1 Hydrogen

Hydrogen is the lightest element known. It was first prepared by Robert Boyle by the action of dilute sulphuric acid on iron nails. Cavendish studied the gas and called it inflammable air, as the gas burns when kindled.

Occurrence and Preparation of Hydrogen

Occurrence of Hydrogen

The stars (including our sun) are mainly composed of hydrogen. In fact, hydrogen is the most abundant element in the universe. On the earth, however, hydrogen occurs in very small amounts in the free state—in the air, in volcanic gases and in the earth's crust.

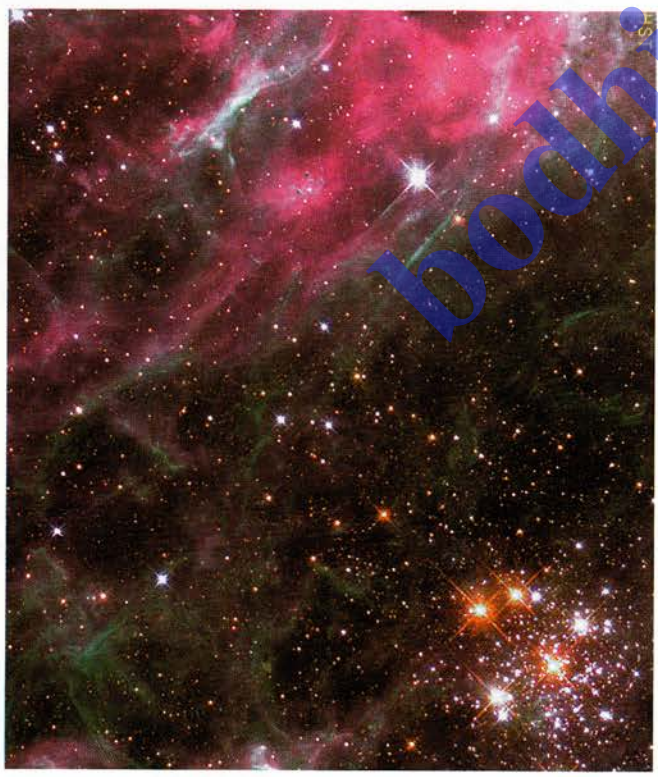

Fig. 1.1 The stars are mainly composed of hydrogen.

But, there is plenty of hydrogen on earth in combination with other elements, i.e., as part of compounds. Water is an important source of hydrogen. Every nine parts by mass of water contains one part of hydrogen. In combination with carbon, hydrogen is present in natural gas and petroleum, as well as, in all living things. Acids and alkalis also contain hydrogen.

Preparing Hydrogen

Since hydrogen is available as part of compounds, it can be obtained by displacement from a compound by a more active element. You have learnt in the previous class that in a displacement reaction, one element displaces another from its compound, and a new compound is formed.

A reactive metal like sodium, magnesium, zinc or iron displaces hydrogen from water, an acid (like dilute hydrochloric or sulphuric acid) or an alkali.

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

$$Mg + \underset{\text{steam}}{H_2O} \rightarrow MgO + H_2$$

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

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$

$$Zn + 2NaOH \rightarrow Na_2ZnO_2 + H_2$$

Hydrogen is liberated when an electric current is passed through water containing a small amount of sulphuric acid.

$$2H_2O \xrightarrow[\text{current}]{\text{electric}} 2H_2 + O_2$$

The laboratory method

Principle Hydrogen is prepared in the laboratory by the action of dilute hydrochloric or sulphuric acid on granulated zinc.

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

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2\uparrow$$

As the gas is almost insoluble in water, it is collected by the displacement of water.

Procedure A conical flask is fitted with a thistle funnel and a delivery tube. The other end of the delivery tube passes through a beehive shelf placed in a water trough. A gas jar full of water is inverted over the beehive shelf. Some granulated zinc is placed in the conical flask. Dilute hydrochloric or sulphuric acid is added through the thistle funnel till the lower end of the funnel dips in the liquid. Hydrogen then begins to evolve. The gas is collected by the downward displacement of water. It is not collected by the downward displacement of air since a mixture of hydrogen and air is explosive.

Initially, the air inside the flask and the delivery tube is driven out. So, whatever is collected in the first one or two jars is air, and is rejected. The gas collected afterwards is hydrogen.

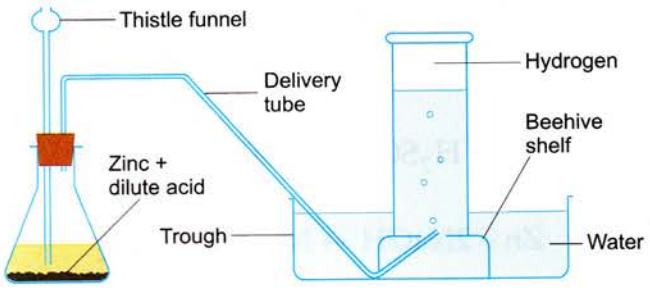

Fig. 1.2 The laboratory preparation of hydrogen

Properties of Hydrogen

Physical Properties

1. Hydrogen is a colourless and odourless (having no smell) gas.
2. It is the lightest element and the lightest gas known. It is 14.6 times lighter than air.
3. It is almost insoluble in water.

Chemical Properties

1. Reaction with oxygen (or air) When kindled, hydrogen burns in air or oxygen to form water.

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

A large amount of heat is produced in this reaction. So, a mixture of hydrogen and oxygen may explode.

2. Reaction with chlorine When kindled, hydrogen burns in chlorine to form hydrogen chloride gas. Also, a mixture of hydrogen and chlorine, when placed in sunlight, explodes to form the same product.

$$H_2 + Cl_2 \rightarrow \underset{\text{hydrogen chloride}}{2HCl\uparrow}$$

Hydrogen chloride gas can be dissolved in water to obtain hydrochloric acid.

3. Reaction with sulphur Hydrogen reacts with molten sulphur to give hydrogen sulphide gas, which smells like rotten eggs.

$$H_2 + \underset{\text{(molten)}}{S} \rightarrow \underset{\text{hydrogen sulphide}}{H_2S\uparrow}$$

4. Reaction with nitrogen Hydrogen reacts with nitrogen, only under special conditions, to form an appreciable amount of ammonia.

$$3H_2 + N_2 \underset{\text{Fe catalyst}}{\overset{500°C/200\,atm}{\rightleftharpoons}} \underset{\text{ammonia}}{2NH_3\uparrow}$$

The ammonia gas formed, in turn, decomposes back to hydrogen and nitrogen. So, this reaction occurs both ways. Such reactions are called reversible reactions.

5. Reactions with some metal oxides When passed over some hot metal oxides like zinc oxide, lead oxide, copper oxide and iron oxides, hydrogen gas converts them into the corresponding metals.

$$ZnO + H_2 \xrightarrow{\text{heat}} Zn + H_2O$$

$$PbO + H_2 \xrightarrow{\text{heat}} Pb + H_2O$$

$$CuO + H_2 \xrightarrow{\text{heat}} Cu + H_2O$$

$$FeO + H_2 \xrightarrow{\text{heat}} Fe + H_2O$$

$$Fe_2O_3 + 3H_2 \xrightarrow{\text{heat}} 2Fe + 3H_2O$$

The oxides of metals like potassium, calcium, sodium and magnesium are not converted into the metals.

Hydrogen is a reducing agent

The addition of hydrogen to or the removal of oxygen from a substance is called reduction. On the other hand, the addition of oxygen to or the removal of hydrogen from a substance is called oxidation. Also, a substance causing reduction is known as a reducing agent and one causing oxidation is called an oxidising agent.

You have just seen that hydrogen

- adds itself to oxygen, chlorine, sulphur and nitrogen, and
- removes oxygen from some metal oxides.

Thus, hydrogen is a reducing agent. It reduces

O to H_2O Cl to HCl S to H_2S N to NH_3	by adding H

ZnO to Zn PbO to Pb CuO to Cu FeO to Fe Fe_2O_3 to Fe	by removing O

You will learn more about reduction and oxidation in a later chapter.

Reactions of Metals with Water

All metals do not have similar reactivities. Some are more reactive than others. Metals may, therefore, be arranged in order of activity, and the series is called the activity series of metals. As many of the chemical reactions of hydrogen are similar to those of metals, hydrogen is also included in the series. The activity of metals decreases as one goes down the series.

A more active metal displaces a less active metal from its compound. Similarly, metals that are more active than hydrogen, i.e., higher than hydrogen in the activity series, can displace hydrogen from water. Also, the greater the activity of the metal, the more vigorously does it react with water.

Activity series
K
Na
Ca
Mg
Al
Zn
Fe
Sn
Pb
H
Cu
Hg
Ag
Au

Potassium, sodium and calcium react with water in cold conditions, displacing hydrogen from it and forming their hydroxides.

$$2K + 2H_2O \rightarrow \underset{\text{potassium hydroxide}}{2KOH} + H_2\uparrow$$

$$2Na + 2H_2O \rightarrow \underset{\text{sodium hydroxide}}{2NaOH} + H_2\uparrow$$

$$Ca + 2H_2O \rightarrow \underset{\text{calcium hydroxide}}{Ca(OH)_2} + H_2\uparrow$$

Magnesium reacts with steam to form magnesium oxide and hydrogen.

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

When aluminium comes in contact with water, it forms a protective layer of aluminium hydroxide over itself. The aluminium hydroxide thus formed does not allow the metal to react further with water.

Zinc and iron displace hydrogen from water when steam is passed over the red-hot metal.

$$\underset{\text{(red hot)}}{Zn} + \underset{\text{steam}}{H_2O} \rightarrow \underset{\text{zinc oxide}}{ZnO} + H_2\uparrow$$

$$\underset{\text{(red hot)}}{3Fe} + \underset{\text{steam}}{4H_2O} \rightarrow \underset{\text{ferrosoferric oxide}}{Fe_3O_4} + 4H_2\uparrow$$

Metals such as copper, silver and gold, which are below hydrogen in the activity series, do not displace hydrogen from water.

Test for Hydrogen

Hydrogen burns with a characteristic sound, or 'pop'. This property is used as a test for hydrogen.

Uses of Hydrogen

1. For manufacturing ammonia

Hydrogen is used in large quantities to manufacture ammonia. As you know, when a mixture of hydrogen and nitrogen is passed over an iron catalyst at 500°C and 200 atm, ammonia is formed. (A catalyst is an element or a compound that hastens a reaction without taking part in it.) The process is known as Haber's process. Ammonia is used in large quantities in the manufacture of nitrogenous fertilisers.

2. For the hydrogenation of oils

Vegetable oils react with hydrogen in the presence of a catalyst (like nickel) to form solid fats. Such addition of hydrogen is called hydrogenation.

3. As a fuel

On the combustion of hydrogen, i.e., when hydrogen is burnt, heat is produced along with water.

$$2H_2 + O_2 \xrightarrow{\text{burning}} 2H_2O + \text{heat}$$

So, hydrogen can be used as a fuel. The product of the reaction is water, which does not pollute the environment. Hence, hydrogen is a clean fuel.

In fact, hydrogen produces the maximum heat among all the known fuels. It is used in rockets. However, it is not widely used as it is difficult to handle and store.

4. The oxyhydrogen flame

Hydrogen is used to produce an oxyhydrogen flame, which is employed for welding and cutting metals. The two gases—oxygen and hydrogen—passed through different pipes, mix at a point where the mixture is kindled. A high-temperature (2800°C) flame, called an oxyhydrogen flame, is produced. The metal melts at this temperature, enabling it to be cut or welded.

5. As a reducing agent

Hydrogen is a reducing agent in the laboratory and industry.

6. For filling balloons

As hydrogen is lighter than air, a balloon filled with hydrogen rises in the air and drifts in the wind. If a weather instrument is placed in it, the balloon can be used for studying weather conditions. At one time, such weather balloons were much in use. But the practice was stopped as such weather balloons often caught fire due to the inflammability of hydrogen. As helium—the next lightest gas—is available in plenty, it is preferred to hydrogen. Helium does not catch fire.

In the 1930s, airships using hydrogen to float were used for transport. But they were discontinued after the airship Hindenberg exploded in 1937, killing 36 people.

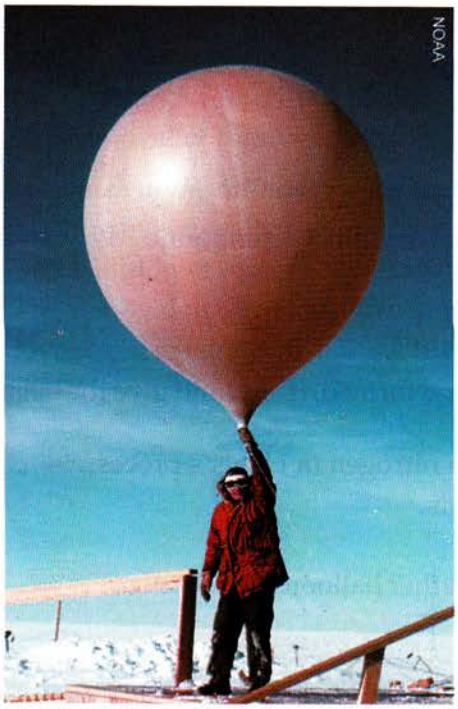

Fig. 1.3 A weather balloon

Fig. 1.4 Hydrogen is commonly used to fill balloons.

Points to Remember

- Hydrogen is the lightest and the most abundant element.
- It can be displaced from water or an acid by an active metal like sodium, magnesium, zinc or iron.
- Hydrogen is prepared in the laboratory by the action of dilute hydrochloric or sulphuric acid on granulated zinc. It is collected by the downward displacement of water.
- When kindled, hydrogen burns in oxygen to form water (H_2O), and in chlorine to form hydrogen chloride (HCl) gas.
- Hydrogen reacts with molten sulphur to form hydrogen sulphide (H_2S) gas.
- Hydrogen reacts with nitrogen under special conditions (500°C and 200 atm in the presence of an iron catalyst) to form ammonia.
- Hydrogen converts the oxides of metals like zinc, lead, iron and copper to the respective metals.
- The addition of hydrogen to or the removal of oxygen from a substance is called *reduction*.
- The addition of oxygen to or the removal of hydrogen from a substance is called *oxidation*.
- A substance causing reduction is known as a *reducing agent*, and one causing oxidation is called an *oxidising agent*.
- Metals more active than hydrogen displace it from water.
- Hydrogen is used (i) for manufacturing ammonia, (ii) for the hydrogenation of oils, (iii) as a fuel, (iv) for producing an oxyhydrogen flame, (v) as a reducing agent, and (vi) for filling balloons.

Exercise

Short-Answer Questions

1. Name the lightest element and the lightest gas known.
2. In a reaction, one element displaces another from its compound to form a new compound. What is such a reaction called?
3. By which method is hydrogen gas collected? Explain your answer.
4. How many times lighter or heavier than air is hydrogen?
5. When kindled, will hydrogen burn in oxygen? Name the compound formed, if any, and give the balanced equation for the reaction.
6. State the conditions under which hydrogen is made to react with nitrogen in Haber's process.
7. Name the catalyst commonly used in the manufacture of solid fats.
8. Why is hydrogen considered a clean fuel?
9. Give reasons why helium is preferred to hydrogen for filling weather balloons.

Long-Answer Questions

1. Describe how hydrogen is prepared in the laboratory.
2. Give three examples to show that hydrogen is a reducing agent.
3. Write a note on the oxyhydrogen flame.

Objective Questions

Choose the correct option.

1. Which of the following pairs of elements will react to give a gas which dissolves in water to form an acid?
   (a) Hydrogen and oxygen (b) Hydrogen and chlorine
   (c) Hydrogen and nitrogen (d) None of these
2. With which of the following elements will hydrogen react to give a gas that smells like rotten eggs?
   (a) Oxygen (b) Chlorine
   (c) Nitrogen (d) Sulphur
3. Which among the following metals reacts with water most vigorously?
   (a) Sodium (b) Magnesium
   (c) Zinc (d) Iron
4. Which of the following metals will not displace hydrogen from water?
   (a) Sodium (b) Potassium
   (c) Calcium (d) Copper

Fill in the blanks.

1. A reactive metal like potassium, sodium or calcium displaces _____ from water. (hydrogen/oxygen)
2. Complete the following equations and balance them.

   (a) $Zn + HCl \rightarrow$ _____ + _____

   (b) $Fe + H_2SO_4$ (dilute) $\rightarrow$ _____ + _____

   (c) $CuO +$ _____ $\rightarrow Cu + H_2O$

   (d) Fe (red hot) $+ H_2O$ (steam) $\rightarrow Fe_3O_4 +$ _____

   (e) Zn (red hot) $+ H_2O$ (steam) $\rightarrow$ _____ + _____

3. Lead oxide is _____ by hydrogen to lead. (oxidised/reduced)
4. Magnesium reacts with steam to form _____ and _____ . (magnesium oxide/magnesium hydroxide/oxygen/hydrogen)
5. The removal of hydrogen from a substance is called _____ . (oxidation/reduction)

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

1. Hydrogen is usually found in the free state.
2. The addition of oxygen to a substance is called reduction.
3. The removal of oxygen from a substance is called reduction.
4. Hydrogen cannot be used as a fuel.

❑