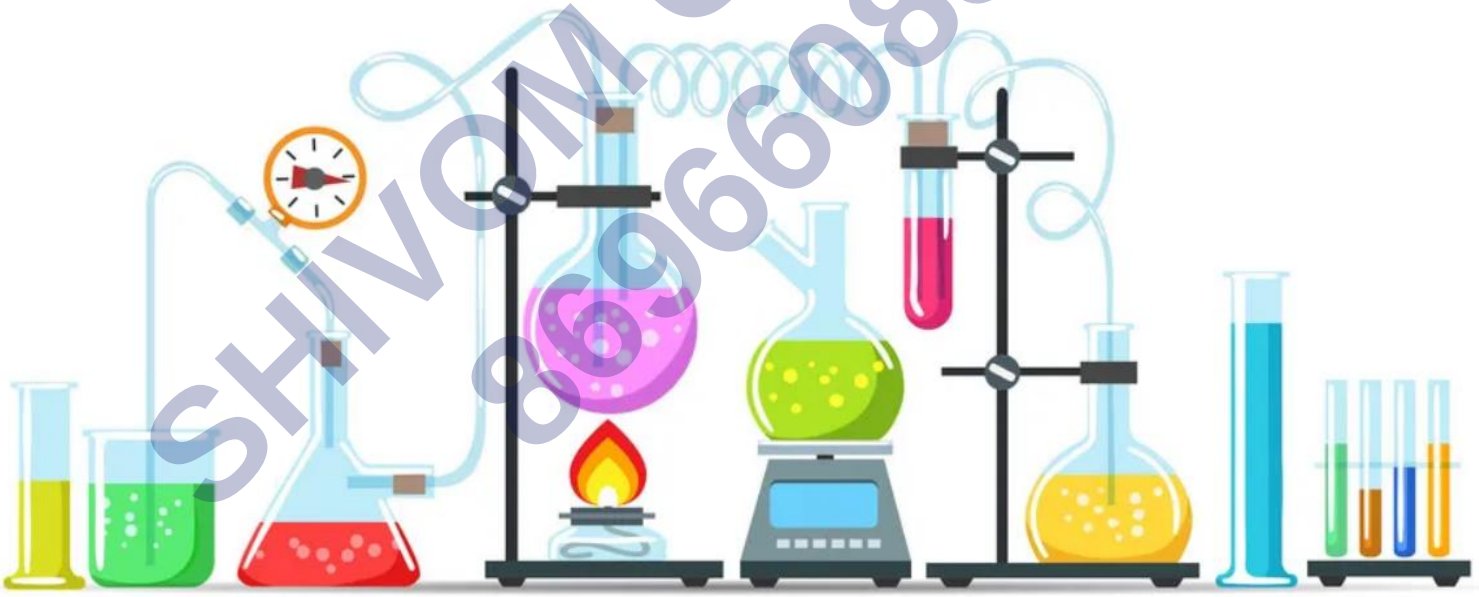
CHEMISTRY

CHAPTER 9: HYDROGEN



HYDROGEN

Introduction

In this chapter we will study the preparation, properties of dihydrogen and of some important compounds formed by hydrogen like H_2O and H_2O_2.

Hydrogen is the first element of the periodic table. The atomic structure of hydrogen is the most simplest one with only one proton and one electron. Hydrogen occurs in its atomic form only at very high temperatures. Water is one of the most important compounds formed by hydrogen. Even its name hydrogen was given by Lavoisier because of its ability to form water as in Greek, hydro means water and gene means forming.

Position of Hydrogen in the Periodic Table

Hydrogen is the first element in the periodic table. The electronic configuration of hydrogen is $1s^1$, yet its position in the periodic table is not certain and unsatisfactory. Hydrogen exhibits properties similar to both alkali metals (Group 1) and halogens (Group 17).

Resemblance with Alkali Metals

Like alkali metals, hydrogen has only one electron in its outer shell.

Alkali metals have a strong tendency to lose one electron from their outermost shell. Similarly, hydrogen also loses electron to form H^+ ion.

Alkali metals form stable oxides, halides and sulphides. Similarly, hydrogen also forms stable oxide (H_2O), halides (HF) and sulphide (H_2S).

Resemblance with Halogens

Halogens have a tendency to gain one electron. Similarly, hydrogen ($1s^1$) gains one electron to form H^- ion.

Hydrogen molecule is diatomic (H_2) and so are the molecules of halogens (say F_2).

Hydrogen forms hydrides with carbon (e.g., CH_4), just like halogens form halides with carbon (CCl_4).

Isotopes of Hydrogen

Isotopes are the different forms of the same element having same atomic number but different mass numbers. There are three isotopes of hydrogen namely protium, deuterium and tritium.

1. **Protium or ordinary hydrogen ($_1H^1$):** It has one proton and no neutron in the nucleus and one electron revolves around the nucleus.

2. **Deuterium ($_1H^2$ or D):** It is also known as heavy hydrogen. It has one proton and one neutron in the nucleus around which one electron revolves.

3. **Tritium ($_1H^3$ or T):** This isotope of hydrogen is radioactive and emits low energy β– particles having half-life period of 12.33 years. It has one proton and two neutrons in the nucleus. The concentration of tritium is very low.

Dihydrogen

Occurrence

Dihydrogen is the most abundant element in the universe. It constitutes about 70% of the total mass of the universe. But its abundance in earth's atmosphere is very less. It is just 0.15% by mass in the earth's atmosphere. In free state hydrogen is present in volcanic gases and in the combined form it constitutes 15.4% of the earth's crust and the oceans. However, it is also present in the plant and animal tissues, carbohydrates, proteins etc. Even hydrogen is present in mineral resources like coal and petroleum.

Hydrogen is the principal element in the solar atmosphere. It is present in the outer atmosphere of Sun and other stars of the universe+ like Jupiter and Saturn.

Preparation of Dihydrogen

1. Laboratory Preparation of Dihydrogen

i. In laboratory dihydrogen is prepared by the reaction of granulated zinc with dilute hydrochloric acid or dilute sulphuric acid.

$Zn + 2H^+(dil) \longrightarrow Zn^{2+} + H_2$

ii. Zinc reacts with aqueous alkali to give dihydrogen

$Zn + 2NaOH \longrightarrow Na_2ZnO + H_2$

2. Commercial Production of Dihydrogen

i. **By the electrolysis of water:** Electrolysis of acidified water using platinum electrodes is used for the bulk preparation of hydrogen.

$2H_2O \longrightarrow 2H_2 + O_2$

ii. **By the action of steam on coke:** Dihydrogen is prepared by passing steam over coke or

hydrocarbons at high temperature (1270 K) in the presence of Nickel catalyst.

$C + H_2O \longrightarrow CO + H_2$

The mixture of CO(g) and H_2(g) is called water gas. It is also known as synthesis gas or simply 'syn gas' because it is used in the synthesis of methanol and many other hydrocarbons.

Properties of Dihydrogen

i. Physical Properties

- Dihydrogen is a colorless, odourless, tasteless, combustible gas.
- It is lighter than air.
- It is insoluble in water.

ii. Chemical Properties

Reaction with halogens: It reacts with halogens, X_2 to give hydrogen halides, HX,

$H_2 + X_2 \longrightarrow 2HX$ (X F,Cl, Br,I)

Reaction with dioxygen: It reacts with dioxygen to form water. The reaction is highly exothermic.

$2H_2 + O_2 \longrightarrow 2H_2O$

Reaction with dinitrogen: With dinitrogen it forms ammonia.

$3H_2 + N_2 \longrightarrow NH_3$

Reactions with metals: Dihydrogen reacts with metals to yield hydrides at high temperature.

$H_2 + 2M(g) \longrightarrow 2MH(s)$

where M is an alkali metal.

Hydrogenation of vegetable oils: Edible oils (unsaturated) like cotton seed oil, groundnut oil are converted into solid fat (saturated) also called vegetable ghee by passing hydrogen through it in the presence of Ni at 473 K.

Vegetable oil + $H_2 \longrightarrow$ Fat

Uses of Dihydrogen

1. **Synthesis of ammonia:** Dihydrogen is used in Haber's process in the synthesis of ammonia.
2. **Hydrogenation of oils:** Dihydrogen is added to oils like soyabean oil, cotton seed oil for manufacturing vanaspati fat.
3. **Manufacture of methyl alcohol:** Water gas enriched with hydrogen gas in the presence of cobalt catalyst gives methanol.
4. **Manufacture of hydrogen chloride:** It is used in the manufacturing of hydrogen chloride which is a very important chemical.
5. **Manufacture of metal hydrides:** It is used in the manufacture of many metal hydrides.
6. **Metallurgical processes:** Since, dihydrogen is used to reduce heavy metal oxides to metals, as it is a reducing agent. Therefore, it finds its use in metallurgical processes.
7. **Rocket fuel:** It is used as a rocket fuel for space research in the form of liquid hydrogen and liquid oxygen.
8. **Fuel Cells:** Dihydrogen is used in fuel cells for the generation of electrical energy.
9. It is used in the atomic hydrogen torch and oxyhydrogen torches for cutting and welding purposes.

Hydrides

Hydrogen combines with a large number of other elements including metals and non-metals, except noble gases to form binary compounds called hydrides. If 'E' is the symbol of the element then hydrides are represented as EH_x (e.g., BeH_2)

Based on their physical and chemical properties, the hydrides have been classified into three main categories:

- Ionic or saline or salt like hydrides.
- Covalent or molecular hydrides.
- Metallic or non-stoichiometric hydrides.

Ionic or Saline Hydrides

The ionic hydrides are stoichiometric which are formed when hydrogen combines with

elements of s-block elements except Be. Ionic hydrides are formed by transfer of electrons from metals to hydrogen atoms and contain hydrogen as H– ion e.g., sodium hydride (Na^+H^-)

Covalent or Molecular Hydrides

Covalent or molecular hydrides are the compounds of hydrogen with p-block elements. The most common hydrides are CH_4, H_2O, NH_3 etc. Covalent hydrides are volatile compounds.

Metallic or Non-Stoichiometric Hydrides

The elements of group 3, 4, 5 (d-block) and f-block elements form metallic hydrides. In group 6, only chromium forms hydride (CrH). Metals of group 7, 8, 9 do not form hydrides. These hydrides are known as metallic hydrides because they conduct electricity.

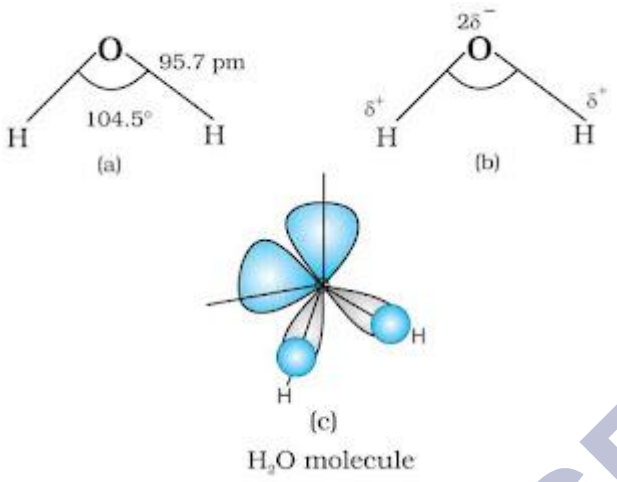
Water

Water is an oxide of hydrogen. It is an important component of all living organisms. Water constitutes about 65% of human body and 95% of plants. It is therefore essential for life. The ability of water to dissolve so many other substances makes it a compound of great importance. Almost three-fourth of the earth's surface is covered with water.

Physical Properties of Water

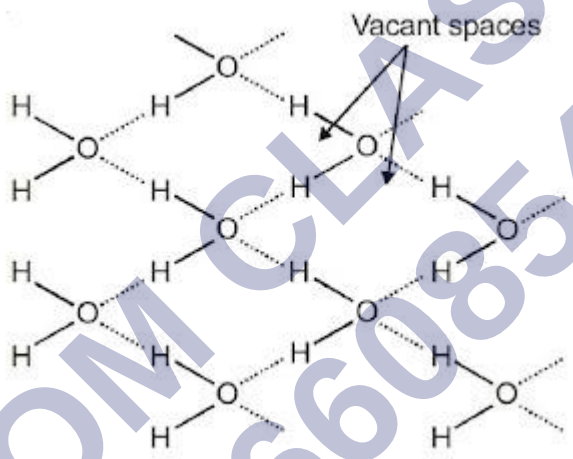
1. Pure water is colourless, odourless and tasteless.
2. Water is present in the liquid state at room temperature.
3. Water boils at 100°C and changes into the gaseous state whereas it freezes at 0°C to form ice.
4. Water molecules undergo extensive hydrogen bonding.
5. It is an excellent solvent for many thing like alcohols and carbohydrates dissolve in water.

Structure of Water



H_2O molecule

Structure of Ice



Chemical Properties

1. **Amphoteric nature:** Water can act both as an acid as well as a base and is thus said to be an amphoteric substance.

   Water as base: Water acts as a base towards acids stronger than it as shown below,

   $H_2O + HCl \longrightarrow H_3O^+ + Cl^-$

   Water as an acid: Water acts as an acid towards bases stronger than it.

   $H_2O + NH_3 \longrightarrow OH^- + NH_4^+$

2. **Redox reactions involving water:** Water can act both as oxidising as well as reducing agent.

   Oxidising agent: Water acts as an oxidising agent when it gets reduced.

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

Reducing agent: Water acts as a reducing agent when it gets oxidised.

$2H_2O + 2F_2 \longrightarrow 4H^+ + 4F^- + O_2$

3. **Hydrolysis reaction:** Water is an excellent solvent due to its high dielectric constant (78.39). In addition, water can easily hydrolyses many ionic and covalent compounds.

   Water hydrolyses oxides and halides of non-metals forming their respective acids

   $P_4O_{10} + 6H_2O \longrightarrow 4H_3PO_4$

4. **Hydrates Formation:** From aqueous solutions many salts can be crystallised as hydrated salts. Hydrates are of three types:

   i. Coordinated water

   For example: $[Ni(H_2O)_6]_{2+}$ $(NO_{3-})_2$ and $[Fe(H_2O)_6]Cl_3$

   ii. Interstitial water

   For example: $BaCl_2.2H_2O$

   iii. Hydrogen bonded water

   For example: $[Cu(H_2O)_4]^{2+}$ SO_4^{2-} H_20 in $CuS0_4.5H_2O$

Hard and Soft Water

Hard water is the one which does not produce lather with soap easily due to the presence of calcium and magnesium salts in the form of their bicarbonates, chlorides and sulphates. For example, sea water etc.

Soft water is the one which is free from the soluble salts of calcium and magnesium. It gives lather with soap easily. For example, distilled water, rain water etc.

Types of Hardness

1. **Temporary hardness:** It is due to the presence of bicarbonates of calcium and magnesium. Temporary hardness is called so because it can be easily removed by boiling.

2. **Permanent hardness:** This type of hardness is due to the presence of chlorides and sulphates of calcium and magnesium dissolved in water. As this type of hardness cannot be removed by simple boiling, therefore it is known as permanent hardness.

Softening of Water

The process of removal of hardness from water is called softening of water.

i. **Removal of temporary hardness:** Temporary hardness can be removed by the following methods:

a) **Boiling:** The temporary hardness of water can easily be removed by boiling the water in large boilers. During boiling the soluble $Mg(HCO_3)_2$ is converted into $Mg(OH)_2$ instead of $MgCO_3$ because $Mg(OH)_2$ is precipitated easily, whereas $Ca(HCO_3)_2$ is changed to insoluble $CaCO_3$ and gets precipitated. These precipitates can be removed by filtration process. So, the filtrate obtained will be soft water.

$Mg(HCO_3)_2 \longrightarrow Mg(OH)_2 + 2CO_2$

$Ca(HCO_3)_2 \longrightarrow Ca(OH)_2 + H_2O + 2CO_2$

b) **Clark's method:** In this process the calculated amount of lime is added to hard water containing bicarbonates of calcium and magnesium. It precipitates out calcium carbonate and magnesium hydroxide which are then filtered to obtain soft water.

$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3\downarrow + 2H_2O$

$Mg(HCO_3)_2 + 2Ca(OH)_2 \longrightarrow 2CaCO_3\downarrow + Mg(OH)_2\downarrow + 2H_2O$

ii. **Permanent hardness:** Permanent hardness of water is due to the presence of chlorides and sulphates of calcium and magnesium. It cannot be removed by simple boiling. So, the following methods are employed for removing permanent hardness:

a) **Treatment with washing soda:** When calculated amount of Na2CO3 (washing soda) is added to hard water containing soluble sulphates and chlorides of calcium and magnesium, then these soluble salts get converted into insoluble carbonates which get precipitated.

$CaCl_2 + Na_2CO_3 \longrightarrow 3CaCO_3\downarrow + 2NaCl$

$MgSO_4 + Na_2CO_3 \longrightarrow 3MgCO_3\downarrow + Na_2SO_4$

d) **Ion-exchange method:** This process employs the use of zeolite or permutit which is hydrated sodium aluminium silicate ($NaAlSiO_4$), therefore, it is also known as zeolite/permutit process. For the sake of simplicity sodium aluminium silicate is written as NaZ. When zeolite is added to hard water, the cations present in hard water are exchanged for sodium ions.

$2NaZ(s) + M^{2+}(aq) \longrightarrow MZ_2(s) + 2Na^{+}(aq)$ (M = Mg, Ca)

Hydrogen Peroxide

Hydrogen peroxide was discovered by a French chemist J. L. Thenard. It is an important chemical used in pollution control treatment of domestic and industrial effluents.

Preparation

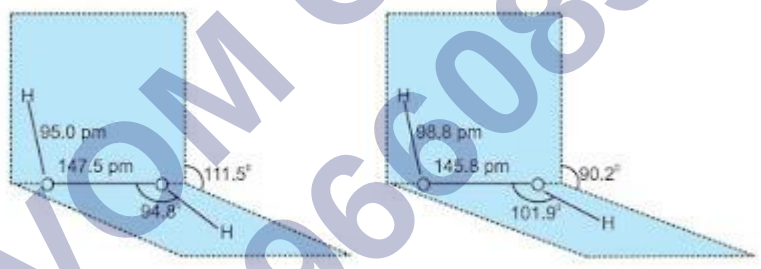
By the action of sulphuric acid on hydrated barium peroxide

$BaO.8H_2O + H_2SO_4 \longrightarrow BaSO_4 + H_2O_2 + H_2O$

Physical Properties

1. Pure hydrogen peroxide is a syrupy liquid. It is colourless but gives a bluish tinge in thick layers.
2. It is soluble in water, alcohol and ether in all proportions.
3. It is more viscous than water. This is due to the fact that molecules of H_2O_2 are more associated through H-bonding.

Structure



(a) Gas phase (b) Solid phase

Chemical Properties

a) **Oxidising property:** Hydrogen peroxide acts as an oxidising agent both in acidic as well as in alkaline medium.

$H_2O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O$

b) **Reducing Property:** In presence of strong oxidising agents, hydrogen peroxide behaves as a reducing agent in both the medium.

$H_2O_2 + O_3 \longrightarrow H_2O + 2O_2$

c) **Decomposition:** H2O2 is an unstable liquid

$2H_2O_2 \longrightarrow 2H_2O + O_2$

Uses

1. In daily life it is used as a material to bleach delicate materials like hair, cotton, wool, silk

etc.

2. It is used as a mild disinfectant. It is also a valuable antiseptic which is sold under the name of perhydrol.
3. In the manufacture of sodium perborate, sodium percarbonate. These are used in high quality detergents.
4. In the synthesis of hydroquinone, tartaric acid and certain food products and pharmaceuticals (cephalosporin) etc.
5. It is used in industries as a bleaching agent for paper pulp, leather, oils, fats and textiles etc.

Heavy Water (D_2O)

Method Heavy water is chemically deuterium oxide (D_2O). It was discovered by Urey in 1932.

Preparation

It is prepared by the exhaustive electrolysis of water. When prolonged electrolysis of water is done, then H_2 is liberated much faster than D_2 and the remaining water becomes enriched in heavy water.

$H_2O + D_2 \longrightarrow D_2O + H_2$

Uses

1. Heavy water is used as a moderator in nuclear reactors.
2. It is used as a tracer compound, in studying the reaction mechanisms.
3. It is used as a starting material for the preparation of a number of deuterium compounds.

Hydrogen Economy

Hydrogen Economy

One proposed way to meet the need for new energy sources is to burn hydrogen as a fuel in industry and power plants and possibly also in homes and motor. This proposal is referred to hydrogen economy.

Advantages of hydrogen econor

1) Dihydrogen releases large quantities of heat on combustion. The energy released by combustion of fuels like dihydrogen, methane, LPG as compared in terms of the same amount in mole, mass and volume.On mass to mass basis, dihydrogen can release more energy than gasoline i.e. Octane number is about 3 times.

Energy released on combustion (in KJ)	Dihydrogen (in gaseous state)	Dihydrogen (in liquid state)	LPG	CH_4 gas	Octane(in liquid state)
per mole	286	285	2220	880	5511
per gram	143	142	50	53	47
per litre	12	9968	25590	35	34005

2) Burning of hydrogen in air or dioxygen not only liberates large amount of energy but yields water as the only product. Burning of hydrogen produces no pollutant like SO2 that are responsible for acid rain ,nor carbon dioxide that is responsible for the greenhouse effect ,nor carcinogenic hydrocarbons nor lead compounds.

There are two major barriers in achieving the goal of hydrogen economy

1) To find out a cheap method for large scale production of dihydrogen.

Two methods which have been proposed are :

a)Electrolysis of water and the thermochemical reactions cycle. The first method is not economically viable since the cost of production of dihydrogen by electrolysis of water is so high that almost all dihydrogen is obtained from natural gas which itself is in short supply.

b) The other method involves series of thermochemical reactions in which the only things consumed are water and heat and only products are hydrogen and oxygen while all the other species are recycled.

2) To find out an effective means of storing dihydrogen.

The gaseous dihydrogen because of its bulk, is difficult to store, but liquid dihydrogen can be stored relatively easily and safely in cryogenic tanks.

It is also feasible to transport liquid dihydrogen by road or rail tankers of 20000 US gallons capacity.It can also be stored in underground tanks and transported by pipelines. However it may not be convenient to store liquid dihydrogen in a home or in a car since the boiling point

of dihydrogen is very low.

Dihydrogen must be kept out of contact with oxygen or air with which it forms explosive mixture. The only alternative left is to store dihydrogen or metal in an alloy as interstitial hydride.

Methods to remove hardness

Temporary hardness : It can be removed by following methods :

- Boiling
- Clarks method

Boiling : In this when we boil hard water, bicarbonates are convereted into hydroxides and calcium bicarbonate is converted into carbonates. These precipitates are filtered and thus, hardness is removed .

Clark's method: In this method calculated amount of lime is added that precipitates Calcium and Magnessium carbonates .

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

calcium bicarbonate calcium hydroxides calcium carbonate water

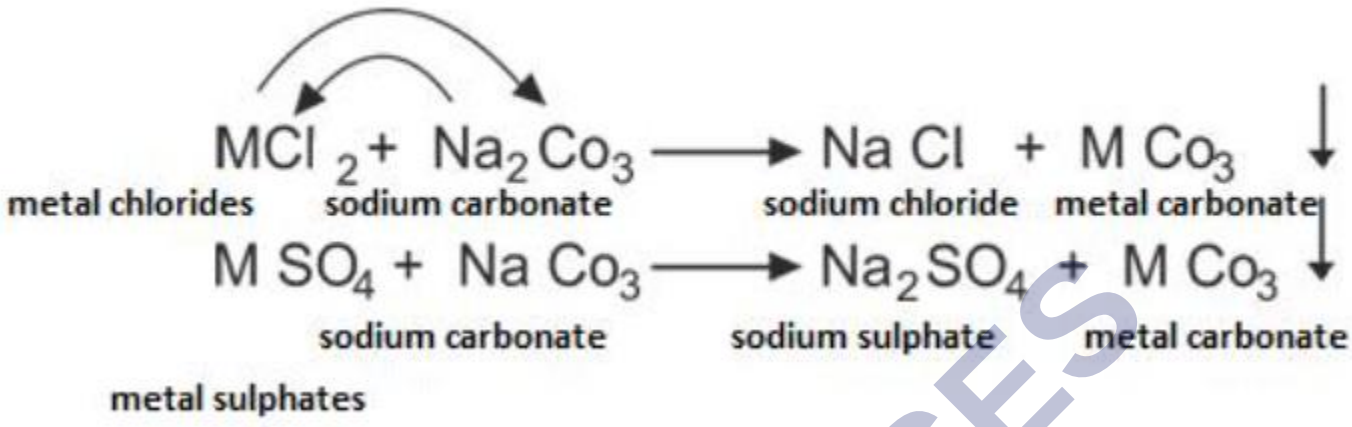
$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O + Mg(OH)_2$$

Magnessium bicarbonate calcium hydroxide calcium carbonate magnessium hydroxide

Permanent hardness : It is removed by following methods :

- With washing soda
- Calgon's process
- Ion exchange method
- Synthetic resin method

1. With washing soda : In this washing soda is added .It reacts with calcium and magnessium chlorides and sulphates to form soluble carbonates as shown :

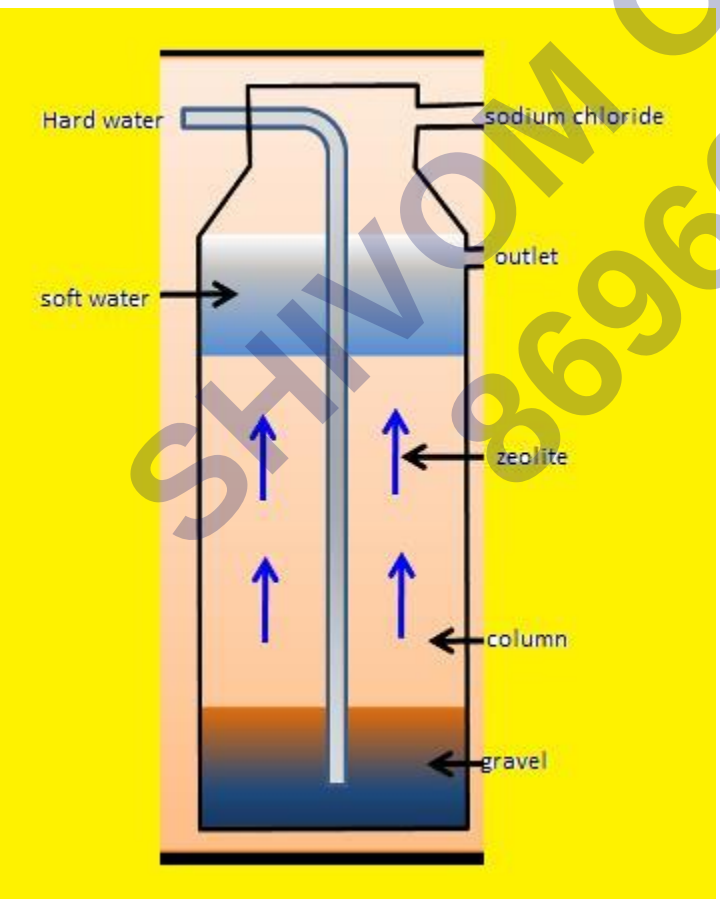


Ion – exchange method

In this a substance called zeolite or permutit is added. This zeolite exchange Sodium with Calcium and Magnessium ions of hard water .

Example of permutit are many like :hydrated Sodium Aluminium Silicates ($Na_2Al_2Si_2O_8.xH_2O$)commonly can be indicated as NaZ .

The apparatus is set as shown :



Procedure :

- The zeolite is loosely packed over layers of gravel and sand in big tank .

- Hard water is introduced from top into the base of tank.
- From the bottom water rises up through gravel and sand layers.
- Finally it percolates through the bed of permutit.
- During this the ions are exchanged .
- So ,the water above the permutit layer is generally soft water .

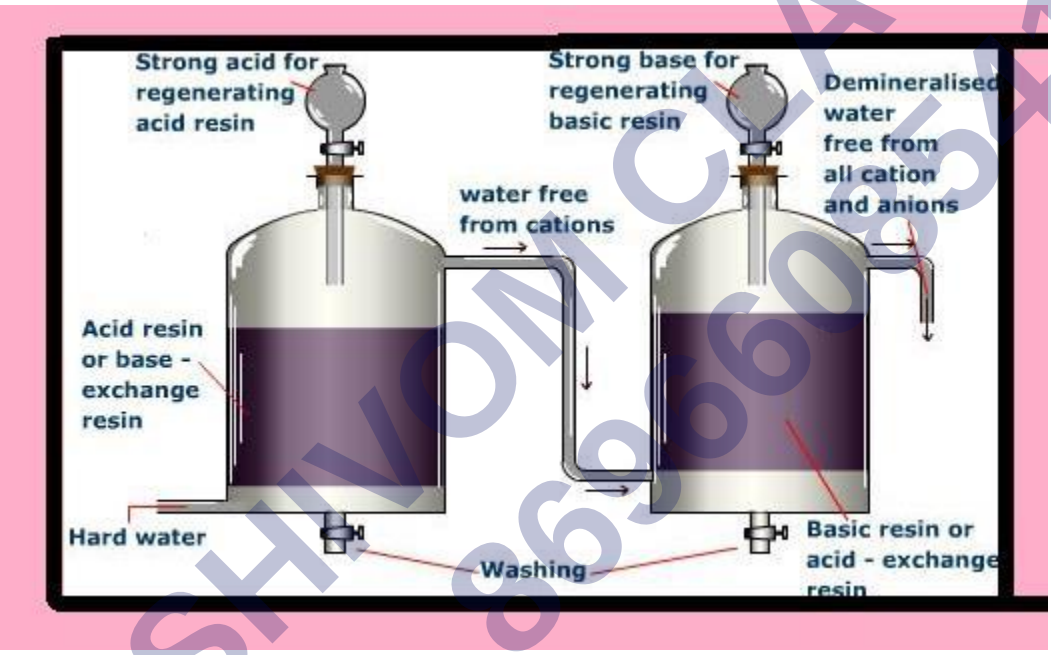
Mg^{2+} + Na Z -------- MgZ_2 + $2Na^+$

magnessium ion Zeolite ion exchnaged

Ca^{2+} + Na Z -------- CaZ_2 + $2Na^+$

calcium ion zeolite ion exchanged

3.Synthetic Resin Method



Synthetic resin methods are more superior then the ion exchange method as they remove all types of cations and anions and the resultant water is distilled water .

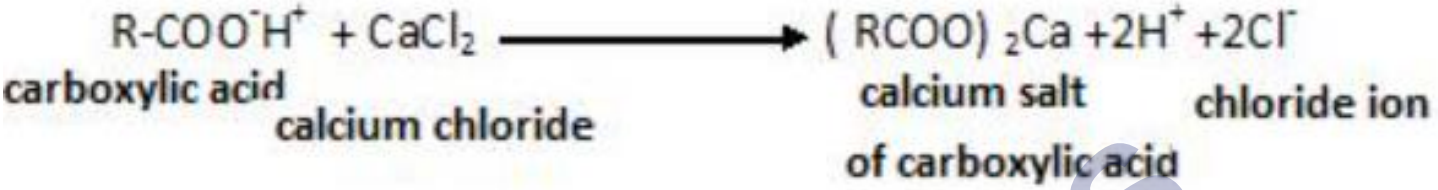
These resins are generally of two types :

- Cation exchange resin
- Anion exchnage resin

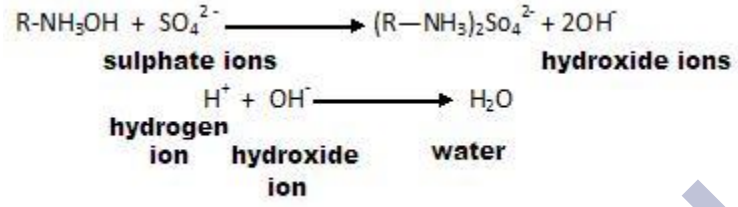
Cation exchange resin : It consist of giant hydrocarbon framework attached to basic groups . They are represented by general formula R-COOH or $R\text{-}SO_3H$ .In this R is giant hydrocarbon .These resins can exchange H^+ ions with cations present in hard water .

Anion exchange resin : It consist of giant hydrocarbon frmaework attached to basic groups like

OH- ions, usually in the form of subsituted ammonium hydroxides. They are represented as R-NH_3OH- where R denotes giant hydrocarbon framework .These resins can exchange hydroxide ion with anions like chloride ions and sulfate ions present in hard water .



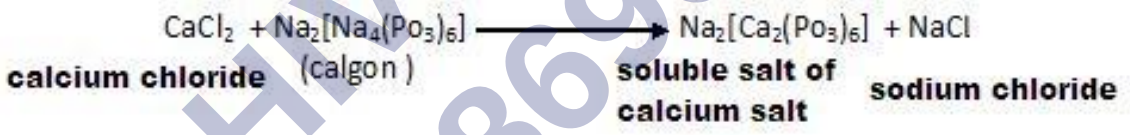
Thus the water that comes out from the tank is richer in hydrogen ions,this water is then passed through second tank ,here the anions are exchanges with hydroxide ion to form distilled water.



4.Calgon process

In this procss calcium and magnessium ions are rendered ineffective by treatment with sodium polymetaphosphate . The trade name for it is calgon .when Calgon is added to hard water the Calcium ,Magnessium ions present in it combine with this Calgon to form soluble complex of Calcium and Magnessium salts .

That is :



Summary-

1. Hydrogen has the simplest atomic structure with only one proton and one electron. It is the only element which has no neutron.
2. Hydrogen has properties similar to both alkali metals as well as halogens. Therefore, its position in the periodic table was not certain and it is best placed separately.
3. There are three isotopes of hydrogen namely protium ($_1H^1$), deuterium ($_1H^2$, D) and tritium ($_1H^3$, T) . The predominant form of hydrogen is protium which has no neutron, deuterium has one neutron, tritium which is radioactive has two neutrons.
4. Hydrogen in its elemental form exists as dihydrogen. Dihydrogen is the most abundant element in the universe.

5. 'Syn gas' or 'water gas' is a mixture of CO and H_2.
6. Dihydrogen is colourless, odourless and combustible gas. The H–H bond dissociation enthalpy is the highest for a single bond between two atoms of any element.
7. The main use of dihydrogen is in the formation of vegetable ghee by hydrogenation of vegetable oils and also the formation of ammonia by Haber's process.
8. Atomic hydrogen and oxyhydrogen torches are used for cutting and welding purpose.
9. It acts as a rocket fuel and even has a promising potential for use as a non-polluting fuel of the near future (hydrogen economy).
10. Hydrogen forms three category of hydrides namely ionic hydrides, covalent hydrides and metallic hydrides.
11. Covalent hydrides are further classified into electron-deficient, electron-precise and electronrich hydrides based on the relative number of electrons and bonds in their Lewis structures.
12. Water is a substance which is of great chemical and biological significance. It is a solvent of great importance.
13. Water has highest density at 4°C.
14. Water reacts with large number of substances. It exhibits amphoteric nature.
15. Water dissolves many salts in it making it hard. Hard water is the one which contains calcium and magnesium salts in the form of hydrogencarbonate, chlorides and sulphates.
16. The temporary hardness of water is due to the presence of magnesium and calcium hydrogencarbonates which can be removed simply by boiling.
17. The permanent hardness of water is due to the presence of soluble salts of magnesium and calcium in the form of chlorides and sulphates. It is mainly removed by the ion-exchange methods.
18. Hydrogen peroxide has a non-planar open-book like structure. It is a good bleaching agent and is used in pollution control treatment of industrial and domestic effluents.

Class : 11th Chemistry
Chapter- 9: Hydrogen

Occurrence: Most abundant in universe.

Preparation:

– Laboratory Method:

- $Zn+2H^+ \rightarrow Zn^{2+}+H_2$
- $Zn+2NaOH \rightarrow Na_2ZnO_2+H_2$

–Commercial Method:

- $2H_2O(l) \xrightarrow[\text{Traces of acid/base}]{\text{Electrolysis}} 2H_2(g)+O_2(g)$
- By electrolysing warm aqueous barium hydroxide solution between Nl electrodes.
- $C_nH_{2n+2}+nH_2O \xrightarrow[\text{Ni}]{1270\ K} nCO+(2n+1)H_2$

–$CO+H_2$ is called water gas

–Cool Gasification : $C(s)+H2O(g) \xrightarrow{1270\ K} CO_{(g)}+H_{2(g)}$

–Water-gas shift reaction : $CO(g)+H_2O_{(g)} \xrightarrow[\text{Catalyst}]{673\ K} CO_{2(g)}+H_{2(g)}$

Physical Properties:

- Colourlers, odourless, tasteless and combustible.
- Lighter than air, insoluble in water.

Chemical Properties:

$H_{2(g)}+X_{2(g)} \longrightarrow 2HX_{(g)}$ (X=F, Cl,Br,I)

$2H_{2(g)}+O_{2(g)} \xrightarrow[\text{Heating}]{\text{Catalyst or}} 2H_2O(l)\ \Delta H^\circ = -285.9\ \text{KJmol}^{-1}$

$3H_{2(g)}+N_{2(g)} \xrightarrow[\text{Fe}]{673\ K,\ 200\ atm} 2NH_{3(g)}\ \Delta H^\circ = -92.6\ \text{KJmol}^{-1}$

$H_{2(g)}+2M_{(g)} \longrightarrow 2MH_{3(s)}$ Where M= alkali metal

$H_{2(g)}+Pd^{2+}_{(aq)} \longrightarrow Pd_{(s)}+2H^+_{(aq)}$

$H_2+CO+RCH=CH_2 \longrightarrow RCH_2CH_2CHO$

$H_2+RCH_2CH_2CHO \longrightarrow RCH_2CH_2CH_2OH$

Uses:

- Synthesis of ammonia.
- In manufacture of vanaspati fat.
- In manufacture of bulk organic chemicals.
- For manufacture of metal hydrides
- Preparation of HCl.
- In metallurgical processes.
- As a rocket fuel
- In fuel cells

Preparation: By exhaustive electrolysis of water.
Uses:
- As a moderator in nuclear reactors.
- In exchange reactions for the study of reaction mechanisms.

Heavy Water (D_2O)

Protium: Predominant form. ($_1^1H$)
Deuterium: ($_1^2H$)
Tritium : Radioactive ($_1^3H$)

Isotopes

- Resembles alkali metals (lose one e- to form unipositive ions).
- Resembles halogens (gain one e- to form uninegative ion).
- Forms oxides, halides and sulphides.
- Very high ionization enthalpy.
- Does not possess metallic characters under normal conditions.
- Forms diatomic molecules

Properties

Hydrogen

Types:
(i). Ionic/saline/saltlike: Stoichiometric compounds of dihydrogen formed with s-block elements.
(ii). Covalent/molecular: Formation of molecular compounds from dihydrogen and p-block elements.
(iii). Metallic/non-stoichiometric/interstitial: Formed by d-block and f-block elements.

Hydrides

Water

Electronic Configuration
$1S^1$

Dihydrogen (H_2)

Hydrogen Peroxide
(H_2O_2)

Preparation

- $BaO_2.8H_2O_{(s)}+H_2SO_{4(aq)} \rightarrow BaSO_{4(s)}+H_2O_{2(aq)}+8H_2O_{(l)}$
- $2HSO^-_{4(aq)} \xrightarrow{\text{Electrolysis}} HO_2SOOSO_3H_{(aq)} \longrightarrow 2HSO^-_{4(aq)}+2H^+_{(aq)}+H_2O_{2(aq)}$
- 2– ethylanthraquinol $\underset{H_2/Pd}{\overset{O_2(air)}{\rightleftharpoons}}$ H_2O_2+ Oxidised Product

Physical Properties

- Colourless, miscible with water.
  Structure: Non-Planar
  Chemical Properties:
  $PbSO_{4(s)}+4H_2O_{2(aq)} \rightarrow PbSO_{4(s)}+4H_2O_{(l)}$
  $HOCl+H_2O_2 \rightarrow H_3O^++Cl+O_2$
  $Mn^{2+}+H_2O_2 \rightarrow Mn^{4+}+2OH^-$
  $I_2+H_2O_2+2OH^- \rightarrow 2I^-+2H_2O+O_2$
  Decomposes on exposure

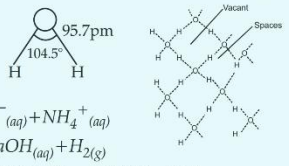
Uses

- As hair bleach, disinfectant.
- Manufacture chemicals used in detergents.
- In industries as bleaching agent.
- In environmental chemistry.

(Human body: 65%, Plants: 95%)

Physical Properties:
- Colourless and tasteless
- Presence of extensive H bonding.
- High freezing point, high B.P., high heat of vaporization, high heat of fusion

Structure:



Chemical Properties:

$H_2O_{(l)}+NH_{3(aq)} \rightleftharpoons OH^-_{(aq)}+NH_4^+{}_{(aq)}$

$2H_2O_{(l)}+2Na_{(s)} \longrightarrow 2NaOH_{(aq)}+H_{2(g)}$

$6CO_{2(g)}+12H_2O_{(l)} \longrightarrow C_6H_{12}O_{6(aq)}+6H_2O_{(l)}+6O_{2(g)}$

$P_4O_{10(s)}+6H_2O_{(l)} \longrightarrow 4H_3PO_{4(aq)}$

Difference: Hard water does not give lather with soap whereas soft water gives lather easily. Temporary hardness: Removed by boiling, Clark's method. (Due to presence of magnesium and calcium hydrogen carbonates)

Permanent hardness: Removed by treatment with washing soda, Calgon's method, Ion exchange method, synthetic resins methods. (Due to presence of soluble salts of Mg and Ca in the form of chlorides and sulphate)

Important Questions

Multiple Choice questions-

Question 1When water is dropped over sodium peroxide, the colourless gas produced is:

(a) DiNitrogen

(b) DiOxygen

(c) DiHydrogen

(d) Hydrogen Peroxide

Question 2. The atomic weights of isotopes of all element are different due to different number of _____.

(a) Protons

(b) Electrons

(c) Neutrons

(d) None of Above

Question 3. During the reaction of natural gas and steam the catalyst used is

(a) Fe

(b) Zn

(c) Ni

(d) Cr

Question 4. Cavendish in 766 discovered.

(a) Nitrogen

(b) Oxygen

(c) Hydrogen

(d) Helium

Question 5. Dihydrogen gas may be prepared by heating caustic soda on

(a) Cu

(b) Zn

(c) Na

(d) Ag

Question 6. Hydrogen set free at the time of its preparation from its compound in atomic form are called _____.

(a) Nascent Molecular Hydrogen

(b) Nascent Atomic Hydride

(c) Both (1) and (2)

(d) Nascent Hydrogen

Question 7. Which substance does not speed up decomposition of H_2O_2

(a) Glycerol

(b) Pt

(c) Gold

(d) MnO_2

Question 8. Water shows anomalous behavior between

(a) 0 to 4 °C

(b) 0 to 5 °C

(c) 0 to -4 °C

(d) 4 to 0 °C

Question 9. Which of the following pair of substance will not evolve H_2 gas?

(a) Iron and aqueous H_2SO_4

(b) Copper and HCl(aq)

(c) Sodium and Ethanol

(d) Iron and Steam

Question 10. Tritium _____ radio active isotope.

(a) Beta-Emitting

(b) Alpha – Emitting

(c) Gamma-Emitting

(d) None of the Above

Question 11. The maximum density of water at 40C is:

(a) 1.0 g / cm^3

(b) 0.998 g / cm^3

(c) 0.918 g / cm^3

(d) 1.2 g / dm^3

Question 12. Water gas is mixture of hydrogen H_2 and

(a) CO

(b) CO_2

(c) Cl_2

(d) SO_2

Question 13. The volume of oxygen gas evolved at STP by decomposition of 0.68 g "20 volume" hydrogen peroxide is:

(a) 112 ml

(b) 224 ml

(c) 56 ml

(d) 336 ml

Question 14. Which of the following statements regarding hydrogen peroxide is/are incorrect?

(a) As aerating agent in production of sponge rubber

(b) As an antichlor

(c) For restoring white colour of blackened lead painting

(d) All of the above

Question 15. _____ on water decolourises H_2O_2

(a) O_3

(b) Acidic $KMnO_4$ solution

(c) Black Suspension of Lead Sulphide(PbS)

(d) None of these

Very Short:

1. Which gaseous compound on treatment with dihydrogen produces methanol?
2. What are the constituents of water gas?
3. Arrange H_2, D_2, T_2 in the decreasing order of their

(i) Boiling point

(ii) Heat of fusion.

4. Which isotope of hydrogen

(i) does not contain neutron

(ii) is radioactive?

5. Out of the following metals which can be used to liberate H2 gas on reaction with dil.

hydrochloric acid?

(i) Cu,

(ii) Zn,

(iii) Iron,

(iv) Silver,

(v) Magnesium

6. Name one compound each of hydrogen in which it exists in:

(i) Positive oxidation state

(ii) Negative oxidation state.

7. What is the importance of heavy water in nuclear power generation?

8. State two properties in which hydrogen resembles alkali metals.

9. Give an example of each anionic and covalent hydride.

10. Why is H_2O_2 concentrated at low pressure?

Short Questions:

1. Hydrogen forms three types of bonds in its compounds. Describe each type of bonding using suitable examples.
2. Name one example of a reaction in which dihydrogen acts as

   (i) an oxidizing agent

   (ii) a reducing agent.
3. The process $\frac{1}{2}H_2(g) + e^- \rightarrow H^-(g)$ is endothermic ($DH = +151\ kJ\ mol^{-1}$), yet salt- like hydrides are known. How do you account for this?
4. Find the volume strength of 1.6 N H_2O_2 solution.
5. A sample of hard water is allowed to pass through an anion exchanger. Will it produce lather with soap easily?
6. Anhydrous Ba02 is not used for preparing H_2O_2 Why?

Long Questions:

1. (a) Compare atomic hydrogen with nascent hydrogen.

   (b) What is (i) active hydrogen

   (ii) heavy hydrogen? How are they formed?

2. How is the solution of H_2O_2 concentrated?
3. What are the different methods used for the softening of hard water? Explain the principle of each method.
4. Show how hydrogen peroxide can function both as an oxidising and a reducing agent
5. Calculate the percentage strength & strength in g/L of 10 volume hydrogen peroxide solution.

Assertion Reason Questions:

1. In the following questions, a statement of Assertion (A) followed by a statement of Reason (R) is given. Choose the correct option out of the choices given below each question.

   Assertion (A) : Permanent hardness of water is removed by treatment with washing soda.

   Reason (R) : Washing soda reacts with soluble magnesium and calcium sulphate to form insoluble carbonates.

   (i) Statements A and R both are correct and R is the correct explanation of A.

   (ii) A is correct but R is not correct.

   (iii) A and R both are correct but R is not the correct explanation of A.

   (iv) A and R both are false.

2. In the following questions, a statement of Assertion (A) followed by a statement of Reason (R) is given. Choose the correct option out of the choices given below each question.

   Assertion (A) : Some metals like platinum and palladium, can be used as storage media for hydrogen.

   Reason (R) : Platinum and palladium can absorb large volumes of hydrogen.

   (i) Statements A and R both are correct and R is the correct explanation of A.

   (ii) A is correct but R is not correct.

   (iii) A and R both are correct but R is not the correct explanation of A.

   (iv) A and R both are false.

Case Study Based Question:

1. Read the passage given below and answer the following questions :

Hydrogen can exist in three isotopic forms, viz., protium, deuterium and tritium, which differ from each other in the number of neutrons.

Out of these three isotopes, tritium is formed in the upper atmosphere by reaction induce by cosmic rays. It decays to emit low energy β-particles.

$$\underset{\text{Tritium}}{{}_{1}^{3}\mathrm{H}} \longrightarrow {}_{2}^{3}\mathrm{He} + \underset{\beta\text{-particle}}{{}_{-1}e^{0}}$$

Tritium is used for making thermonuclear devices and for carrying out researches in fusion reactions as a source of energy. It is also used as a radioactive tracer as it is relatively cheap and easy to work with.

(1) The relative atomic mass of isotopes of hydrogen is:

(a) 1 : 2 : 3

(b) 1 : 1 : 2

(c) 2 : 4 : 5

(d) 1 : 2 : 4

(2) The n/ p ratio for ${}_{1}H^{2}$ is:

(a) 1 : 2

(b) 1 : 1

(c) 2 : 1

(d) 2 : 3

(3) Which is the most reactive isotope of hydrogen?

(a) Tritium

(b) Deuterium

(c) Protium

(d) All are equally reactive

(4) What type of reactions are generated by tritium?

(a) Chemical reaction

(b) Radioactive reaction

(c) Addition reaction

(d) All of these

2. Read the passage given below and answer the following questions:

Water is the main constituent of earth's hydrosphere and fluids of all known living organisms. It is vital for all known forms of life, even though it provides no chlorines or organic nutrients.

Water cover approximately 70.9% of earth's surface, mostly in seas and oceans. Water plays an important role in the world economy. Approximately 70% of the fresh water used by humans goes to agriculture. Water is the excellent solvent for a wide variety of substance both mineral and organic; as such it is widely used in industrial processes and in cooking and washing. Water, ice and snow are also central to many sports and other forms of entertainment pure water has a low electrical conductivity, which increases with the dissolution of a small amount of ionic material such as common salt.

(1) Which one of the following statements about water is incorrect?

(a) Water can act both as an acid and as a base

(b) Water can be easily reduced to dihydrogen by highly electronegative elements.

(c) Ice formed by heavy water sinks in normal water

(d) Presence of water can be detected by adding a drop to anhydrous $CuSO_4$

(2) In nuclear reactors, ordinary water is not used as a moderator because

(a) it cannot slow down the fast moving neutrons

(b) it cannot remove the heat from the reactor core

(c) it has corrosive action on the metallic parts of the nuclear reactor

(d) None of the above

(3) Consider the following statements about intermolecular and intramolecular hydrogen bonding.

I. Both types of H-bonds are temperature dependent.

II. Water exhibits amphoteric nature.

III. The boiling points of compounds having intramolecular H-bond are lower than those having intermolecular H-bond.

Which of the statements given above are correct?

(a) I and III

(b) Both II and III

(c) I and II

(d) All of these

(4) Consider the following statements regarding water.

I. There is extensive hydrogen bonding between water molecules .

II. Water has high melting point in comparison to H_2S and H_2Se.

III. High heat of vaporisation and heat capacity of water are responsible for moderation of climate and body temperature of living beings.

IV. Covalent compounds like alcohol and carbohydrates dissolve in water.

Select the correct statements among above.

(a) Both I and II

(b) Both II and IV

(c) I, II and III

(d) All of these

Answer Key:

MCQ

1. (b) DiOxygen
2. (c) Neutrons
3. (c) Ni
4. (c) Hydrogen
5. (b) Zn
6. (a) Nascent Molecular Hydrogen
7. (b) Pt
8. (a) 0 to 4 °C
9. (b) Copper and HCl(aq)
10. (a) Beta-Emitting
11. (a) 1.0 g / cm^3
12. (a) CO
13. (b) 224 ml

14.(d) All of the above

15.(c) Black Suspension of Lead Sulphide (PbS)

Very Short Answer:

1. Carbon monoxide (CO).

2. Carbon monoxide and hydrogen.

3. T2 > D2 > H2
   T2 > D2 > H2.

4. Protium
   Tritium.

5. Only Zn, Fe, Mg.

6. HCl

   NaH.

7. It is used as a moderator in nuclear reactions to slow down the speed of fast-moving neutrons.

8. Both form unipositive ion

   Both have one electron in their s orbital (ns1).

9. Ionic Hydride NaH Covalent hydride NH_3.

10. Because it decomposes at ordinary pressure or on heating.

Short Answer:

Ans: 1. Hydrogen forms compounds in three different ways:

1. By loss of electrons as in the reactions of H_2 with CuO

$$CuO(s) + H_2(g) \xrightarrow{\text{Heat}} Cu(s) + H_2O(g)$$

[Hydrogen bonding]

2. By gain of electrons as in reactions of H_2 with metals.

$$Na(s) + H_2(g) \xrightarrow{Heat} 2NaH(s)$$

[Ionic bonding]

$$Ca(s) + H_2(g) \xrightarrow{Heat} CaH_2$$

3. By sharing of electrons as in the reactions of H_2 with halogens

$$H_2(g) + F_2(g) \longrightarrow 2H-F(l)$$

[Covalent bonding]

$$H_2(g) + Cl_2(g) \longrightarrow 2H-Cl(g)$$

Ans: 2. As an oxidizing agent

$$2Na(s) + H_2(g) \xrightarrow{Heat} 2Na^+H^-(s)$$

Here Na has been oxidized to Na while dihydrogen has been reduced to H^+ ion.

(ii) a reducing agent.

$$CuO(s) + H_2(g) \xrightarrow{Heat} Cu(s) + H_2O(g)$$

Here CuO has been reduced to copper and H_2 has been oxidized to H_2O.

Ans: 3. This is due to the reason that high lattice energy released (energy released during the formation of solid metal hydride from their corresponding gaseous ions, i.e., M^+ and H^+) more than compensates the energy, needed for the formation of H– ions from H_2 gas.

Ans: 4. Strength = Normality × EQuestion wt.

Eq. wt.of H_2O_2 = 17

∴ Strength of 1.6N H_2O_2 solution = 1.6 × 17g L^{-1}

Now 68g of H_2O_2 gives 22400 mL O_2 at NTP/STP

∴ 1.6 × 17g of H_2O_2 will give = $\frac{22400}{68}$ × 1.6 × 17

= 8960 mL of O_2 at STP

But 1.6 × 17g of H_2O_2 are present in 1000 mL of H_2O_2 solution

Hence 1000 mL of H_2O_2 solution gives 8960 mL of O_2 at STP 1 mL of H_2O_2 will give = 8.96 mL of O_2 at STP.

Hence the volume strength of 1.6N H_2O_2 solution is = 8.96 volume

Ans: 5. No. Ca^{2+} and Mg^{2+} ions are still present, and these will react with soap to form curdy white ppt. Therefore, it will not produce lather with soap solution easily.

Ans: 6. $BaSO_4$ formed during the reaction of BaO_2 with H_2SO_4 forms a protective layer around unreacted BaO2 and the reaction stops after some time.

Long Answer:

Ans: 1. Comparison of atomic and nascent hydrogen

The main point of differences are:

1. Nascent hydrogen can be produced even at room temperature, but atomic hydrogen is produced only at very high temperature.

2. Nascent hydrogen can never be isolated, but atomic hydrogen can be isolated.

3. The reducing power of atomic hydrogen is much greater than that of nascent hydrogen.

In general reactivity of the three forms of hydrogen increases in order.
Molecular hydrogen (H_2) < Nascent hydrogen < Atomic hydrogen.

Active Hydrogen: It is obtained by subjecting a stream of molecular hydrogen at ordinary temperature to silent electric discharge at about 30,000 volts. It is very reactive in nature (half-life = 0.33 second, and combines directly at ordinary temperatures with Pb and S forming their hydrides

Heavy hydrogen: It is manufactured by the electrolysis of heavy water containing a little of IT SO, or NaOH to make the solution conducting.

$$\underset{\text{(Heavy water}}{3D_2O(l)} \longrightarrow \underset{\text{at cathode}}{2D_2(g)} + \underset{\text{at anode}}{O_2(g)}$$

In the laboratory, it can be prepared by the action of heavy water on sodium metal.

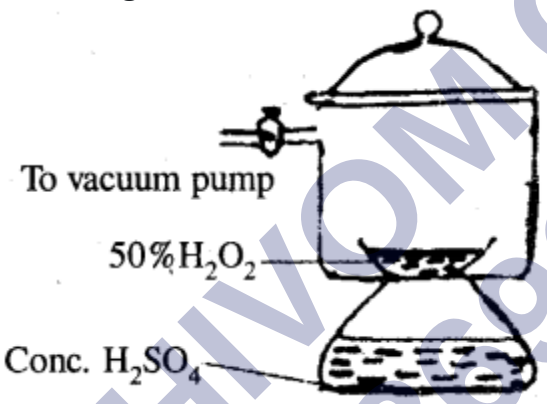
$2D_2O(l) + 2Na(s) \rightarrow 2NaOD(aq) + D_2(g)$.

Ans: 2. The concentration of hydrogen peroxide: Hydrogen peroxide obtained by any method is always in the form of a dilute solution. Great care is to be taken for concentrating its solution because it is unstable and decomposes on heating.
$2H_2O_2 \rightarrow 2H_2O + O_2$

The decomposition of H_2O_2 is catalysed by the ions of heavy metals present as impurities.

The solution of H_2O_2 is concentrated by the following methods.
1. By careful evaporation on a water bath: A dilute solution of H_2O_2 is taken in a shallow evaporating dish and is heated at 313K – 323 K. Water evaporates slowly and a hydrogen-peroxide solution of about 15 – 50% strength is obtained.

2. By dehydration in a vacuum desiccator: The dilute (50 %) solution of H_2O_2 obtained as above, is further concentrated by placing the same in a vacuum desiccator containing concentrated H_2SO_4 as a dehydrating agent. Here, water vapours are absorbed by concentrated sulphuric acid. This is shown in the diagram



(Concentration of H_2O_2 in vacuum desiccator)

3. By distillation under reduced pressure: The solution of hydrogen peroxide is further concentrated by subjecting it to distillation under reduced pressure. The solution is distilled at 308 – 313 K under a reduced pressure of 15 mm Hg. Water present in the solution distils over leaving behind about 98 – 99% concentrated solution of hydrogen peroxide.

4. By crystallization: The last traces of water present in H_2O are removed by freezing it in a freezing mixture of solid CO_2 and others. The crystals of hydrogen peroxide separate out. These crystals are removed, dried and then remitted to obtain 100% pure hydrogen peroxide.

5. Storage of hydrogen peroxide: In order to check the decomposition of hydrogen peroxide, a

small amount of acetanilide (i.e. negative catalyst) is added to it before storing the hydrogen peroxide.

Hydrogen peroxide cannot be concentrated by distillation at ordinary pressure because it undergoes decomposition into water and oxygen as it is a highly unstable liquid. It decomposes even on long-standing or on heating.

Ans: 3. Hard water can be softened by the following methods depending upon the nature of hardness.

(a) Temporary hardness:

1. By boiling: It can be removed by merely boiling the water. Boiling decomposes the bicarbonates to give carbon dioxide and insoluble carbonates, which can be removed by filtration.

$$Ca(HCO_3)_2 \xrightarrow{\text{heat}} \underset{\text{white ppt.}}{CaCO_3} + H_2O + CO_2$$

$$Mg(HCO_3)_2 \xrightarrow{\text{heat}} \underset{\text{white ppt.}}{MgCO_3} + H_2O + CO_2$$

2. Clark's process: Temporary hardness can be removed by the addition of a calculated amount of lime, whereupon magnesium and/or calcium carbonates is precipitated.

$Ca(HCO3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$

$Mg(HCO3)_2 + Ca(OH)_2 \rightarrow CaCO3_3 + MgCO_3 + 2H_2O$

(b) Permanent hardness:

1. With sodium carbonate: On treatment with washing soda, Ca^{2+} and Mg^{2+} in hard water are precipitated. The precipitate of the insoluble carbonates thus formed is removed by filtration.

$$Ca^{2+} + CO_3^{2-} \longrightarrow \underset{\text{white ppt.}}{CaCO_3}$$

$$Mg^{2+} + CO_3^{2-} \longrightarrow MgCO_3$$

2. Ion-exchange method: The common substance used for this process is zeolite which is hydrated sodium aluminum silicate, $NaAl(SiO)_2$, The exchange occurs when passing over the zeolite bed, sodium ions from zeolite are replaced by calcium and magnesium ions. Thus

$Na(Ze) + Mg^{2+} \rightarrow (Ze)_2Ca + 2Na^+$

$2NaZe + Mg^{2+} \rightarrow (Ze)_2Mg + 2Na^+$

when all the sodium ions of the zeolite have been replaced, the zeolite is said to be exhausted. It can be regenerated by treatment with a strong solution of sodium chloride.

$2Na + (Ze)_2Ca \rightarrow 2ZeNa + Ca^{2+}$.

Ans: 4. Oxidising properties: H_2O_2 has a tendency to accept electrons in chemical reactions and thus behaves as an oxidising agent in both acidic and alkaline medium.

$H_2O_2 \rightarrow H_2O + O$

In acidic medium

$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$

In alkaline medium

$H_2O_2 + OH^- + 2e^- \rightarrow 3OH^-$

Example:

(a) In acidic medium:

$2Fe^{2+} + 2H^+ + H_2O_2 \rightarrow 2Fe^{3+} + 2H_2O$

(b) In alkaline medium:

$3Cr^{3+} + 4H_2O_2 + 100H^- \rightarrow 3CrO4^{2-} + 8H_2O$

Reducing properties: H_2O_2 can give electrons in a few reactions and thus behaves as a reducing agent.

In acidic medium

$H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$

In alkaline medium

$H_2O_2 + 2OH^- \rightarrow 2H_2O + O_2 + 2e^-$

Reducing property in acidic medium:

$2MnO4^{2-} + 6H+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$

Reducing property in basic medium:

$2Fe^{3+} + H_2O_2 + 2OH^- \rightarrow 2Fe^{2+} + O_2 + 2H_2O$

Ans: 5. H_2O_2 decomposes on heating according to the equation

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

$2 \times 34g$ 22.4 L at N.T.P.

or 22400 cm^3 at N.T.P.

From the equation

22.4L of O_2 at N.T.P are obtained from 68g of H_20_2

∴ 10 ml of O_2 at N.T.P will be obtained from $\frac{68}{22400} \times 10g$ of H_2O_2

But 10 ml of O_2 at N.T.P are produced from 1 ml. of 10 volume H_2O_2 solution.

Thus 1 ml of 10 volume H_2O_2 solution contains $\frac{68}{22400} \times 10$ g of H_2O_2

∴ 100 ml. of 10 volume H_2O_2 solution will contain

$\frac{68}{22400} \times \frac{10}{1} \times 100 = 3.036g$.

Thus a 10 volume H_2O_2 solution is approx. 3%

Alternatively, 1000 ml of 10 volume of H_2O_2will contain H_2O_2

$\frac{68}{22400} \times 10 \times 1000 = 30.36g$

Therefore, strength of H_2O_2 in 10 volume H_2O_2 is 30.36 g/L

Assertion Reason Answer:

1. (i) Statements A and R both are correct and R is the correct explanation of A.
2. (i) Statements A and R both are correct and R is the correct explanation of A.

Case Study Answer:

1. **Answer:**

(1) (a) 1 : 2 : 3

(2) (b) 1 : 1

(3) (a) Tritium

(4) (b) Radioactive reaction

2. Answer:

(1) (b) Water can be easily reduced to dihydrogen by highly electronegative elements.

(2) (d) None of the above

(3) (d) All of these

(4) (c) I, II and III