STEPPING STONE SCHOOL (HIGH)

CLASS :IX

Subject: Chemistry **Date:01/07/2020**

Topic: Hydrogen **Time Limit:40 min.**

Worksheet No.14

IMPORTANT INSTRUCTIONS

- Please read the chapter from your text book and the attached notes
- Then workout the exercises neatly in your notebook henceforth
- Do not write above the red line of the notebook pages
- Use note book with 96 pages and write with black ink(From worksheet no. 13, Dated: 30/06/2020)
- Each page of your note book should be marked with the page number.
- Make a contents page first with columns under the heads as given below:

CONTENTS				
DATE	WORKSHEET NO.	CHAPTER NO. AND DATE	PAGE NO.	TEACHER'S SIGNATURE

- Every new chapter (topic)should be started on a new page
- Ensure neat and tidy work

MANUFACTURE OF HYDROGEN GAS

How is hydrogen manufactured

Water is one of the most abundant and cheaper source of hydrogen. Hydrogen is commercially obtained from water using different methods. Some of them are described below.

From water gas: Bosch process

The largest amount of commercial hydrogen is manufactured from water gas. This process consists of three steps:

Step 1. Steam is passed through a mass of red hot coke (> 1000°C). A mixture of equal volumes of hydrogen and carbon monoxide, known as **water gas** is formed.

$$\underset{\text{red hot}}{C(s)} + \underset{\text{steam}}{H_2O(g)} \xrightarrow{\Delta} \underbrace{CO(g) + H_2(g)}_{\text{water gas}}$$

Step 2. Water gas is mixed with excess of steam and passed over a heated catalyst, ferric oxide and little chromium oxide at 450°C. Carbon monoxide is oxidised to CO_2.

$$\underset{\text{from water gas}}{CO(g)} + \underset{\text{steam}}{H_2O(g)} \xrightarrow[450°C]{Fe_2O_3 + Cr_2O_3} CO_2(g) + H_2(g)$$

Step 3. The mixture of CO_2 and H_2 is passed through water under a pressure of 25 - 30 atm, when CO_2 gets dissolved in water and hydrogen gas is collected.

$$H_2O(l) + H_2(g) + CO_2(g) \xrightarrow[\text{pressure}]{\text{under}} \underset{\text{carbon dioxide dissolves in water}}{H_2CO_3(aq)} + H_2(g)$$

Removal of CO and CO_2. Water gas is an equimolar mixture of CO and H_2. CO is oxidised to CO_2, and CO_2 is removed by dissolving in water under pressure. Thus, hydrogen obtained is free from both CO and CO_2.

By electrolysis

Hydrogen is also manufactured by the electrolysis of acidulated water at places where electric power is cheap.

$$\underset{\text{water (acidulated)}}{2H_2O(l)} \xrightarrow{\text{electricity}} \underset{\text{at cathode}}{2H_2(g)} + \underset{\text{at anode}}{O_2(g)}$$

The electrochemical reactions that take place at the electrodes are,

At cathode: $4H^+ + 4e^- \rightarrow 2H_2(g)$

At anode: $OH^- \rightarrow OH + e^-] \times 4$

$4OH \rightarrow 2H_2O + O_2(g)$

An electrolytic cell used for manufacturing hydrogen by the electrolysis of water is shown in Fig. 9.3.

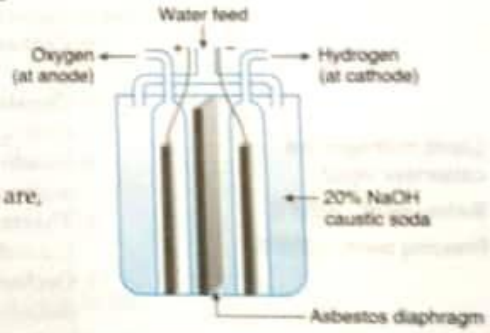

Fig. 9.3 Manufacture of hydrogen by the electrolysis of water

By Lane's process

When steam is passed over red hot iron, it decomposes to give ferrosoferric oxide (Fe_3O_4) and hydrogen.

$$3Fe(s) + 4H_2O\ (steam) \xrightleftharpoons{\Delta} Fe_3O_4(s) + 4H_2(g)$$

Iron is regenerated by reducing iron oxide by passing water gas ($CO + H_2$) over it.

$$Fe_3O_4(s) + \underbrace{2CO(g) + 2H_2(g)}_{\text{water gas}} \xrightarrow{\text{heat}} 3Fe(s) + 2CO_2(g) + 2H_2O(g)$$

In actual practice, steam is passed over hot iron for 10 minutes (*gassing period*) and water gas is blown over heated oxide for 20 minutes (*reduction period*). In order to make the process continuous, both the reactions are carried out alternately.

From hydrocarbons

Hydrogen can also be obtained on commercial scale from lower hydrocarbons, such as methane, natural gas (it contains methane as the major component) and from methanol by **steam reformer process** (or steam reforming).

High molecular mass hydrocarbons obtained from oil refineries, such as naphtha and fuel oil are cracked to produce low molecular mass hydrocarbons and hydrogen can be obtained as a by-product.

Lower hydrocarbons, such as methane (CH_4) when mixed with steam and passed over a nickel catalyst at 800-900°C produce a mixture containing CO, CO_2 and H_2.

$$\underset{\text{methane}}{CH_4(g)} + \underset{\text{steam}}{H_2O(g)} \xrightarrow[\text{800-900°C, 30 atm.}]{\text{nickel catalyst}} CO(g) + 3H_2(g)$$

$$\underset{\text{methane}}{CH_4(g)} + \underset{\text{steam}}{2H_2O(g)} \xrightarrow[\text{800-900°C, 30 atm.}]{\text{nickel catalyst}} CO_2(g) + 4H_2(g)$$

Very recently, scientists at the University of Wisconsin, USA, have developed a method to produce hydrogen from **glucose solution**. Glucose being a plant product, this method provides a way to obtain cheaper hydrogen through a **renewable natural cycle**.

The mixture containing $CO(g)$, $CO_2(g)$ and $H_2(g)$ is mixed with more steam, cooled to 400°C and passed over an iron-copper catalyst. Here $CO(g)$ gets oxidised to $CO_2(g)$.

$$CO(g) + \underset{\text{steam}}{H_2O(g)} \xrightarrow[\text{400°C}]{\text{iron-copper catalyst}} CO_2(g) + H_2(g)$$

The CO_2 gas present in the mixture is removed by absorbing in a solution of potassium carbonate (K_2CO_3) or ethanolamine. Potassium carbonate and ethanolamine are regenerated by heating.

PHYSICAL AND CHEMICAL PROPERTIES OF HYDROGEN

What are the physical properties of hydrogen

Some characteristic properties of hydrogen are described below.

- **Colour, odour, taste.** Hydrogen is a colourless, odourless and tasteless gas.
- **Density.** Hydrogen is the lightest element known. The density of hydrogen gas is 0.098 g/L.
- **Solubility.** Hydrogen is slightly soluble in water — 21.5 mL per litre of water at NTP.
- **Thermal conductivity.** Hydrogen is the best gaseous conductor of heat. It conducts heat five times better than air.
- **Occlusion.** Hydrogen is adsorbed/absorbed by metals like platinum, palladium in large quantities. Palladium can hold 800 times its volume of hydrogen. Such hydrogen can be recovered by heating palladium in vacuum. This process is known as **occlusion.**

Liquid hydrogen is a colourless liquid.

Boiling point : -253°C

Freezing point : -259°C

What are the chemical properties of hydrogen

- **Reactivity.** Hydrogen is quite reactive. It can form compounds by losing or by sharing its only electron in the first (K) shell.
  Hydrogen also reacts by gaining one electron from highly electropositive metals.
- **Action on litmus.** Hydrogen has no effect on litmus because it is **neutral.**
  Some typical chemical reactions of hydrogen are described below.

Reactions of hydrogen with nonmetals

- **With oxygen or air.** Hydrogen burns in air (or oxygen) with a nonluminous (blue) flame. The reaction is highly exothermic and vigorous.

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

Hydrogen-air mixture burns **explosively.**

- **With halogens.** Hydrogen also combines **explosively** with fluorine and chlorine, and **less readily** with bromine and iodine to produce volatile covalent compounds. Hydrogen and fluorine combine even in the dark at temperature as low as –250°C (23 K).

$$H_2(g) + F_2(g) \xrightarrow{\text{dark}} 2HF(g)$$

Hydrogen reacts quite vigorously with chlorine when heated or exposed to sunlight.

$$H_2(g) + Cl_2(g) \xrightarrow{\text{sunlight}} 2HCl(g)$$

Bromine which is less reactive, combines with hydrogen at temperature above 400°C.

$$H_2(g) + Br_2(g) \xrightarrow{\text{above } 400°C} 2HBr(g)$$

The reactivity of hydrogen with halogens follows the order : $F_2 > Cl_2 > Br_2 > I_2$

Hydrogen and iodine vapour combine under proper conditions in the presence of catalyst. This reaction is reversible.

$$H_2(g) + I_2(g) \underset{200\text{ atm}}{\overset{\text{Fe/Mo, 700 K}}{\rightleftharpoons}} 2HI(g)$$

- **With nitrogen.** Hydrogen reacts with nitrogen at about 450-500°C and under high pressure (200-900 atm) in the presence of a catalyst to give ammonia.

$$N_2(g) + 3H_2(g) \underset{200\text{ atm, }450°C}{\overset{\text{Fe/Mo}}{\rightleftharpoons}} 2NH_3(g) + \text{heat}$$

This reaction forms the basis of the **Haber's process** for the manufacture of ammonia from nitrogen and hydrogen.

- **With sulphur.** Hydrogen also combines directly when heated with sulphur or bubbled through molten sulphur giving H_2S.

$$\underset{\text{hydrogen}}{H_2(g)} + \underset{\text{sulphur}}{S} \xrightarrow{\text{heat}} \underset{\text{hydrogen sulphide}}{H_2S(g)}$$

or, $$H_2(g) + S(molten) \rightarrow H_2S(g)$$

- **With carbon.** When heated over 1100°C, hydrogen directly combines with carbon forming methane, CH_4.

If an arc is struck between carbon electrodes in an atmosphere of hydrogen, acetylene (C_2H_2) is formed.

$$\underset{\text{carbon}}{C(s)} + \underset{\text{hydrogen}}{2H_2(g)} \xrightarrow{1100°C} \underset{\text{methane}}{CH_4(g)}$$

$$\underset{\text{carbon}}{2C(s)} + \underset{\text{hydrogen}}{H_2(g)} \xrightarrow{\text{electric arc}} \underset{\text{acetylene}}{C_2H_2(g)}$$

Reactions of hydrogen with metals

Highly electropositive metals, such as sodium, lithium and calcium react at high temperatures with hydrogen to form **hydrides.**

In such compounds, each hydrogen atom accepts one electron to become a negative hydride ion, H^-. These hydrides are ionic compounds and very unstable in water. These react with water giving hydroxide of the metal and hydrogen gas.

Metals like iron, nickel, palladium, etc. take up hydrogen and form **interstitial** or **metallic hydrides**.

$$\underset{\text{sodium}}{2Na(s)} + \underset{\text{hydrogen}}{H_2(g)} \xrightarrow{\Delta} \underset{\text{sodium hydride}}{2NaH(s)} \rightarrow 2Na^+H^-$$

$$NaH(s) + H_2O(l) \xrightarrow{\Delta} NaOH(aq) + H_2(g)$$

$$\underset{\text{calcium}}{Ca(s)} + \underset{\text{hydrogen}}{H_2(g)} \xrightarrow{\Delta} \underset{\text{calcium hydride}}{CaH_2(s)} \rightarrow Ca^{2+}(H^-)_2$$

$$CaH_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + 2H_2(g)$$

Reducing character of hydrogen – Reaction with metal oxides

Hydrogen is a good reducing agent. Hydrogen reduces many metal salts, *e.g.*, halides and oxides, to the corresponding metals. This reducing property of hydrogen is used in obtaining certain metals from their oxides where carbon cannot be used for reduction purposes.

$$\underset{\text{mercury(II) oxide}}{HgO(s)} + \underset{\text{hydrogen}}{H_2(g)} \rightarrow \underset{\text{mercury}}{Hg(l)} + \underset{\text{water}}{H_2O(l)}$$

$$\underset{\text{copper(II) oxide}}{CuO(s)} + H_2(g) \rightarrow \underset{\text{copper}}{Cu(s)} + H_2O(l)$$

$$\underset{\text{copper(I) oxide}}{Cu_2O(s)} + H_2(g) \rightarrow \underset{\text{copper}}{2Cu(s)} + H_2O(l)$$

$$\underset{\text{silver oxide}}{Ag_2O(s)} + H_2(g) \rightarrow \underset{\text{silver}}{2Ag(s)} + H_2O(l)$$

$$\underset{\text{ferroferric oxide}}{Fe_3O_4(s)} + 4H_2(g) \rightarrow \underset{\text{iron}}{3Fe(s)} + 4H_2O(l)$$

Tungsten (W) and molybdenum (Mo) are extracted from their oxides by **hydrogen reduction** process. **Hydrogen cannot reduce heated Al_2O_3.**

$$\underset{\text{tungsten oxide}}{WO_3(s)} + 3H_2(g) \rightarrow \underset{\text{tungsten}}{W(s)} + 3H_2O(l)$$

$$\underset{\text{molybdenum oxide}}{MoO_3(s)} + 3H_2(g) \rightarrow \underset{\text{molybdenum}}{Mo(s)} + 3H_2O(l)$$

Hydrogenation reaction

Unsaturated organic compounds combine directly with hydrogen to produce saturated compounds. Such a reaction is known as **hydrogenation.** This is illustrated by the reaction of ethylene (ethene) and H_2 to form ethane, C_2H_6.

$$\underset{\text{ethene}}{H_2C = CH_2(g)} + H_2(g) \xrightarrow[250°C]{Ni} \underset{\text{ethane}}{H_3C - CH_3(g)}$$

Unsaturated oils are hydrogenated on commercial scale for converting liquid fats, such as vegetable oils into solid fats (vegetable ghee).

$$\text{Oils}(l) + H_2(g) \xrightarrow[250°C]{\text{Finely divided Ni}} \text{Vegetable ghee}$$

Coal can be hydrogenated to produce a mixture of liquid hydrocarbons which is distilled to obtain **synthetic petroleum.**

USES OF HYDROGEN

What are the uses of hydrogen

Hydrogen is a very valuable element from commercial point of view. Some of its major industrial uses are as follows:

- **For manufacturing industrial compounds.** It is used for the manufacture of ammonia (Haber's process), hydrochloric acid, methanol, etc.
- **In hydrogenation reactions.** It is used for the hydrogenation of oils, *i.e.*, for the manufacture of vegetable ghee.
- **In meteorological balloons.** It is used in filling balloons and airships. Because of its combustible nature and high diffusion rate, generally a mixture of 85% helium and 15% hydrogen is used for this purpose. Nowadays, however, only hot air balloons are used.
- **In oxy-hydrogen torch.** It is used for producing oxy-hydrogen flame to be used for welding purposes due to its high temperature (3000°C).
- **As a fuel in space vehicles.** Hydrogen is used as a fuel in rockets and guided missiles. This is because hydrogen has the highest calorific value.
- **As an alternative source of energy.** As an alternative source of energy in industry and automobiles through the fuel-cell route.
- **In extractive metallurgy.** Hydrogen is used as a reducing agent to obtain metals from their oxides.

Hydrogen has the highest calorific value.

Many motor companies including Daimler-Chrysler and Ford have already produced prototypes of **hydrogen-powered** vehicles run on fuel cells.

LET US ANSWER SOME MORE QUESTIONS

1. Why is hydrogen assigned a special position in the periodic table?
2. Give two facts each to support
   (*a*) hydrogen resembles alkali metals (*b*) hydrogen resembles halogens.
3. (*a*) How will you prepare hydrogen using magnesium?
   (*b*) Write chemical equation of the reaction.
4. (*a*) Write the chemical equation describing the electrolysis of water.
   (*b*) At which electrode is hydrogen gas evolved?
5. Mention the physical property of hydrogen that made it suitable for using in meteorological balloons.
6. How is ammonia obtained using hydrogen?
7. Give one reaction describing the reducing character of hydrogen.
8. Give balanced chemical equations for the preparation of hydrogen using the following substances.
   (*a*) acidulated water (*b*) cold water
   (*c*) a metal hydride (*d*) steam
9. Complete and balance the following chemical equations.
   (*a*) $Zn(s) + H_2O(g) \rightarrow$ _____ (steam)
   (*b*) $K(s) + H_2O(l) \rightarrow$ _____
   (*c*) $Zn(s) + NaOH(aq) \rightarrow$ _____ (hot, conc.)
   (*d*) $Fe_2O_3(s) + H_2(g) \rightarrow$ _____ (hot)
   (*e*) $C_2H_4(g) + H_2(g) \rightarrow$ _____
   (*f*) $N_2(g) + H_2(g) \rightarrow$ _____
10. You are provided with dilute hydrochloric acid and samples of the following metals: Sodium, calcium, magnesium, iron, zinc, lead, copper and silver.
    Name:
    (*a*) The metals that would not liberate hydrogen from the acid.
    (*b*) The metal(*s*) that would react explosively with the acid.
    (*c*) A metal that is above hydrogen in the activity series, yet does not displace hydrogen. Also give a reason for this behaviour.
    (*d*) A metal that liberates hydrogen very slowly from the acid.
    (*e*) A metal that reacts moderately with the acid.
    Instead of dilute hydrochloric acid, you are provided with nitric acid, would hydrogen be liberated? Explain.
11. Name a black
    (*a*) oxidising agent (*b*) reducing agent
12. Name the products formed when steam is reacted with water gas at 800°C in the presence of a catalyst.
    (*a*) name the catalyst (*b*) write the balanced chemical equation.
13. Why are nitric acid and conc. sulphuric acid not used in the preparation of hydrogen?
14. How can you justify that hydrogen is very useful for industry?
15. Tick (✔) the correct answer.
    (i) Hydrogen was first prepared by
    (*a*) Henry Cavendish ❑ (*b*) Paracelsus ❑
    (*c*) Antoine Lavoisier ❑ (*d*) Robert Boyle ❑

(ii) Which of the following metals is used for preparing hydrogen?

(a) nickel ❑ (b) molybdenum ❑

(c) copper ❑ (d) iron ❑

(iii) In the reaction involving water, an active metal produces

(a) oxygen ❑ (b) nitric acid ❑

(c) a base ❑ (d) nitrogen ❑

(iv) In the preparation of vanaspati ghee, the chemical reaction involving hydrogen in the presence of catalyst is called

(a) reduction ❑ (b) dehydrogenation ❑

(c) hydrogenation ❑ (d) oxidation ❑

(v) Hydrogen does not reduce heated

(a) Al_2O_3 ❑ (b) CuO ❑

(c) SnO_2 ❑ (d) Fe_3O_4 ❑