4 Redox Reactions

Look at the picture of children doing experiments in the laboratory. Several chemical reactions are conducted there.

What changes are generally observed during chemical reactions?

Let us do an experiment.

Take a trough and fill three fourth of it with water. Add two drops of phenolphthalein to it and stir well. Cut a small piece of sodium and put it into the trough carefully (Figure 4.1).

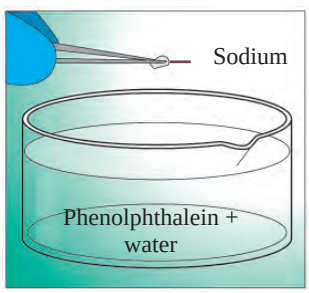


Fig. 4.1

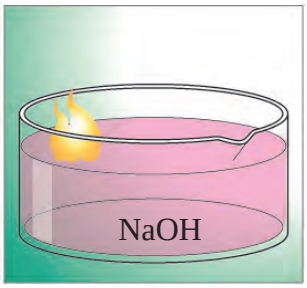


Fig. 4.2

What changes can be observed? (Figure 4.2)

- What is the reason? Analyse the chemical equation and find out.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2\uparrow$$

.....

You have learnt that chemical changes are accompanied by energy changes.

Is there any change in the total mass of substances during chemical reactions?

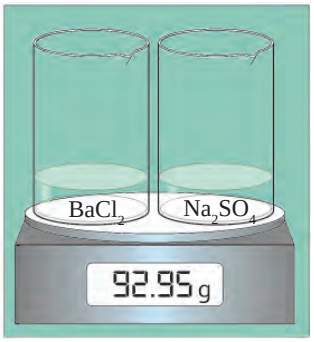


Fig. 4.3

During the combustion of fuels and the burning of paper, the total mass appears to be decreasing. Is this true? Let us do an experiment.

Take 20 mL barium chloride ($BaCl_2$) solution in a beaker. Take 20 mL sodium sulphate (Na_2SO_4) solution in another beaker. Place both the beakers together on an electronic balance and note the reading (Figure 4.3). Now, pour the solution from one beaker to the other. What do you observe? (Figure 4.4)

.....

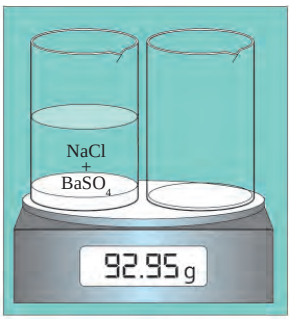


Fig. 4.4

After some time, note the reading of the electronic balance again. Compare this with the previous reading. What is your inference?

.....

Is there any change in the total mass as a result of this chemical reaction?

.....

In this chemical reaction, barium chloride reacts with sodium sulphate to form barium sulphate and sodium chloride.

Let us write the equation of this chemical reaction.

.....

$$BaCl_2 + Na_2SO_4 \rightarrow BaSO_4\downarrow + 2\ NaCl$$

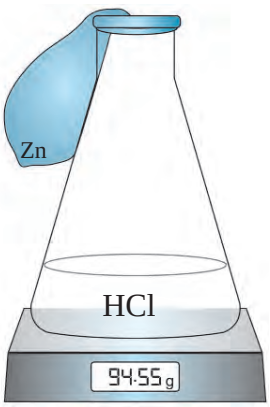


Fig. 4.5

Now, let us do another experiment.

Take 20 mL dilute hydrochloric acid (HCl) in a conical flask. Drop some zinc (Zn) granules in a balloon. Fix the balloon firmly to the mouth of the conical flask as shown in the Figure 4.5. Place the conical flask on an electronic balance and note the mass.

Then, carefully raise the balloon and drop the zinc granules into the acid in the flask.

- What do you see? (Figure 4.6)

.....

- Note the reading of the electronic balance. Compare this reading with the previous one. What do you understand?

.....

- Which gas is collected in the balloon?

.....

Let us write the equation of the chemical reaction.

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

- What can be inferred from these experiments?

.....

- Does the total mass change during chemical reactions?

.....

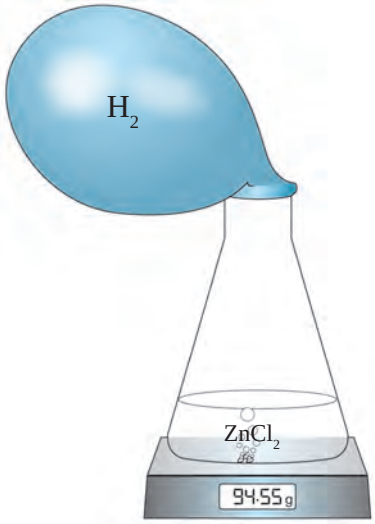


Fig. 4.6

The major products, formed during the combustion of fuels and burning of paper are carbon dioxide and water vapour. They are lost in the atmosphere. If these products are collected without any loss and weighed, what will be the observation?

There will be no change in the total mass in such experiments too.

Based on experiments and observations, the French scientist Antoine Lavoisier, stated the law of conservation of mass. Based on this law:

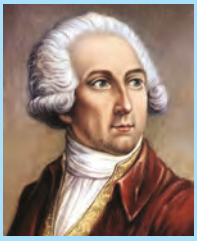
In a chemical reaction, the total mass of the reactants will be equal to the total mass of the products.

The total mass remains unchanged in a chemical reaction. Why? Let us examine.

The atomic mass of elements are expressed using the unit, unified atomic mass unit (u).

You are familiar with the chemical reaction in which hydrogen, having atomic mass 1u and oxygen having atomic mass 16u combine together to form water. Let us write the equation of this chemical reaction.

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



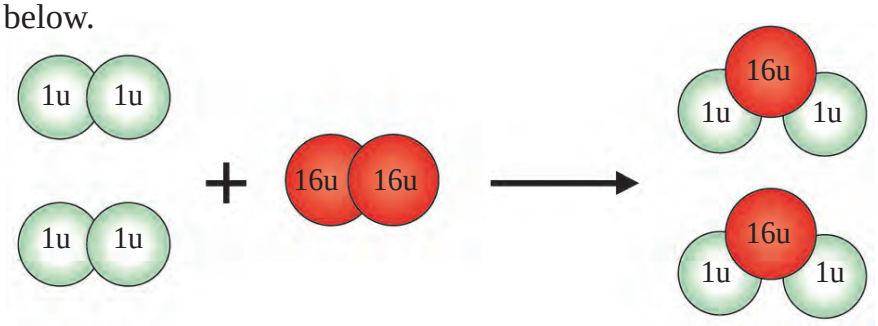
Antoine Lavoisier

(1743 - 1794)

Discovered the role of oxygen in the process of combustion. Found out that oxygen is inhaled and carbon dioxide is exhaled during respiration. Discovered the presence of oxygen in acids.

Proposed the names of hydrogen and oxygen. Classified the known elements into metals and non metals. This versatile genius was guillotined in 1794 following the political consequences of the French Revolution of 1789.

See the symbolic representation of this chemical reaction given below.



$2H_2 + O_2 \longrightarrow 2H_2O$

Analyse Table 4.1 given below.

Total mass of the reactants	4 u + 32 u = 36 u
Total mass of the products	18 u + 18 u = 36 u

Table 4.1

We can see that the total mass of the reactants and the total mass of the products are equal.

When reactants combine in a specific mass proportion to form products, the atoms in them undergo a rearrangement. There will not be any change in the total number of atoms or in the total mass.

- Carbon and oxygen combine to form carbon dioxide. Analyse the symbolic representation of this chemical reaction.

$C + O_2 \longrightarrow CO_2$

Complete Table 4.2 given below.

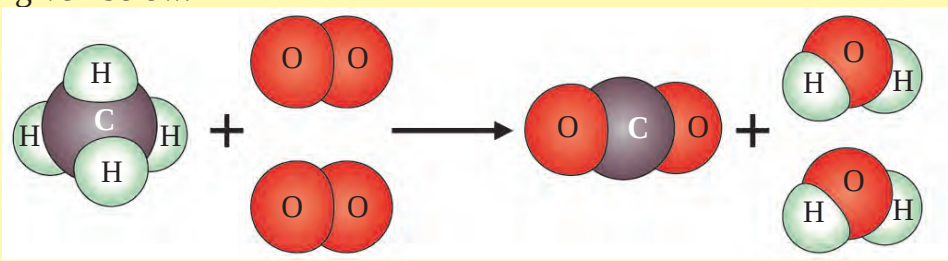
Total mass of the reactants	.....
Total mass of the products	.....

Table 4.2

Record your inference.

.....

Methane (CH_4) burns in air to form carbon dioxide and water vapour. The symbolic representation of this chemical reaction is given below.



Write down the equation of the chemical reaction.

Check whether this chemical reaction obeys the law of conservation of mass. (Hint : H=1 u, C=12 u, O=16 u.)

Balancing of Chemical Equations

Chemical equation is the symbolic representation of a chemical reaction using symbols and chemical formulae. When a chemical reaction is written in accordance with the law of conservation of mass, the total mass of the reactants must be equal to the total mass of the products. This can be done by equalising the number of atoms of the same type on either sides of the equation.

You know that oxygen and hydrogen are diatomic molecules

- How are these molecules represented using symbols?

Oxygen ....., Hydrogen .....

- What is the total number of atoms in water (H_2O) molecule?

.....

- Calculate the number of molecules and the total number of atoms present in $5H_2O$.

Total number of molecules ..... Total number of atoms .....

Consider the formation of water from hydrogen and oxygen. Let us have a look at the method of balancing this chemical equation.

Step 1

$$\text{Hydrogen} + \text{Oxygen} \rightarrow \text{Water}$$

$$H_2 + O_2 \rightarrow H_2O$$

Observe Table 4.3.

Number of atoms in the reactants	Hydrogen = 2	Oxygen = 2
Number of atoms in the products	Hydrogen = 2	Oxygen = 1

Table 4.3

The number of oxygen atoms in the products also must be 2. How is this possible? Let us make the number of water molecules 2.

Step 2

$$H_2 + O_2 \rightarrow 2H_2O$$

Observe Table 4.4.

Number of atoms in the reactants	Hydrogen = 2	Oxygen = 2
Number of atoms in the products	Hydrogen = 4	Oxygen = 2

Table 4.4

The number of hydrogen atoms in the reactants also must be 4. How is this possible?

Let us make the number of hydrogen molecules in the reactants 2.

Step 3

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

Analyse Table 4.5.

Number of atoms in the reactants	Hydrogen = 4	Oxygen = 2
Number of atoms in the products	Hydrogen = 4	Oxygen = 2

Table 4.5

The number of the same type of atoms in the reactants as well as the products are the same now. The balanced chemical equation of the reaction between hydrogen and oxygen to form water is given below.

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

Balancing a chemical equation is the method of equalising the number of the same type of atoms in both the reactants and the products. The equation thus obtained is known as a balanced chemical equation.

Let us practice balancing equations, using other chemical equations.

1. Magnesium + Oxygen → Magnesium oxide

Step 1 $Mg + O_2 \rightarrow MgO$

Step 2 $Mg + O_2 \rightarrow 2MgO$

Step 3 $2Mg + O_2 \rightarrow 2MgO$

Balanced chemical equation $\mathbf{2Mg + O_2 \rightarrow 2MgO}$

2. Hydrogen + Chlorine → Hydrogen chloride

Step 1 $H_2 + Cl_2 \rightarrow HCl$

Step 2 $H_2 + Cl_2 \rightarrow \underline{2}HCl$

Balanced chemical equation $\mathbf{H_2 + Cl_2 \rightarrow 2HCl}$

3. Zinc + Hydrochloric acid → Zinc chloride + Hydrogen

Step 1 $Zn + HCl \rightarrow ZnCl_2 + H_2$

Step 2 $Zn + \underline{2}HCl \rightarrow ZnCl_2 + H_2$

Balanced chemical equation $\mathbf{Zn + 2HCl \rightarrow ZnCl_2 + H_2}$

4. Aluminium + Oxygen → Aluminium oxide

Step 1 $Al + O_2 \rightarrow Al_2O_3$

Step 2 $Al + \underline{3}O_2 \rightarrow Al_2O_3$

Step 3 $Al + 3O_2 \rightarrow \underline{2}Al_2O_3$

Step 4 $\underline{4}Al + 3O_2 \rightarrow 2Al_2O_3$

Balanced chemical equation $\mathbf{4Al + 3O_2 \rightarrow 2Al_2O_3}$

5. Nitrogen + Hydrogen → Ammonia

Step 1 $N_2 + H_2 \rightarrow NH_3$

Step 2 $N_2 + H_2 \rightarrow \underline{2}NH_3$

Step 3 $N_2 + \underline{3}H_2 \rightarrow 2NH_3$

Balanced chemical equation $\mathbf{N_2 + 3H_2 \rightarrow 2NH_3}$

?

- Balance the chemical equations given below and record them in science diary.

$H_2 + I_2 \rightarrow HI$

$Na + H_2O \rightarrow NaOH + H_2$

$Mg + HCl \rightarrow MgCl_2 + H_2$

Oxidation and Reduction

You have learnt how the atoms of elements combine to form molecules of compounds. Atoms engage in chemical bonding by losing, gaining or sharing electrons.

Chemical equations

While writing chemical equations, the physical states of reactants and products, energy changes, presence of catalysts, temperature, pressure etc. are also indicated usually.

E.g.

$N_2(g) + 3H_2(g) \xrightarrow{Fe} 2NH_3(g) + Heat$

You know how sodium (Na) and chlorine (Cl) combine to form sodium chloride (NaCl).

Which atom loses electron and becomes a positively charged ion in this process? Let us write the equation of the chemical reaction.

$$Na \rightarrow Na^{+} + 1e^{-}$$

The process involving loss of electrons in a chemical reaction is called oxidation.

Which atom gains electron and becomes a negatively charged ion?

Let us write the equation of the chemical reaction.

$$Cl + 1e^{-} \rightarrow Cl^{-}$$

The process involving gaining of electrons in a chemical reaction is called reduction.

The positively charged sodium ion (Na^{+}) and the negatively charged chloride ion (Cl^{-}) combine together to form sodium chloride (NaCl).

$$Na^{+} + Cl^{-} \rightarrow NaCl$$

Given below are some equations of oxidation.

$K \rightarrow K^{+} + 1e^{-}$

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

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

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

$Al \rightarrow Al^{3+} + 3e^{-}$

Sodium (Na), potassium (K) etc. are metals. Generally, metals undergo oxidation during chemical reactions.

See some equations of reduction given below.

$F + 1e^{-} \rightarrow F^{-}$

$Cl + 1e^{-} \rightarrow Cl^{-}$

$Br + 1e^{-} \rightarrow Br^{-}$

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

Fluorine (F), chlorine (Cl) etc. are non-metals. Generally, non metals undergo reduction during chemical reactions.

Positive ions also can gain electrons and change into atoms. Such reactions are also reduction reactions.

e.g.

$Ag^{+} + 1e^{-} \rightarrow Ag$

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

Similarly negative ions lose electrons and change into atoms. Such reactions are also oxidation reactions.

e.g.

$I^{-} \rightarrow I + 1e^{-}$

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

Oxidising agent and reducing agent

Look at the chemical equation regarding the formation of sodium chloride.

$$2Na + Cl_2 \rightarrow 2NaCl$$

Which atom undergoes oxidation ?

Sodium loses electron and undergoes oxidation.

Which atom supports oxidation? (sodium/chlorine)

Chlorine gains electron and helps oxidation.

The species that helps oxidation in a chemical reaction is the Oxidising agent.

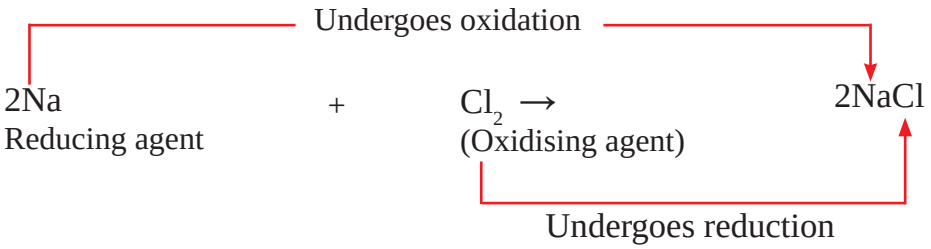
The oxidising agent gets reduced in a chemical reaction.

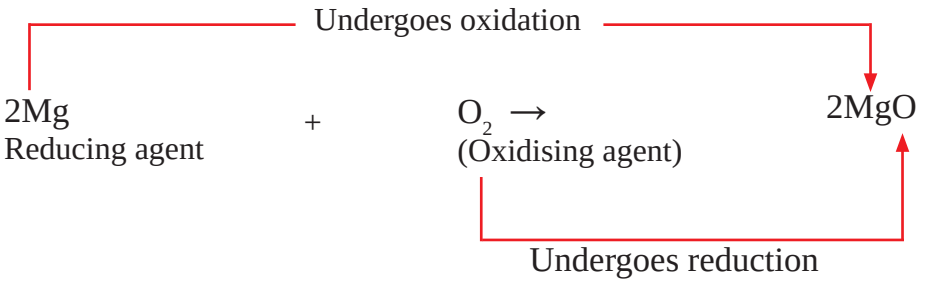
In the above chemical reaction, chlorine undergoes reduction. Which atom supports reduction? (sodium/chlorine)

Sodium donates electron and helps reduction.

The species that helps reduction is the reducing agent. The reducing agent gets oxidised in a chemical reaction.

See the illustrations given below.





- Analyse the chemical reactions given below and complete the table.

1) $Mg + F_2 \rightarrow MgF_2$

2) $Ca + Cl_2 \rightarrow CaCl_2$

3) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Sl.No.	Equation of oxidation	Equation of reduction	Oxidising agent	Reducing agent
1	$Mg \rightarrow Mg^{2+} + 2e^-$	.....	F	.....
2	.....	$Cl + 1e^- \rightarrow Cl^-$	.....	Ca
3	$Fe \rightarrow Fe^{3+} + 3e^-$	.....	O	.....

Oxidation Number

You are familiar with the valency of elements.

Analyse Table 4.6 given below.

Element	Atomic number	Electron configuration	Valency
Sodium (Na)	11	2, 8 1	1
Potassium (K)	19	2, 8, 8, 1	1
Fluorine (F)	9	2, 7	1
Chlorine (Cl)	17	2, 8, 7	1
Magnesium (Mg)	12	2, 8, 2	2
Calcium (Ca)	20	2, 8, 8, 2	2
Oxygen (O)	8	2, 6	2
Aluminium (Al)	13	2, 8, 3	3

Table 4.6

Is it possible to guess whether an element loses or gains electron in a chemical reaction from its valency? Oxidation number is used to indicate it.

When an electron is lost, a positive ion is formed and when an electron is gained, a negative ion is formed.

If all the chemical bonds in a compound are considered to be ionic, the charge formed on each atom is considered as its oxidation number or oxidation state.

Sodium chloride (NaCl) is composed of sodium ion (Na^+) and chloride ion (Cl^-). In ionic compounds, the charge of such ions are the oxidation number. So, the oxidation number of sodium is +1 and that of chlorine is −1.

- The oxidation number of magnesium is +2 and that of oxygen is −2 in magnesium oxide (MgO). What do you understand from this?

Covalent compounds are formed by the sharing of electrons. In such compounds, the oxidation number is assigned assuming

that the shared electrons are shifted to the more electronegative element.

For example, in the covalent compound HF, it is considered that the more electronegative fluorine (F) attracts the electron pair and attains –l oxidation number. Hydrogen is assumed to lose one electron and it attains +1 oxidation number.

- The sum of the oxidation numbers of all atoms in a compound is zero.
- In element molecules, electrons are equally shared by the atoms. So, at elemental state the oxidation number is considered to be zero.

Method of calculating oxidation number

The common oxidation number of certain elements in their compounds are given in Table 4.7.

Is it possible to find out the oxidation number of an element in a compound, whose oxidation number is not known?

Let us examine Table 4.7 and see how the oxidation number of nitrogen (N) in HNO_3 can be found out.

Oxidation number of H = +1

Oxidation number of O = –2

Let the oxidation number of nitrogen be *x*. We know that the sum of oxidation numbers of atoms in a molecule is zero.

Element	Oxidation number
H	+1
Na	+1
K	+1
Ca	+2
Al	+3
F	–1
Cl	–1
Br	–1
I	–1
O	–2

Table 4.7

Then, in HNO_3

$(+1) + (1 \times x) + (-2 \times 3) = 0$

$+1 + x + (-6) = 0$

$x - 5 = 0$

$x = +5$

Oxidation number of nitrogen in HNO_3 = +5

- Find out the oxidation number of nitrogen in HNO_2 and NO_2

Let us find out the oxidation number of chromium (Cr) in potassium dichromate ($K_2Cr_2O_7$). If the oxidation number of chromium is considered to be '*x*',

$(+1 \times 2) + (2 \times x) + (-2 \times 7) = 0$

$2 + (2x) + (-14) = 0$

$2x - 12 = 0$

$2x = +12$

$x = \frac{+12}{2}$

$= +6$

Oxidation number of chromium in $K_2Cr_2O_7$ = +6

- Find out the oxidation number of chromium in Cr_2O_3 .
- Find out the oxidation number of manganese (Mn) in the following compounds and record it in your science diary.

  (Hint: Oxidation number of O = −2, K = +1.)

  a) MnO_2 b) Mn_2O_7 c) $KMnO_4$

Construct and compare the structures of MnO_2, Mn_2O_7 using Ghemical software.

Oxidation number and oxidation - reduction reactions

Analyse the chemical equation of the formation of sodium chloride (NaCl).

$$2Na + Cl_2 \rightarrow 2NaCl$$

During the formation of sodium chloride sodium loses one electron and gets one positive charge and chlorine gains one electron and gets one negative charge. So the oxidation number of sodium is +1 and the oxidation number of chlorine is –1.

- What is the oxidation number of sodium and chlorine in their elemental state?

.....

Let us write the chemical equation including their oxidation numbers.

$$2\overset{0}{Na} + \overset{0}{Cl_2} \rightarrow 2\overset{+1\ -1}{NaCl}$$

- What happened to the oxidation number of sodium as a result of this reaction (increased/decreased)?

.....

- What happened to the oxidation number of chlorine?

.....

Oxidation number increases during oxidation reactions. Reduction reactions involve a decrease in oxidation number.

- Which atom undergoes oxidation during the formation of sodium chloride?

  .....

- What is the oxidising agent in this reaction? Why?

  .....

- Which atom undergoes reduction in this reaction? Why?

  .....

- What is the reducing agent in this case?

  .....

Analyse the chemical equation given below. Find out the oxidation number of atoms and complete Table 4.8.

$$H_2 + Cl_2 \rightarrow 2HCl$$

• The atom whose oxidation number is increased.	.....
• The atom which has undergone oxidation.	.....
• The atom whose oxidation number is decreased.	.....
• The atom which has undergone reduction.	.....
• Oxidising agent	.....
• Reducing agent	.....

Table 4.8

Let us analyse another chemical equation.

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

Write the oxidation number of each atom.

Find out the following.

- The oxidation number of magnesium changes from ..... to .....
- The change that happened to magnesium. (oxidation/ reduction)
- What is the oxidising agent in this case? …… (Mg/HCl)
- What is the reducing agent? …… (Mg/HCl)

- Analyse the chemical reaction given below and complete Table 4.9.

$$C + O_2 \rightarrow CO_2$$

Element	Oxidation number		Oxidation/ Reduction	Oxidising agent/ Reducing agent
	Before reaction	After reaction		
C	…….	+4	…….	…….
O	…….	…….	Reduction	…….

Table 4.9

The equation for the chemical reaction between hydrogen and chlorine to form hydrogen chloride is given below.

$$\overset{0}{H_2} + \overset{0}{Cl_2} \rightarrow 2\overset{+1\ -1}{HCl}$$

- Which atom has undergone oxidation in this reaction?

  .....

- Which atom has undergone reduction?

  .....

Here, oxidation and reduction take place simultaneously. Such reactions are called redox reactions.

In a redox reaction, oxidising agent undergoes reduction and reducing agent undergoes oxidation.

Some familiar redox reactions in daily life are given below.

- Glucose molecules decompose and release energy during cellular respiration.
- Formation of oxide coating on the surface of metals.
- Combustion of fuels.
- Decomposition of organic substances in the presence of oxygen.
- Production of electricity in electrochemical cells.

- Analyse the above redox reactions and present a seminar on the importance of redox reactions in daily life.

Let's Assess

1. The unbalanced chemical equation regarding the formation of ammonia from nitrogen and hydrogen is given below.

$$N_2 + H_2 \rightarrow NH_3$$

   a) Balance the chemical equation.

   b) Find out the total number of atoms of the same type in both the reactants and the products.

   c) If 28 g of nitrogen combines with 6 g of hydrogen, find out the mass of ammonia formed. (Hint : Atomic mass H=1u N=14u)

2. $C + 4HNO_3 \rightarrow 2H_2O + CO_2 + 4NO_2$

   a) Find out and mark the oxidation number of carbon in this reaction.

   b) What happens to the oxidation number of carbon in this reaction?

   c) What happens to carbon-oxidation or reduction?

   d) What are the oxidising and reducing agents in this reaction?

3. Find out the oxidation number of sulphur in the following compounds.

   (Hint : Oxidation number H = +1, O = –2)

   a) SO_2 b) SO_3 c) H_2SO_3 d) H_2SO_4

4. Certain statements are given below. Write whether they are true or false.

a) The process involving an increase in oxidation number is oxidation.

b) The process involving a decrease in oxidation number is oxidation.

c) In a chemical reaction, oxidising agent undergoes reduction.

d) In a chemical reaction, oxidising agent undergoes oxidation.

5. Balance the chemical equations given below.

   a) $SO_2 + O_2 \rightarrow SO_3$ b) $H_2O_2 \rightarrow H_2O + O_2$

   c) $CH_4 + O_2 \rightarrow H_2O + CO_2$ d) $Fe + HCl \rightarrow FeCl_2 + H_2$

6. Two chemical reactions are given below. Find out the oxidation number of atoms and check whether these reactions are redox reactions.

   a) $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$ b) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

7. The gaseous fuel carbon monoxide burns in oxygen to form carbon dioxide.

   a) Write the balanced equation of this chemical reaction.

   b) Is this a redox reaction? Why?

   c) What is the oxidising agent in this reaction? What is the reducing agent?

8. Analyse the chemical equation given below.

$$Ca + 2HCl \rightarrow CaCl_2 + H_2$$

a) Mark the oxidation number of atoms before and after the chemical reaction.
b) Which atom undergoes oxidation?
c) Which atom undergoes reduction?
d) What are the oxidising and reducing agents?

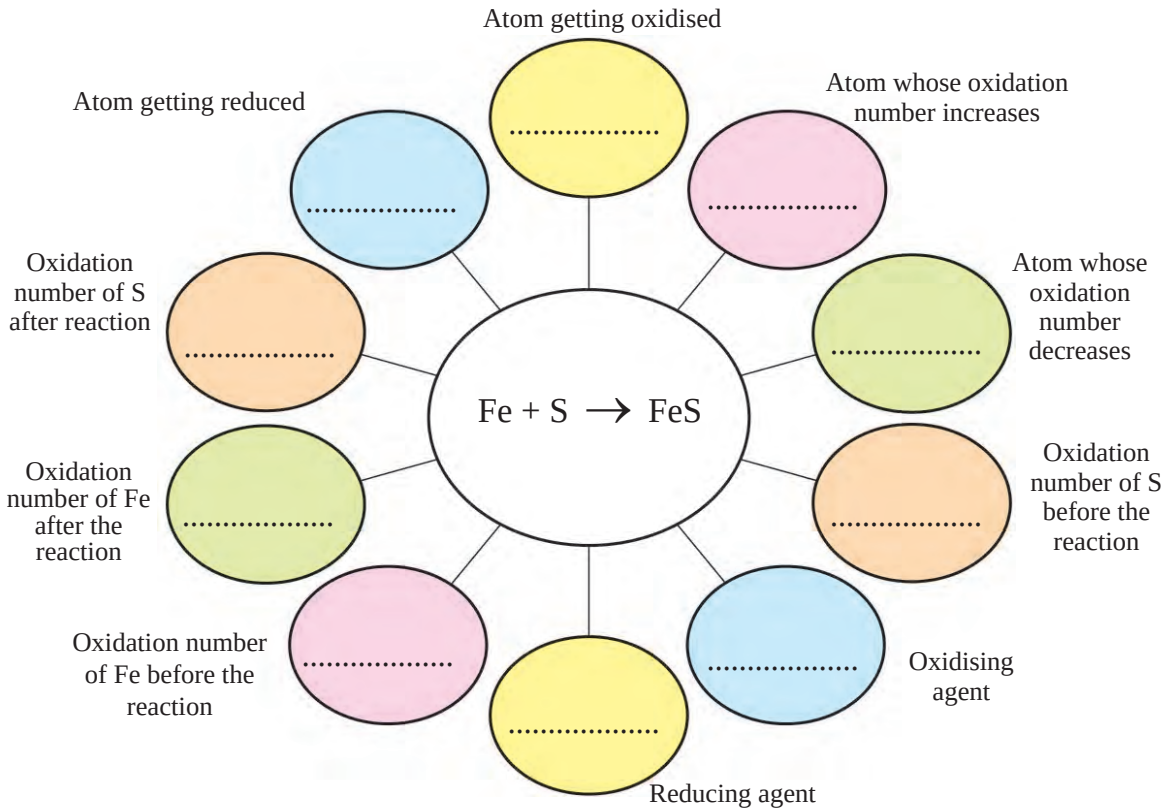
9. Analyse the chemical equations given below and find out whether they are redox reactions.

a) $NaOH + HCl \rightarrow NaCl + H_2O$

b) $H_2S + Cl_2 \rightarrow 2HCl + S$

10. A chemical reaction is given in the concept map below. Find out the oxidation number of each atom. On the basis of this, fill up the blanks.

(Hint : Valency S = 2, Fe = 2)



Extended Activities

1. Mix iron powder and sulphur in the mass ratio 7:4 in a china dish. Heat the mixture well. After sometime cool the china dish. Check whether iron can be separated using magnet.

   Examine whether the product dissolves in carbon disulphide.

   What is your inference?

   Write down the equation of the chemical reaction. Check whether it is a redox reaction.

2. Take some sand in a tray. Place calcium carbide (CaC_2) on it. Place some more sand on top of it. Place some ice cubes on the sand. Ignite the ice cubes carefully. What do you see?

   Calcium carbide reacts with water and forms acetylene (C_2H_2) gas. Acetylene is an inflammable gas.

   Write the chemical equation of the combustion.

   Check whether it is a redox reaction.

3. Make a mixture of aluminium powder and powdered iodine crystals in the mass ratio 1 : 2. Make a heap of it in a china dish. Make a small hole at the top of the heap. Add one or two drops of water into the hole. What do you see?

   Here aluminium and iodine combine to form aluminium triiodide.

   The valency of Al = 3 I = 1

   a) Write the equation of the chemical reaction.

   b) Find out the oxidation number of each atom. Check whether it is a redox reaction.

4. Conduct a study tour to understand the importance of redox reactions in industry.