Chemical Reactions and Equations

Chemical changes and their representation in the form of chemical equations

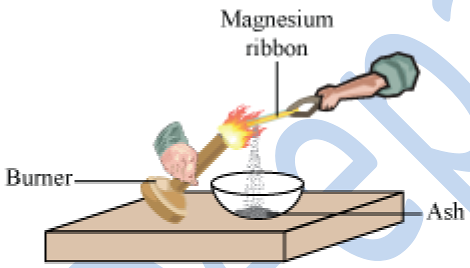
You must have observed that when an iron material is kept in the open for a long period of time, it gets rusted. Similarly, when we cook food, raw vegetables get changed into cooked vegetables. In all these examples, the formation of new substances takes place with different chemical properties. Hence, rusting of iron and cooking of food are examples of chemical changes.

A chemical change can be confirmed by any or all of the following observations:

- change in state
- change in colour
- change in temperature
- when gas is evolved

A chemical change is always accompanied by a chemical reaction. **Reaction** is the term used for depicting a change or transformation in which a substance decomposes, combines with other substances, or interchanges constituents with other substances.
Let us perform a small activity to understand a chemical change.

Activity:
Take a magnesium ribbon. Hold it at an appropriate height over a Bunsen burner with the help of a pair of tongs. You will observe that the magnesium ribbon starts burning. Collect the ashes in a watch glass. (Ensure that magnesium ribbon is burnt at a considerable distance from your eyes)



What do you observe?
Magnesium ribbon burns with a white flame and changes into white powder. This white powder is magnesium oxide, which is formed as a result of a chemical reaction between magnesium ribbon and oxygen present in the air.

Hence, it can be said that magnesium reacts with oxygen to produce magnesium oxide.
Representing a reaction in a sentence form can be quite complex and laborious at times. Thus, to write a concise chemical reaction, equations of the reactions are written. These equations can be written in different ways such as word equations and chemical equations. For example, the above activity (in which magnesium ribbon was burnt) can be written in the form of a word equation as follows:

$$\underset{\text{(Reactant)}}{\text{Magnesium} + \text{Oxygen}} \longrightarrow \underset{\text{(Product)}}{\text{Magnesium oxide}}$$

In a word equation, reactants are written on the left hand side of a forward arrow. Each reactant is separated by a plus sign (+). The products are written on the right hand side of this arrow.

The arrow signifies that the reaction proceeds from the reactants towards the products.
A word equation can further be written in a concise form by using symbols and formulae of chemical compounds, molecules, or elements involved in the reaction.

The chemical equation of the above reaction can be written as:

$$\underset{\text{Magnesium}}{2Mg} + \underset{\text{Oxygen}}{O_2} \longrightarrow \underset{\text{Magnesium oxide}}{2MgO}$$

A chemical equation has reactants on the left hand side. Reactants are substances that are present at the initiation of a reaction. Hence, magnesium (Mg) and oxygen (O_2) are reactants. On the other hand, new substances formed after the completion of the reaction are termed as products. Thus, magnesium oxide (MgO) which is written on the right hand side of the equation is a product. The arrow in the equation signifies the direction of change. Thus, a chemical equation is an easier and more concise method for representing a chemical reaction. It involves writing symbols and formulae (instead of words) for all substances involved in the reaction. A chemical equation also indicates the number of atoms of each element involved in a reaction.

Try to represent the statements given below as chemical equations.
(a) Potassium metal reacts with water to give potassium hydroxide and hydrogen gas.
(b) Hydrogen gas combines with nitrogen to form ammonia.
Symbols of elements:
Potassium = K
Hydrogen =H
Nitrogen = N

Balanced Chemical Equations

When zinc is dipped in a solution of hydrochloric acid, zinc chloride and hydrogen gas are produced. This is an example of a chemical reaction. Representing a reaction in a sentence form can be quite complex and laborious at times. **Can the same chemical reaction be explained in a manner that is more concise and simple to write and understand?**
To describe a chemical reaction more concisely, equations of the reactions are written. These equations can be written in different ways such as word equations and chemical equations.

Word equations

The above chemical reaction between zinc and mineral acid can be represented as:

Zinc + Hydrogen chloride → Zinc chloride + Hydrogen

In a word equation, the reactants are written on the left hand side of a forward arrow. The products are written on the right hand side of this arrow.The arrow signifies that the reaction proceeds from the reactants towards the products.

Chemical equations

A word equation can be further written in a concise form by using symbols and formulae of the chemical compounds, molecules, or elements involved in the reaction.
The chemical equation of the above reaction can be written as:

$$\underset{(\text{Zinc})}{Zn} + \underset{(\text{Hydrochloric acid})}{2HCl} \longrightarrow \underset{(\text{Zinc chloride})}{ZnCl_2} + \underset{(\text{Hydrogen})}{H_2}$$

A chemical equation also indicates the number of atoms of each element involved in a reaction.
Now, we know how to write chemical equations. We also know that the law of conservation of mass states that mass can neither be created nor destroyed. **Thus, in a chemical reaction, the total mass of the reactants should be equal to the total mass of the products**. This means that the total number of atoms of each element should be equal on both sides of a chemical equation. Such an equation is called a **balanced chemical equation**, and the method by which it is obtained is called balancing of chemical equations. Therefore, we need to balance every chemical equation we write.

An equation having an equal number of atoms of each element on both the sides is called a balanced chemical equation.

We will now learn how to balance a chemical equation.

$$\underset{\substack{(\text{Reactants})\\(\text{L.H.S})}}{Zn + HCl} \rightarrow \underset{\substack{(\text{Products})\\(\text{R.H.S})}}{ZnCl_2 + H_2}$$

If you observe the above equation carefully, you will notice that the number of hydrogen and chlorine atoms present on the right hand side and the left hand side are not equal. On the left hand side, there is one atom of both hydrogen and chlorine, but on the right hand side, there are two atoms each of hydrogen and chlorine.

The balanced equation of the given equation can be written as:

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

This equation has an equal number of atoms of Zn, H, and Cl on both sides of the equation.
Let us now learn the step-by-step process of balancing a chemical equation.

In the reaction of barium chloride and aluminium sulphate, barium sulphate and aluminium chloride are produced.

Step I:Write the unbalanced chemical equation for the given reaction.

$BaCl_2 + Al_2(SO_4)_3 \rightarrow BaSO_4 + AlCl_3$

Step II: List the number of atoms of the various elements present in the unbalanced equation in the form of a table.

Element	Number of atoms on the reactant side (L.H.S)	Number of atoms on the product side (R.H.S)
Ba	1	1
Cl	2	3
Al	2	1
S	3	1
O	12 (4×3)	4

Here, we can see that only barium has an equal number of atoms on both sides of the equation.

Step III: In the next step, select a compound which contains the maximum number of atoms. In this case, the compound will be aluminium sulphate (it has 2 atoms of Al, 3 atoms of S, and 12 atoms of O). From this compound, select the element which has the maximum number of atoms, and which is present in only one compound on both sides i.e. oxygen in this case. To balance the number of oxygen atoms, we can multiply barium sulphate present on the right hand side by 3 (as shown below). It should be kept in mind that coefficient '3' will be written as $3BaSO_4$ and not as $(BaSO_4)_3$.

Oxygen atoms	Number of atoms on L.H.S	Number of atoms on R.H.S
Before balancing	12 in $Al_2(SO_4)_3$	4 in $BaSO_4$
To balance	12	3 × 4

Now, the equation becomes:

$BaCl_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4 + AlCl_3$

Again, compare the number of atoms of the various elements present in the chemical equation (as shown in the table below).

Element	Number of atoms on L.H.S	Number of atoms on R.H.S
Ba	1	3
Cl	2	3
Al	2	1
S	3	3
O	12	12

Step IV: As the atoms of both oxygen and sulphur are balanced, we will now balance the atoms of aluminium.

Aluminium atoms	Number of atoms on L.H.S	Number of atoms on R.H.S
Before balancing	2 in $Al_2(SO_4)_3$	1 in $AlCl_3$
To balance	2	2 ×1

Now, the equation becomes:

$$BaCl_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4 + 2AlCl_3$$

Make the table again to compare the number of atoms of the elements on both sides of the equation.

Element	Number of atoms on L.H.S	Number of atoms on R.H.S
Ba	1	3
Cl	2	6
Al	2	2
S	3	3
O	12	12

We can see that the atoms of aluminium, sulphur, and oxygen are balanced.

Step V: Now, only the atoms of barium and chlorine are unbalanced. We will first balance the atoms of barium.

Barium atoms	Number of atoms on L.H.S	Number of atoms on R.H.S
Before balancing	1 in $BaCl_2$	3 in (3 $BaSO_4$)
To balance	3 ×1	3

Now, the equation becomes:

$$3BaCl_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4 + 2AlCl_3$$

Let us again prepare a table to compare the number of atoms of the elements on both sides of the equation.

Element	Number of atoms on L.H.S	Number of atoms on R.H.S
Ba	3	3
Cl	6	6
Al	2	2
S	3	3
O	12	12

It can be observed that the chemical equation is balanced now.

$$3BaCl_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4 + 2AlCl_3$$

This method of balancing a chemical equation is called the hit-and-trial method.

- **Solids** are denoted by writing **(s)**,
- **Liquids** are denoted by writing **(l)**,
- **Gases** are denoted by writing **(g)**, and
- **Solutions in water** are denoted by writing **(aq)**.

For example, the reaction of limewater with carbon dioxide that results in the formation of a precipitate of calcium carbonate and water is represented as:

$$\underset{\text{Calcium hydroxide}}{Ca(OH)_2(aq)} + \underset{\text{Carbon dioxide}}{CO_2(g)} \rightarrow \underset{\text{Calcium carbonate}}{CaCO_3(s)} + \underset{\text{Water}}{H_2O(l)}$$

In this reaction, calcium hydroxide is present in the form of a solution in water, carbon dioxide is present as gas, calcium carbonate is produced as a precipitate i.e. in the solid state, and water is formed in the liquid state.

The energy changes involved in a reaction are denoted by writing the changes involved in the equation itself.

If energy is used in the reaction, then it will be written on the left hand side. If it is released in the process, then it is written on the right hand side.

For example, combustion of butane is accompanied by the evolution of heat and light energy. Therefore, the equation for the same will be written as:

$$2C_4H_{10} + 13O_2 \rightarrow 10H_2O + 8CO_2 + \text{Heat} + \text{Light}$$

The reaction conditions (such as temperature, pressure, catalyst etc.) for a reaction are indicated above or below the forward arrow in a reaction.
Below are some balanced chemical equations:

(1) $CO_{(g)} + 2H_{2(g)} \xrightarrow[ZnO+CrO_3]{300\text{ atm, }300^\circ C} CH_3OH_{(aq)}$

Carbon monoxide — Hydrogen — Methyl alcohol

(2) $2KClO_{3(s)} \xrightarrow[MnO_2]{\Delta} 2KCl_{(s)} + 3O_{2(g)}$

Potasium chlorate — Potassium chloride — Oxygen

Type of Reactions:

You know that chemical changes involve chemical reactions. Chemical reactions are primarily of five types. They are listed as follows:

1. Combination reactions
2. Decomposition reactions
3. Displacement reactions
4. Double displacement reactions
5. Oxidation and reduction reactions

Here, we will discuss combination reactions in detail. **Do you know what actually happens in a combination reaction?**

Combination reactions

In these reactions, two or more substances combine to form a new compound. The reactants in such reactions can be elements as well as compounds. The general equation used to represent a combination reaction is:

$A + Z \longrightarrow AZ$

For example, coal is primarily carbon. When it burns, it combines with oxygen present in the air to form carbon dioxide.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Carbon (From coal) — Oxygen — Carbon dioxide

Some other examples of combination reactions are discussed below.

1. Combination of two elements

On heating, magnesium combines with oxygen present in the air to form magnesium oxide.

$$\underset{\text{Magnesium (From coal)}}{2Mg_{(s)}} + \underset{\text{Oxygen}}{O_{2(g)}} \rightarrow \underset{\text{Magnesium oxide}}{2MgO_{(g)}}$$

Hydrogen and oxygen combine to form water.

$$\underset{\text{Hydrogen}}{2H_{2(g)}} + \underset{\text{Oxygen}}{O_{2(g)}} \rightarrow \underset{\text{Water}}{2H_2O_{(l)}}$$

2. Combination of two compounds

Calcium oxide, also known as quick lime, when mixed with water reacts with it to form calcium hydroxide, also known as slaked lime. The chemical equation for the same is given as:

$$\underset{\text{Calcium oxide (Quick lime)}}{CaO(s)} + \underset{\text{Water}}{H_2O(l)} \rightarrow \underset{\text{Calcium hydroxide (Slaked lime)}}{Ca(OH)_2(aq)}$$

Hence, in combination reactions, two or more compounds combine to produce only one product. Generally, combination reactions are exothermic in nature i.e., energy is released when two or more compounds combine.

What happens when coal is burned? On burning, coal combines with oxygen to produce carbon dioxide. It also gives a lot of heat energy. Hence, burning of coal is an exothermic reaction.

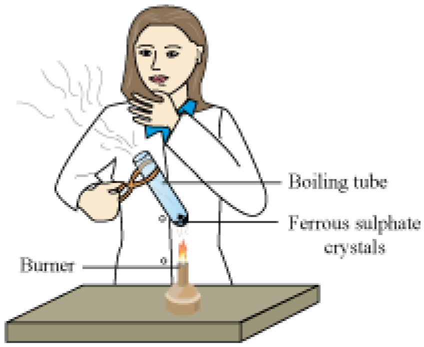
DO YOU KNOW?
Lime water or slaked lime (Ca $(OH)_2$) is used in white washing walls. It combines with carbon dioxide present in the air to form a thin layer of calcium carbonate. The chemical formula of calcium carbonate is $CaCO_3$. The chemical equation involved in the reaction can be represented as:

$$\underset{\text{Slaked lime}}{Ca(OH)_{2(aq)}} + \underset{\text{Carbon dioxide}}{CO_{2(g)}} \longrightarrow \underset{\text{Calcium carbonate}}{CaCO_{3(s)}} + \underset{\text{Water}}{H_2O_{(l)}}$$

<u>Decomposition Reactions</u>

In this part, we will discuss decomposition reactions in detail. **Do you know what actually happens in a decomposition reaction?** The following activity can be performed to understand decomposition reactions.

Activity:
Take 3 g of green ferrous sulphate crystals in a dry boiling tube. Heat the boiling tube over the flame of a burner (as shown in **Figure 1)**. Observe the change in colour of the crystals on heating.



It will be observed that the colour of the crystals undergo a change. Also, the characteristic smell of burning of sulphur is observed. **Do you know why this happens?**

Here, green crystals of ferrous sulphate lose water on heating. Hence, a change in colour is seen in the crystals. On further heating, it decomposes into ferric oxide, sulphur dioxide, and sulphur trioxide. The chemical equation involved in the reaction can be represented as:

$$\underset{\text{Ferrous sulphate}}{2FeSO_{4(s)}} \xrightarrow{\text{Heat}} \underset{\text{Ferric oxide}}{Fe_2O_{3(s)}} + \underset{\text{Sulphur dioxide}}{SO_{2(g)}} + \underset{\text{Sulphur trioxide}}{SO_{3(g)}}$$

Here, ferrous sulphate breaks down or decomposes to form three new substances. Hence, it is an example of decomposition reactions.

What are decomposition reactions?

In these reactions, a compound breaks down or decomposes to form two or more substances. These reactions are exactly opposite to combination reactions. We know that there is only one product in combination reactions. Similarly, there is only one reactant in decomposition reactions. The general equation used to represent a decomposition reaction is:

$$XY \longrightarrow X + Y$$

Decomposition reactions require a source of energy in the form of heat, light, or electricity to decompose the compound involved. Hence, these reactions can be classified into three types, depending on the source of energy for the reaction.

a) Decomposition by heat or thermal decomposition
b) Decomposition by electricity or electrolysis
c) Decomposition by light or photolysis

Let us now study three different types of decomposition reactions.

a) Decomposition by heat or thermal energy

One of the most common examples of thermal decomposition reactions is the decomposition of calcium carbonate. Calcium carbonate when heated decomposes to form calcium oxide and carbon dioxide.

$$\underset{\text{Calcium carbonate}}{CaCO_3(s)} \xrightarrow{\Delta} \underset{\text{Calcium oxide}}{CaO(s)} + \underset{\text{Carbon dioxide}}{CO_2(g)}$$

In this reaction, one compound i.e., calcium carbonate breaks down to form two compounds, namely calcium oxide and carbon dioxide. Hence, it is an example of decomposition reactions. Commercially, this reaction is very important as calcium oxide (obtained as a product in this reaction) is used in cement and glass industries.

The Taj Mahal is made up of marble. **Do you know that chemically, marble is nothing but calcium carbonate?**

b) Decomposition by electricity

When electricity is passed through water containing a few drops of sulphuric acid, it breaks down to give its constituent elements as products i.e., hydrogen and oxygen. This is known as electrolysis of water.

$2H_2O \longrightarrow 2H_2 + O_2$

c) Decomposition by light

When silver chloride is kept in the sun, it decomposes to form chlorine gas and silver. As the reaction proceeds, the white coloured silver chloride turns grey because of the formation of silver. Chlorine produced in the reaction escapes into the environment as it is produced in the gaseous state.

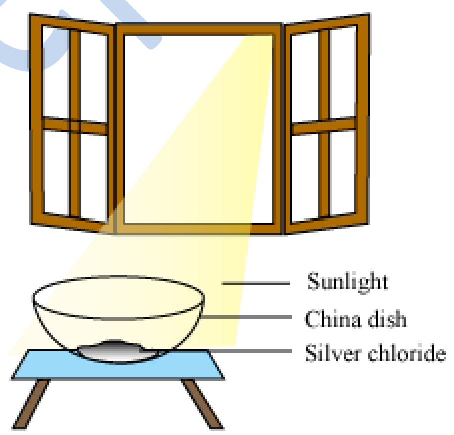


Figure 3: Photolysis of silver chloride

$$\underset{\text{Silver chloride}}{2AgCl(s)} \xrightarrow{\text{Light}} \underset{\text{Silver}}{2Ag(s)} + \underset{\text{Chlorine}}{Cl_2(g)}$$

Silver bromide also undergoes decomposition in a similar manner when exposed to sunlight.

$$\underset{\text{Silver bromide}}{2AgBr(s)} \xrightarrow{\text{Light}} \underset{\text{Silver}}{2Ag(s)} + \underset{\text{Bromine}}{Br_2(g)}$$

As the above reactions are sensitive to light, they are used in black and white photography. It is seen that decomposition reactions require a source of energy in the form of heat, light, or electricity to decompose the compound involved. Hence, it can be concluded that decomposition reactions are **endothermic** in nature.

Rancidity And Corrosion As Examples Of Oxidation And Reduction Reactions

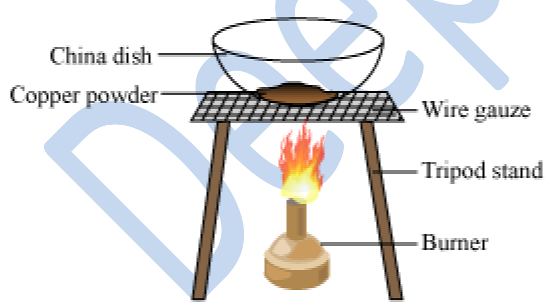
You must have observed that when butter is kept in the open for a long time, it becomes rancid. Also, its smell and taste undergoes a change.**Do you know why?** This is because butter undergoes oxidation i.e. it reacts with oxygen and gets oxidized. This process is called rancidity.

What is Oxidation?

Oxidation is defined as a process that involves a gain of oxygen or a loss of hydrogen. When a substance gains oxygen or loses hydrogen during a reaction, it is oxidized.

Let us perform an activity to understand more about these reactions.

Activity:
Take around 1g copper powder (reddish brown in colour) in a china dish and heat it over a burner (as shown in the given figure).



What do you observe?

It will be observed that after sometime, the surface of the powder is covered by the layer of a black substance. When copper powder is heated, it combines with oxygen to form copper oxide.

Actually, in the process, copper powder gains oxygen. Thus, it gets oxidized to form copper oxide when heated. This process is called **oxidation**.

$$\underset{\text{Copper}}{2Cu} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Copper oxide}}{2CuO}$$

Now, if hydrogen gas is passed over heated copper (II) oxide, then the black coating on the surface turns brown. This is because a reverse reaction takes place and copper is re-obtained.

$$\underset{\text{Copper oxide}}{CuO} + \underset{\text{Hydrogen}}{H_2} \xrightarrow{\Delta} \underset{\text{Copper}}{Cu} + \underset{\text{Water}}{H_2O}$$

Here, copper (II) oxide loses oxygen and gets reduced to copper. This process is called **reduction**.

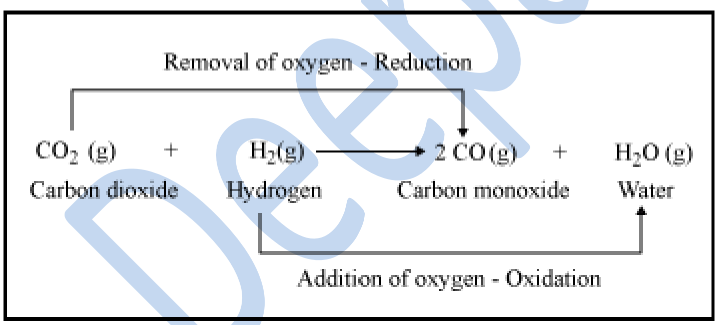
What is Reduction?

Reduction is defined as a process that involves a gain of hydrogen or a loss of oxygen. When a substance loses oxygen or gains hydrogen during a reaction, it is reduced.

Oxidation and reduction always take place simultaneously. **Therefore, reactions involving oxidation and reduction are known as Redox ('Red' for reduction and 'ox' for oxidation) reactions.** In a redox reaction, one substance is oxidized, while the other is reduced.

The substances that are reduced (provide oxygen or remove hydrogen) in course of the reaction are called **oxidizing agents**. These substances oxidize other chemicals in the reaction and are reduced in the process. On the other hand, the substances that are oxidized (remove oxygen or provide hydrogen) are called **reducing agents**.

For example:



In the above reaction, CO_2 gets reduced to CO and here, CO_2 is the oxidizing agent. On the other hand, hydrogen gets oxidized to form water and here, H_2 is the reducing agent.

We come across many examples of redox reactions in our daily life. For example, in the process of corrosion, metal combines with oxygen and gets corroded. Again, food gets spoilt, when it is oxidized and the process is called rancidity. We will discuss them separately.

Corrosion:

It may be defined as a process where materials, usually metals, are deteriorated because of a chemical reaction with air, moisture, chemicals, etc. For example, corrosion causes damage to car bodies, bridges, iron railings, ships, and all objects made of metals (especially those made from iron). Iron, in the presence of moisture, reacts with oxygen to form iron (III) oxide. This reaction is represented as:

$$\underset{\text{Iron}}{4Fe} + \underset{\text{Oxygen}}{3O_2} + \underset{\text{Water}}{2H_2O} \longrightarrow \underset{\substack{\text{Hydrated iron (III) oxide} \\ \text{(Rust)}}}{2Fe_2O_3 \cdot H_2O}$$

This hydrated iron (III) oxide is **rust**. If not controlled, rusting can corrode the entire iron present in an object. As rust is softer than iron, the strength of the object decreases when rusting takes place. Every year, a large amount of money is spent for the maintenance of structures made of iron such as bridges, rails, ships etc.

Rancidity:

When fats and oils are oxidized, they become rancid and their smell and taste also changes. Thus, the oxidation of fats and oils can be easily observed by a change in their taste and smell. Oxidation of food can be prevented in many ways. Two common methods are discussed below.

1. Storing food in air tight containers. By doing so, the oxygen available for oxidation becomes limited. Hence, oxidation can be prevented.
2. Sometimes, antioxidants are added to food to prevent their oxidation. These antioxidants are oxidized first, which slows down the process of rancidity. These are reducing agents. Normally, vitamin C and vitamin E are added as antioxidants.