Unit 1 - Foundations of Chemistry

Chapter 2 - Chemical Reactions

2.1 - Chemical Equations

Physical and Chemical Changes

Physical change: A substance changes its physical appearance, but not its composition. **Example:** All changes of state.

Chemical change: A substance is transformed into a chemically different substance. **Example:** The burning of hydrogen in air.

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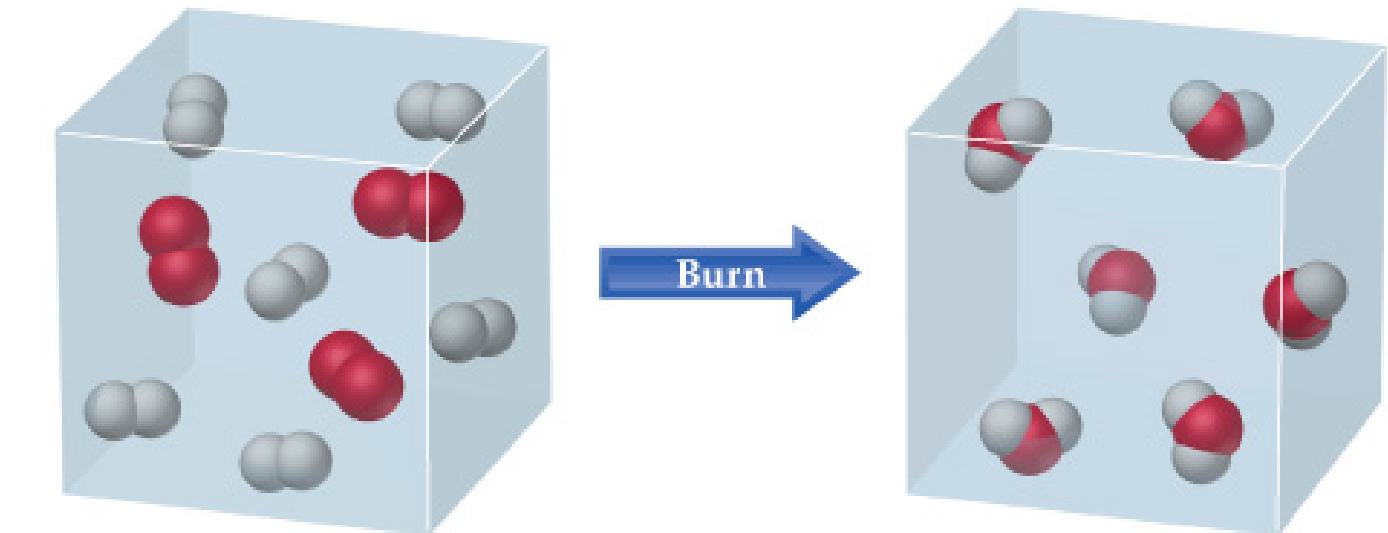

Indicators of a Chemical Reaction

Chemical change:

- Heat and/or light is given off
- A new colour appears
- A gas is produced
- A solid precipitate (ppt) is formed

Watch: Nitric acid + copper

Watch: Lead nitrate + potassium iodide

Form of a Chemical Reaction

How can we describe a wide range of reactions?

Chemical Equations:

$$\text{Reactants} \longrightarrow \text{Products}$$

We further separate both the reactants and the products by a plus sign:

$$\text{Reactant 1} + \text{Reactant 2} \longrightarrow \text{Product 1} + \text{Product 2}$$

Examples of word equations:

- iron + oxygen $\longrightarrow$ iron(III) oxide
- copper + silver nitrate $\longrightarrow$ silver + copper(II) nitrate

Examples of skeleton equations:

- $Zn + HCl \longrightarrow H_2 + ZnCl_2$
- $H_2 + O_2 \xrightarrow{\text{heat}} H_2O$ **or** $H_2 + O_2 \xrightarrow{\triangle} H_2O$

Examples: Write skeleton equations for the following reactions:

1. $AgNO_3$ and NaCl react to form AgCl and $NaNO_3$

2. potassium sulphate reacts with barium nitrate to form potassium nitrate and barium sulphate

Indicating the States of Reactants and Products

The **physical state** of each reactant and product is often added to the formulas in balanced equations. We use the symbols *(g)*, *(l)*, *(s)*, and *(aq)* for gas, liquid, solid, and aqueous (water) solution.

Examples:

- $\mathrm{Fe_{(s)} + O_{2(g)} \longrightarrow Fe_2O_{3(s)}}$
- $\mathrm{Zn_{(s)} + 2\,HCl_{(aq)} \longrightarrow H_{2(g)} + ZnCl_{2(aq)}}$
- $\mathrm{CH_{4(g)} + 2\,O_{2(g)} \longrightarrow CO_{2(g)} + 2\,H_2O_{(g)}}$

The Law of Conservation of Mass

In a chemical reaction, the total mass of the reactants is always equal to the total mass of the products.

What does this imply?

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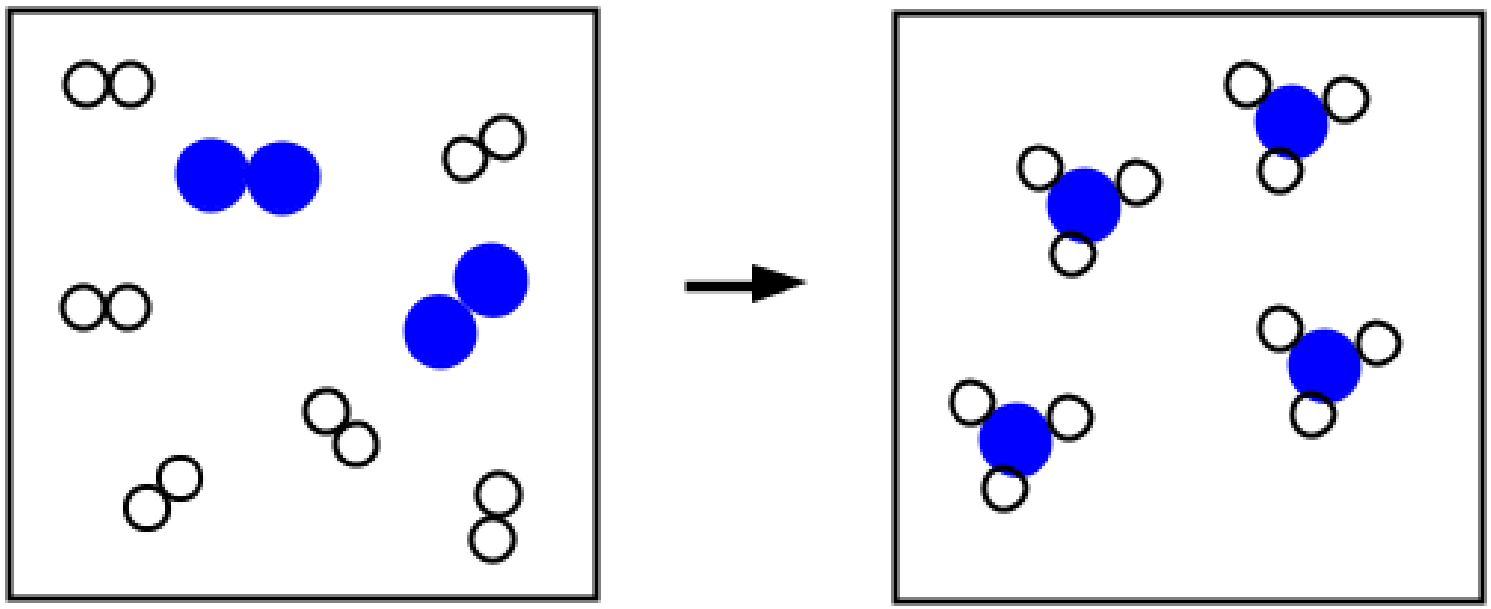

In chemical reactions, the atoms of the reactants are simply *rearranged* to form the products.

2.2 - Balancing Chemical Equations

What's incorrect with the chemical equation below?

$$Fe + Cl_2 \longrightarrow FeCl_3$$

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Problem! - The Law of Conservation of Mass states that the mass of the reactants equals the mass of the products.

We *cannot* change the subscripts of the formulas to fix this imbalance, as this completely changes the compounds. Instead, we must **change the numbers of molecules** rather than their formulas.

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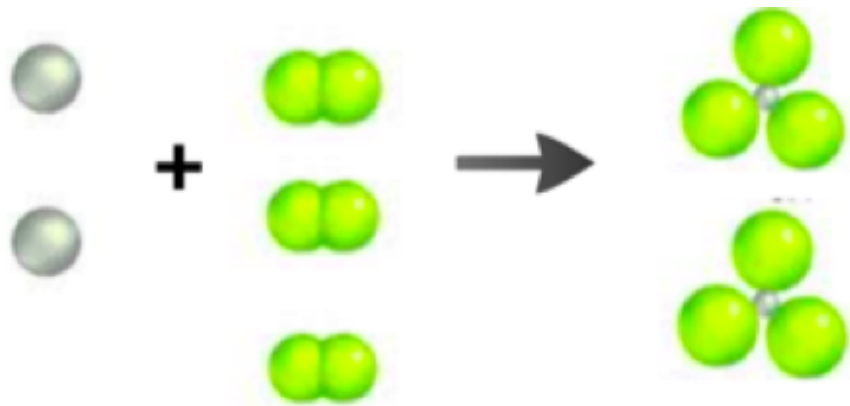
$$\mathrm{Fe} + \mathrm{Fe} + \mathrm{Cl_2} + \mathrm{Cl_2} + \mathrm{Cl_2} \longrightarrow \mathrm{FeCl_3} + \mathrm{FeCl_3}$$



$$\boxed{2\mathrm{Fe} + 3\mathrm{Cl_2} \longrightarrow 2\mathrm{FeCl_3}}$$

Steps to balancing chemical equations:

1. Balance metal elements
2. Balance non-metal elements *excluding* hydrogen and oxygen
3. Balance hydrogen
4. Balance oxygen
5. Reduce coefficients if possible

Tip! - If any *polyatomics* are present balance them as one unit. This only only work if it occurs on both sides of the equation.

Balance the following equations:

1. $\_\_\_\_\_ Al + \_\_\_\_\_ Br_2 \longrightarrow \_\_\_\_\_ AlBr_3$
2. $\_\_\_\_\_ N_2 + \_\_\_\_\_ H_2 \longrightarrow \_\_\_\_\_ NH_3$
3. $\_\_\_\_\_ N_2H_4 + \_\_\_\_\_ O_2 \longrightarrow \_\_\_\_\_ H_2O + \_\_\_\_\_ N_2$
4. $\_\_\_\_\_ Na + \_\_\_\_\_ H_2O \longrightarrow \_\_\_\_\_ NaOH + \_\_\_\_\_ H_2$
5. $\_\_\_\_\_ Ca + \_\_\_\_\_ HNO_3 \longrightarrow \_\_\_\_\_ H_2 + \_\_\_\_\_ Ca(NO_3)_2$
6. $\_\_\_ Fe(NO_3)_3 + \_\_\_(NH_4)_2CO_3 \longrightarrow \_\_\_Fe_2(CO_3)_3 + \_\_\_NH_4NO_3$

2.3 - Types of Chemical Reactions

We shall investigate **five** types of chemical reactions:

1. Combustion
2. Synthesis
3. Decomposition
4. Single Displacement
5. Double Displacement

Combustions Reactions

A **combustion** reaction is a reaction of the form:

$$\text{hydrocarbon} + \text{oxygen} + \xrightarrow{\triangle} \text{carbon dioxide} + \text{water}$$

$$C_nH_{2n+2} + O_2 \longrightarrow CO_2 + H_2O$$

For example:

$$2\,C_4H_{10} + 13\,O_2 \longrightarrow 8\,CO_2 + 10\,H_2O$$

Demonstration: $2\,CH_3OH + 3\,O_2 \xrightarrow{\triangle} 2\,CO_2 + 4\,H_2O$

Balancing Combustion Reactions

For combustion reactions, we usually balance in this order:

1. Balance carbons
2. Balance hydrogens
3. Balance oxygens

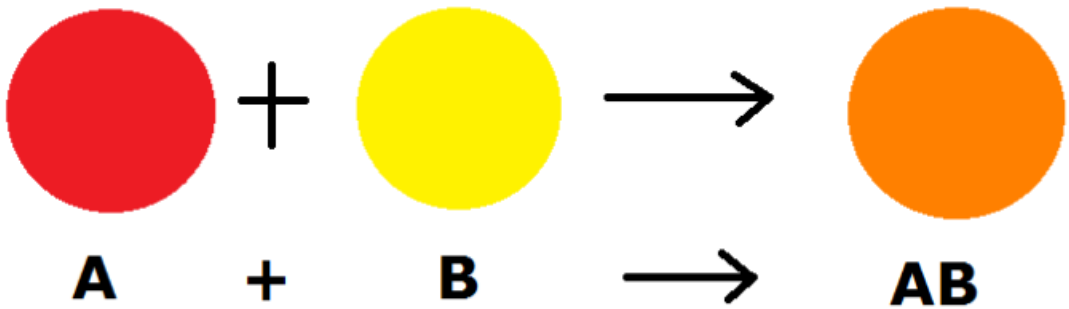
Examples:

1. $CH_4 + O_2 \longrightarrow CO_2 + H_2O$
2. $C_2H_5OH + O_2 \longrightarrow CO_2 + H_2O$
3. $C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$

Synthesis (Combination) Reactions

Synthesis reactions involve the combination of smaller atoms and/or molecules into larger molecules.

Simple synthesis reactions have the following general formula:



Simple (elements): $A + B \longrightarrow AB$

Some **complex** synthesis reactions have the following general formulas:

- Metal oxide + water $\longrightarrow$ Metal hydroxide (a base)

  Ex: $K_2O + H_2O \longrightarrow 2\,KOH$

  $CaO + H_2O \longrightarrow Ca(OH)_2$

- Non-metal oxide + water $\longrightarrow$ Non-metal hydride (an acid)

  Steps:

  1) Add one oxygen to the non-metal oxide
  2) This creates a new polyatomic ion. Reference its charge and place the appropriate amount of hydrogens out front to balance the charges.

  Ex: $CO_2 + H_2O \longrightarrow H_2CO_3$

Complete and balance the following:

Examples:

1. $Na + Cl_2 \longrightarrow$
2. $K + Cl_2 \longrightarrow$
3. $Li_2O + H_2O \longrightarrow$
4. $SO_3 + H_2O \longrightarrow$

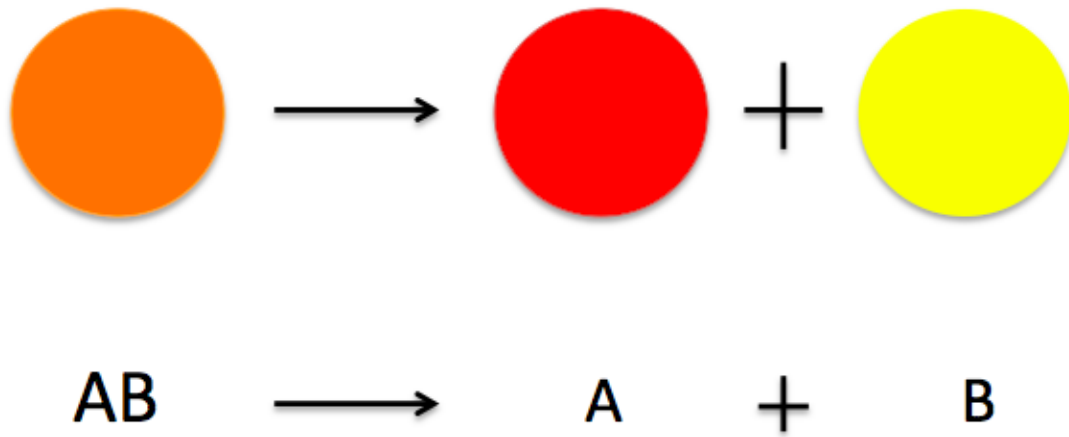
Practice:

1. $Li + Br_2 \longrightarrow$
2. $Mg + N_2 \longrightarrow$
3. $SO_2 + H_2O \longrightarrow$
4. $BaO + H_2O \longrightarrow$

Decomposition Reactions

Decomposition reactions involve the splitting of a large molecule into elements or smaller molecules.

Simple decomposition reactions have the following general formula:



Simple (elements): $AB \longrightarrow A + B$

Some **complex** decomposition reactions have the following general formulas:

- Metallic carbonates: $MCO_3 \longrightarrow MO + CO_2$
- Metallic sulfates: $MSO_4 \longrightarrow MO + SO_3$
- Metallic hydroxides: $MOH \longrightarrow MO + H_2O$
- Metallic chlorates: $MClO_3 \longrightarrow MCl + O_2$

Demonstration: $2\,H_2O_2 \longrightarrow 2\,H_2O + O_2$

Complete and balance the following:

Examples:

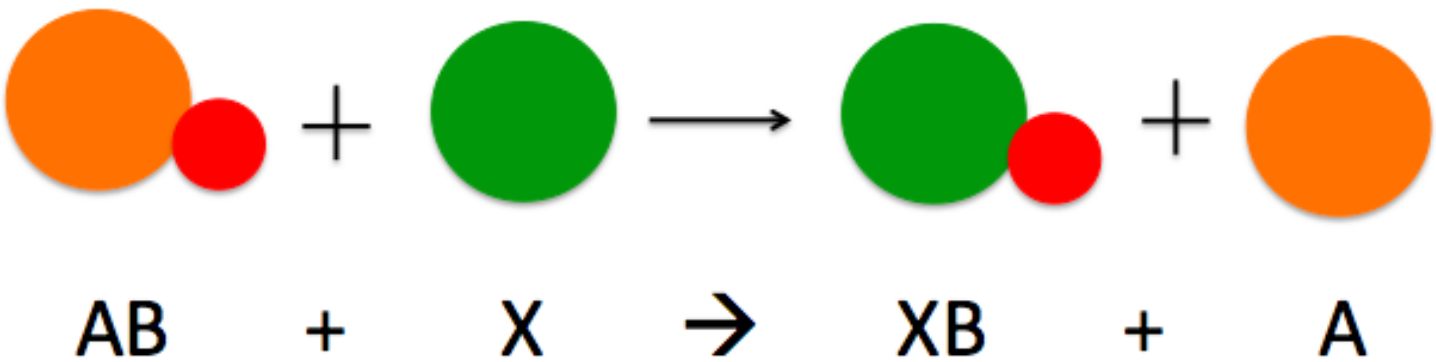
1. $HgO \longrightarrow$
2. $Ca(OH)_2 \longrightarrow$
3. $CaCO_3 \longrightarrow$
4. $ZnSO_4 \longrightarrow$
5. $KClO_3 \longrightarrow$

Practice:

1. $AgCl \longrightarrow$
2. $MgCO_3 \longrightarrow$
3. $Mg(OH)_2 \longrightarrow$
4. $Sr(ClO_3)_2 \longrightarrow$
5. $FeSO_4 \longrightarrow$

Single Displacement Reactions

Single displacement reactions are chemical changes where one element displaces or replaces another element from a compound. They have the following general formula:



Note: Cations replace cations and anions replace anions!

Demonstration: $CuCl_2 + Al \longrightarrow$

Examples: Complete and balance the following:

1. $Zn_{(s)} + NiCl_{2(aq)} \longrightarrow$

2. $Cu_{(s)} + AgNO_{3(aq)} \longrightarrow$

3. $Na_{(s)} + H_2O_{(l)} \longrightarrow$

Practice: Complete and balance the following:

1. $Zn_{(s)} + CuCl_{2(aq)} \longrightarrow$

2. $AuN_{(aq)} + Ca_{(s)} \longrightarrow$

3. $Ca_{(s)} + H_2O_{(l)} \longrightarrow$

Double Displacement Reactions

Double displacement reactions occur when elements in different compounds displace each other or exchange places. They have the following general formula:

Note: Cations are always written first!

Demonstration: $CuCl_2 + Na_3PO_4 \longrightarrow$

Examples: Complete and balance the following:

1. $CaCl_{2(aq)} + Na_2SO_{4(aq)} \longrightarrow$

2. $AgNO_{3(aq)} + NaI_{(aq)} \longrightarrow$

Practice - Complete and balance the following:

1. $MgSO_{4(aq)} + NaOH_{(aq)} \longrightarrow$

2. $(NH_4)_2SO_{4(aq)} + KOH_{(aq)} \longrightarrow$

Question 1

1. **Classify** each of the following reactions as a combustion, synthesis, decomposition, single or double displacement reaction.
2. **Balance** the chemical equation.

1) $\_\_\_\_\_ Mg + \_\_\_\_\_ S_8 \longrightarrow \_\_\_\_\_ MgS$

2) $\_\_\_\_\_ NaN_3 \longrightarrow \_\_\_\_\_ Na + \_\_\_\_\_ N_2$

3) $\_\_\_\_\_ AgNO_3 + \_\_\_\_\_ Ni \longrightarrow \_\_\_\_\_ Ni(NO_3)_2 + \_\_\_\_\_ Ag$

4) $\_\_\_\_\_ C_2H_6 + \_\_\_\_\_ O_2 \longrightarrow \_\_\_\_\_ CO_2 + \_\_\_\_\_ H_2O$

5) $\_\_\_\_\_ AgNO_3 + \_\_\_\_\_ NaCl \longrightarrow \_\_\_\_\_ NaNO_3 + \_\_\_\_\_ AgCl$

Question 2

1. **Predict** the products of the following reactions.
2. **Balance** the chemical equation.

1) $\_\_\_\_\_ CaCO_{3(s)} \longrightarrow$

2) $\_\_\_\_\_ C_3H_{8(g)} + \_\_\_\_\_ O_{2(g)} \longrightarrow$

3) $\_\_\_\_\_ Al_{(s)} + \_\_\_\_\_ HCl_{(aq)} \longrightarrow$

4) $\_\_\_\_\_ MgO_{(s)} + \_\_\_\_\_ H_2O_{(l)} \longrightarrow$

5) $\_\_\_\_\_ K_2SO_{4(aq)} + \_\_\_\_\_ Ba(NO_3)_{2(aq)} \longrightarrow$

The Activity Series

Single Displacement reactions don't always occur, even if the general form is present.

Consider the following reactions:

$$NaCl + K \longrightarrow KCl + Na$$

$$KCl + Na \longrightarrow ?$$

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Consider the following reactions:

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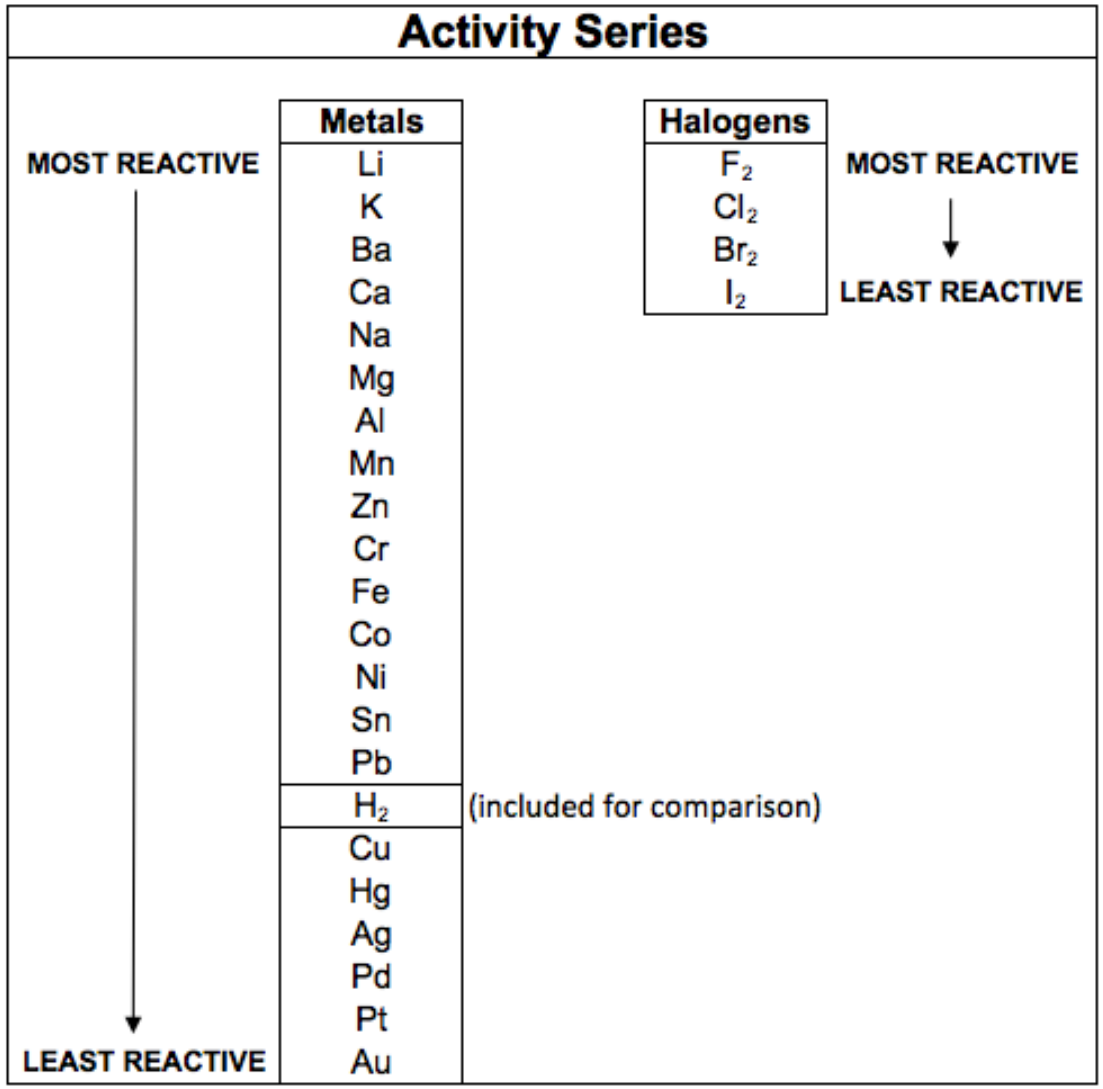
$$KCl + Na \longrightarrow ?$$

The last reaction **does not occur**, because sodium (Na) is **less reactive** than potassium (K).

General Rule: More reactive elements will generally be able to displace elements that are less reactive.



Any element on the table will displace an element *below* it.

Example: In which of the following cases will a reaction not occur? For the reactions that you predict will occur, complete and balance the equation.

1. $\_\_\_\_\_ Al_{(s)} + \_\_\_\_\_ H_2O_{(s)} \longrightarrow$
2. $\_\_\_\_\_ Cu_{(s)} + \_\_\_\_\_ Hg(NO_3)_{2(aq)} \longrightarrow$
3. $\_\_\_\_\_ Br_{2(aq)} + \_\_\_\_\_ MgI_{2(aq)} \longrightarrow$
4. $\_\_\_\_\_ Br_{2(aq)} + \_\_\_\_\_ CaCl_{2(aq)} \longrightarrow$

Ionic Compounds in Water

Example: Solid NaCl consists of Na^+ and Cl^- ions. What happens when NaCl (table salt) is dissolved in water?

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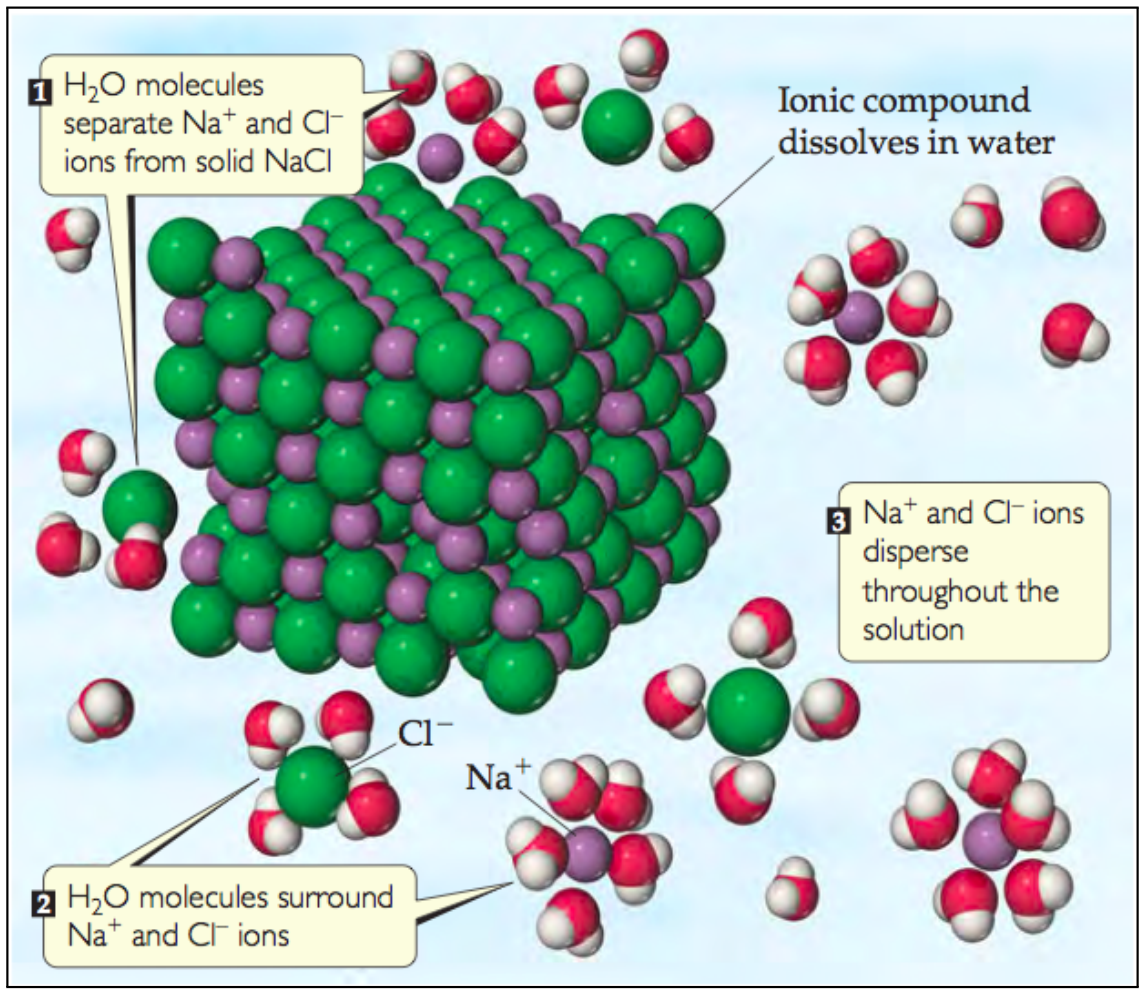

When NaCl dissolves in water, each ion separates from the solid structure and disperses throughout the solution. The ionic solid *dissociates* into its component ions as it dissolves.

Dissociation is the process where ionic compounds dissolve in water and split up into their individual ions.

Examples:

- $NaCl_{(s)} \longrightarrow$
- $Ba(NO_3)_{2(s)} \longrightarrow$
- $Al_2(SO_4)_{3(s)} \longrightarrow$

Solubility

Solubility refers to the ability of a compound to dissolve in a solvent. The compound being dissolved is called the *solute* and the liquid doing the dissolving is called the *solvent* (usually water for ionic compounds).

Insolubility refers to a compound's tendency to remain undissolved in a solvent.

Example:

- Oil + water
- Iced tea + water

Types of Double Displacement Reactions

There are **three** main types of double displacement reactions.

1. Reactions in which precipitates are formed.
2. Reactions that produce water.
3. Reactions that produce a gas.

Note: If a precipitate, water, or gas is NOT produced in a double displacement reaction, **no reaction has occurred**.

We'll only focus on the **first two** types.

1) Precipitation Reactions

A **precipitate** is an insoluble solid formed by a reaction. Reactions that result in the formation of an insoluble product are known as **precipitation reactions**.

Example: $Pb(NO_3)_{2(aq)} + 2\,KI_{(aq)} \longrightarrow PbI_{2(s)} + 2\,KNO_{3(aq)}$

How do we know if a compound will form a precipitate?

Solubility Rules

Anions	Positive Ions that form soluble compounds	Positive Ions that form insoluble compounds
nitrates (NO_3^-) acetates (CH_3COO^-) chlorates (ClO_3^-) perchlorates (ClO_4^-)	all	none
chlorides (Cl-) bromides (Br-) iodides (I-)	most	silver mercury (I) lead (II)
fluorides (F^-)	most	magnesium calcium strontium barium lead (II)
sulfates (SO_4^{2-})	most	barium lead (II) strontium
carbonates (CO_3^{2-}) sulfites (SO_3^{2-}) phosphates (PO_4^{3-}) chromates (CrO_4^{2-})	Group I metals ammonium	most
sulfides (S^{2-}) hydroxides (OH^-)	Group I metals, ammonium, calcium, barium, and strontium	most

Note: All common ionic compounds of the Group 1 metals and of the ammonium ion (NH_4^+) are *soluble* in water.

Note: A double displacement reaction **will not** have occurred if the solubility rules indicate that:

- Both products are precipitates

OR

- Both products are aqueous

Example: Indicate which of the following double displacement reactions will go to completion. Indicate the precipitate of the reaction (if any).

1. $\_\_\_\_\_ Pb(NO_3)_2 + \_\_\_\_\_ HCl \longrightarrow$

2. $\_\_\_\_\_ Mg(NO_3)_{2(aq)} + \_\_\_\_\_ NaOH_{(aq)} \longrightarrow$

3. $\_\_\_\_\_ NaOH_{(aq)} + \_\_\_\_\_ CaBr_{2(aq)} \longrightarrow$

2) Reactions that Produce Water

This a special type of double displacement reaction. It only occurs when the reactants include an **acid** and a **base**. This reaction is also known as a *neutralization* reaction.

$$HA_{(aq)} + BOH_{(aq)} \longrightarrow BA_{(aq)} + H_2O_{(l)}$$

Example:

1) $\_\_\_\_\_HCl_{(aq)} + \_\_\_\_\_Ba(OH)_{2(aq)} \longrightarrow$

Practice: Complete the following double displacement reactions.

1. $\_\_\_\_\_ H_2SO_{4(aq)} + \_\_\_\_\_ LiOH_{(aq)} \longrightarrow$

2. $\_\_\_\_\_ HCl_{(aq)} + \_\_\_\_\_ NaOH_{(aq)} \longrightarrow$

3. $\_\_\_\_\_ H_2SO_{4(aq)} + \_\_\_\_\_ NH_4OH_{(aq)} \longrightarrow$