Chapter 2: Hydrogen

Hydrogen is the first element in the periodic table and is also the lightest element known. The chemist **Lavoisier** gives the name hydrogen. It got its name from the Greek word "**hydro**" meaning water. Hydrogen has the simplest atomic structure among all the elements around us in nature. In atomic form it consists of only one proton and one electron. However, in elemental form it exists as a diatomic (H_2) molecule and is called dihydrogen.

It also has properties that are similar to both halogens and alkali metals. So hydrogen can be placed both in group 1 and group 17.

Electron Configuration of Hydrogen

The atomic number of hydrogen is 1. Therefore, a hydrogen atom contains 1 electron. The electron configuration of hydrogen is **$1s^1$**

The hydrogen atom can lose or gain an electron:

H^+ : To lose an electron the reaction $H \rightarrow H^+ + é$; consumes 13.6 eV.

H^- : The gain of an electron provides 0.7 eV $H + é \rightarrow H^-$; consumes 0.7 eV.

Properties of Dihydrogen

Physical Properties

Under standard conditions, hydrogen is a gas, the lightest of all substances.

- odorless
- colorless
- tasteless
- After helium, it is the most difficult gas to liquefy
- Dangerous: combustible gas (explosive mixture with air in the presence of a flame)
- Atomic number: 1
- Atomic mass: 1.008
- Melting point: − 259.14 °C (liquefies with difficulty)
- Boiling point: − 252.87 °C (very low boiling point, reflects its non-polarity, low polarizability and low molar mass)
- Density: 0.0799 g/cm3,
- It is lighter than air and insoluble in water.

Chemical Properties

- Dihydrogen is a relatively stable gas that only dissociates into hydrogen atoms at temperatures above 2000 K.
  $H_2 \rightarrow H + H$.
- It has a very high bond dissociation energy of H, $\Delta H = 435.9$ kJ/mol.

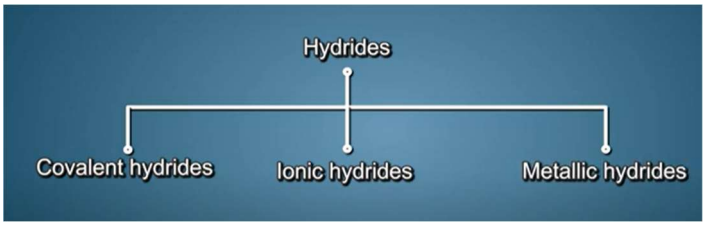
- It is not highly reactive due to its high bond dissociation energy. It does, mix with a variety of elements or compounds.
- Saturated hydrocarbons are formed when H_2 reacts with unsaturated hydrocarbons like ethylene and acetylene.

Hydrides

Dihydrogen combines with a number of elements to form binary compounds called hydrides. Their general formula being MH_X where M represents the element and x the number of hydrogen atoms.

Depending upon the physical and chemical properties, the hydrides have been divided into the following three broad categories:

1. Ionic or saline hydrides
2. Metallic or Interstitial hydrides
3. Covalent hydrides



Saline Hydrides or Ionic hydrides

When a hydrogen anion combines with highly electropositive s-block components (Alkali Metals and Alkaline Earth Metals (except Be)), they produce Ionic Hydrides or Saline Hydrides. Ionic hydrides are crystalline, non-conducting, and non-volatile solid compounds.

Saline hydrides are formed by the transference of electron from metal to hydrogen. Some common examples of this category are: LiH, NaH,CaH_2,CrH_2 etc.

$$CaH_2\,(melt) \longrightarrow Ca^{2+} + 2H^-$$

Covalent Hydrides

If the hydrogen anions reacts with other similar electronegative elements such that, Si, C, etc. Thus, if hydrogen anion react with non-metals they form covalent hydrides. In the covalent hydrides the bond form is covalent bond. These covalent hydrides are volatile or non-volatile in nature. The covalent hydrides exist in liquid and gaseous form. Halogens form the

p-block reacts with hydrogen to form Halogen Hydrides and their general form is HX where H is hydride ion and X is Halogen ion. Some example of HX are, HCl, HBr, HI, etc.

These are binary compounds of hydrogen and elements of comparatively high electronegativity such as p- block elements. In these hydrides, H atoms are bonded to the other atoms by covalent bonds. Some examples of covalent hydrides are, HCl,H_2O, PH_3, NH_3, CH_4…etc.

However, elements of group 13 are exception to this formula. The elements of group 13 such as B, Ga form polynuclear hydrides which are electron deficient compounds. B_2H_6,Ga_3H_2 etc,

Interstitial Hydride or Metallic Hydrides

If the hydrogen react with the transition elements of the d-block and f-block then compounds so formed are called metallic hydrides. They are stable compound and are boned by the metallic bonds. The metallic hydride formed by other d-block elements are in Solid State. These compounds are good conductors of electricity and have high thermal capacity.

Main Group Elemental Hydrides

All species deemed to be inthe gas phase and molecular

1	2	13	14	15	16	17	18
H_2							He
LiH	BeH_2	BH_3	CH_4	NH_3	H_2O	HF	Ne
NaH	MgH_2	AlH_3	SiH_4	PH_3	H_2S	HCl	Ar
KH	CaH_2	GaH_3	GeH_4	AsH_3	H_2Se	HBr	Kr
RbH	SrH_2	InH_3	SnH_4	SbH_3	H_2Te	HI	Xe
CsH	BaH_2						

Reactive	**Reaction of H_2**
M (GI)	$2M (s) + H_2(g) \rightarrow 2MH (s)$
M (GII, sauf le Be)	$M (s) + H_2(g) \rightarrow MH_2 (s)$
M (bloc d)	$2M (s) + xH_2(g) \rightarrow 2MH_x (s)$
Oxygène	$O_2 (g) + 2H_2(g) \rightarrow 2H_2O (l)$
Azote	$N_2 (g) + 3H_2(g) \rightarrow 2NH_3 (g)$
Halogène (X_2)	$X (g, l, s) + H_2(g) \rightarrow 2HX (g)$

Uses of Hydride

- They are used as reducing agents in many chemical industries.
- Hydrides are highly significant in battery storage technologies such as nickel hydride batteries.
- They are used as drying agents.
- They are used as strong bases in organic synthesis.
- Metal hydrides are also used for their heat storage, hydrogen storage and compressors capabilities.

How are they named?

The name is formed by two words. The first word is the name of the metal. The second word is the root of hydrogen plus the suffix "–ide"

METAL hydride

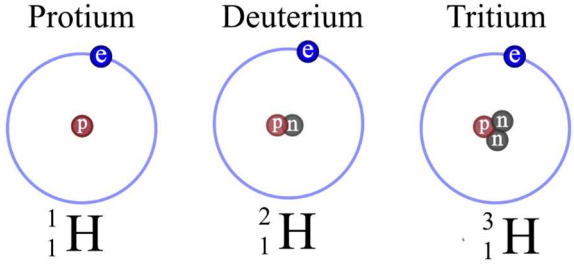
LiH	Lithium hydride
CaH_2	Calcium hydride
AlH_3	Aluminium hydride
GeH_4	Germanium hydride
SnH_4	Tin hydride

- hydrogen sulphide H_2S
- hydrogen chloride HCl
- hydrogen phosphide PH_3
- hydrogen nitride NH_3

Isotopes of hydrogen

Isotopes of hydrogen are hydrogen atoms with the same number of protons (1) but a different number of neutrons.

There are three isotopes of hydrogen: protium (1H), deuterium (2H), and tritium (3H).



	Protium	Deuterium	Tritium
symbol	$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$
neutrons	0	1	2
mass (amu)	1.00783	2.0140	3.01605
abundance (%)	99.9885	0.0115	$\sim 10^{-17}$
half-life (years)	—	—	12.32
boiling point of X_2 (K)	20.28	23.67	25
melting point/boiling point of X_2O (°C)	0.0/100.0	3.8/101.4	4.5/?

1. Protium (^{1}H)

Protium or light hydrogen refers to isotopically pure hydrogen-1, ^{1}H. The nucleus consists of only one proton, with no neutrons, and is the most common type of atom in the universe. It is plenty in nature with an abundance of 99.98%. Mass of protium is 1.007825 amu. Hydrogen generally combines with other atoms in compounds and are usually found in H_2.

2. Deuterium (^{2}H)

Deuterium or heavy hydrogen is a stable hydrogen isotope with a neutron in the nucleus. The deuterium content of hydrogen on Earth varies in the range from 0.0026 to 0.0184 atomic percent. It is not radioactive.

Applications of Deuterium

- Drugs
- Nuclear weapons
- NMR spectroscopy
- Nuclear reactors

3. Tritium (^{3}H)

Tritium (superheavy hydrogen) is a radioisotope that only occurs in traces. It comprises 2 neutrons and 1 proton in its nucleus. Hydrogen 3 has an atomic mass of 3.0160492 u. On Earth, tritium is found mainly in the atmosphere and in the water of the oceans, formed by the interaction of cosmic rays with atoms in the Earth's atmosphere, e.g.:

$^{14}N + n \rightarrow {}^{12}C + {}^{3}H.$

Artificially, tritium can be produced by neutron activation of lithium-6

$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H + 4{,}78\ MeV$

Applications of Tritium

- Analytical chemistry
- Tritium in hydrogen bomb

- Nuclear weapons

Preparation of Hydrogen

Breaking chemical bonds is required to produce elemental hydrogen from molecules. The following are the most popular hydrogen preparation methods:-

- Laboratory method
- Industrial Method

I- Preparation of Hydrogen by the industrial method

Raw materials for industrial processing should be inexpensive and readily available. Water, hydrocarbons, and coke are the primary ingredients utilized in the large-scale preparation of hydrogen gas.
The following are some of the most important methods of preparation:

1. By electrolysis of water

Electrolysis is typically performed in a specific vessel known as an electrolytic cell or voltameter. The preparation of hydrogen is carried out by the process known as the electrolysis of water. hydrogen forms at the cathode, and oxygen forms at the anode.

Reaction involved:

$$2\ H_2O \rightarrow O_2 + 2\ H_2$$

$$H_2O \rightleftharpoons H^+ + OH^-$$

At anode:

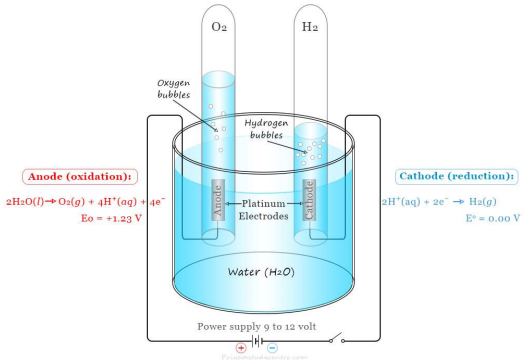
$$H^+ + e^- \rightarrow H \text{ (atomic hydrogen)}$$

$$H + H \rightarrow H_2 \text{ (molecular hydrogen)}$$

At cathode:

$$OH^- + e^- \rightarrow OH$$

$$4\ OH \rightarrow 2\ H_2O + O_2$$



2- By the action of water vapor on hydrocarbons

This method is preferred to electrolysis because it requires inexpensive substances. Hydrocarbons (alkanes) are used, with the general formula CnH2n+2, over which water vapor is passed in the presence of catalysts (Ni, Fe, Cu, Ru, etc.) and at a high temperature.

$$C_nH_{2n+2}\,(g) + n\,H_2O(g) \rightarrow n\,CO(g) + (2n+1)\,H_2(g)$$

$$C_nH_{2n+2}\,(g) + 2n\,H_2O(g) \rightarrow n\,CO_2(g) + (3n+1)\,H_2(g)$$

note : n = 1, 2, 3, ...

- preparation of H_2 from H_2O using a hydrogenated compound.

Exp. 1 - The reaction of oil with water vapor (at 400 °C)

$$C_3H_8\,(g) + 3H_2O\,(g) \rightarrow 7H_2\,(g) + 3CO\,(g)$$

$$3CO\,(g) + 3H_2O\,(g) \rightarrow 3H_2\,(g) + 3CO_2\,(g)$$

$$C_3H_8\,(g) + 6H_2O\,(g) \rightarrow 10H_2\,(g) + 3CO_2\,(g)$$

Exp.2 - The reaction of methane with water vapor (900-1000°C)

$$CH_4(g) + H_2O(g) \rightarrow 3H_2(g) + CO(g)$$

$$CO(g) + H_2O(g) \rightarrow H_2(g) + CO_2(g)$$

$$CH_4(g) + 2H_2O(g) \rightarrow 4H_2(g) + CO_2(g)$$

- By the action of water vapor on carbon

H_2 is obtained by passing water over carbon heated to red (1000°C).

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g$$

$$C(s) + 2H_2O(g) \rightarrow CO_2(g) + 2H_2(g)$$

II- Preparation of Hydrogen in Laboratory

1. Action of a diluted acid on a metal (Mg, Zn, Fe,….)

This is one of the best-known methods of preparing hydrogen in the laboratory.

Exp. 1 - By reacting hydrochloric acid with magnesium

$$Mg\,(s) + 2\,HCl\,(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

Exp.2 - By reacting sulfuric acid with Zinc

$$Zn\,(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$$

(preparation of H_2 without H_2O using a metal)

2- Action of a metal on water (Na, Li, Ba, Ca, Sr, Al…)

Alkali metals and some alkaline earth metals, such as calcium, are powerful reducing agents that react spontaneously with water.

Exp. - Reduction of water by sodium

$$2Na\,(s) + 2\,H_2O\,(l) \rightarrow 2NaOH\,(aq) + H_2(g)$$

(preparation of H_2 with H_2O using a reducing agent)

3- Action of water on metal hydrides (CaH_2, LiH, ….)

Exp. – The action of water on calcium hydride

$$2CaH_2\,(s) + 2\,H_2O\,(l) \rightarrow CaOH_2(aq) + 2H_2(g)$$

(preparation of H_2 with H_2O using a reducing agent)

Uses of Hydrogen Gas

Hydrogen gas is used in many applications, including the following:

- Hydrogen can be used as a clean alternative to non-renewable fuels without fear of any harmful emissions; hydrogen is produced from water and turns into water after burning.
- It can be used in various means of transportation, such as cars and buses.
- Hydrogen is essential in the process of hydrogenating oils to produce fats, an example of which is its use in the manufacture of ghee.

$$….C{=}C…. + H_2\,(g) \rightarrow …..CH{-}CH…..$$

- Hydrogen gas enters the industrial sector through its use in the manufacture of ammonia, which is important in the production of agricultural fertilizers, plastics, in addition to some types of medicines.

$$N_2(g) + 3H_2\,(g) \rightarrow 2NH_3(g)$$

- Hydrogen gas can be used for the purposes of welding and softening metals at high temperatures.
- Hydrogen is used in the manufacture of methanol.

$$2H_2\,(g) + CO(g) \rightarrow CH_3OH(l)$$