INTRODUCTION:

Hydrogen gas was first discovered by Cavendish in 1766 by the action of Zinc metal over dilute hydrochloric acid.

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2\uparrow$$

Symbol	H
Atomic Number	1
Atomic Mass	1
State	Gas at S.T.P
Nature	Non – metallic
Valence	Monovalent
Oxidation State	+1, –1
Behavior	Reducing agent
Electronic Configuration	K^1, $1S^1$
Percentage In Earth Crust	9^{th} most abundant element
Density	$0.09g/dm^3$
Type Of H_2 Molecule	Diatomic molecule
Molecular Formula	H_2
Molecular Mass	2.016 a.m.u
Meaning Of Hydrogen	Water producer

INDUSTRIAL PREPARATION OF HYDROGEN GAS

1. BY PASSING STEAM OVER COKE / FROM WATER GAS:

When steam is passed over red hot coke at about 1000°C, a mixture of carbon monoxide and hydrogen gas is obtained which is called water gas.

$$C + H_2O \xrightarrow{1000°C} \underbrace{CO + H_2}_{\text{Water Gas}}$$

2. FROM NATURAL GAS:

Hydrogen is also obtained by passing steam over hydrocarbons, such as methane in the presence of Ni catalyst at about 900°C to produce water gas.

$$CH_4 + H_2O \xrightarrow{Ni/1000°C} \underbrace{CO + 3H_2}_{\text{Water Gas}}$$

3. BY CRACKING OF METHANE:

When methane is heated above 700°C in the absence of air, CH_4 decomposes to produce carbon black and H_2 gas.

$$CH_4 \xrightarrow[\text{Absence of air}]{\text{Above 700°C}} C + H_2$$

- Carbon black is used in rubber industry as filler for tiers. It is also used in the preparation of inks, paints, polishes carbon paper and plastics.

4. BY ELECTROLYSIS OF WATER:

H2 gas can also be prepared by the electrolysis of water. When electric current is passed through water in the presence of few drops of acids or alkali, H_2 gas is liberated at cathode and O_2 gas collects at anode.

$$H_2O \xrightarrow{\text{electricity}} \underset{\text{Cathode}}{2H_2} + \underset{\text{anode}}{O_2}$$

SEPARATION OF H_2 GAS FROM WATER GAS

From water gas H_2 gas is separated by two methods.

a. BY LIQUEFACTION:

When water gas is cooled upto – 200°C. carbon monoxide liquiefies and leaving behind H_2 gas. Remaining traces of CO are dissolved in NaOH solution to form sodium formate leaving behind pure H2 gas.

$$CO + NaOH \longrightarrow \underset{\text{Sodium Formate}}{HCOONa}$$

b. BY OXIDATION:

In this process more steam is passed through water gas at 500°C in the presence of iron oxide (FeO) or (Cr_2O_3) catalyst. Carbon monoxide gas in water gas oxidizes to CO_2 gas which is soluble in water under high pressure, liberating pure H_2 gas.

$$\underbrace{CO + 3H_2}_{\text{Water Gas}} + H_2O \xrightarrow{FeO} CO_2 + 2H_2\uparrow$$

PHYSICAL PROPERTIES OF H_2 GAS:

i. It is a colorless, odorless and tasteless gas.
ii. It is insoluble in water.
iii. It is highly inflammable and burns with blue flame. It does not support combustion.
iv. It absorbs on the surface of some transition metals, to form interstitial hydrides.
v. It is non toxic in nature.
vi. It liquefies at –252°C and freezes at –259°C.
vii. Its electro negativity is 2.1 and its ionization energy is 13.54 eV.
viii. Its bond dissociation energy is 104Kcal/mol.

CHEMICAL PROPERTIES OF H_2 GAS:

1. Thermal Stability:

Molecular hydrogen H_2, contains a stable covalent bond and relatively inert at ordinary temperature. Its bond energy is very high +104 K.cal/mol (435 KJ/mol)

$$H - H \xrightarrow{1000K} \underset{\text{Atomic Hydrogen}}{H + H} \qquad \Delta H = 104\text{kcal/mol}$$

2. Reaction With Metals:

Hydrogen forms ionic hydrides with alkali metals and alkaline earth metals.

For Example:

1. $2Na + H_2 \xrightarrow{200°C} 2Na^+H^-$

2. $2K + H_2 \xrightarrow{200°C} 2K^+H^-$
3. $Ca + H_2 \xrightarrow{200°C} Ca^{+2}H_2^-$

3. <u>Reaction With Non Metals:</u>

Hydrogen reacts with many non metals under different conditions to form addition products. For Example:

i. $N_2 + 3H_2 \xrightarrow{500°C / 200atm} 2NH_3$
ii. $P + H_2 \xrightarrow{\Delta} PH_3$
iii. $O_2 + 2H_2 \xrightarrow{500°C / 200atm} 2H_2O$
iv. $H_2 + S \xrightarrow{500°C / 200atm} H_2S$
v. $Cl_2 + H_2 \xrightarrow{500°C / 200atm} 2HCl$

4. <u>Hydrogenation Reaction:</u>

The addition of hydrogen into other compounds is called hydrogenation reactions. H_2 gives addition reaction products with some molecular compounds, when heated in the presence og Pt, Pd or Ni catalyst.

i. $CO + 2H_2 \xrightarrow{ZnO/Cr2O3} CH_3 - OH$ (Methanol)
ii. $CH_2{=}CH_2$ (Ethene) $+ H_2 \xrightarrow{Ni/300°C} CH_3 - CH_3$ (Ethane)
iii. Edible oil (Unsaturated oil) $+ H_2 \xrightarrow{Ni/\ high\ temp}$ Vegetable Ghee (Saturated solid)

5. <u>As Reducing Agent:</u>

Hydrogen shows greater affinity for oxygen and reduces many metal oxides into free metals.

i. $CuO + H_2 \xrightarrow{\Delta} Cu + H_2O$
ii. $WO_3 + 3H_2 \xrightarrow{\Delta} W + H_2O$

NASCENT HYDROGEN

Definition:

Hydrogen in atomic form at the time of its generation is chemically more reactive than ordinary molecular hydrogen and is called nascent hydrogen.

Preparation:

Reason of high reactivity:

Evidence for high reactivity:

1. Brownish
2. Similarly acidic $KMnO_4$ (pink) solution can be reduced by nascent hydrogen to the colorless solution.

ISOTOPES OF HYDROGEN

Definition Of Isotopes:

Isotopes are defined as atoms of the same element having same atomic number but different atomic masses.

Or atoms of the same element having same number of protons but having different number of neutrons.

Nearly all the elements found in nature are mixture of several isotopes. There are three isotopic forms of hydrogen, namely,

i. Protium
ii. Deuterium
iii. Tritium

PROTIUM

Naturally occurring hydrogen has the largest percentage of protium atoms present in it. It is denoted by symbol $^{1}_{1}H$.

- It has no neutron.
- It has one proton.
- It has one electron.
- Its atomic number is 1 and mass number is also 1.

DEUTERIUM

The presence of Deuterium in naturally occurring hydrogen is 0.015%. It is denoted by symbol $^{2}_{1}H$ or D.

- It has one neutron.
- It has one proton.
- It has one electron.
- Its atomic number is 1 and mass number is also 2.

TRITIUM:

The number of tritium isotopes is one in ten millions. It is denoted by $^{3}_{1}H$ or T.

- It has two neutrons.
- It has one proton.
- It has one electron.
- Its atomic number is 1 and mass number is also 3.

CHEMICAL PROPERTIES OF WATER

1. REACTION OF WATER WITH METALS:

Water reacts with metals in number of ways. The degree of reactivity depends upon the nature of metals and their positions in the electrochemical series.

a. With More Electropositive Metals:

Group I – A and II – A metals like Na, K, Ca reacts with cold water to form their hydroxides with the liberation of H_2 gas. Na and K react vigorously while Ca reacts slowly.

i. $Na + 2H_2O \xrightarrow{cold} 2NaOH + H_2$

ii. $K + 2H_2O \xrightarrow{cold} 2KOH + H_2$

iii. $Ca + 2H_2O \xrightarrow{cold} Ca(OH)_2 + H_2$

b. With Less Electropositive Metals:

Less electropositive metals like Mg, Zn and Fe react with hot water to liberate H2 gas with the formation of their oxides.

i. $Mg + H_2O \xrightarrow{hot} MgO + H_2$

ii. $Zn + H_2O \xrightarrow{hot} ZnO + H_2$

iii. $3Fe + 4H_2O \xrightarrow{hot} Fe_3O_4 + 4H_2$

c. Noble metals Cu, Au, Ag and Hg do not react with H_2O

2. REACTION OF WATER WITH NON – METALS

a. With Chlorine:

Chlorine reacts with water to form HCl and HOCl Hyprochlorous acid (HOCl) is unstable and readily liberates atomic oxygen which can bleach dyes and kill bacteria by oxidation.

$Cl_2 + H_2O \longleftrightarrow HCl + HOCl$

$HOCl \longrightarrow HCl + \underbrace{[O]}_{\text{Nascent oxygen}}$

b. With Carbon:

When steam is passed over red hot coke at 1000°C, a mixture of H_2 and CO is obtained called water gas.

$C + H_2O \xrightarrow{1000°C} \underbrace{CO + H_2}_{\text{Water gas}}$

c. With Silicon:

Silicon reacts with steam at high temperature to form an oxide of silicon i.e. silica with liberation of H_2 gas.

$Si + 2H_2O \xrightarrow{\text{high temp:}} SiO_2 + 2H_2$

3. REACTION OF WATER WITH METAL OXIDES:

Metal oxides dissolve in water to form bases.

For Example:

i. $Na_2O + H_2O \xrightarrow{25 - 30\ atm} NaOH$

ii. $MgO + H_2O \longrightarrow Mg(OH)_2$

iii. $CaO + H_2O \longrightarrow Ca(OH)_2$

4. REACTION OF WATER WITH NON – METALS OXIDES:

Non – metallic oxides dissolve in water to produce oxyacids.

For Example:

i. $CO_2 + H_2O \longrightarrow H_2CO_3$

ii. $N_2O_5 + H_2O \longrightarrow 2HNO_3$

iii. $SO_3 + H_2O \longrightarrow H_2SO_4$

iv. $Cl_2O_7 + H_2O \longrightarrow HClO_4$

5. HYDROLYSIS OF SALTS:

Water undergoes hydrolysis with salts to form acidic or basic solution.

For Example:

i. $Na_2CO_3 + H_2O \longrightarrow NaOH + H_2CO_3$

ii. $NH_4Cl + H_2O \longrightarrow HCl + NH_4OH$

WATER AS UNIVERSAL SOLVENT

Water is an excellent solvent. It dissolves majority of ionic compounds and many of the covalent compounds. The great dissolving power of water is due to its large value of dielectric constant 80.10 at 20°C and polar nature.

In water oxygen being more electro negative than hydrogen atom, acquires a partial negative charge and hydrogen atoms gets partial positive charge, so the molecule becomes polarized.

$$\begin{matrix} & & O^- & & \\ H^+ & & & & H^+ \end{matrix}$$

- As a result of this polar structure water acts as an excellent solvent for ionic solutes such as salts, acids and alkalis.
- All covalent compounds containing hydroxyl group (– OH) are also water soluble.
  For example: $C_6H_{12}O_6$, $C_{12}H_{22}O_{11}$ and alcohols.
- Some gases are highly soluble in water such as NH_3, HCl, N_2O_5.
- Some gases are fairly soluble in water.
  For Example: CO_2, O_2, Cl_2

WATER OF CRYSTALLIZATION

Definition:

"In the formation of crystals a definite number of water molecules become a part of it. These water molecules are called water of crystallization."

Hydrates:

Compounds which contain water molecules as a part of their crystals are called as "Hydrates" or "Hydrated compounds".

Example:

i.	Washing soda	$Na_2CO_3.10H_2O$
ii.	Green Vitriol	$FeSO_4.7H_2O$
iii.	Potash Alum	$K_2SO_4.Al_2(SO_4)_3.24H_2O$
iv.	Blue stone	$CuSO_4.5H_2O$
v.	Epsom salt	$MgSO_4.7H_2O$

When crystals are heated the lose water of crystallization forming powdered substances called anhydrous compound.

HYGROSCOPIC SUBSTANCES

Definition:

Substance which absorbs moisture from atmosphere when kept open are called hygroscopic substances.

Hygroscopic substances just become sticky or moist in open air and do not form a solution.

Example:

i.	Sodium Nitrate	$NaNO_3$
ii.	Copper Oxide	CuO
iii.	Calcium Oxide	CaO
iv.	Conc: Sulphuric Acid	H_2SO_4

Importance:

Hygroscopic substance are commonly employed as dying agent in the the laboratory. They have strong affinity for moisture or water.

HEAVY WATER

When a heavier isotope of hydrogen, deuterium (A = 2) combines with oxygen the compound formed is deuterium oxide (D_2O) called heavy water.

Naturally occurring water contains one part of heavy water out of its seven thousand parts.

Properties Of Heavy Water:

1. Its density is slightly greater than ordinary water. It is 1.104g/cm^3.
2. It has low vapor pressure than ordinary water.
3. Its freezing point is 3.81°C and boiling point is 101.42°C.
4. Refractive index of water is much smaller than ordinary water.
5. Molecular mass of heavy water is 20 a.m.u while that of ordinary water is 18 a.m.u.

Uses:

1. It is used as moderator in nuclear fission power reactor.
2. It is also used as a tracer in biological and chemical researches.

SOFT WATER AND HARD WATER

1. SOFT WATER:

"The water containing dissolved impurities (salts) of bicarbonates, chlorides and sulphates of calcium and magnesium in small quantities which easily produce lather with soap is known as soft water."

2. HARD WATER:

"The water containing dissolved impurities (salts) of bicarbonates, chlorides and sulphates of calcium and magnesium in large amount which do not produce lather with soap is known as hard water."

CAUSES OF HARDNESS:

Rain water dissolves carbon dioxide from air. When this water passes dowm the layer of air, insoluble carbonates of Ca and Mg are dissolved as bicarbonates.

$$CaCO_3 + CO_2 + H_2O \longrightarrow Ca(HCO_3)_2$$

$$MgCO_3 + CO_2 + H_2O \longrightarrow Mg(HCO_3)_2$$

Sulphates and chlorides of Ca and Mg are also dissolved. The presence of Ca^{+2} and Mg^{+2} are also dissolved. The presence of Ca^{+2} and Mg^{+2} ions in water make it hard.

TYPES OF HARDNESS

There are two types of hardness in water.

i. TEMPORARY HARDNESS

Temporary hardness in water is due to presence of dissolved bicarbonates of Ca and Mg.

$$Ca(HCO_3)_2 \longleftrightarrow Ca^{+2} + 2HCO_3^{-1}$$

$$Mg(HCO_3)_2 \longleftrightarrow Mg^{+2} + 2HCO_3^{-1}$$

ii. PERMANENT HARDNESS

Permanent hardness in water is due to presence of dissolved chlorides and sulphates of Ca and Mg.

$CaCl_2 \longleftrightarrow Ca^{+2} + 2Cl^-$

$CaSO_4 \longleftrightarrow Ca^{+2} + SO_4^{-2}$

$MgCl_2 \longleftrightarrow Mg^{+2} + 2Cl^-$

$CaSO_4 \longleftrightarrow Mg^{+2} + SO_4^{-2}$

METHODS OF REMOVING HARDNESS

a. METHODS OF REMOVING TEMPORARY HARDNESS:

i. By Boiling:

Temporary hardness of water is due to the presence of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. On heating $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ are decomposed to form insoluble $CaCO_3$ and $MgCO_3$ which can be remove easily by filtration.

$Ca(HCO_3)_2 \longrightarrow CaCO_3 + CO_2 + 2H_2O$

$Mg(HCO_3)_2 \longrightarrow MgCO_3 + CO_2 + 2H_2O$

ii. Clark's Method: (By Adding Lime Water)

In this method a calculated amount of slaked lime is mixed with hard water containing bicarbonates of Ca and Mg. after treatment with lime water bicarbonates of Ca and Mg are separated as insoluble carbonates and are removed by filtration easily.

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

$Mg(HCO_3)_2 + Ca(OH)_2 \longrightarrow MgCO_3 + CaCO_3 + 2H_2O$

b. METHODS OF REMOVING PERMANENT HARDNESS:

i. By Using Washing Soda:

When washing soda is added to permanent hard water, insoluble $CaCO_3$ and $MgCO_3$ are precipitated from the soluble salts of Ca and Mg.

$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4$

$MgCl_2 + Na_2CO_3 \longrightarrow MgCO_3 + 2NaCl$

ii. By Using Caustic Soda:

When caustic soda is added to the permanent hard water, insoluble hydroxides of Mg^{+2} ions is precipitated from the salt of Mg while $Ca(OH)_2$ is partially soluble in water.

$MgSO_4 + 2NaOH \longrightarrow Mg(OH)_2 + Na_2SO_4$

iii. By Using Zeolite: (Ion Exchange Method)

Zeolite or permetit is a naturally occurring sodium aluminum silicate, commonly known as sodium zeolite. It is usually used in industry and home for softening water. As hard water is passed through it, the sodium ions will go into the solution while the unwanted Ca and Mg ions take their place in the complex insoluble Ca and Mg zeolite, and their hardness is removed.

$CaSO_4 +$ Sodium Zeolite $\longrightarrow$ Ca – Zeolite $+ Na_2SO_4$

Insoluble