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Sample Printable: Chemical Reactions

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Learning Objectives

By studying this tutorial you will learn…

- How chemical reactions are written.
- What types of chemical reactions are common.
- How to determine redox reactions.
- How to determine if a product will be a precipitate.
- How to predict products of simple chemical reactions.

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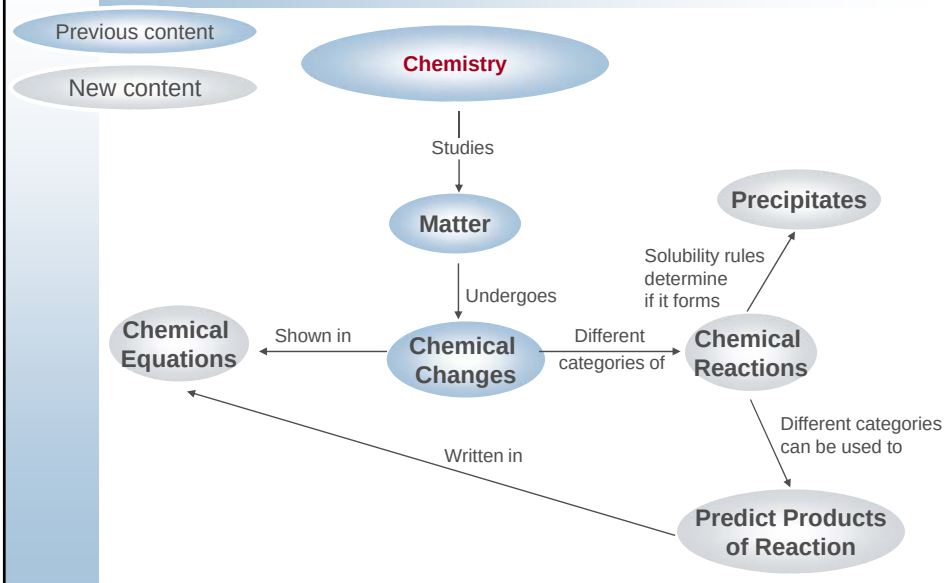
Concept Map



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What is Chemical Reaction?

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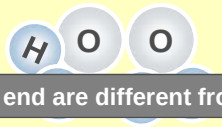
Definition: Chemical Reaction

Chemical Reaction – Bonds and atoms are rearranged to form new compounds.

$2\ H_2 + O_2 \rightarrow 2\ H_2O$



The compounds in the end are different from those in the beginning.

Watch as $2\ H_2$ and $1\ O_2$ undergo a chemical reaction.

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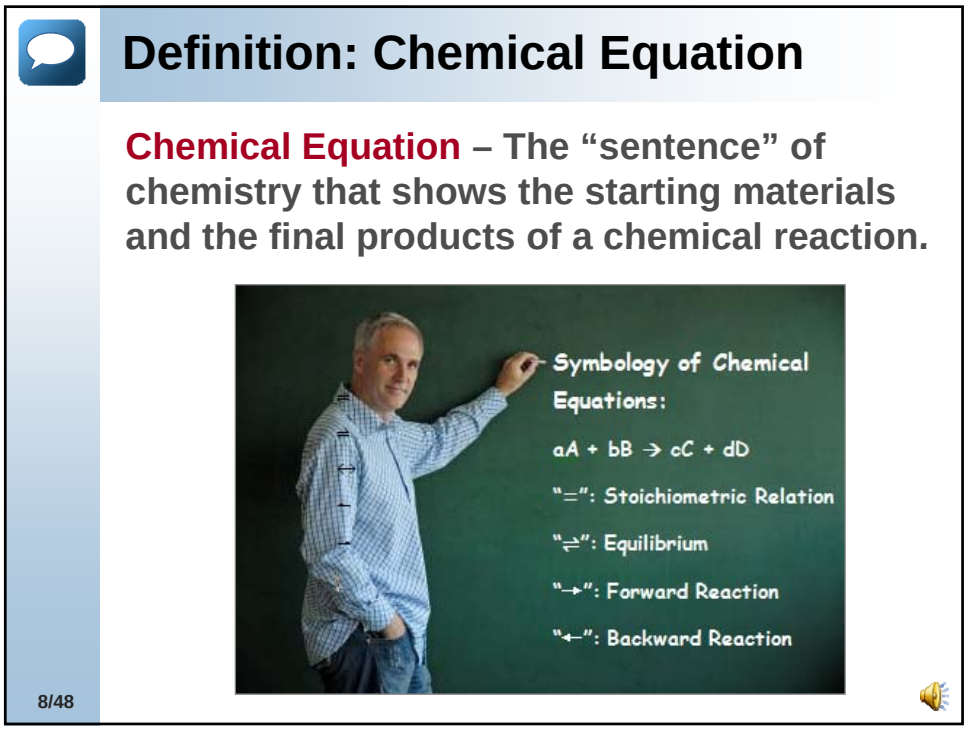

Anatomy of a Chemical Equation

The starting materials for the reaction—each compound is separated by a "+".

Formed in the reaction.

Reactants — **Products**

$$NaCl\ (aq) + AgNO_3\ (aq) \rightarrow AgCl\ (s) + NaNO_3\ (aq)$$

States of Matter

s = solid
l = liquid
g = gas
aq = aqueous (dissolved in water)

Arrow

Read as:
Yields
Produces
Forms
Makes
etc.

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Mole Ratios in Chemical Equations

One of the most important pieces of information in a chemical reaction is the mole ratio or stoichiometric ratio (shown by the coefficients).

For every 2 moles of H_2…

2 moles of H_2O are produced…

2 **2**

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

No Coefficient = 1

1 mole of O_2 is needed to react…

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Equilibrium Reactions

Equilibrium reaction – Some reactions can proceed in both directions. When the rate of the forward reaction (→) equals the rate of the reverse reaction (←) then it is at equilibrium.

$N_2 + 3\ H_2 \leftrightarrows 2\ NH_3$

Double Arrow
Indicates a reaction can proceed in both directions.

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Types of Reactions

Six main types of reactions:

1. Composition or Synthesis Reactions
2. Decomposition Reactions
3. Single Displacement Reactions
4. Double Displacement Reactions
5. Neutralization (Acid-Base) Reactions
6. Redox Reactions (Combustion)

Six Reaction Types Mnemonic: Redox, Decomposition, Double Displacement, Neutralization, Composition, Single Replacement = "RiDDaNCeS"

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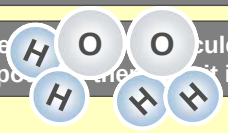
Composition Reactions

Type 1: Composition Reactions
– More than one compounds combine to form one compound (also called a synthesis reaction).
General Form: A + B → AB

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Even though there are [illegible]cules in the end, there is still only one type of compo[illegible] it is a composition reaction.



Watch as two types of compounds combine to form one compound.

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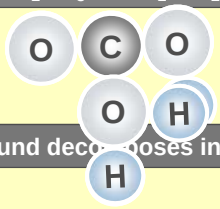
Decomposition Reactions

Type 2: Decomposition Reactions
– A compound decomposes to form more than one compounds.
General Form: AB → A + B

$H_2CO_3 \rightarrow CO_2 + H_2O$



Watch as one compound deco[illegible]oses into more than one compound.

As H_2CO_3 is heated, it decomposes.

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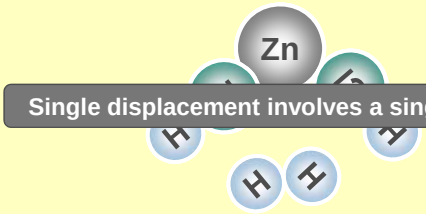
Single Displacement Reactions

Type 3: Single Displacement Reactions - A single element replaces an ion in a compound.

General Form: A + BC → AC + B

$2\ HCl + Zn \rightarrow ZnCl_2 + H_2$



Single displacement involves a single element replacing an ion.

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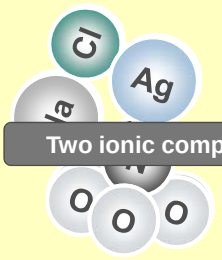
Double Displacement Reactions

Type 4: Double Displacement Reactions – The cations from two compounds replace each other.

General Form: AB + CD → AD + CB

$NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$



Two ionic compounds switch ions.

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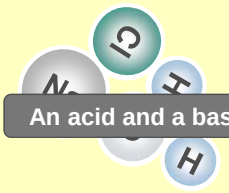
Neutralization Reactions

Type 5: Neutralization Reactions
– A double displacement reaction between an acid and a base. Also called Acid-Base Reactions.

General Form: HA + BOH → AB + H_2O

HCl + NaOH → NaCl + HOH
Acid + base → salt + water



An acid and a base undergo double displacement.

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Gas Forming Reactions

Many reactions form gases. This becomes important when discussing equilibrium as the production of gases can "drive" a reaction to one side or another.

Examples:

$2\ HCH_3COO\ (aq) + CaCO_3\ (aq) \rightarrow Ca(CH_3COO)_2\ (aq) + H_2CO_3$

$H_2CO_3\ (aq) \rightarrow H_2O\ (l) + CO_2\ (g)$ **H_2CO_3 is unstable at room temperatures.**

The gas escapes into the environment and drives the reaction to create more products.

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Other Reactions

Not all reactions fit one of these types, some are "**uncategorized**" or they may be a combination of other reactions. The Type 6 reactions are Redox (next to discuss).

Example:

$NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$

Is a combination of:

$NaHCO_3 + HCl \rightarrow H_2CO_3 + NaCl$ (a double displacement)

and

$H_2CO_3 \rightarrow CO_2 + H_2O$ (a decomposition)

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Redox Reactions

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Definition: Redox

Type 6 – Redox (i.e. Combustion Reaction).
Redox – Abbreviation for Reduction-Oxidation Reaction (a change in oxidation state).

i.e. Combustion: $C_{10}H_8 + 12O_2 \rightarrow 10CO_2 + 4H_2O$

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Reduction Versus Oxidation

Reduction Reaction – Gain of electrons, e^-. (Charge is "reduced" by adding negative electrons).

Examples:

$Cu^{2+} + 2\ e^- \rightarrow Cu$

$F_2 + 2\ e^- \rightarrow 2\ F^-$

Oxidation Reaction – Loss of electrons, e^-.

Examples:

$Cu \rightarrow Cu^{2+} + 2\ e^-$

$2\ F^- \rightarrow F_2 + 2\ e^-$

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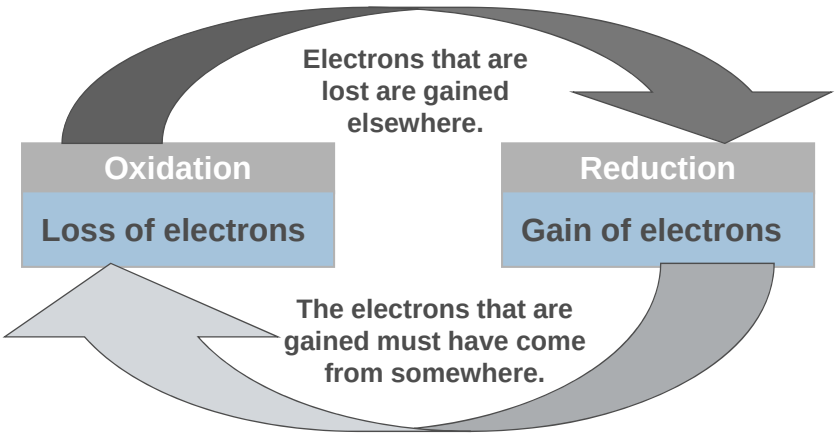
Reduction and Oxidation

Reduction and oxidation must always occur together:



Redox Mnemonic: *Oil Rig* = Oxidation is loss (of electrons) and Reduction is gain (of electron).

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Definition: Oxidation Number

Determined by the ratio of protons to electrons.

Oxidation Number – **Charge** that would occur on an atom if shared electrons were assigned to the most **electronegative atom**.

The atom that has the greatest pull for electrons being shared in a covalent bond.

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Assigning Oxidation Numbers

A set of rules for assigning oxidation numbers:

1. The sum of the oxidation numbers equals 0 for a compound or element, or the charge of the polyatomic ion.
2. Hydrogen is +1 when bonded to non-metals and –1 when bonded to metals.
3. Oxygen is usually -2.
4. All halogens (Group 7 or VII) are usually -1.
5. The oxidation number of an ion in an ionic compound is equal to the charge of the ion.

Example:

H_2SO_4

Rule 2: H = +1

Rule 3: O = -2

Rule 1: 2×H + 1×S + 4×O = 0

2×1 + 1×S + 4×-2 = 0

Therefore S = +6

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Identifying Redox Reactions - 1

All single displacement reactions are redox.

$HCl + Mg \rightarrow MgCl_2 + H_2$

HCl	Mg	$MgCl_2$	H_2
H = +1 When with non-metals	**Mg = 0** Single element	**Cl = -1** Cl is a halogen.	**H = 0** Single element

Cl = -1
Cl is a halogen.

Mg = +2
2 × -1 = -2
-2 + Mg = 0

H: +1 → 0 → Oxidation number is reduced. → H is reduced.

Mg: 0 → +2 → Oxidation number is increased. → Mg is oxidized.

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Identifying Redox Reactions - 2

But not all redox reactions are single displacement.

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

CH_4	O_2	CO_2	H_2O
H = +1 When with non-metals	O = 0 Single element	O = -2	H = +1 When with non-metals
C = -4		C = +4	O = -2
4 × +1 = +4		2 × -2 = -4	
+4 + C = 0		-4 + C = 0	

C: -4 → +4 → Oxidation number is increased. → C is oxidized.

O: 0 → -2 → Oxidation number is reduced. → O is reduced.

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Half-Reactions

Redox reactions can be split in half - into a reduction reaction and an oxidation reaction.

$HCl + Mg \rightarrow MgCl_2 + H_2$

$H^+ \rightarrow H_2$ — Oxidation Reaction

$Cl^- + Mg \rightarrow MgCl_2$ — Reduction Reaction

Although this method isn't always necessary to balance redox reactions, it is needed in more complex problems.

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Precipitation Reactions & Solubility Rules

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Definition: Precipitation Reaction

Precipitation Reaction – One type of double displacement reaction: Two soluble compounds react to form an insoluble compound (the **precipitate**) in an aqueous solution.

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Solubility Rules

Look up the anion in the left column to see which cations it forms insoluble compounds with:

	Forms insoluble compounds with (*N'*=NH_4^+, *G1A*=Group 1A)
NO_3^-	No common cations
CH_3COO^-	Ag^+ (moderately soluble)
Cl^-, Br^-, I^-	Hg_2^{2+}, Ag^+, Pb^{2+} (*HAP for Halogens*)
SO_4^{2-}	Ag^+, Pb^{2+}, Ba^{2+}, Sr^{2+}, Ca^{2+} (*CAPBS for Sulfates*)
CrO_4^{2-}	All cations except NH_4^+, 1A elements (C - *N' G1A*)
S^{2-}	All cations except NH_4^+, 1A elements (S - *N' G1A*)
OH^-	All cations except NH_4^+, 1A elements (O - *N' G1A*) Ba^{2+} and Sr^{2+}(moderately soluble)
CO_3^{2-}, PO_4^{3-}	All cations except NH_4^+, 1A elements (C,P - *N' G1A*)

NH_4^+, Na^+ and K^+ (Group 1A) are soluble with all common anions.

Solubility Rule Mnemonic: All precipitates = "*HAP for Hal; CAP BS for Sully; CCOPS except N' G1A (Gia)*".

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Using Solubility Rules

Will each of the following compounds be soluble?

$NaNO_3$

NO_3^- is insoluble with no common cations. → Soluble

$AgCl$

Cl^- is insoluble with Ag^+, Pb^{2+}, Hg_2^{2+}, Tl^+ . → Insoluble

$Mg(OH)_2$

OH^- is insoluble except with NH_4^+, cations of column 1, Ba^{2+}, Sr^{2+} . → Insoluble

$Na_2Cr_2O_7$

There is no rule for $Cr_2O_7^{2-}$, but Na^+ is soluble with all anions. → Soluble

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Designating a Precipitate

If an insoluble compound is formed from aqueous solutions of two soluble compounds, it is a **precipitate** and should be designated with an "(s)".

Example:

$AgNO_3\,(aq) + NaCl\,(aq) \rightarrow AgCl\,(s) + NaNO_3\,(aq)$

Precipitate

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Net Ionic Equations

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Definition: Net Ionic Equations

When an ionic compound dissolves in water, the ions dissociate (separate) and move freely throughout the solution.

Ionic Equation – Any soluble ionic compound is dissociated into ions.

Net Ionic Equation – Only ions necessary for the chemical reaction are shown.

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Writing Net Ionic Equations

1. **Dissociate all soluble ionic compounds.**
   Only dissociate soluble, ionic compounds in water ("aq").
   Only subscripts within a polyatomic ion remain as subscripts.
   All other subscripts are moved to coefficients.
2. **Cross out any ion that is dissociated on both sides.**
   These are called spectator ions.
3. **Re-write the final net ionic equation.**

Example: Write the net ionic equation for:
$AgNO_3$ (aq) + NaCl (aq) → AgCl (s) + $NaNO_3$ (aq)

1 2

$Ag^+ + \cancel{NO_3^-} + \cancel{Na^+} + Cl^- \rightarrow AgCl\ (s) + \cancel{Na^+} + \cancel{NO_3^-}$

3

$Ag^+ + Cl^- \rightarrow AgCl\ (s)$

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Writing Net Ionic Equations - 2

1. **Dissociate all soluble ionic compounds.**
   Only dissociate soluble, ionic compounds in water ("aq").
   Only subscripts within a polyatomic ion remain as subscripts.
   All other subscripts are moved to coefficients.
2. **Cross out any ion that is dissociated on both sides.**
   These are called spectator ions.
3. **Re-write the final net ionic equation.**

Examples: Write the net ionic equation for:

$2\ NaOH\ (aq) + Mg(NO_3)_2\ (aq) \rightarrow Mg(OH)_2\ (s) + 2\ NaNO_3\ (aq)$

1 → $2\ Na^+ + 2\ OH^- + Mg^{+2} + \cancel{2\ NO_3^-} \rightarrow Mg(OH)_2\ (s) + \cancel{2\ Na^+} + \cancel{2\ NO_3^-}$ ← 2

3 → $Mg^{+2} + 2\ OH^- \rightarrow Mg(OH)_2\ (s)$

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Predicting Products of Chemical Reactions

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A Difficult Task

Predicting the products of a chemical reaction can be difficult.

As you gain experience (see more reactions, take more courses and learn more about properties of elements & compounds), it will become easier.

But in the meantime, there are some guidelines you can follow for simple reactions…

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Double Displacement - 1

1. Determine it's a double displacement reaction (two compounds, each with a cation and anion).

$CaCl_2\ (aq) + AgNO_3\ (aq) \longrightarrow$

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Double Displacement - 2

2 Combine the cation of the first reactant with the anion of the second reactant.

Ca^{2+} NO_3^-

$CaCl_2$ (aq) + $AgNO_3$ (aq) ⟶

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Double Displacement - 3

3 Combine the cation of the second reactant with the anion of the first reactant.

Ag^+ Cl^-

$CaCl_2$ (aq) + $AgNO_3$ (aq) ⟶ Ca^{2+} NO_3^-

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Double Displacement - 4

4 Remember to write cations first … & balance charges with subscripts when writing formulas.

Ag^+ Cl^-

$CaCl_2$ (aq) + $AgNO_3$ (aq) ⟶ Ca^{2+} NO_3^-

$Ca(NO_3)_2$ + AgCl

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Double Displacement - 5

5 Determine if there are any precipitates using solubility rules.

$CaCl_2$ (aq) + $AgNO_3$ (aq) ⟶ Ca^{2+} NO_3^- Ag^+ Cl^-

$CaCl_2$ (aq) + $AgNO_3$ (aq) ⟶ $Ca(NO_3)_2$ (aq) + AgCl (s)

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Double Displacement - 6

6 **Balance the equation with coefficients (covered in a future tutorial).**

$CaCl_2\ (aq) + AgNO_3\ (aq) \longrightarrow Ca^{2+}\ NO_3^-\quad Ag^+\ Cl^-$

$CaCl_2\ (aq) + 2\ AgNO_3\ (aq) \longrightarrow Ca(NO_3)_2\ (aq) + 2\ AgCl\ (s)$

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Learning Summary

- Solubility rules can be used to predict if a precipitate (insoluble compound) will form.
- Chemical reactions rearrange the bonds and atoms to form new compounds.
- The products of a reaction can sometimes be predicted based upon the type of reactions.
- Chemical equations show the starting materials and the final products in a chemical reaction.
- There are several categories of types of reaction.

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