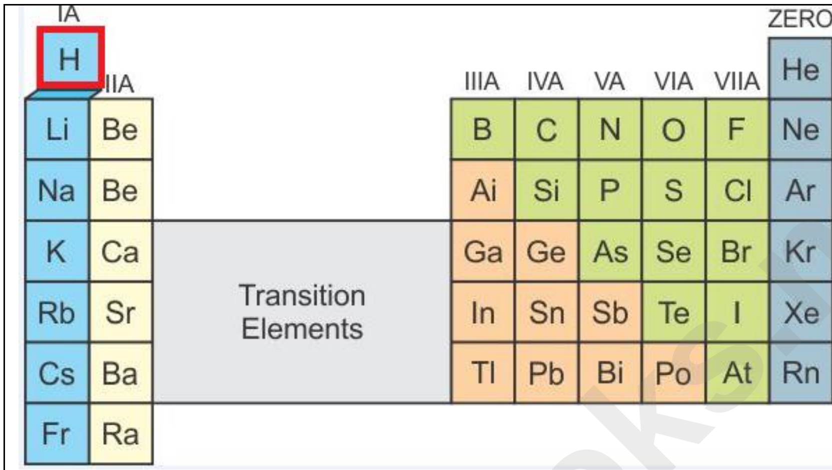
Study of the First Element – Hydrogen

Hydrogen is the first element of the periodic table. It was discovered by Cavendish and named by Lavoisier.



Position of hydrogen in the periodic table

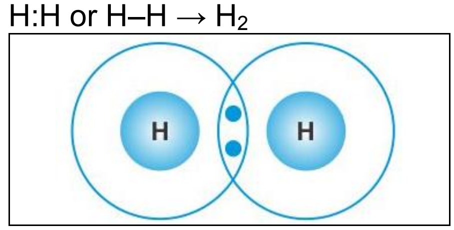
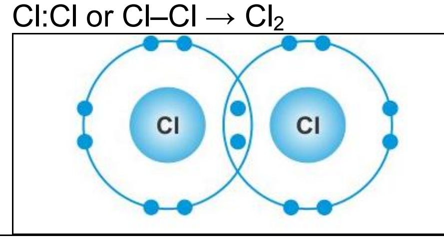
- Hydrogen belongs to the first group and the first period of the periodic table.
- Although the properties of hydrogen should be similar to those of the other members of the first group, this is not the case.
- Some of the properties of hydrogen resemble the properties of Group IA elements (Alkali metals), and some of the properties resemble the properties of Halogens (VIIA).
- Thus, hydrogen was put at the top of the periodic table so that the symmetry of the modern periodic table is not disturbed.

Dual Nature of Hydrogen

Hydrogen has an electronic configuration of 1.

- Hydrogen **loses** 1 electron and behaves like electropositive alkali metals [Group 1 (IA)].
- Hydrogen **gains** 1 electron and behaves like electronegative halogens [Group 17 (VIIA)].

Similarity of Hydrogen with Alkali Metals and Halogens

	Similarity of hydrogen with alkali metals [Group 1 (IA)]	**Similarity of hydrogen with halogens [Group 17 (VIIA)]**
Electronic configuration	Electronic configuration = 1. Thus, there is 1 electron in the outermost valence shell. Examples: H = **1**; Li = 2, **1**; Na = 2, 8, **1**; K = 2, 8, 8, **1**	One electron less than the nearest noble gas. Examples: H = 1 (He = 2) F = 2, 7 (Ne = 2, 8) Cl = 2, 8, 7 (Ar = 2, 8, 8)
Ion formation	Electropositive character exhibited. Examples: $H - 1e^{-} \rightarrow H^{1+}$ $Li - 1e^{-} \rightarrow Li^{1+}$ $Na - 1e^{-} \rightarrow Na^{1+}$	Electronegative character exhibited. Examples: $H + 1e^{-} \rightarrow H^{1-}$ $F + 1e^{-} \rightarrow F^{1-}$ $Cl + 1e^{-} \rightarrow Cl^{1-}$
Valency	Electrovalency of one exhibited. H^{1+}, Li^{1+} , Na^{1+}	Electrovalency and covalency exhibited. Hydrogen forms NaH (electrovalent) CH_4 (covalent) Chlorine forms NaCl (electrovalent) CCl_4 (covalent)
Reactions	Strong affinity for non-metals. Examples: O, S, Cl Hydrogen forms H_2O, H_2S, HCl Sodium forms Na_2O, Na_2S, NaCl	—
Reducing agent	Acts as a reducing agent. Hydrogen: $CuO + H_2 \rightarrow Cu + H_2O$ Sodium: $CuO + 2Na \rightarrow Cu + Na_2O$	—
Atomicity	—	Diatomic molecules are formed (Two atoms linked by a single bond). **Hydrogen** H:H or H–H → H_2  **Chlorine** Cl:Cl or Cl–Cl → Cl_2 

Preparation of Hydrogen – General Methods

1. General methods – From cold water and metals

Metals react with cold water to form metal hydroxide and liberate hydrogen gas.

Reactions:

$2K + 2H_2O \rightarrow 2KOH + H_2\uparrow$
$2Na + 2H_2O \rightarrow 2NaOH + H_2\uparrow$
$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2\uparrow$

2. General methods – From boiling water/steam and metals

Magnesium	$Mg + H_2O \rightarrow MgO + H_2\uparrow$ (boiling water)	• Mg, Al, Zn and Fe do not react with cold water. They react with boiling water and liberate hydrogen gas, but the reaction is very slow. • Mg, Al, Zn and Fe react with hot steam in the heated state and form the corresponding oxide and hydrogen gas. • Iron reacts with steam, and the reaction is reversible.
Aluminium	$2Al + H_2O \rightarrow Al_2O_3 + 3H_2\uparrow$ (steam)	
Zinc	$Zn + H_2O \rightarrow ZnO + H_2\uparrow$ (steam)	
Iron	$Fe + 4H_2O \rightleftharpoons Fe_3O_4 + 4H_2\uparrow$ (steam)	

3. General methods – From acids

Magnesium	$Mg + 2HCl \rightarrow MgCl_2 + H_2\uparrow$
Aluminium	$2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2\uparrow$
Zinc	$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2\uparrow$
Iron	$Fe + 2HCl \rightarrow FeCl_2 + H_2\uparrow$

4. General methods – From concentrated alkalis

Aluminium	$2Al + 6NaOH \rightarrow 2Na_3AlO_3 + 3H_2\uparrow$ (Sodium aluminate) $2Al + 2KOH + 2H_2O \rightarrow 2KAlO_2 + 3H_2\uparrow$ (Potassium meta aluminate)
Zinc	$Zn + 2NaOH \rightarrow Na_2ZnO_2 + H_2\uparrow$ (Sodium zincate) $Zn + 2KOH \rightarrow K_2ZnO_2 + H_2\uparrow$ (Potassium zincate)
Lead	$Pb + 2NaOH \rightarrow Na_2PbO_2 + H_2\uparrow$ (Sodium plumbate)

Preparation of Hydrogen – Laboratory Method

Laboratory method by using granulated zinc, dilute hydrochloric acid or dilute sulphuric acid.

Reactions:

$Zn + 2HCl \rightarrow ZnCl_2 + H_2\uparrow$
(dilute)

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2\uparrow$
(dilute)

Collection:

Hydrogen gas is collected by the downward displacement of water.

Manufacture of Hydrogen – By the Electrolysis of Water

Hydrogen is commercially obtained by the electrolysis of water.

Water is a poor conductor of electricity. Thus, a less volatile acid such as sulphuric acid is added to water to make it a good conductor of electricity. This is called **acidulated water**.

On passing electric current through this acidulated water, water dissociates.

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

H^+, being positively charged, moves towards the cathode (negatively charged electrode).

At cathode,

$H^+ + e^- \rightarrow H$

$H + H \rightarrow H_2$

At anode,

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

$OH + OH \rightarrow H_2O + O$

$O + O \rightarrow O_2$

Hence, water dissociates to give hydrogen and oxygen by passing an electric current through acidulated water.

$2H_2O \rightarrow 2H_2 + O_2$

Bosch Process

The Bosch process consists of the following steps.

Step 1:

Steam is passed over hot coke (at 1000°C) in a special type of furnace called a converter to form carbon monoxide and hydrogen gas. This mixture is called water gas.

$$\underset{\text{White hot charcoal}}{C} + \underset{\text{Super heated steam}}{H_2O} \xrightarrow{1000^0 C} \underset{\text{(Equivolume mixture of CO and } H_2\text{) (Water gas)}}{CO + H_2}$$

Step 2:

Excess of steam is mixed with water gas, and the entire mixture is passed over heated ferric oxide and chromic oxide. Ferric oxide acts as a catalyst and chromic oxide as a promoter.

$$\underbrace{CO + H_2}_{\text{Water gas}} + H_2O \xrightarrow[450^0 C]{Fe_2O_3/Cr_2O_3} 2H_2 + CO_2$$

Step 3:
In this step, carbon dioxide is removed from the reaction mixture. The mixture of carbon dioxide and hydrogen is forced through cold water under pressure at 30 atmospheric pressure or through caustic potash solution, which dissolves carbon dioxide leaving behind hydrogen gas.

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$$

Step 4:
In this last step, the mixture is passed through ammoniacal solution of cuprous chloride solution so as to dissolve carbon monoxide. Thus, hydrogen gas is obtained.

$$CuCl + CO + 2H_2O \rightarrow CuCl.CO.2H_2O$$

Physical Properties of Hydrogen

- Colourless, odourless and tasteless gas.
- Non-poisonous.
- Solubility is very low.
- It can be liquefied.
- Vapour density is 1, much lighter than air.

Chemical Properties of Hydrogen

- It is neutral to litmus.
- It is combustible but does not support combustion.
- Nascent hydrogen: Fresh hydrogen formed at the time of generation is called nascent hydrogen.

- **Reaction with oxygen**
  Hydrogen burns with a **pop sound** in oxygen and burns with a pale blue flame forming water.
  $2H_2 + O_2 \rightarrow 2H_2O$

- **Reaction with Chlorine**

  $H_2 + Cl_2 \xrightarrow{\text{Sunlight}} 2HCl$

- **Reaction with Hydrogen (Haber process)**

  Three volumes of hydrogen and one volume of nitrogen react at temperature 450–500°C at a pressure of 200–900 atm in the presence of finely divided iron (catalyst) and molybdenum (promoter).

  $$N_2 + 3H_2 \underset{\text{Molybdenum (Promoter)}}{\overset{\text{Iron (Catalyst)}}{\rightleftharpoons}} 2NH_3$$

- **Reaction with sulphur**

  Hydrogen gas when passed through molten sulphur reacts to give another gas, hydrogen sulphide.

  $H_2 + S \rightarrow H_2S$

- **Reaction with metals**
  Dry hydrogen when passed over heated metals, such as Na, K and Ca, reacts to give their corresponding hydrides.
  $2K + H_2 \rightarrow 2KH$
  $2Na + H_2 \rightarrow 2NaH$
  $Ca + H_2 \rightarrow CaH_2$

- **Reaction with metallic oxides**
  Hydrogen reduces metal oxides to give metals; thus, hydrogen is a reducing agent.
  $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$
  $Fe_3O_4 + 4H_2 \rightarrow 3Fe + 4H_2O$
  $PbO + H_2 \rightarrow Pb + H_2O$
  $CuO + H_2 \rightarrow Cu + H_2O$

Uses of Hydrogen

- As a fuel in oxy-hydrogen blow torch
- In meteorological balloons
- In the manufacture of ammonia
- In the manufacture of hydrogenated oils
- For producing artificial petrol from coal
- In the extraction of metals
- As a reducing agent