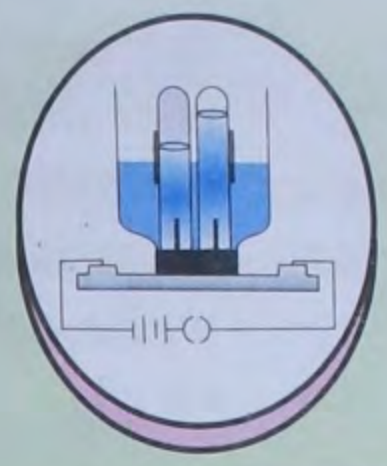
2 HYDROGEN



In This Chapter You Will Learn :

S.T ✓ Introduction

- *Discovery and occurrence*
- *General methods of preparation of hydrogen*
- *Laboratory preparation of hydrogen*
- *Properties and uses*

Symbol of hydrogen : H, ***Formula of hydrogen :*** H_2, ***Valency :*** 1, ***Atomic number :*** 1, ***Atomic mass :*** 1·00794 amu.

INTRODUCTION

Hydrogen is the *lightest* of all elements known to mankind. This gas was first prepared by **Robert Boyle** in 1672. **Henry Cavendish** studied the properties of hydrogen in 1776 and called it the *inflammable gas* due to its *combustible* nature. In 1783, **Lavoisier** named the gas "*hydrogen*" meaning *water producer*.

OCCURRENCE

In free state : Hydrogen is the most abundant element in the universe. The outer atmospheres of the sun and the stars consist largely of hydrogen. The outermost layer of the earth's atmosphere contains hydrogen, but in traces. On the earth, free hydrogen occurs in very small quantities, mainly in volcanic gases.

In combined state : *Hydrogen is much more common in the form of compounds. The most important compound of hydrogen is water,* which covers 70% of the earth's surface. Acids, alkalis, petroleum and natural gas, all are compounds containing hydrogen. Hydrogen is one of the main constituents of the compounds which form the body of the animal and vegetable matter.

Today hydrogen is widely seen as the mass fuel of the future, when there will be no petroleum or coal or gases acting as fuel.

Do You Know ?

There would have been no sunlight or heat if there were no hydrogen in the universe.

PREPARATION OF HYDROGEN

The principal sources of hydrogen on the earth are water, acids and alkalis. These compounds liberate the gas when they react with chemically active metals.

1. ***By the action of water or steam on metals***

   (a) From cold water : *The very active metals like sodium, potassium and*

calcium liberate hydrogen gas from cold water, the other product being a metallic hydroxide. Sodium and potassium react violently with water, while calcium reacts comparatively slowly.

Metal + Cold water → Metallic hydroxide + Hydrogen

$$2Na + 2H_2O \xrightarrow{\text{Fast}} \underset{\text{sodium hydroxide}}{2NaOH} + H_2$$

$$2K + 2H_2O \xrightarrow{\text{Fast}} \underset{\text{Potassium hydroxide}}{2KOH} + H_2$$

$$Ca + 2H_2O \xrightarrow{\text{Slow}} \underset{\text{Calcium hydroxide}}{Ca(OH)_2} + H_2$$

(b) From hot water : Magnesium liberates hydrogen from boiling water. However, the reaction is a slow one.

$$Mg + \underset{\text{Hot water}}{H_2O} \xrightarrow{\text{Slow}} \underset{\text{Calcium hydroxide}}{Mg(OH)_2} + H_2$$

(c) From steam : When steam is passed over heated metals like magnesium, zinc, aluminium and iron, hydrogen is liberated. The other product is a metallic oxide.

Hot metal + Steam → Metallic oxide + Hydrogen

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

$$Zn + \underset{\text{(steam)}}{H_2O} \rightarrow ZnO + H_2$$

$$2Al + \underset{\text{(steam)}}{3H_2O} \rightarrow Al_2O_3 + 3H_2$$

$$\underset{\text{(red hot)}}{3Fe} + \underset{\text{(steam)}}{4H_2O} \rightleftharpoons^{*} Fe_3O_4 + 4H_2$$

** Reaction between iron and steam is reversible.*

2. *By the action of dilute acids on active metals*

Metals like magnesium, zinc and iron react with dilute hydrochloric (or dilute sulphuric) acid to liberate hydrogen gas and their respective salts.

Metal + Dilute acid → Salt + Hydrogen

$$Mg + H_2SO_4 \rightarrow \underset{\text{Magnesium sulphate}}{MgSO_4} + H_2$$

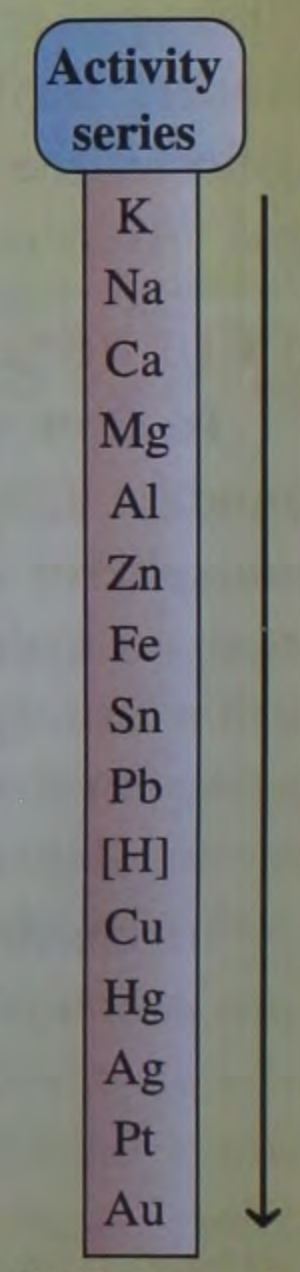
$$Zn + H_2SO_4 \rightarrow \underset{\text{Zinc sulphate}}{ZnSO_4} + H_2$$

$$Zn + 2HCl \rightarrow \underset{\text{Zinc chloride}}{ZnCl_2} + H_2$$

$$Fe + 2HCl \rightarrow \underset{\text{Ferrous chloride}}{FeCl_2} + H_2$$

The metals are arranged in a series in the descending order on the basis of their reactivity known as **metal activity series**. The most reactive metal is placed at the top and the least reactive one is placed at the bottom of the series. Though hydrogen is not a metal, it is placed in the series as many of its chemical reactions are similar to those of metals.

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



Metals arranged in the descending order of their reactivity.

3. *By the action of alkalis on metals*

Metals like zinc, aluminium, lead, *etc.*, react with hot alkali solutions to liberate hydrogen gas.

Metal + *Alkali* → *Salt* + *Hydrogen*

$Zn + 2NaOH \rightarrow \underset{\text{(sodium zincate)}}{Na_2ZnO_2} + H_2$
(sodium hydroxide)

$2Al + 2NaOH + 2H_2O \rightarrow \underset{\text{(sodium aluminate)}}{2NaAlO_2} + 3H_2$

$Pb + 2NaOH \rightarrow \underset{\text{(sodium plumbate)}}{Na_2PbO_2} + H_2$
(sodium hydroxide)

Zinc, aluminium and lead are amphoteric in nature *i.e.* they can react with acid as well as with base to produce hydrogen gas.

4. *By the electrolysis of water*

When an electric current is passed through acidulated water*, it dissociates into hydrogen and oxygen.

$\underset{\text{(Acidulated water)}}{2H_2O} \xrightarrow[\text{Current}]{\text{Electric}} \underset{\text{(Hydrogen)}}{2H_2} + \underset{\text{(Oxygen)}}{O_2}$

Hydrogen is collected at the cathode (negative electrode) and oxygen is collected at the anode (positive electrode). The ratio of hydrogen and oxygen thus collected is 2 : 1 by volume.

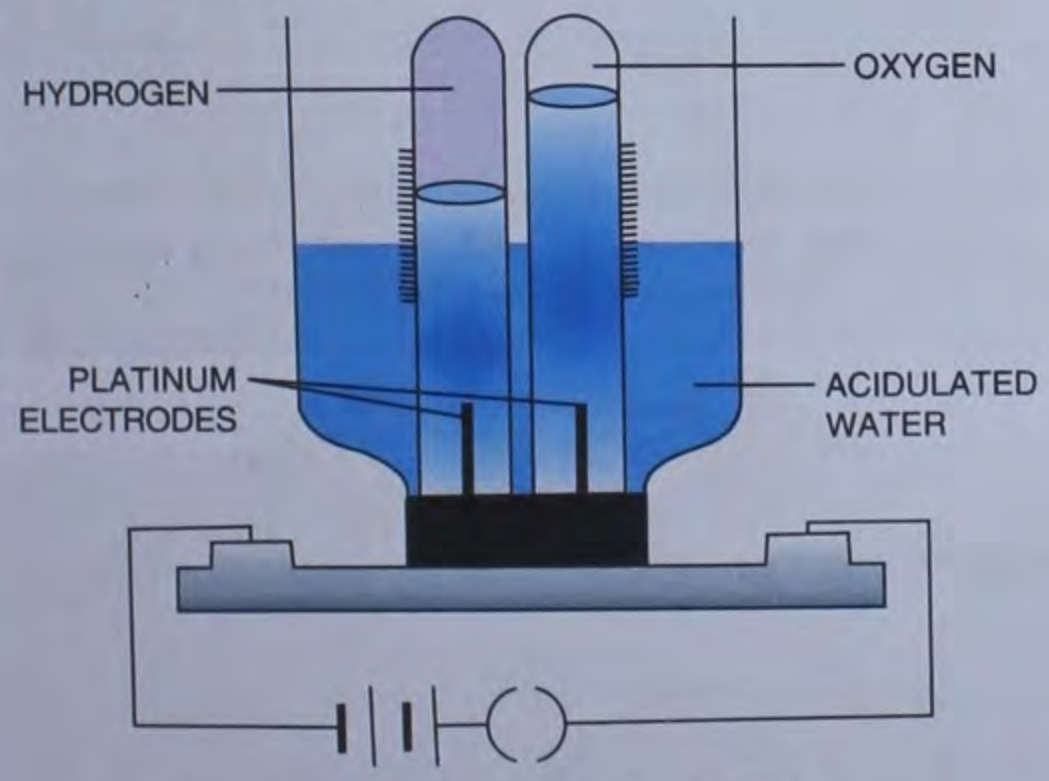


Fig. 2.1 Electrolysis of water.

* *Water containing a little sulphuric acid.*

LABORATORY PREPARATION OF HYDROGEN

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

Balanced equation for the reaction :

Metal + *Dilute acid* → *Salt* + *Hydrogen*

$Zn + 2HCl \rightarrow ZnCl_2 + H_2(g)$

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2(g)$

Why is granulated zinc preferred ?

Granulated zinc contains an impurity, copper, which acts as a positive catalyst* for the reaction. This is why granulated zinc is preferred over pure zinc for laboratory preparation of hydrogen.

The set-up for the experiment is as shown in Fig. 2.2.

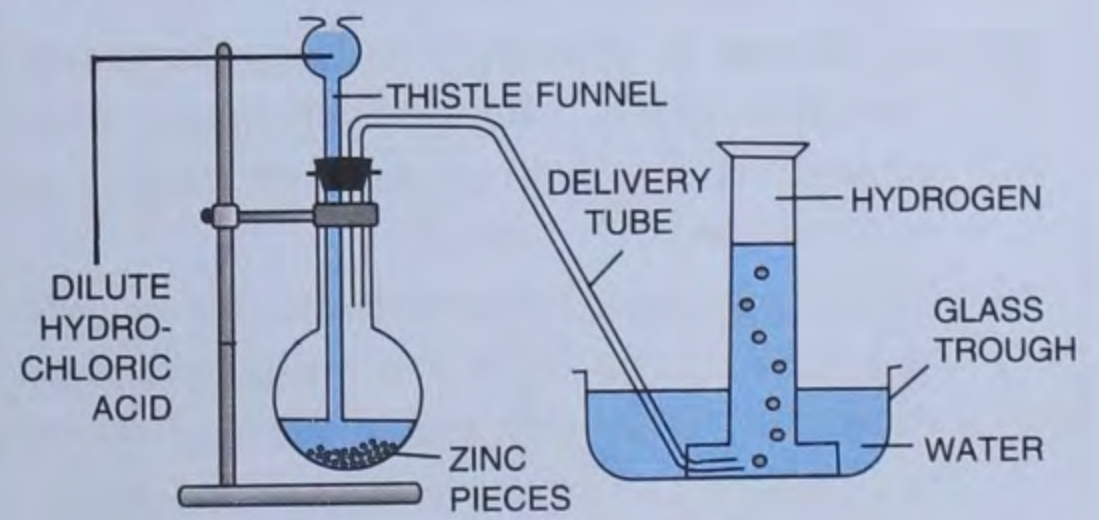


Fig. 2.2 Preparation of hydrogen.

Procedure : Take a few pieces of granulated zinc in a round bottom flask. Fix a two-holed air tight stopper in the mouth of the flask. Pass a thistle funnel through a hole and pass one end of a delivery tube through the other hole. Place the other end of the delivery tube inside a beehive shelf kept in a trough containing water.

* *Catalyst is a substance (an element or a compound) that modifies the rate of a chemical reaction, but does not itself undergo any change in its composition during the reaction. A positive catalyst increases the rate of a reaction.*

Now pour some dilute hydrochloric acid through the thistle funnel. A brisk effervescence occurs. This indicates the liberation of hydrogen gas. Allow the first few bubbles of gas to escape. Then invert over the beehive shelf a gas jar completely filled with water. Hydrogen displaces water and gets collected in the gas jar. This method of collecting gas is known as *"downward displacement of water"*.

Precautions !

(i) Do not collect the first few bubbles of hydrogen gas, since they contain air too.

(ii) Do not bring a flame near the apparatus, since hydrogen is inflammable.

Note :

(i) Hydrogen is sparingly soluble in water. Therefore, as it is collected over water, it picks up moisture. Dry hydrogen gas is obtained when it is collected over mercury.

(ii) Since hydrogen is lighter than air, it is possible to collect the gas by downward displacement of air. But it is not safe to do so since a mixture of hydrogen and air can lead to an explosion.

PROPERTIES OF HYDROGEN GAS

(a) Physical properties :

1. **Nature :** Hydrogen is a colourless, odourless and tasteless gas. It is non-poisonous in nature.
2. **Solubility :** Hydrogen is sparingly soluble in water. One litre of water dissolves about 20 ml of hydrogen gas at ordinary temperature and pressure.
3. **Liquefaction :** Hydrogen gas cannot be easily liquefied. Only at –240°C and at 20 atmospheric pressure it liquefies into a colourless liquid.
4. **Density :** Hydrogen is the lightest of all the gases. One litre of the gas weighs 0·09 g at S.T.P. *i.e.* at one atmospheric pressure and at 0°C. Air is 14·4 times heavier than hydrogen.

Activity 1

To prove that hydrogen gas is lighter than air.

Take a delivery tube and place one of its ends in a soap solution kept in a trough and the other one in a flat bottom jar as shown in Fig. 2.3. The soap bubbles containing hydrogen rise upward the air. The rising soap bubbles prove that hydrogen is lighter than air.

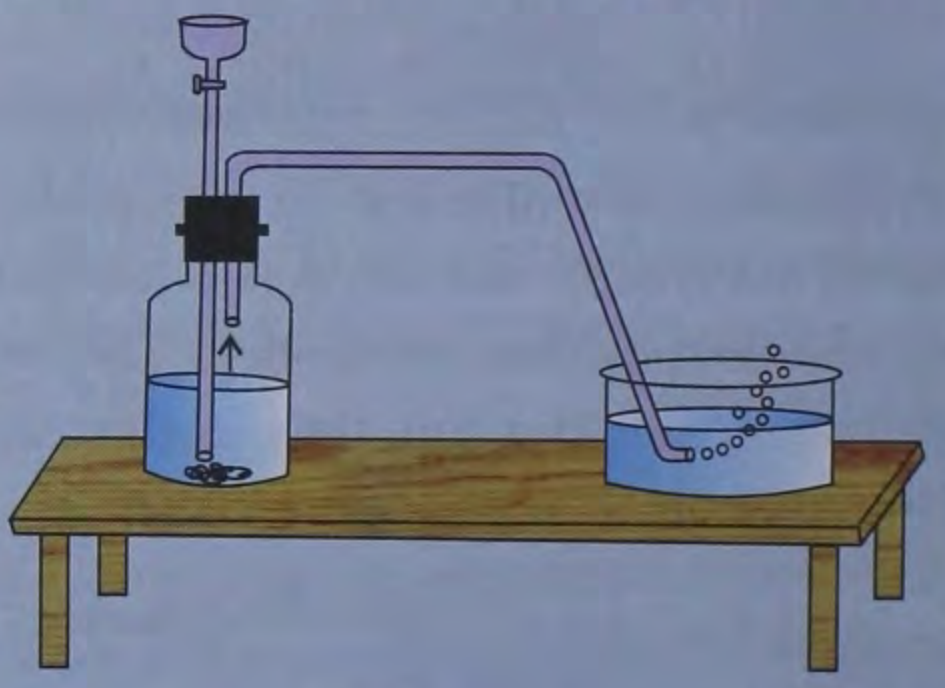


Fig. 2.3 Hydrogen-filled soap bubbles rising upward in the soap solution and into the air shows that hydrogen is lighter than air.

Activity 2

Another example of hydrogen gas being lighter than air.

Take two jars of equal size. One jar contains air while the other one has an equal volume of hydrogen. Place these two jars, with their lids, on the two pans of a balance.

What do you observe ? You will find that the jar containing hydrogen is lighter than the jar with air.

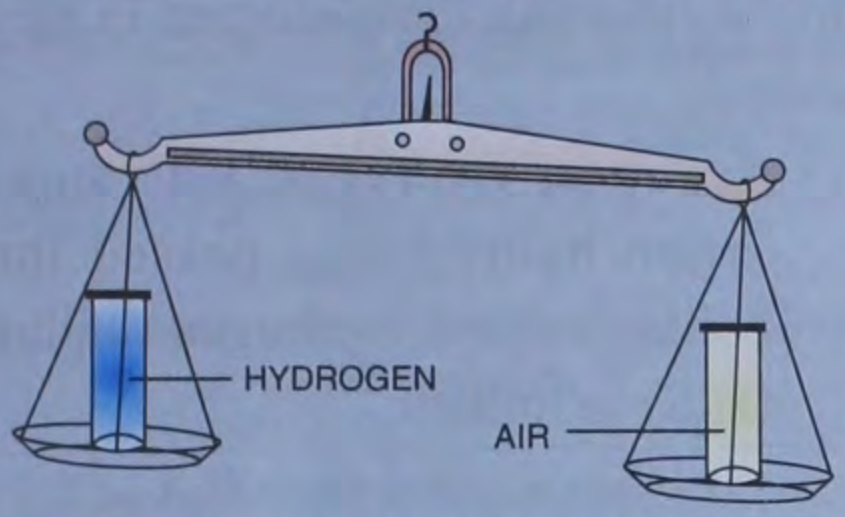


Fig. 2.4 Hydrogen is lighter than air.

Hydrogen gas is lighter than air is best seen in hydrogen-filled balloons that immediately rise up in the air.

(b) Chemical properties :

1. Action with litmus

Hydrogen gas is neutral to litmus *i.e.* no change is observed in the colour of either blue or red litmus paper when it is introduced into a jar containing hydrogen.

2. Combustibility

Hydrogen is **combustible** by nature. In air pure hydrogen burns silently, with a pale blue flame. But ordinary, *i.e.* impure hydrogen gas burns in air with a pop sound. This is because of the presence of impurities in it. This method is widely used as a test for hydrogen. However hydrogen itself is a **non-supporter of combustion**.

Activity 3

To show that hydrogen is combustible but is a non-supporter of combustion.

Hold a hydrogen gas-filled jar with its mouth downwards. Place a lighted candle inside the jar. The candle gets extinguished but the gas burns with a pop sound. This shows that hydrogen is combustible but is a non-supporter of combustion.

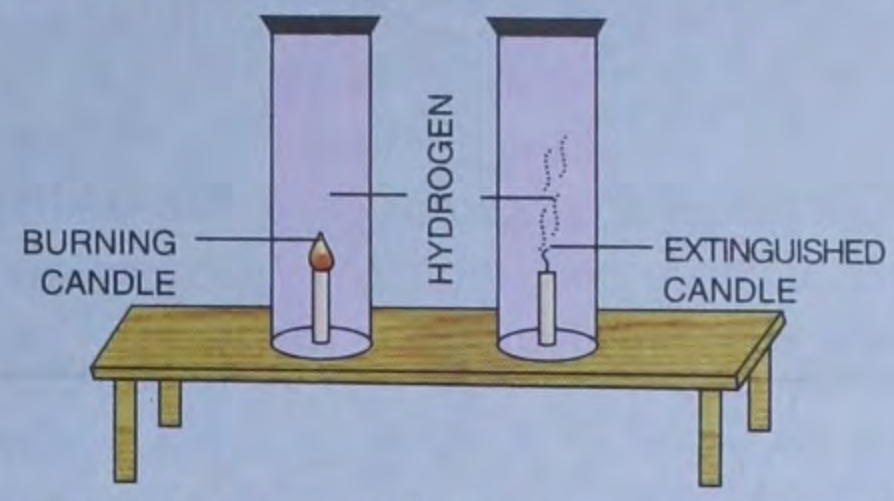


Fig. 2.5 Hydrogen gas does not support combustion.

Hydrogen is a reactive element. It reacts with non-metals, metals and metallic oxides to produce compounds.

3. Reactions of hydrogen with some non-metals

(i) *Action with oxygen* : Hydrogen burns in oxygen with a blue flame to form steam which on condensation, forms water. The process is as shown in Fig. 2.6.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Heat}$$

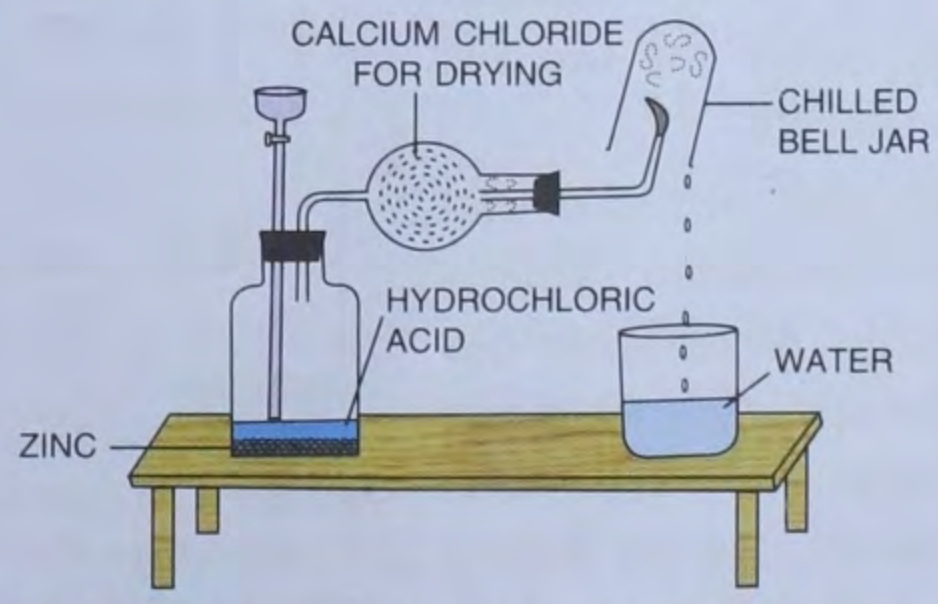


Fig. 2.6 Hydrogen when burns in air forms water.

The reaction is highly exothermic. In fact, it is this released energy that is harnessed to propel some space rockets. Inside these rockets liquid hydrogen and liquid oxygen are stored together in tanks. Their leakage is prevented at all costs.

Note : Hydrogen forms an explosive mixture with air (due to the oxygen present in air). If the amount of air is less in the mixture, the explosion is not dangerous *i.e.* the gas burns with a pop sound only. But a large volume of mixture causes a dangerous explosion leading to serious damage and injuries. (*Hydrogen-oxygen mixture is called* **detonating mixture**).

(ii) *Action of hydrogen with chlorine gas* : In diffused sunlight hydrogen combines with an equal volume of greenish yellow chlorine gas to form colourless hydrogen chloride gas.

$$\underset{\text{(hydrogen)}}{H_2} + \underset{\text{(chlorine)}}{Cl_2} \rightarrow \underset{\text{(hydrogen chloride)}}{2HCl}$$

Activity 4

To show the formation of hydrogen chloride gas

Place an inverted gas jar filled with chlorine (g) over a jar of hydrogen (g). Expose the two jars to sunlight.

You will observe that the greenish yellow colour of chlorine gas disappears and white fumes of hydrogen chloride gas are formed in both the jars.

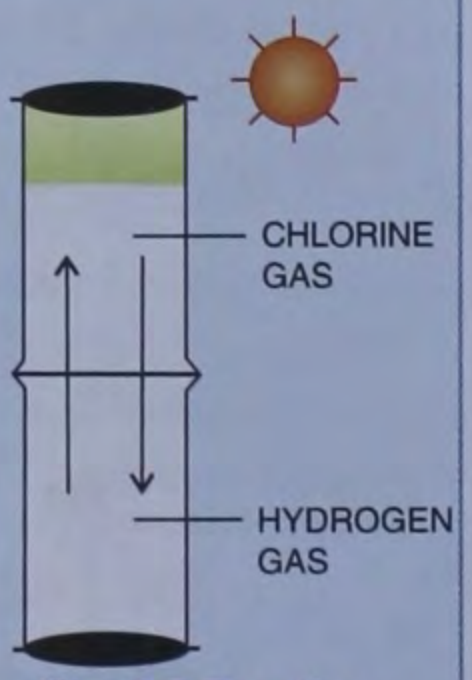


Fig. 2.7 Reaction between hydrogen and chlorine to give hydrogen chloride (g).

(iii) *Action of hydrogen with nitrogen gas* : In the presence of iron as a catalyst and at 450°C temperature and 200 atmospheric pressure, hydrogen reacts with nitrogen in the ratio of 3 : 1 by volume to produce ammonia gas.

$$3H_2 + N_2 \underset{450^\circ C}{\overset{Fe}{\rightleftharpoons}} 2NH_3 + \text{Heat}$$

In this reaction molybdenum is used as a promoter.*

(iv) *Action of hydrogen with sulphur* : When hydrogen is passed through boiling sulphur, hydrogen sulphide gas (H_2S) is formed.

$$\underset{}{H_2} + \underset{\text{(boiling sulphur)}}{S} \rightarrow \underset{\text{(hydrogen sulphide)}}{H_2S}$$

4. Reactions of hydrogen with metals

Hydrogen reacts with certain heated metals to form metal hydrides.

$$2Na + H_2 \rightarrow \underset{\text{(sodium hydride)}}{2NaH}$$

$$Ca + H_2 \rightarrow \underset{\text{(calcium hydride)}}{CaH_2}$$

Most of the metallic hydrides are unstable in nature.

5. Reactions of hydrogen with metallic oxides (hydrogen as a reducing agent)

When hydrogen gas is passed over hot oxides of metals like copper, lead and iron, it removes oxygen from them and thus reduces them to their corresponding metal. In this reaction hydrogen itself gets oxidised into water.

$$\underset{\text{(cupric oxide)}}{CuO} + H_2 \rightarrow \underset{\text{(copper)}}{Cu} + H_2O$$

$$\underset{\text{(lead monoxide)}}{PbO} + H_2 \rightarrow \underset{\text{(lead)}}{Pb} + H_2O$$

*These reactions are redox reactions** because hydrogen acts as a reducing agent by removing oxygen from metallic oxide and itself it gets oxidised into water.*

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* *A promoter activates the catalyst.*

** *For details of redox reactions refer to the last topic of this chapter.*

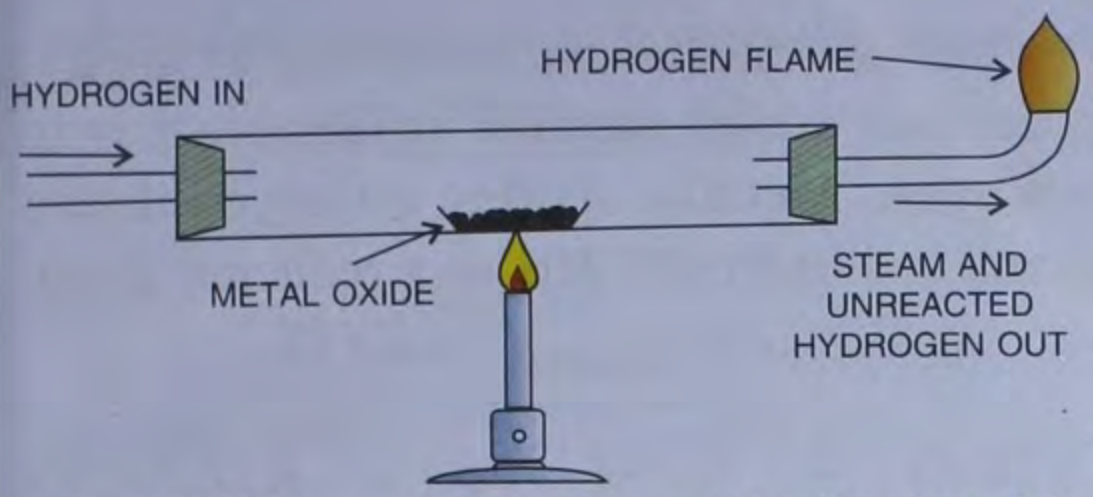

Fig. 2.8 Hydrogen reduces hot metal oxides into their respective metals.

Note : The oxides of active metals like sodium, potassium, aluminium, calcium and magnesium do not get reduced by hydrogen into their corresponding metals.

TESTS FOR HYDROGEN

1. Ordinary hydrogen burns in air with a characteristic pop sound.
2. Hydrogen burns in air or oxygen with a pale blue flame and water is formed, which can be tested by sprinkling a few drops of it on white anhydrous copper sulphate. The latter turns into blue hydrated copper sulphate.

USES OF HYDROGEN

1. **For cutting and welding metals :** Hydrogen and oxygen when burnt together give a flame known as **oxy-hydrogen flame**. It has a temperature of about 2800°C–3000°C. The flame is used for cutting and welding of metals.
2. **As a fuel :** Because of its **high heat of combustion** hydrogen is used as a fuel. Coal gas, water gas ($CO + H_2$) and liquid hydrogen are some significant hydrogen-based fuels. Liquid hydrogen is used as a rocket fuel. Hydrogen can become the mass fuel of the future, replacing the hydrocarbons. In addition, hydrogen is a pollution-free fuel.
3. **For hydrogenation of vegetable oil :** Hydrogen is used in the preparation of solid *vanaspati ghee* from liquid vegetable fats like groundnut oil, coconut oil, etc. This process is called **catalytic hydrogenation of oils** because it takes place in the presence of finely divided nickel or platinum or palladium acting as a catalyst.

Catalytic hydrogenation is a process by which hydrogen gas is passed through vegetable oils in the presence of catalyst like Ni, Pt or Pd to convert them (the oils) into solid vanaspati ghee.

4. **For the manufacture of chemicals :** Hydrogen gas is used extensively in the manufacture of ammonia gas which in turn, is used to produce fertilizers and nitric acid. The gas is used also in the manufacture of hydrochloric acid, methanol, etc.
5. **As a reducing agent in the extraction of metals :** As hydrogen is a good reducing agent it is used for the extraction of the lesser reactive metals, like copper, lead, tin, *etc*., from their respective oxides. But the use of hydrogen for large-scale extraction of metals from their ores is not common due to the explosive mixture formed by hydrogen and oxygen.
6. **For meteorological purposes :** Earlier hydrogen-filled balloons equipped with meteorological instruments were sent up in the atmosphere to record temperature, wind speed, air pressure, etc., for help in weather forecasting. However,

due to the inflammable nature of the gas, it has gradually been replaced by helium for filling in weather forecasting balloons.

OXIDATION AND REDUCTION : REDOX REACTIONS

Those reactions in which hydrogen combines with a substance or oxygen is removed from a substance, are known as *reduction reactions*. The substance that removes oxygen or supplies hydrogen during such a reaction is called *reducing agent*. (Hydrogen acts as a good reducing agent)

The converse of reduction is oxidation. As such, a reaction in which a substance combines with oxygen, or in which hydrogen is removed, is called *oxidation reaction*. The substance that removes hydrogen or supplies oxygen is known as *oxidising agent*.

Let us consider the following examples, in each of which metallic oxides react with hydrogen. Metallic oxides act as oxidising agents and hydrogen acts as a reducing agent.

Removal of O_2 [reduction]

1. $CuO + H_2 \rightarrow Cu + H_2O$

Addition of O_2 [oxidation]

Reduction

2. $Fe_3O_4 + 4H_2 \rightarrow 3Fe + 4H_2O$

Oxidation

We see that, in both the above reactions, oxidation and reduction take place simultaneously. One of the reactants (metal oxide) acts as an oxidising agent and gets reduced while the other reactant (hydrogen) acts as a reducing agent and gets oxidised. These reactions are called redox reactions.

> Redox reactions are those in which reduction and oxidation take place simultaneously.

EXERCISE

1. Fill in the blanks :

(a) Hydrogen is ..... than air.

(b) Hydrogen is ..... soluble in water.

(c) Hydrogen burns with a ..... flame and ..... sound is heard.

(d) A metal ..... hydrogen in the activity series gives hydrogen with .....

(e) Hydrogen reacts with metal oxides to form ..... and .....

(f) Oxidation is the removal of ..... and addition of .....

(g) Oxidation and reduction occur .....

2. Indicate which of the following statements are ***true*** and which are ***false*** :

(a) Hydrogen molecule is monovalent.

(b) The removal of hydrogen from a substance is called reduction.

(c) The reaction between hydrogen and nitrogen to form ammonia is reversible.

(d) Zinc can liberate hydrogen from water, acid and alkali solution.

(e) Hydrogen is combustible as well as a supporter of combustion.

(f) Hydrogen gas is easily liquefiable.

3. Complete and balance the following equations :

(a) H_2 + ... → HCl

(b) H_2 + S → .....

(c) Zn + ... → $ZnCl_2$ + H_2

(d) CuO + ... → Cu + ...

(e) Al + NaOH + ... → ..... + ...

(f) Fe + H_2O → ..... + ...

(g) K + H_2O → ..... + ...

4. Give reasons for the following :

(a) Why can hydrogen be used as a fuel ?

(b) Though hydrogen is lighter than air it cannot be collected by downward displacement of air. Why ?

(c) Why is there a pop sound when hydrogen is burnt ?

(d) Why has helium replaced hydrogen in weather observation balloons ?

5. Name the following :

(a) Two metals which give hydrogen with cold water.

(b) A metal which liberates hydrogen only when steam is passed over red hot metal.

(c) The process in which oxygen is added or hydrogen is removed.

(d) A metallic oxide which can be reduced into metal by hydrogen.

6. (a) Name the chemicals required to prepare hydrogen gas in the laboratory.

(b) Give a balanced chemical equation for the reaction.

(c) Draw a neat and well-labelled diagram for the laboratory preparation of hydrogen.

(d) How is hydrogen gas collected ?

7. How would you show that hydrogen :

(a) is a non-supporter of combustion ?

(b) is lighter than air ?

8. Hydrogen is a good reducing agent. What do you understand by the above statement ? Explain with the help of copper oxide as an example.

9. State four uses of hydrogen.

10. Define :

(a) catalytic hydrogenation

(b) oxidation

(c) reduction

11. Match the statements in Column A with those in Column B.

Column A	Column B
1. A metal which reacts with cold water to form hydrogen.	1. Reduction
2. A gas which is inflammable and a non-supporter of combustion.	2. Hydrogenation
3. A process in which vanaspati ghee is prepared from vegetable oils.	3. Oxidation
4. The removal of hydrogen or addition of oxygen.	4. Sodium
5. The addition of hydrogen or removal of oxygen.	5. Hydrogen.

12. Multiple Choice Questions

(a) Equal volumes of hydrogen and chlorine are exposed to diffused sunlight to prepare

(i) hydrogen chloride (ii) water

(iii) sodium hydroxide

(iv) hydrochloric acid

(b) The metal which reacts with cold water to produce hydrogen is

(i) magnesium

(ii) aluminium

(iii) calcium

(iv) iron

(c) In metal activity series the more reactive metals are at
  (i) top (ii) bottom
  (iii) middle (iv) none

(d) Hydrogen is responsible for producing
  (i) heat and light
  (ii) hydrogenated oil
  (iii) fertilizers
  (iv) all of the above

(e) Hydrogen is
  (i) combustible
  (ii) non-combustible
  (iii) supporter of combustion
  (iv) non-supporter of combustion

RECAPITULATION

- Hydrogen is the most abundant element found in the Universe. On the earth it is found in the form of compounds.
- The chief sources of hydrogen are water, acids and alkalis.
- Hydrogen is prepared by the action of water, acids or alkalis on active metals.
- Electrolysis of water results in the formation of hydrogen and oxygen.
- Hydrogen is a combustible gas but it does not support combustion.
- Hydrogen burns in air to produce water.
- Hydrogen acts as a reducing agent and helps in the extraction of metals from their respective oxides.
- Hydrogen burns in air with a pop sound. This helps in testing the gas.
- Hydrogen is used to produce oxyhydrogen flame and in weather forecast balloons.