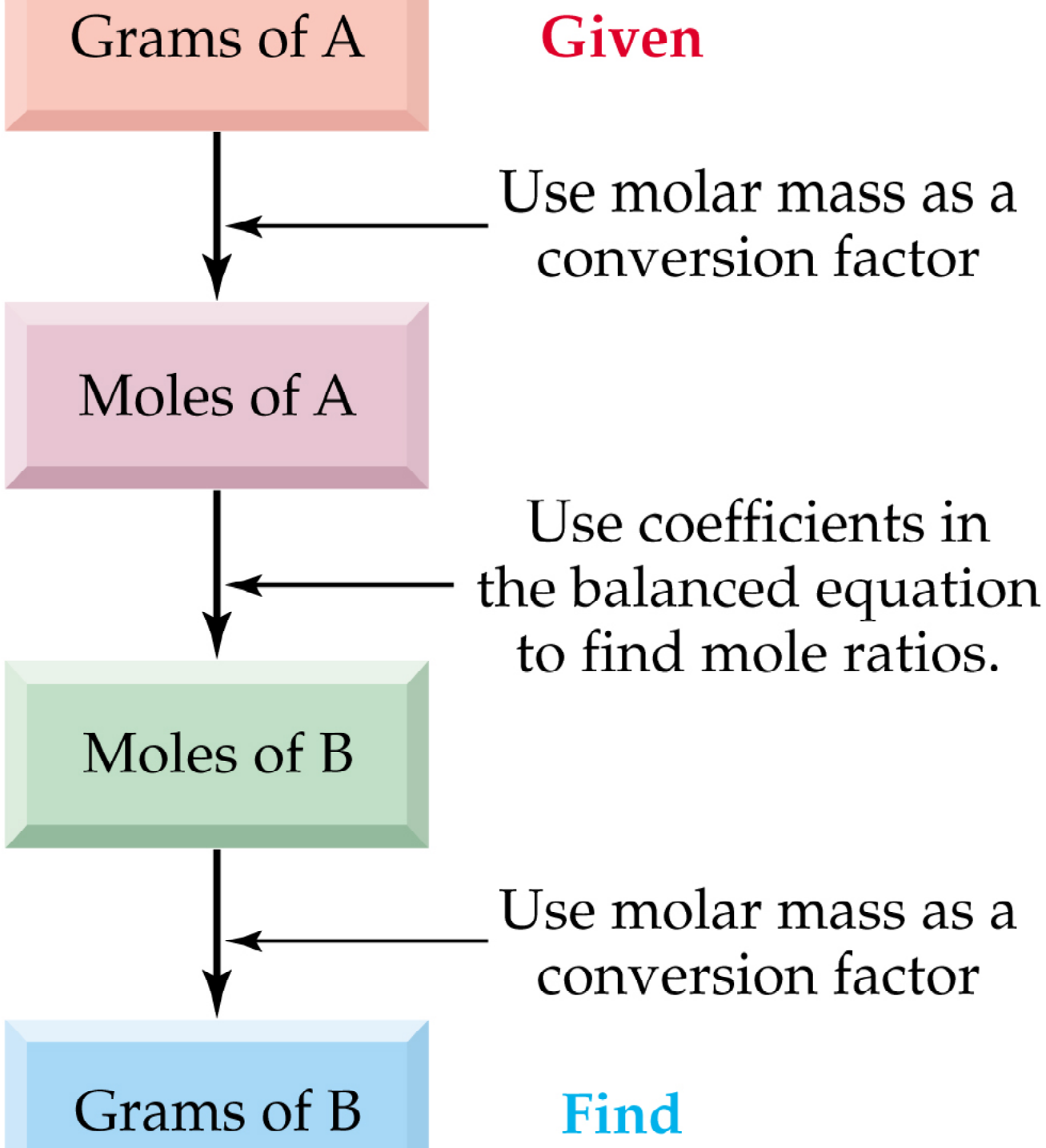
Molar mass of CO_2 = 12.01 g + 15.9988 g

= 44.0088 g

- Calculate the molar mass of $FeCl_3$, NaCl and SO_2

Mass calculation

- In this section we will learn to correlate the mass of the reactant with the mass of the product.
- This will also require the knowledge of converting mass to moles and then back to mass again.


Grams of A
Given
Use molar mass as a conversion factor
Moles of A
Use coefficients in the balanced equation to find mole ratios.
Moles of B
Use molar mass as a conversion factor
Grams of B
Find

Steps to do a Stoichiometry problem

- Write a balanced chemical reaction
- Convert the grams of given material to moles (using dimensional analysis)
- Check the molar ratio between the given and the asked
- Find the moles of asked
- Convert that to grams if needed (using dimensional analysis).

Mass of reactant → moles of reactant → to moles of product → to mass of product.

In the reaction

$2\ Al\ (s) + 3\ I_2(s) \rightarrow 2\ AlI_2(s)$

How many grams of I_2 are needed to react with 35 g of aluminum?

Percent composition of an element in a compound

% composition of an element in a compound

=

$$\frac{\text{atomic mass of the element}}{\text{molecular mass of the compound}} \times 100$$

Find the percent composition of CO_2

Percent Yield

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$

Types of Chemical Reactions

- Precipitation Reactions
- Acid Base Reactions
- Redox Reactions

Precipitation Reactions

- When soluble reactants combine to form a solid precipitate the reaction is called a precipitation reaction.
- Most precipitation reactions happen when a double displacement reaction takes place -that is the cations and anions of two ionic compounds change partners.

- $AB + CD \rightarrow AD + CB$

$2AgNO_3(aq) + Na_2CO_3(aq) \rightarrow Ag_2CO_3(s) + 2NaNO_3(aq)$

Precipitation Guidelines

- To know if the precipitation reaction will occur, we must first know the solubility of the products formed.
- If the solubility of the product is low then the product is likely to precipitate.
- If the product has a high solubility then the product is not likely to form a precipitate.

	acetate	bromide	carbonate	chloride	chromate	hydroxide	iodide	nitrate	phosphate	sulfate	sulfide
Aluminum	ss	s	n	s	n	i	s	s	i	s	d
Ammonium	s	s	s	s	s	s	s	s	s	s	s
Barium	s	s	i	s	i	s	s	s	i	i	d
Calcium	s	s	i	s	s	ss	s	s	i	ss	d
Copper II	s	s	i	s	i	i	n	s	i	s	i
Iron II	s	s	i	s	n	i	s	s	i	s	i
Iron III	s	s	n	s	i	i	n	s	i	ss	d
Lead	s	ss	i	ss	i	i	ss	s	i	i	i
Magnesium	s	s	i	s	s	i	s	s	i	s	d
Mercury I	ss	i	i	i	ss	n	i	s	i	ss	i
Mercury II	s	ss	i	s	ss	i	i	s	i	d	i
Potassium	s	s	s	s	s	s	s	s	s	s	s
Silver	ss	i	i	i	ss	n	i	s	i	ss	i
Sodium	s	s	s	s	s	s	s	s	s	s	s
Zinc	s	s	i	s	s	i	s	s	i	s	i

i = insoluble, ss = slightly soluble, s = soluble, d = decomposes, n = not isolated

Acid Base Neutralization Reaction

When an acid reacts with a base to produce water and an ionic compound – a salt.

Recall the previous definition that an acid is a substance that produces H^+ ion and the base is a substance that produces

OH^- ion.

Thus a neutralization reaction removes H^+ and OH^- ions from a solution and produces water.

$$HA\ (aq) + MOH\ (aq) \rightarrow H2O(l) + MA\ (aq)$$

Acid Base Water A salt

$$HCl(aq) + KOH(aq) \rightarrow H_2O(l) + KCl(aq)$$

$$HCl(aq) + NaOH(aq) \rightarrow H2O(l) + NaCl(aq)$$

Another kind of neutralization reaction:

- When an acid and a carbonate or bicarbonate ion react to yield -water, a salt and carbon dioxide.

$$2HCl(aq) + K_2CO_3(aq) \rightarrow H_2O(l) + 2KCl(aq) + CO_2$$

This reaction occurs because the carbonate ion reacts with H^+ to yield H_2CO_3 which is unstable and decomposes to yield CO_2 and H_2O.

$$2HCl(aq) + K_2CO_3(aq) \longrightarrow 2KCl(aq) + [H_2CO_3] \downarrow H_2O(l) + CO_2$$

Net Ionic Equations

An ionic equation an equation in which the ions are explicitly shown.

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

An ionic compound breaks down into its ions in aqueous solutions.

Only the soluble ionic compounds are represented by their ions.

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

Spectator ions are the ions that appear unchanged in both sides of the reaction.

$Pb^{2+}(aq) + 2NO_3^-(aq) + 2K^+(aq) + 2I^-(aq)$

$\rightarrow 2K^+(aq) + 2NO_3^-(aq) + PbI_2(s)$

The colored ions are spectator ions.

Net ionic equation:

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

Redox reactions

- Re – dox
- Reduction – Oxidation reactions.

Historic definition

Oxidation : combination of an element with oxygen to form an oxide

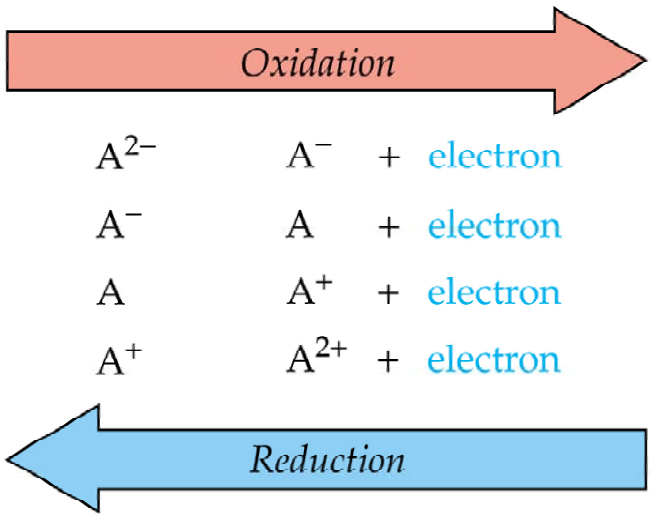
Reduction : removal of oxygen from an oxide to regain the element.

Today

Oxidation : Loss of one or more electrons by an atom

Reduction: Gain of one or more electrons by an atom

Therefore oxidation reduction reactions are the reactions in which the electrons are transferred from one atom to another.



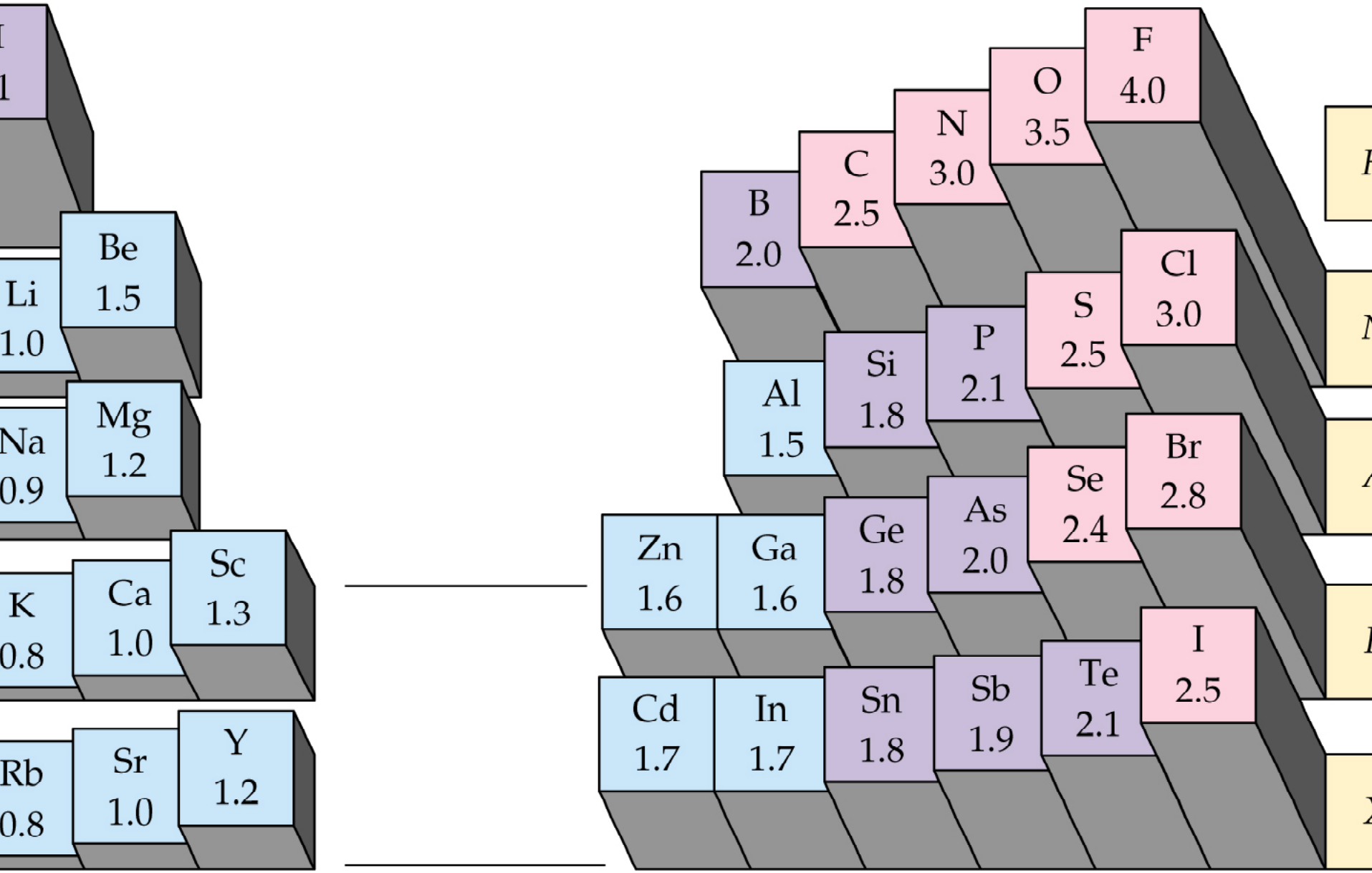
Reactant A might be Anything:
a neutral atom,
a monatomic ion,
a polyatomic ion,
or a molecule.

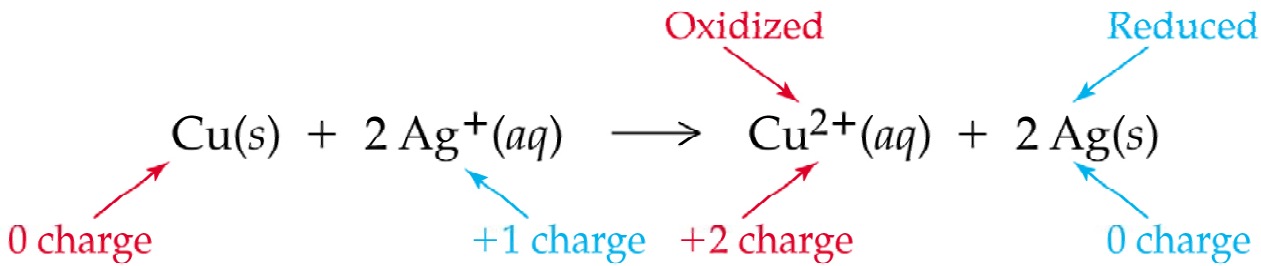
Recognizing Redox Reactions

- The redox reactions are easy to recognize in an ionic reaction
- When molecular substances react we have to look at the change in their ***oxidation number*** .

- An atom in its neutral state has an oxidation number of zero.
- A monoatomic ion has an oxidation number equal to its charge.
- In a molecular compound the atom usually has the same oxidation number it would have it were a monoatomic ion.
- The sum of oxidation numbers in a neutral compound is zero.

- Find the oxidation numbers of the most electropositive element:
- Fe_2O_3
- H_2O
- HNO_3
- $Cu(NO_3)_2$


Be
1.5
Li
1.0
Mg
1.2
Na
0.9
Sc
1.3
Ca
1.0
K
0.8
Y
1.2
Sr
1.0
Rb
0.8
B
2.0
C
2.5
N
3.0
O
3.5
F
4.0
Cl
3.0
S
2.5
P
2.1
Si
1.8
Al
1.5
Br
2.8
Se
2.4
As
2.0
Ge
1.8
Ga
1.6
Zn
1.6
I
2.5
Te
2.1
Sb
1.9
Sn
1.8
In
1.7
Cd
1.7


Oxidized
Reduced
Cu(s) + 2 Ag+(aq) ⟶ Cu2+(aq) + 2 Ag(s)
0 charge
+1 charge
+2 charge
0 charge

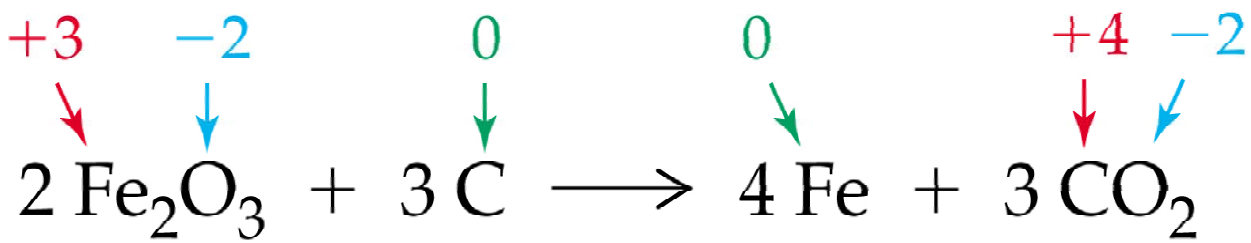
Corrosion involves redox reaction:

$$4\,Fe(s) + 3O2(g) \xrightarrow{H_2O} 2Fe2O3.H2O\,(s)$$

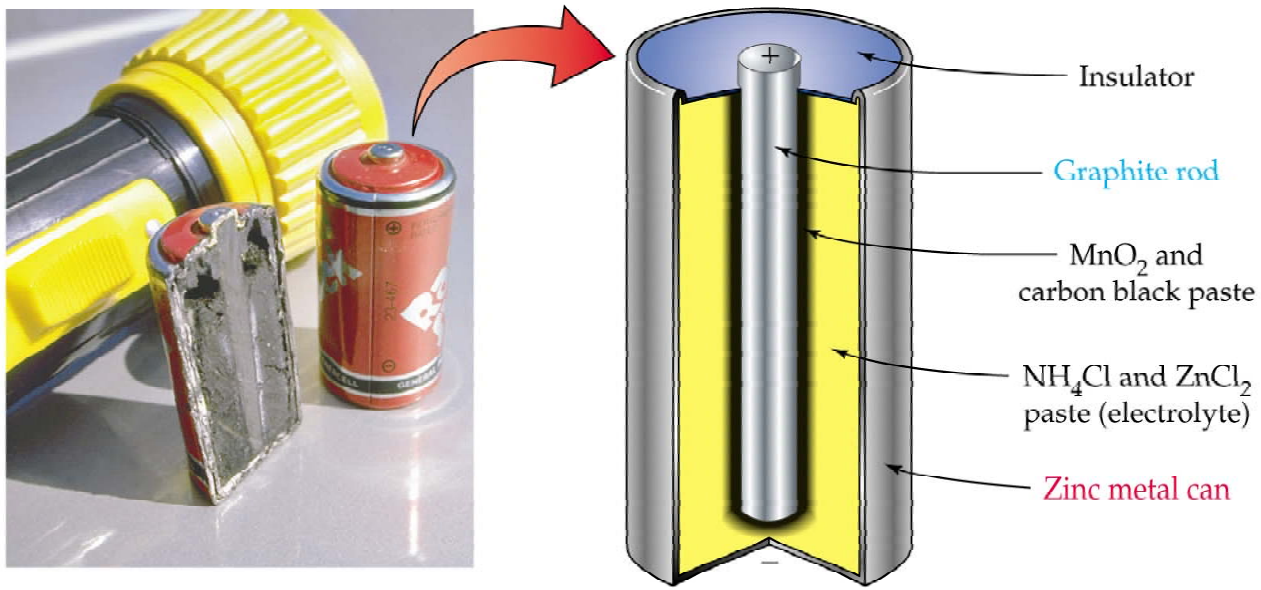
Combustion is also a redox reaction

$$CH_4(g) + 2O_2 \rightarrow CO_2(g) + H_2O\,(l)$$

Iron is extracted from iron ore by reducing it with carbon



Batteries are powered by spontaneous chemical redox



Reaction in a dry cell battery

$Zn\ (s) + 2\ MnO_2\ (s) + 2\ NH_4Cl\ (s) \rightarrow$

$ZnCl_2(aq) + Mn_2O_3(s) + 2NH_3\ (aq) + H_2O$

Alkaline Battery:

$$Zn\ (s) + 2MnO_2(s) \rightarrow ZnO\ (aq) + Mn_2O_3(s)$$

Lithium-iodine Battery:

$$2Li(s) + I_2\ (s) \rightarrow 2LiI\ (aq)$$