7. HYDROGEN

7.1 Introduction

Hydrogen occurs in nature mainly in the combined state. It occurs in water which is widely and abundantly distributed in rivers, lakes and oceans. It constitutes one-ninth by mass of water It also occurs in organic compounds like hydrocarbon. It is a constituent of all plants and animals, hydrated salts and coal. It occurs in very small amounts as free hydrogen in the atmosphere.

7.2 Position of Hydrogen in the Periodic Table

It is not easy to place hydrogen in any particular group in the Periodic Table because of its peculiar nature. It has some characteristics similar to those of group I and group VII, yet it does not belong to either of these.

Electronically it is similar to the group I metals as it has one electron in its outermost and only shell. It undergoes similar reactions like the group I metals as it loses one electron in the formation of hydrogen ion H+ in acidic solutions. But unlike the group I metals, it is a non-metal and has a high ionization energy. That is, a large amount of energy is required for it to lose its outermost electron. Hydrogen is gaseous and a non-conductor of electricity, unlike the group I metals. Also, unlike the group I metals which form basic oxides with oxygen, hydrogen forms a neutral oxide.

In the formation of ionic bonds, it is similar to the Group VII elements. It requires only one electron to attain the noble gas structure of helium, like the group VII elements which accept one electron per atom in forming ionic compounds with the group I metals.

$2Na(s) + Cl_2(g)_1$ â†’ $2Na^+Cl^-(s)$

$2Na(s) + H_2(g)$ â†’ $2Na^+H^-(s)$

In the formation of a covalent bond it donates one electron per atom for sharing, like the group VII elements. But unlike the group VII elements it is colourless and less reactive. It has a low ionization energy when compared with the halogens. Oxides of the halogens are acidic while that of hydrogen, H_2O, is neutral.

It is as a result of this that hydrogen is at times placed in either group I or VII. Sometimes it is placed at the top central position of the

Periodic Table.

7.3 Laboratory Preparation of Hydrogen.

Experiment 7.1: Preparation of hydrogen by the reaction of a dilute acid with a metal:

Fit a cork carrying a delivery tube and thistle funnel to a flat bottomed flask containing some zinc granules as in Figure 7.1. The delivery tube leads to a trough of water with a gas jar full of water. Close the tap of the thistle funnel. Fill the thistle funnel with dilute hydrogen chloride acid (hydrochloric acid), and open the tap to run in the acid. Effervescence occurs and hydrogen gas is given off. Before collecting the gas in the gas jar, allow the air in the flask to bubble off for a few seconds. Collect a few gas jars of hydrogen by displacement of water in the gas jar.

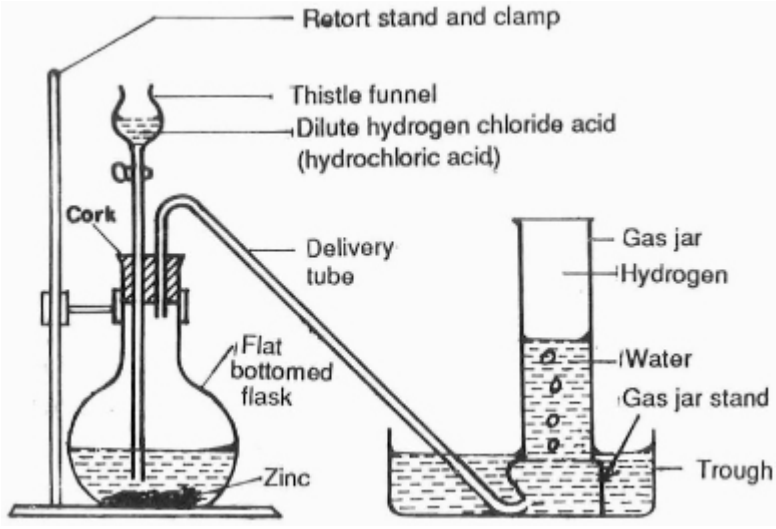

Figure 7.1 Laboratory Preparation of hydrogen

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

If dry hydrogen is required the gas from the flat-bottomed flask is first passed through water to remove acid spray, and finally dried by passing it through a wash bottle containing concentrated tetraoxosulphate(VI) acid. It is collected by downward displacement of air as in Figure 7.2.

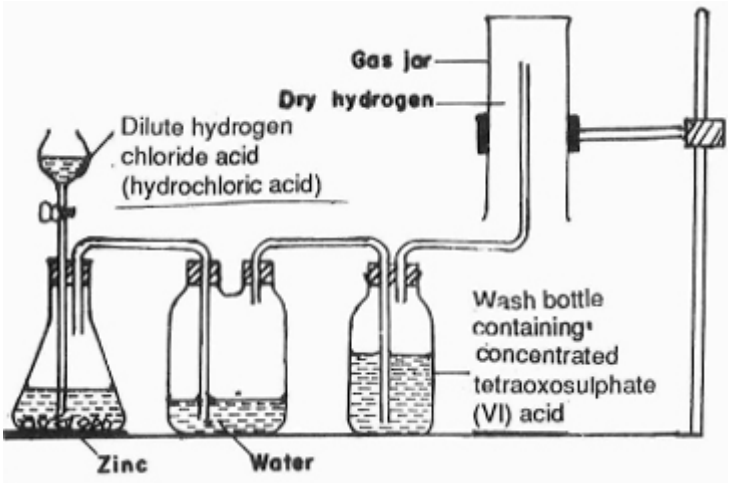

Figure 7.2. Preparation of dry hydrogen gas.

Hydrogen can be prepared by several other methods in the laboratory. These include:

1. By the action of alkali metals on water. This reaction is dangerous. As a result, calcium which reacts mildly with water is used (Figure 7.3).

$Ca(s) + 2H_2O(l)$ â†’ $Ca(OH)_2(aq) + H_2(g)$

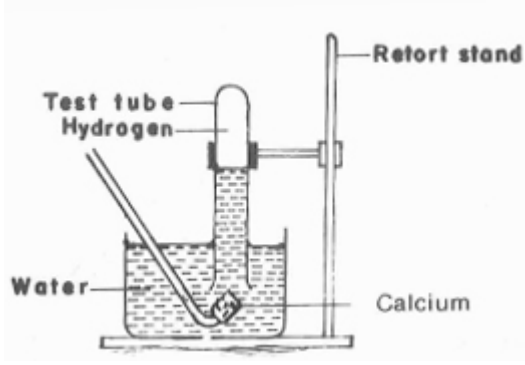

Figure 7.3. Preparation of hydrogen by the reaction of calcium metal with cold water.

2. By warming a concentrated solution of potassium or sodium hydroxide with an amphoteric metal such as zinc or aluminium.

$Zn(s) + 2NaOH(aq) + 2H_2O(l)$ â†’ $Na_2Zn(OH)_4(aq) + H_2(g)$

3. By passing steam over heated iron fillings.

$3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$

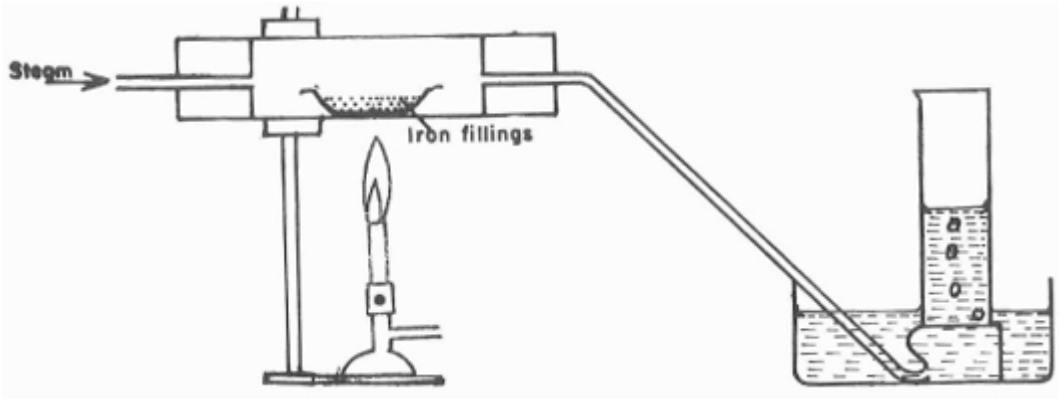

Figure 7.4 Preparation of hydrogen by the action of steam on iron fillings.

7.4 Properties of Hydrogen

Experiments 7.2: To investigate the properties of hydrogen

1. Examine the gas in the gas jar and note its colour and smell.
2. Put dilute hydrogen chloride acid (hydrochloric acid) in a test-tube and add a few granules of zinc. There is effervescence, and a gas is liberated. Apply a burning splint to the mouth of the test-tube. The gas explodes, giving a â€œpop soundâ€. This is the test for confirming the presence of hydrogen.
3. Ignite the dry hydrogen coming out of the delivery tube in Experiment 7.1, and direct the flame to the bottom of a beaker containing cold water (Figure 7.5)

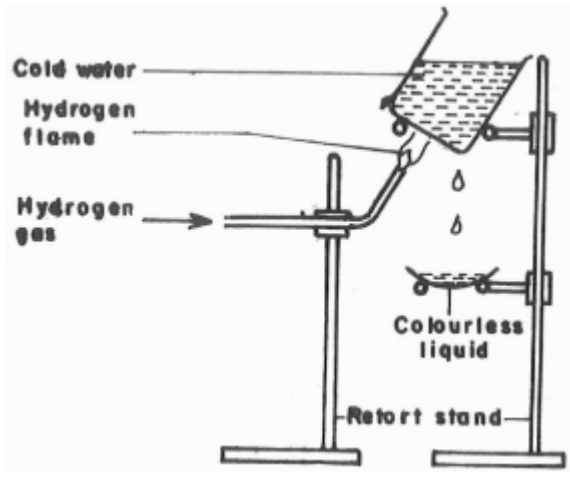

Figure 7.5. Burning of hydrogen in air to form water

Collect the liquid produced and put grey coloured anhydrous copper(II) tetraoxosulphate(VI) into it. You will observe that the anhydrous salt turns blue. Also test some of the anhydrous salt with some distilled water. The salt also turns blue. We therefore conclude that when hydrogen burns in air, it produces water.

$2H_2(g) + O_2(g)$ â†’ $2H_2O(g\text{-}l)$

4. If a stream of dry hydrogen from the reaction in Experiment 7.1 is passed over heated black copper(II) oxide in a combustion tube for some time, the black copper(H) oxide will turn brown showing that it has been reduced to copper. The tube should be ignited at the open end to burn off any unreacted hydrogen (Figure 7.6). This shows that hydrogen is a reducing agent.

$CuO(s) + H_2(g)$ â†’ $Cu(s) + H_2O(g)$

black Brown

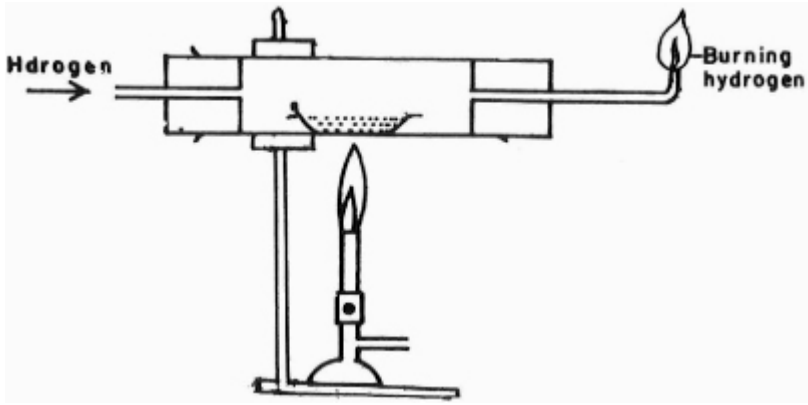

Figure 7.6 Reduction of copper(II) oxide with hydrogen

5. Remove the cover from a gas jar containing hydrogen and invert upon this, another gas jar containing air (Figure 7.7). Allow the set-up to stand for about 2 minutes. Open the gas jars and test for hydrogen in both jars with a lighted splint. A â€˜popâ€™ sound will be heard in the gas jar originally containing air while none will be heard in the one originally containing hydrogen. The hydrogen has risen into the top gas jar and pushed the air into the lower jar. This shows that hydrogen is lighter than air.

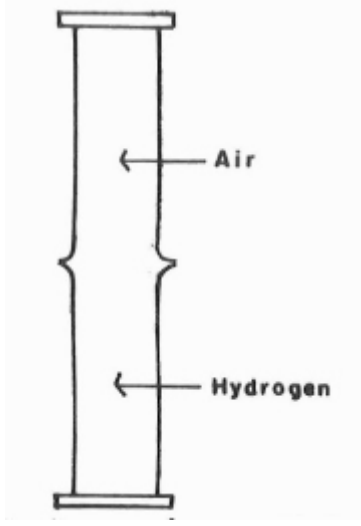

Figure 7.7 Comparing the density of hydrogen with that of air

In general, the properties of hydrogen can be summarized as follows:

1. It is a colourless and odourless gas.
2. It is the lightest known gas
3. It is insoluble in water.
4. It does not support combusion but it burns in air with a pale blue flame. When mixed with air in a test-tube, it explodes with a â€˜popâ€™ sound to form water. This is used as the test for hydrogen.
5. It is a reducing agent. It reduces most metallic oxides to their metal.
6. Hydrogen combines with metals and non-metals to form hydrides. Highly electropositive metals like sodium and potassium react with hydrogen to form ionic hydrides. This is done by bubbling hydrogen through the molten metal. For example:

$2Na(l) + H_2(g)$ â†’ $2NaH(s)$
molten

With non-metals, it forms covalent hydrides.

$H_2(g) + Cl_2(g)$ â†’ $2HCl(g)$
$S(l) + H_2(g)$ â†’ $H_2S(g)$
(molten)

7.5 Industrial Preparation of Hydrogen

Hydrogen can be produced industrially from natural gas, water gas, or by electrolysis. The most important method now, is from natural gas.

1. From natural gas

When natural gas which contains mainly methane is mixed will steam and passed over heated nickel catalyst at a temperature of between 700Â°C and 800Â°C at 30 atmosphere pressure, hydrogen and carbon(II) oxide are produced.

$CH_4(g) + H_2O(g)$ â†’ $CO(g) + 3H_2(g)$

The resulting gaseous mixture is mixed with more steam and passed over iron(III) oxide catalyst at 450Â°C to convert the carbon(II) oxide to carbon(IV) oxide

$CO(g) + 3H_2(g) + H_2O(g)$ â†’ $CO_2(g) + 4H_2(g)$

Carbon(IV) oxide is removed from the gaseous mixture by passing the mixture through water at a pressure of 30 atmosphere. The carbon(IV) oxide dissolves.

Any remaining trace of carbon(II) oxide is absorbed by passing the gas through a solution of copper(I) methanoate in ammonia under pressure.

2. From water gas:
This is an old method of preparing hydrogen, and has been described in the Chapter on carbon in Book I.

3. Electrolysis:
Hydrogen is obtained as a by-product in the electrolysis of concentrated sodium chloride solution. Where electricity is cheap, such as when obtained from hydroelectric power, hydrogen can be produced by the electrolysis of acidified water.

7.6 Uses of Hydrogen

1. Hydrogen is used in the manufacture of ammonia by the Haber process. Ammonia is very important in the manufacture of fertilizers.
2. Hydrogen is used to harden vegetable oil in the process of hydrogenation to produce margarine and solid fat. Hydrogenation is done by bubbling hydrogen through the oil in the presence of finely divided nickel catalyst.
3. It is used in the industrial manufacture of hydrogen chloride.
4. It is used to convert coal to synthetic petrol in the presence of a catalyst. This method has a potential for the future when petroleum may become scarce.
5. Because of its light weight, it is used for filling meteorological balloons which carry meteorological instruments.
6. It is used in oxy-hydrogen torches for welding.
7. Liquid hydrogen is used as a rocket fuel.

Chapter Summary

1 Hydrogen is the lightest element.
2. It is often placed in group I of the Periodic Table along with the alkali metals, but may also be placed in group VII with the halogens.
3. It is prepared in the laboratory by the action of dilute acids on active metals, and manufactured for industrial use from natural gas or from water-gas.
4. In most of its reactions, hydrogen acts as a reducing agent.
5. It is recognised by the â€˜popâ€™ sound it makes with lighted tapers. This indicates its explosive burning in air to form water.

Assessment

1. (a) With the aid of a labelled diagram, show how you would

prepare and collect a few gas jars of dry hydrogen in the laboratory.

(b) Describe the action of hydrogen on

(i) Copper(II) oxide; (ii) Copper(II) chloride

(c) Describe a test for hydrogen.

2. (a) Describe how hydrogen may be prepared in the laboratory.

(b) An electric spark is passed through a mixture containing 100 cm^3 of hydrogen and 100 cm^3 of oxygen at s.t.p. until there is no more reaction.

(i) Write an equation for the reaction.

(ii) Name the gas left in the container.

(iii) What is the volume of residual gas at s.t.p.?

(c) If the oxygen in (b) above is replaced by an equal volume or air;

(i) Name the residual gases

(ii) Calculate the volume of the residual gas mixture at s.t.p. (Assume that air contains 21 % by volume of oxygen and 79% by volume of nitrogen).

(d) Give **three** uses of hydrogen.

3. (c) Describe the industrial preparations of hydrogen from natural gas.

(b) With the aid of a diagram show how hydrogen may be prepared by the action of steam on iron.

(c) Explain the meaning of the sign $\rightleftharpoons$ used in the equation of the reaction:

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

4. (a) How would you prepare hydrogen in the laboratory without an acid, an alkali or a source of heat?

(b) List three uses of hydrogen.

5. (a) Apart from electrolysis, state three methods of preparing hydrogen in the laboratory.

(b) How would hydrogen react with (i) oxygen, (ii) sulphur?

(c) (i) State the disadvantages of too much oxygen in the air.

(ii) List three uses of oxygen.

6. (a) Consider the following elements:

$_1H$, $_7N$, $_8O$, $_9F$, $_{11}Na$, $_{12}Mg$, $_{13}Al$, $_{14}Sl$, $_{16}S$, $_{17}Cl$, $_{18}Ar$.

(a) Give the name and formula of a covalent compound formed between hydrogen and any one of the other elements.

(b) Give the name and formula of an oxide of one of the elements which exists in the liquid state at room temperature.

(c) Name one element which exists in two crystalline forms. Name the crystalline forms.

(d) Write a balanced equation for the reaction between the most electropositive of the elements, and water.

(e) Which of the elements forms an amphoteric oxide? Write balanced equations to show its amphoteric nature.

(f) Which of the elements does not readily form compounds, and why?

(WAEC)