2 Physical and Chemical Changes

In the study of chemistry we come across two kinds of change— physical and chemical.

Physical Changes

A change in which no new substances are formed and which can be reversed by reversing the conditions is called a physical change.

The melting of ice, the freezing of water and the glowing of an electric bulb are some common examples of physical change. These changes are reversed by reversing the conditions. For example, ice when heated gives water, but water when cooled gives back ice. Similarly, on switching on the current, a bulb glows, but on switching off the current, the glow vanishes.

In all these cases, it is obvious that no new substances are formed and the mass of the substance also does not change.

Chemical Changes

A change in which new substances are formed and which cannot be reversed by reversing the conditions is called a chemical change.

The burning of coal or wood, the rusting of iron, the curdling of milk, the charring of sugar, photosynthesis in plants and the digestion of food are common examples of chemical change. All these changes are permanent. Coal when burnt gives carbon dioxide. But the carbon dioxide when cooled does not give back coal. When sugar is heated, it turns brown and ultimately gets charred. (See Figure 2.1.) If you cool charred sugar, you cannot get back sugar in its original form. Once milk forms curd, the curd cannot give back milk. You cannot reverse any of these changes by reversing the conditions. In every case, new substances are formed. As a result, the mass of any individual substance changes. The mass of coal decreases when it burns and that of iron increases when it rusts. However, we will soon learn that the total mass of all the substances taking part in a chemical change remains the same before and after the change.

Table 2.1 Differences between physical and chemical changes

Physical change	Chemical change
1. A physical change is temporary.	A chemical change is permanent.
2. A physical change is reversible.	A chemical change is irreversible.

Fig. 2.1 Sugar gets charred on being heated—the black residue is carbon.

Physical change	Chemical change
3. No new substances are formed after a physical change.	New substances are formed after a chemical change.
4. After a physical change, the mass of the substance does not change.	After a chemical change, the mass of any individual substance changes.

Atoms rearrange themselves during a chemical change

Why are new substances formed in a chemical change? It is because the atoms rearrange themselves in such a change.

When burnt in air, carbon forms carbon dioxide

During the burning of coal, the carbon of coal combines with the oxygen of air to form carbon dioxide.

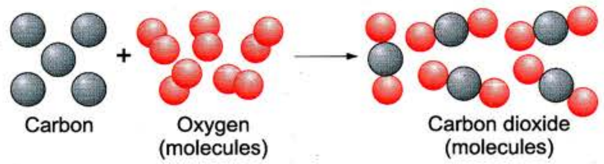

Fig. 2.2 The atoms of carbon and oxygen rearrange themselves to form carbon dioxide.

When burnt in air, hydrogen forms water Again, the atoms contained in the molecules of hydrogen and oxygen rearrange themselves.

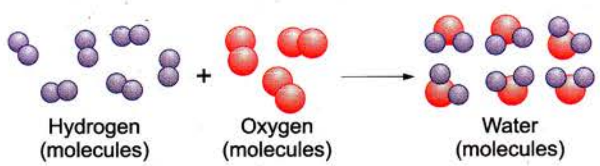

Fig. 2.3 The atoms of hydrogen and oxygen rearrange themselves to form water.

If you could count the atoms of each kind before and after the chemical change, you would find that the number of atoms of each element remains the same.

So, the mass of the substances, taken together, before and after a chemical change also remains the same. This is in accordance with the law of conservation of mass, which is stated as follows.

> Matter can neither be created nor destroyed, so the total quantity of matter, i.e., the total mass, before and after a change remains the same.

If you take 1 g of hydrogen and 8 g of oxygen and kindle the mixture, 9(= 1 + 8) g of water will be formed. All the hydrogen and oxygen will appear to have disappeared. But never think that they are destroyed. They have actually been changed into a new substance, water, which is different from hydrogen or oxygen.

Chemical Changes are Represented by Equations

You know that an element is represented by a symbol and a compound, by a formula. A chemical change is represented by an equation called a chemical equation. For example, the burning of carbon in oxygen to form carbon dioxide is represented by the following equation.

$$\underbrace{C + O_2}_{\text{reactants}} \rightarrow \underbrace{CO_2}_{\text{product}}$$

The substances that react among themselves are called reactants and those that are formed are called products.

Remember that *no atoms are lost or gained in a chemical reaction—the atoms only rearrange themselves*.

> A chemical equation in which the number of atoms of each element on the reactant side is the same as that on the product side is called a balanced chemical equation.

For example, the equation written above for the formation of carbon dioxide is a balanced chemical equation.

How to balance a chemical equation

You can balance an equation in the following steps.

Step 1 Write down the symbols and formulae of the reactants on the left-hand side and those of the products on the right-hand side of an arrow.

Step 2 Count the atoms of each kind on both sides of the arrow.

Step 3 Make the number of atoms of each kind equal on both sides by using proper coefficients.

Showing gases and precipitates on the product side by arrows

Any gases evolved in a reaction are shown by arrows pointing upwards in the equation and any precipitates, by arrows pointing downwards.

$$CaCO_3 \xrightarrow{heat} CaO + CO_2 \uparrow$$

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

EXAMPLE 1 *Hydrogen combines with chlorine to form hydrogen chloride. Write a balanced chemical equation for the reaction.*

Solution

Step 1 The reactants and the products are written as follows.

$$H_2 + Cl_2 \rightarrow HCl$$

Step 2 The atom count shows that the equation is not balanced.

Element	Number of atoms	
	LHS	RHS
H	2	1
Cl	2	1

Step 3 Place the coefficient 2 before the product.

$$H_2 + Cl_2 \rightarrow 2HCl$$

Step 4 The numbers of atoms on the two sides are now as follows.

Element	Number of atoms	
	LHS	RHS
H	2	2
Cl	2	2

The numbers tally.

Therefore, the balanced chemical equation for the given reaction is

$$H_2 + Cl_2 \rightarrow 2HCl$$

EXAMPLE 2 *Hydrogen combines with oxygen to form water. Write a balanced chemical equation for the reaction.*

Solution

Step 1 Write down the reactants and the products.

$$\underset{\text{hydrogen}}{H_2} + \underset{\text{oxygen}}{O_2} \rightarrow \underset{\text{water}}{H_2O}$$

Step 2 Count the number of atoms of each element on both sides.

Element	Number of atoms	
	LHS	RHS
H	2	2
O	2	1

The atom count shows that the equation is not balanced.

Step 3 To balance the number of oxygen atoms on both sides, place the coefficient 2 before H_2O.

$$H_2 + O_2 \rightarrow 2H_2O$$

Step 4 Again count the atoms of each element on both sides.

Element	Number of atoms	
	LHS	RHS
H	2	4
O	2	2

The atom count shows that the equation is still unbalanced.

Step 5 To balance the number of hydrogen atoms on both sides, place the coefficient 2 before H_2 on the LHS.

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

Step 6 Tally the number of atoms of each element on both sides.

Element	Number of atoms	
	LHS	RHS
H	4	4
O	2	2

The numbers tally. Therefore, the balanced chemical equation for the reaction is

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

EXAMPLE 3 *When ignited, a piece of magnesium burns in air to form magnesium oxide. Write a balanced chemical equation for the reaction.*

Solution Let us now see if we can balance a chemical equation without writing the steps so elaborately.

The reactants and the product may be written as follows.

$$Mg + O_2 \rightarrow MgO$$

Balance O: $Mg + O_2 \rightarrow 2MgO$

Balance Mg: $2Mg + O_2 \rightarrow 2MgO$

Therefore, the balanced chemical equation for the reaction is

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

EXAMPLE 4 *On being strongly heated, potassium chlorate ($KClO_3$) gives potassium chloride and oxygen. Write a balanced chemical equation for the reaction.*

Solution The reactant and the products can be written as follows.

$$KClO_3 \rightarrow KCl + O_2$$

Balance O:

$$2KClO_3 \rightarrow KCl + 3O_2$$

Balance K and Cl:

$$2KClO_3 \rightarrow 2KCl + 3O_2$$

Hence, the balanced chemical equation is

$$2KClO_3 \rightarrow 2KCl + 3O_2$$

Types of Chemical Reactions

Among the different types of chemical reactions, the combination and decomposition reactions are the ones which are the most important.

Combination Reactions

In a combination reaction, two or more reactants add up to form a product.

Some examples are given below.

The burning of carbon

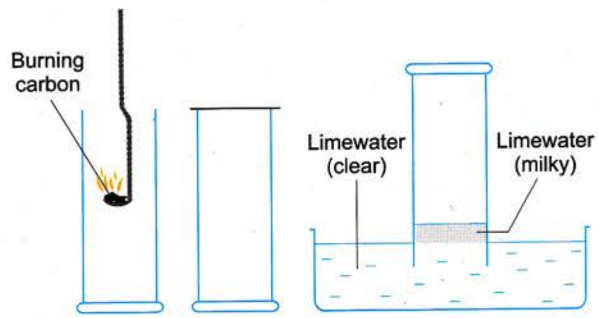

Fig. 2.4 When burnt in air, carbon forms carbon dioxide.

Burn some charcoal (carbon) in a deflagrating spoon. Introduce the spoon into an open gas jar near the mouth of the jar so that the burning charcoal gets a clear supply of air. Close the mouth of the jar with a lid when all the carbon has burnt. Invert the jar and place it in a trough containing clear limewater and open its mouth inside the liquid. The limewater rises in the jar and becomes milky. This proves that carbon dioxide is formed as it is a property of this gas to turn limewater milky.

So, during burning, carbon reacts with oxygen of the air to form carbon dioxide.

$$\underset{\text{carbon (black)}}{C} + \underset{\text{oxygen (colourless)}}{O_2} \longrightarrow \underset{\text{carbon dioxide (colourless)}}{CO_2}$$

The burning of magnesium

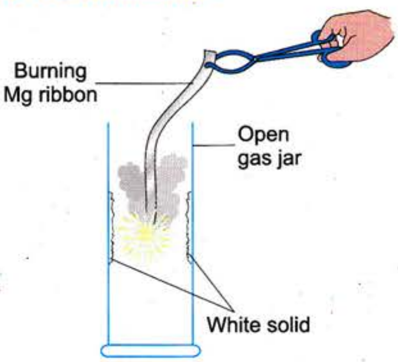

Fig. 2.5 The burning of magnesium in air

Magnesium is a silvery white metal. When ignited in air, say in an open gas jar, it burns with a dazzling white flame. Magnesium oxide, the product, deposits as a white smoky solid on the walls of the jar. Magnesium combines with the oxygen of the air during burning to form the product.

$$\underset{\text{magnesium}}{2Mg} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\substack{\text{magnesium oxide}\\ \text{(white solid)}}}{2MgO}$$

The combination of hydrogen and oxygen

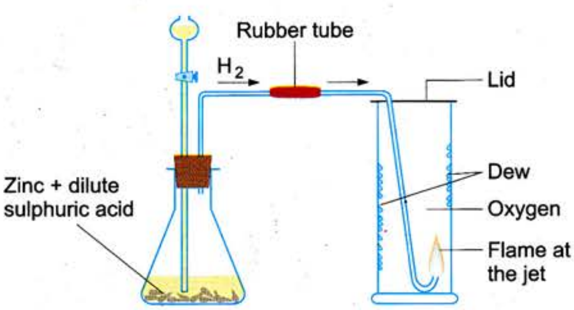

Fig. 2.6 When kindled, hydrogen burns in oxygen to form water.

When kindled, hydrogen burns in oxygen (or air) to form water. Prepare hydrogen by the action of dilute sulphuric acid on zinc metal. Kindle the gas at the jet and introduce the jet into a gas jar full of oxygen. Hydrogen continues to burn with a longer flame. Water vapours condense in the form of dew on the inner walls of the jar.

$$\underset{\text{hydrogen}}{2H_2} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{water}}{2H_2O}$$

The combination of hydrogen and chlorine

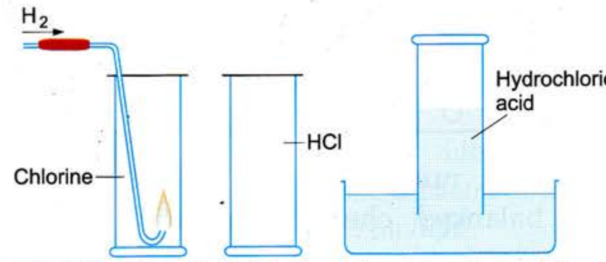

Fig. 2.7 When kindled, hydrogen burns in chlorine to form hydrogen chloride.

Chlorine is a greenish yellow gas. Ignite hydrogen in a jar full of chlorine and close the jar with a lid. Hydrogen burns in chlorine to form a colourless gas, hydrogen chloride. Invert the jar of hydrogen chloride in a trough of water and remove the lid. The water rises to a great height in the jar, showing that hydrogen chloride is highly soluble in water. The solution of the gas in water is hydrochloric acid. It turns blue litmus red. (Acids turn blue litmus red.)

$$\underset{\substack{\text{hydrogen}\\ \text{(colourless)}}}{H_2} + \underset{\substack{\text{chlorine}\\ \text{(greenish yellow)}}}{Cl_2} \longrightarrow \underset{\substack{\text{hydrogen chloride}\\ \text{(colourless)}}}{2HCl}$$

The combination of iron and sulphur

Take an intimate mixture of iron filings and sulphur powder. Under a magnifying glass, you will observe the grey particles of iron and the yellow ones of sulphur. On heating the mixture, however, you will observe only one kind of particles—grey in colour.

This is because iron combines with sulphur, when heated, to form iron(II) sulphide.

$$\underset{\substack{\text{iron}\\ \text{(grey)}}}{Fe} + \underset{\substack{\text{sulphur}\\ \text{(yellow)}}}{S} \xrightarrow{\text{heat}} \underset{\substack{\text{iron(II) sulphide}\\ \text{(grey)}}}{FeS}$$

The combination of carbon dioxide and water

Pass carbon dioxide through water for some time. The water now turns blue litmus wine red, showing that it contains an acid.

Carbon dioxide dissolves to a small extent in water to form carbonic acid.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

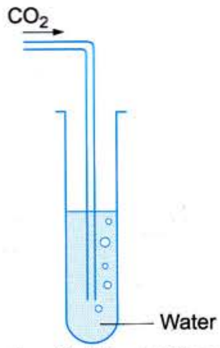

Fig. 2.8 Carbon dioxide combines with water to form carbonic acid.

Aerated or carbonated water Carbon dioxide is highly soluble in water under pressure. The resulting solution is called aerated or carbonated water. Mixed with sweetening and flavouring agents, it gives you an aerated, or a carbonated, soft drink.

Neither water nor carbon dioxide is sour, but the drink is sour because it contains carbonic acid.

Decomposition Reactions

> In a decomposition reaction, one substance breaks down into two or more simpler substances.

Some examples are given below.

Decomposition of water

Water mixed with a very small amount of an acid breaks down into hydrogen and oxygen when electricity is passed through it.

> Electrolysis is a process in which a substance is decomposed, or broken down into simpler substances, by passing an electric current through it.

Pour some water, mixed with a few drops of dilute sulphuric acid, into a beaker. Remove the insulation from the ends of two thick wires. Introduce them into the beaker as shown in Figure 2.9. Invert two test tubes full of water over the naked wires. Connect the wires to a battery and pass current for some time. Gases start collecting in the test tubes. You will observe that the volume of the gas collected in test tube A is twice that of the gas collected in B.

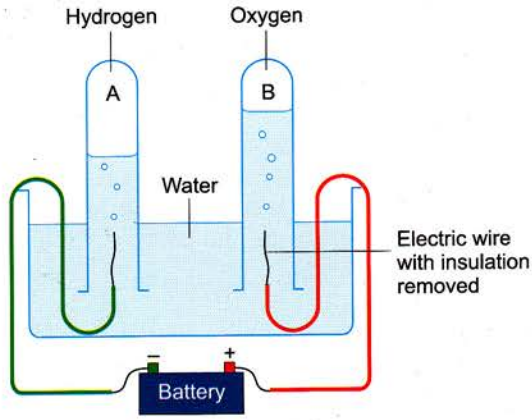

Fig. 2.9 The electrolysis of water

Disconnect the battery when there is enough gas in the test tubes. Cork the test tubes inside the water and take them out. Perform the following experiments.

Test tube A Bring a lighted match near the mouth of the tube and open its mouth. The gas burns with a 'pop' and so it is hydrogen.

Test tube B Bring a glowing matchstick near the mouth of the test tube and remove the cork. The matchstick gets lighted. So the gas is oxygen.

The experiment shows that

(i) water is decomposed into hydrogen and oxygen, and

(ii) the volume ratio of hydrogen and oxygen in water is 2:1.

$$\underset{\text{water}}{H_2O} \xrightarrow{\text{electrolysis}} \underset{\text{hydrogen}}{2H_2\uparrow} + \underset{\text{oxygen}}{O_2\uparrow}$$

The decomposition of baking soda

Sodium hydrogencarbonate ($NaHCO_3$) is called baking soda. On strong heating, baking soda decomposes into sodium carbonate, water (vapour) and carbon dioxide.

$$\underset{\text{sodium hydrogencarbonate}}{2NaHCO_3} \xrightarrow{\text{heat}} \underset{\text{sodium carbonate}}{Na_2CO_3} + \underset{\text{water vapour}}{H_2O\uparrow} + \underset{\text{carbon dioxide}}{CO_2\uparrow}$$

The decomposition of potassium chlorate

When strongly heated, potassium chlorate gives potassium chloride and oxygen.

$$\underset{\text{potassium chlorate}}{2KClO_3} \xrightarrow{\text{heat}} \underset{\text{potassium chloride}}{2KCl} + \underset{\text{oxygen}}{3O_2\uparrow}$$

Displacement Reactions

In a displacement reaction, one element displaces another from its compound and takes its place therein.

Some common examples are given below.

The displacement of hydrogen from water by a metal

When placed in steam, a burning magnesium ribbon continues to burn, forming magnesium oxide and hydrogen.

$$\underset{\text{magnesium}}{Mg} + \underset{\text{water (steam)}}{H_2O} \rightarrow \underset{\text{magnesium oxide}}{MgO} + \underset{\text{hydrogen}}{H_2\uparrow}$$

In this reaction, a magnesium atom displaces two hydrogen atoms and takes their place.

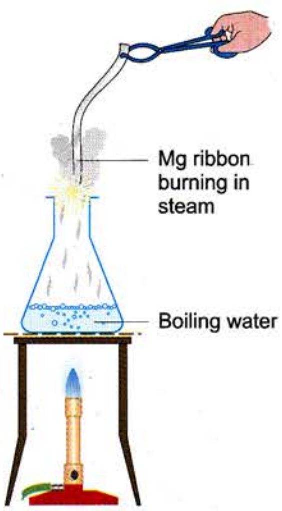

Fig. 2.10 Magnesium burning in steam

The displacement of copper from copper sulphate by iron

When an iron knife or nail is placed in a copper sulphate solution, there is a brown-red deposit of copper over the iron object.

After some time, the blue colour of the solution changes to green, owing to the formation of iron(II) sulphate.

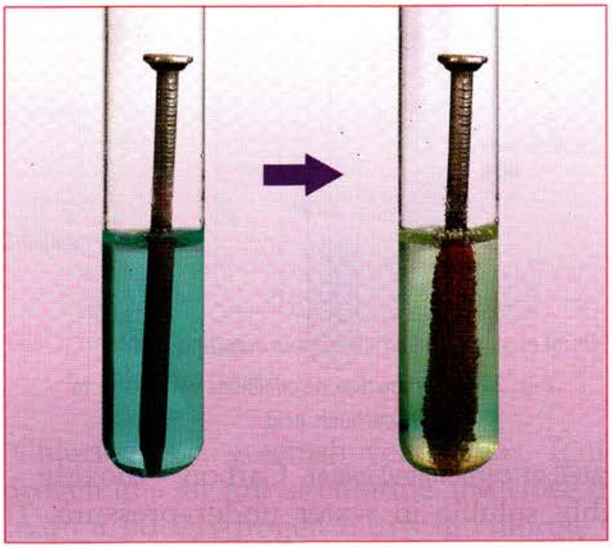

Fig. 2.11 Iron displaces copper from a copper sulphate solution.

$$\underset{\substack{\text{iron}\\\text{(grey)}}}{Fe} + \underset{\substack{\text{copper sulphate}\\\text{solution (blue)}}}{CuSO_4} \rightarrow \underset{\substack{\text{copper}\\\text{(brown-red deposit)}}}{Cu\downarrow} + \underset{\substack{\text{iron(II) sulphate}\\\text{solution (green)}}}{FeSO_4}$$

Double Decomposition Reactions

In a double decomposition reaction, the positive and negative radicals of two reactants are exchanged, leading to the precipitation of a product.

Double decomposition reactions are very fast, and the precipitate is formed as soon as the reactants come in contact. (See Figure 2.12.) Quite often the colour of the precipitate is different from that of the reactants. The following are some common examples.

The reaction between silver nitrate and sodium chloride

When an aqueous solution of silver nitrate is mixed with that of sodium chloride, a white precipitate of silver chloride is formed. The sodium nitrate formed remains in solution.

$$\underset{\substack{\text{silver nitrate}\\\text{solution}\\\text{(colourless)}}}{AgNO_3} + \underset{\substack{\text{sodium chloride}\\\text{solution}\\\text{(colourless)}}}{NaCl} \rightarrow \underset{\substack{\text{silver chloride}\\\text{precipitate}\\\text{(white)}}}{AgCl\downarrow} + \underset{\substack{\text{sodium nitrate}\\\text{solution}\\\text{(colourless)}}}{NaNO_3}$$

$$\begin{matrix} Ag^+ & & Na^+ \\ & \times & \\ NO_3^- & & Cl^- \end{matrix}$$

(exchange of radicals)

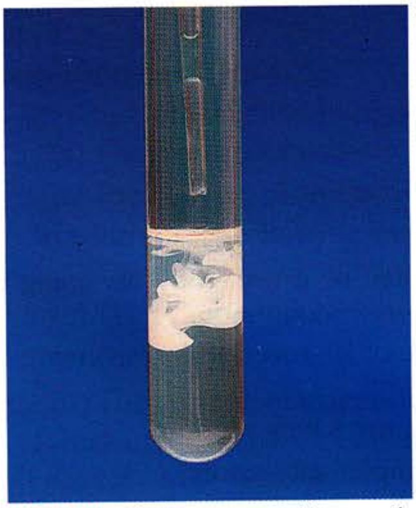

Fig. 2.12 Double decomposition reactions occur very fast.

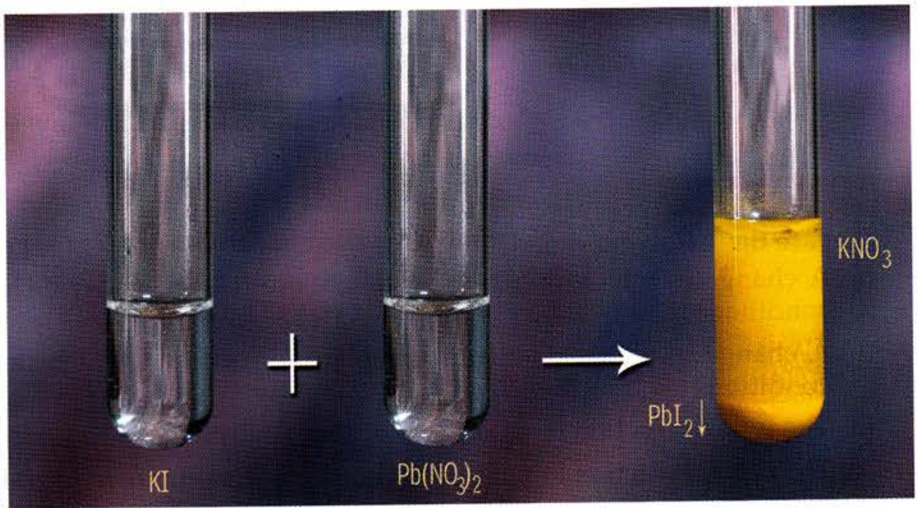

Fig. 2.13 An example of a double decomposition reaction

The reaction between barium chloride and sodium sulphate

When a solution of barium chloride is mixed with that of sodium sulphate, a white precipitate of barium sulphate is formed along with a solution of sodium chloride.

The solution initially appears white but gradually becomes colourless as the precipitate settles down.

$$\underset{\substack{\text{barium chloride}\\\text{solution}\\\text{(colourless)}}}{BaCl_2} + \underset{\substack{\text{sodium sulphate}\\\text{solution}\\\text{(colourless)}}}{Na_2SO_4} \rightarrow \underset{\substack{\text{barium sulphate}\\\text{precipitate}\\\text{(white)}}}{BaSO_4\downarrow} + \underset{\substack{\text{sodium chloride}\\\text{solution}\\\text{(colourless)}}}{2NaCl}$$

The reaction between potassium iodide and lead nitrate

When a solution of potassium iodide is mixed with one of lead nitrate, a yellow precipitate of lead iodide is formed along with a solution of potassium nitrate (Figure 2.13).

The solution initially appears yellow but gradually becomes colourless as the precipitate settles down.

$$\underset{\substack{\text{potassium}\\\text{iodide solution}\\\text{(colourless)}}}{2KI} + \underset{\substack{\text{lead nitrate solution}\\\text{(colourless)}}}{Pb(NO_3)_2} \rightarrow \underset{\substack{\text{lead iodide}\\\text{(yellow)}}}{PbI_2} + \underset{\substack{\text{potassium nitrate}\\\text{solution}\\\text{(colourless)}}}{2KNO_3}$$

Points to Remember

- A change in which no new substances are formed and which can be reversed by reversing the conditions is called a *physical change*.
- A change in which new substances are formed and which cannot be reversed by reversing the conditions is called a *chemical change*.
- Chemical changes are represented by *chemical equations*.
- A chemical equation in which the number of atoms of each element on the reactant side is the same as that on the product side is called a *balanced chemical equation*.
- An equation is balanced by tallying the number of atoms of each element on both sides of the equation.
- When two or more substances add up to form a product, the reaction is called a *combination reaction*.
- When one substance breaks down into two or more simpler substances, the reaction is called a *decomposition reaction*.
- When one element displaces another from its compound and takes its place therein, the reaction is called a *displacement reaction*.
- A reaction in which the positive and negative radicals of two reactants are exchanged, leading to the precipitation of a product, is called a *double decomposition reaction*.

Exercise

Short-Answer Questions

1. What are the following called?
   (a) A change in which no new substances are formed and which can be reversed by reversing the conditions
   (b) A change in which new substances are formed and which cannot be reversed by reversing the conditions
   (c) The type of reaction in which two or more substances add up to form a new product
   (d) The type of reaction in which a substance is broken down into simpler substances
2. Which of the following are physical changes and which are chemical changes?
   (a) The glowing of an electric bulb
   (b) The melting of ice
   (c) The burning of carbon
   (d) The digestion of food
   (e) The freezing of water
   (f) The curdling of milk
3. What would you observe in the following cases?
   (a) Carbon dioxide is passed through limewater.
   (b) An ignited magnesium ribbon is placed in steam.
   (c) A jet of hydrogen is lit and introduced into a gas jar full of oxygen.
   (d) An iron knife is placed in a solution of copper(II) sulphate.
4. Give balanced chemical equations representing the following reactions.
   (a) On being heated with chlorine, iron forms iron(III) chloride.
   (b) Carbon dioxide dissolves in water under pressure to form carbonic acid.
   (c) When burnt in oxygen, magnesium forms magnesium oxide.
   (d) Hydrogen reacts with chlorine in sunlight to give hydrogen chloride.
   (e) When heated with sulphur, iron forms iron(II) sulphide.
5. Balance the following chemical equations.
   (a) $Ca + N_2 \rightarrow Ca_3N_2$
   (b) $Mg + HCl \rightarrow MgCl_2 + H_2$
   (c) $NaNO_3 \rightarrow NaNO_2 + O_2$
   (d) $KClO_3 \rightarrow KCl + O_2$
   (e) $H_2O \rightarrow H_2 + O_2$
   (f) $Fe + O_2 \rightarrow Fe_2O_3$

Long-Answer Questions

1. Mention three differences between physical and chemical changes.
2. Discuss, with an example, the rearrangement of atoms in a chemical change.
3. Describe the electrolysis of water.

Objective Questions

Choose the correct option.

1. In which of the following cases will the mass of the substance change?
   (a) The freezing of water
   (b) The burning of wood
   (c) The glowing of an electric bulb
   (d) The melting of ice
2. In which of the following changes will the atoms not rearrange themselves?
   (a) The combination of hydrogen with chlorine to form hydrogen chloride
   (b) The evaporation of water
   (c) The curdling of milk
   (d) The burning of magnesium
3. Which of the following equations represents a displacement reaction?
   (a) $2H_2 + O_2 \rightarrow 2H_2O$
   (b) $N_2 + 3H_2 \rightarrow 2NH_3$
   (c) $2H_2O \rightarrow 2H_2 + O_2$
   (d) $Mg + H_2O \rightarrow MgO + H_2\uparrow$
4. Which of the following equations represents a double decomposition reaction?
   (a) $H_2 + Cl_2 \rightarrow 2HCl$
   (b) $2NaNO_3 \rightarrow 2NaNO_2 + O_2\uparrow$
   (c) $AgNO_3 + NaCl \rightarrow AgCl\downarrow + NaNO_3$
   (d) $2H_2 + O_2 \rightarrow 2H_2O$

Fill in the blanks.

1. When ignited in air, magnesium burns with a dazzling ...... flame. (white/yellow)
2. A ...... of iron and sulphur contains grey and yellow particles. (mixture/compound)
3. Iron(II) sulphide shows only one kind of particles that are ...... in colour. (grey/yellow)
4. The volume ratio of the hydrogen and oxygen obtained from water is .... (1:2/2:1)
5. On being heated, baking soda undergoes ...... to give sodium carbonate, water vapour and carbon dioxide. (decomposition/double decomposition)
6. A ...... precipitate is formed when an aqueous solution of silver nitrate is mixed with that of sodium chloride. (white/red)

Indicate which of the following statements are true and which are false.

1. Coal gives carbon dioxide when burnt, and carbon dioxide gives back coal when cooled.
2. The mass of iron decreases when rusted.
3. On being strongly heated, potassium chlorate gives potassium chloride and oxygen.
4. The electrolysis of water involves a combination reaction.
5. An exchange of radicals between two reactants takes place in a double decomposition reaction.

❑