Unit - 9

HYDROGEN

Position of Hydrogen in the Periodic Table

Hydrogen is the first element in the table. It is the smallest element on the table. It has one electron and one proton, which means it has atomic number one. [$_{1}^{1}H$]

Hydrogen has only one shell. It is the lightest element on the periodic table.

The position of elements on the periodic table largely depends on electronic configuration. Hydrogen has electronic configuration of 1.

- Hydrogen can get rid of one electron to attain noble gas configuration. This characteristic of hydrogen matches those of alkali metals. on the other hand Hydrogen can also gain on electron similar to halogens.

- Like alkali metals, it has ability to form oxides, halides and sulphides. However

unlike alkali metals, it has high ionization enthalpy and does not possess metallic characteristic under normal conditions.

- Like halogens, it forms a diatomic molecule, combines with elements to form hydrides and a large number of covalent compounds. However in terms of reactivity, it is very low as compared to halogens.

Dihydrogen

A hydrogen atom is extremely reactive in its original form. It has one valance electron in its only shell, which makes it highly reactive and unstable. So hydrogen combines with another atom of hydrogen to give us Dihydrogen. [H_2]

- This molecular form of hydrogen is the most common form of hydrogen on earth. since the molecule is neutral and its orbit is now complete it is a stable gas. A dihydrogen molecule (H_2) is the smallest molecule on the planet.

Isotopes of Hydrogen

- Hydrogen has three naturally occuring isotopes, namely Protium [$^{1}_{1}H$], Deuterium [$^{2}_{1}H$], and Tritium [$^{3}_{1}H$]

- Of these, tritium is the only one not stable, it is infact radioactive. The difference between the three is the number of neutrons.

- Protium : This is the most prevalent isotope of hydrogen in the world. over 99% of all hydrogen is in this form. It has one proton in its nucleus and no neutron at all.

- Deuterium : Having the atomic symbol $^{2}_{1}H$ or D. It has one proton and one neutron in its nucleus. It is also known as heavy hydrogen. most of the deuterium found in the oceans or sea water. It is also a stable isotope.

- Tritium : Tritium is $^{3}_{1}H$. It has one proton and two neutrons in its structure. It is a radioactive isotope.

Preparation of Dihydrogen, H_2

There are number of methods for prep-aring dihydrogen from metals and metal hydrides.

- **Laboratory preparation of Dihydrogen**

i) It is usually prepared by the reaction of granulated zinc with dilute HCl

$$Zn + HCl \longrightarrow ZnCl_2 + H_2$$

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

ii) It can also be prepared by the reaction of zinc with aqueous alkali.

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

Sodium zincate

- **commercial production of Dihydrogen**

i) Electrolysis of acidified water using Platinum electrodes gives hydrogen.

$$2H_2O_{(l)} \xrightarrow[\text{Traces of acid/base}]{\text{Electrolysis}} 2H_{2(g)} + O_{2(g)}$$

ii) Reaction of steam on hydrocarbons or coke at high temperatures in the presence of catalyst yields hydrogen.

$$C_nH_{2n+2} + nH_2O \xrightarrow[Ni]{1270\ K} nCO + (2n+1)H_2$$

eg:-

$$CH_{4(g)} + H_2O_{(g)} \xrightarrow[Ni]{1270\ K} CO_{(g)} + 3H_{2(g)}$$

The mixture of CO and H_2 is called water gas.

Properties of Dihydrogen

Physical Properties

- At room temperature, this diatomic molecule of hydrogen is found in a gaseous state.
- It is an absolutely colourless, odorless. and tasteless gas which makes it very hard to detect.
- It is highly combustible or inflammable.
- It is lighter than air and insoluble in water.

Chemical properties.

- Hydrogen, in nature, occurs in its diatomic form as H_2 known as Dihydrogen.
- Hydrogen has no effect on litmus paper i.e; it is neutral.
- Dihydrogen is a non-metal
- since Dihydrogen is a stable molecule it is not very reactive.
- Dihydrogen has high enthalpy due to its stable H-H bond.
- It is an oxidizing agent when reacting with metals. It forms metal hydrides.
- Reacts with unsaturated Hydrocarbons to form saturated hydrocarbons.

Uses of Dihydrogen

- The larges use of dihydrogen is in the synthesis of ammonia which is used in the manufacture of nitric acid and nitrogenous fertilizers.
- Dihydrogen is used in the manufacture of vanaspati fat, by the hydrgenation of polyunsaturated vegetable oils.
- It is use in the manufacturing of bulk organic chemicals, particularly methanol.

$$CO_{(g)} + 2H_2 \xrightarrow{\text{cobalt}} CH_3OH_{(l)}$$

- It is widely use for the mahufacture of metal hydrides.
- It is used for the preparation of hydrogen chloride, a highly useful chemical.

Hydrides

Dihydrogen, under certain reaction conditions, conbines with almost all elements, except noble gases, to form a binary compounds, called hydrides.

The hydrides are classified into three categories as follown:

1) Ionic or saline Hydrides.

These are hydrides that form when hydrogen reacts with s-Block elements. These are alkali metals and alkali earth metals, which are more electropositive than hydrogen.

- The only two exceptions are beryllium hydride and magnesium hydride.

- These saline hydrides are in solid form. They are actually crystals.
- The have high density since these are stable molecules.
- They conduct electricity in molten state liberating a diatomic molecule of hydrogen gas at the anode.
- one very unique chemical property of saline hydrides is that they react very vigorously with water. and other solvent such as ethanol and ammoniq. In the process, they release pure hydrogen gas.

Covalent Hydrides

These are hydrides that form when hydrogen reacts with P-Block elements. These are highly electronegative elements, far more than hydrogen.

- The general chemical formula for covalent Hydrides is $XH_{(8-n)}$, where 'n' is the number of electrons the element has in its outermost shell.

- These hydrides consist of individual covalent molecules. These covalent bonds are weak and have a weak interparticle force.

- They have very low melting and boiling points.

- Like most non-metals, covalent hydrides are poor conductors of electricity.
- They can be in liquid state if their properties are adapted due to hydrogen bonding.
- Hydrogen forms the most number of hydrides with carbon.

Metallic Hydrides.

- These are compounds that Hydrogen forms by reacting with transition elements.
  i) Transition metals in group 3, 4 and 5
  ii) All the F-block elements
  iii) one metal of group 6 - chromium.
- There are three groups of d-block Groups 7, 8 and 9 that do not form compounds with hydrogen.

This phenomenon is known as the Hydride Gap of the d-block

- They are found in a solid state
- They are good conductors of electricity since they have high thermal capacity.
- They can decompose into metal and hydro-gen gas, but this reaction is easily reversible.

Water

A major part of all living organism is made up of water. It is a crucial compound for the survival of all life forms. It is a solvent of great importance.

Physical Properties of water

- It is a colourless and tasteless liquid. It's chemical formula is H_2O.
- Water has a boiling point of 100°C, This is because the hydrogen bonds in the water molecule are very strong, They require a huge amount of energy to break and start boiling.
- The same concept applies to the freezing point of water as well. The freezing point of water is 0°C.
- One unique property of water is that in the solid state, it is less dense, This is why ice floats in water.

- Water is an excellent solvent. In Fact, it is known as a universal solvent. Due to it's polarity, it can dissolve almost any substance.

Chemical properties of water.

- Amphoteric Nature – one of the unique qualities of water is its amphoteric nature. An amphoteric sub-stance is one which can act as an acid or a base. While water is neither acidic or basic it act as both.

$$H_2O_{(l)} + HCl_{(aq)} \rightleftharpoons H_3O^+ + Cl^-$$

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

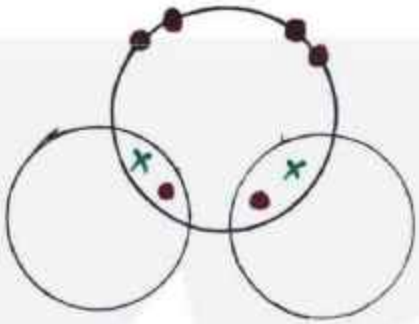
- Hydrolysis Reaction - Water has a very high dielectric constant. This results in it having a strong hydrating tendency. Water has strong reactions with ions of salts and creates hydrating shells around them.

$$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$$

- Redox Reaction - Water is great source to obtain dihydrogen since it can be reduced by reacting it with highly electropositive metals such as sodium

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

Structure of Water

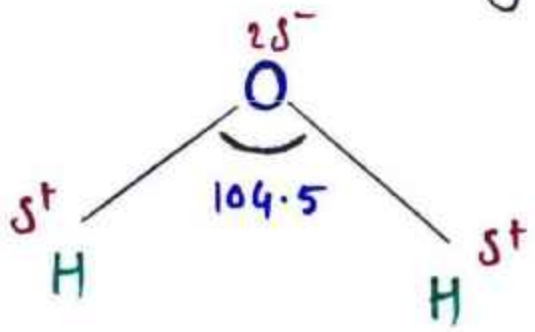


closely observe the structure of a water molecule. you will see one atom of oxygen and two atoms of hydrogen. Each atom of hydrogen bonds covalently with the atom of oxygen. so both atoms of hydrogen shares one pair of electrons with the oxygen atom.

- Oxygen is a more electronegative element in comparison to water. This results in an uneven distribution of electron density. This gives the water molecule an angular bent structure.

- The H-O-H bond has a slight angle of about 104.5°. So it can be said that water molecule is polar.

- It has a slight negative polarity near the oxygen atom and slight positive charge near both the hydrogen atoms.



Structure of Ice

- Ice has a highly ordered three dimensional hydrogen bonded structure. Examination of ice crystals with X-rays shows that each oxygen atom is sourrou -nded tetrahedrally by four other oxygen atoms at a distance of 276 pm.
- Hydrogen bonding gives ice a rather open type structure with wide holes. These holes can hold some other mole -cules of appropriate size interstitially.

Hard and soft water.

Hard Water	soft water
Presence of calcium and magnesium in the form of chloride, hydrogencarbonate and sulphate in water makes it 'Hard'.	Water free from soluble salts of calcium and magnesium is called 'soft water'.
Hard water does not give lather with soap	soft water gives lather with soap easily.
It is not suitable for laundry. and it is harmful for boilers as well.	It is suitable for drinking and laundry.

Hardness of Water (H_2O)

Temporary

- Due to Bicarbonates of calcium and magnesium (mg).

Permanent

- Due to chlorides and sulphates of calcium and magnesium.

Methods to Remove Hardness

Tempory

- By Boiling
- By clark's Method (use lime water, $Ca(OH)_2$)

Permanent

- By washing soda.
- By calgon's method.
- By Ion exchange method.
- By synthetic resins method.

Temporary hardness

i) **Boiling** - During boiling, the soluble $Mg(HCO_3)_2$ is converted into soluble $Mg(OH)_2$ and $Ca(HCO_3)_2$ is changed to insoluble $CaCO_3$.

$$Mg(HCO_3)_2 \xrightarrow{\text{Heating}} Mg(OH)_2 \downarrow + 2CO_2 \uparrow$$

$$Ca(HCO_3)_2 \xrightarrow{\text{Heating}} CaCO_3 \downarrow + H_2O + CO_2 \uparrow$$

ii) **Clark's method** - In this method calculated amount of lime is added to hard water. It precipitates out calcium carbonate and magnesium hydroxide which can be filtered out.

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

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

Permanent Hardness

i) Treatment with Washing soda -

Washing soda reacts with soluble calcium and magnesium chlorides and sulphates in hard water to form insoluble carbonates

$$MCl_2 + Na_2CO_3 \longrightarrow MCO_3 \downarrow + 2NaCl$$

$\therefore (M = Mg, Ca)$

$$MSO_4 + Na_2CO_3 \longrightarrow MCO_3 \downarrow + Na_2SO_4$$

ii) Calgon's method - sodium hexametaphosphate ($Na_6P_6O_{18}$), commercially called 'calgon'.

$$Na_6P_6O_{18} \longrightarrow 2Na^+ + Na_4P_6O_{18}^{2-}$$

$\therefore (M = Mg, Ca)$

$$M^{2+} + Na_4P_6O_{18}^{2-} \longrightarrow [Na_2MP_6O_{18}]^{2-} + 2Na^+$$

iii) Ion - exchange method -

This method is also called zeolite / permutit process. Hydrated sodium aluminium silicate is zeolite / permutit.

$$2NaZ_{(s)} + M^{2+}_{(aq)} \longrightarrow MZ_{2(s)} + 2Na^{+}_{(aq)}$$

$\therefore (M = Mg, Ca)$

iv) synthetic resins method -

$$RSO_3H + NaCl \longrightarrow \boxed{RNa} \longrightarrow \text{cation exchange resin}$$

$$2RNa_{(s)} + M^{2+}_{(aq)} \longrightarrow R_2M_{(s)} + 2Na^{+}_{(aq)}$$

$$2RH_{(s)} + M^{2+}_{(aq)} \rightleftharpoons MR_{2(s)} + 2H^{+}_{(aq)}$$

Hydrogen peroxide (H_2O_2)

Hydrogen peroxide is an important chemical used in pollution control treatment of domestic and industrial effluents.

preparation

1) From Barium peroxide -

This method is for laboratory preparation of Hydrogen peroxide.

$$\therefore \quad BaO_2 . 8H_2O + H_2SO_4 \longrightarrow BaSO_4 + H_2O_2 + 8H_2O$$

2) From sodium peroxide -

Here too, a dilute solution of sulphuric acid and gradually dissolve sodium peroxide in it.

- On reacting these two we get crystals of sodium sulphide and a 30% solution of hydrogen peroxide.
- After performing vacuum distilation on the said solution we get pure hydrogen peroxide.

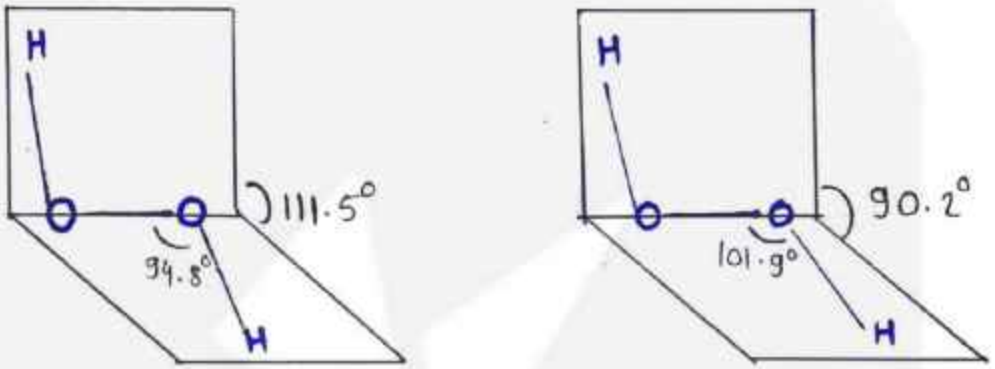
$$Na_2O_2 + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O_{2\,(30\%)}$$

Physical properties -

- In the pure state H_2O_2 is an almost colourless (very pale blue) liquid. H_2O_2 is miscible with water in all proportions and forms hydrate $H_2O_2 . H_2O$.
- A 30% solution of H_2O_2 is marketed as '100 volume' hydrogen peroxide. Which means one millilitre of 30% H_2O_2 will give 100 mL of oxygen at STP.

structure

Hydrogen peroxide has a non-planar structure. The molecular dimensions in the gas phase and solid phase are show below.



(a) Gas phase (b) Solid Phase

chemical properties

- It is acidic in nature
- H_2O_2 is a very strong oxidizing agent. It gives up one oxygen atom and forms water as a byproduct.
- It can also act as a reducing agent if one of the reactants is stronger oxidizing than H_2O_2.

storage

- H_2O_2 decomposes slowly on exposure to light
- In the presence of metal surface or traces of alkali, decomposition reaction gets catalysed.
- Therefore, it is stored in wax-lined glass or plastic vessels in dark.

Uses

- Hydrogen peroxide has been used as an antiseptic for minor cuts, bruises, laceration etc for years.
- Hydrogen peroxide is extensively used for bleaching purposes.
- The most significant use of Hydrogen peroxide is in environmental protection as pollution control agent.

Heavy Water, D_2O

- It is extensively used as a moderator in nuclear reactors and in exchange reactions for the study of reaction mechanisms.
- It is used for the preparation of other deuterium compounds.

$$SO_3 + D_2O \longrightarrow D_2SO_4$$

Dihydrogen as a fuel

- Dihydrogen releases large quantities of heat on combustion.
- moreover, Pollutants in combustion of the dihydrogen will be less than petrol.