Hydrogen

Hydrogen, H2, is the simplest element. It is the first element in the periodic table, and it is placed in Group I of the periodic table. It has three Isotopes

- Atomic Number : 1
- Atomic Mass : 1.008
- Melting Point : -259 degC
- Boiling Point : -253 degC
- Density : 0.09

Deuterium, D2, (which is also known as Heavy Hydrogen) is an isotope of hydrogen. The atomic number of deuterium is 1, its atomic mass is 2.0144, and its boiling point is 23.6 deg K

Discovery

Hydrogen was discovered by Henry Cavendish in 1776AD.

Occurrence

Hydrogen is the lightest element and the most abundant element in the universe.

Hydrogen occurs naturally as a mixture of the three isotopes :

- Protium, H,
- Deuterium, D, (which is also called Heavy Hydrogen) and
- Tritium, T.

Preparation

The preparation of hydrogen gas is usually from a reduction of a compound containing hydrogen that is in the +1 oxidation state. This reduction is accomplished either electrically or chemically.

> **WARNING**
> Before collecting hydrogen great care must be taken to ensure that all the air has been displaced from the apparatus since a mixture of hydrogen with air is highly explosive.
> **WARNING**

Preparation of Hydrogen by Electrolysis

Electrolytic hydrogen is the purest commercially available grade of hydrogen and is made by the electrolysis of water.

Pure hydrogen is best prepared by electrolysis with nickel electrodes of a warm saturated barium hydroxide solution. The gas is passed over hot platinum gauze which oxidises any residual oxygen in the gas, and it is then dried by passing the gas over potassium hydroxide pellets and pure redistilled powdered phosphorus pentoxide. 'Electrolytic Hydrogen' is relatively expensive because of the cost of the electrical energy necessary to make it.

Preparation of Hydrogen by the Action of Metals

The alkali metals, lithium, sodium, and potassium react violently with water at the ordinary temperature, yielding hydrogen.

$$2\,Li + 2\,H_2O \Longrightarrow H_2 + 2\,LiOH$$

Calcium reacts with water more slowly unless the water is hot, when the action is more vigorous.

$$Ca + 2\,H_2O \Longrightarrow H_2 + Ca(OH)_2$$

Preparation of Hydrogen by Decomposition of Water

Cold water is decomposed by amalgamated aluminium (i.e. an alloy of aluminium and mercury which is made by rubbing aluminium foil with damp mercuric chloride).

$$2\,Al + 6\,H_2O \Longrightarrow 2\,Al(OH)_3 + 3\,H_2$$

Hot water is decomposed by zinc-Copper couple (i.e. solid granules of zinc covered by a surface layer of copper which made by pouring a solution of copper sulphate over granulated zinc).

$$Zn + 2H_2O \Longrightarrow Zn(OH)_2 + H_2$$

Boiling water is slowly decomposed by magnesium power.

$$Mg + 2H_2O \Longrightarrow Mg(OH)_2 + H_2$$

Steam is decomposed when passed over heated magnesium, zinc, and iron.

$$Mg + H_2O \Longrightarrow MgO + H_2$$
$$Zn + H_2O \Longrightarrow ZnO + H_2$$
$$3\,Fe + H_2O \Longleftrightarrow Fe_3O_4 + 4H_2$$

The last reaction, (i.e. the action of iron on steam) is reversible, depending on the experimental conditions.

Preparation of Hydrogen from Action of Acids

Hydrogen is prepared in the laboratory by the action of acids on metals. Dilute sulphuric acid containing 1 volume of concentrated acid to 5 volumes of water, or dilute hydrochloric acid containing 1 volume of concentrated acid to 4 volumes of water, is added to granulated zinc. Zinc sulphate or zinc chloride is formed in solution and the hydrogen that is evolved is collected over water in a trough.

$$Zn + H_2SO_4 \Longrightarrow ZnSO_4 + H_2$$
$$Zn + 2\,HCl \Longrightarrow ZnCl_2 + H_2$$

Since hydrogen is very much lighter than air it may also be collected by upward displacement.

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> **WARNING**

Manufacture

Pure hydrogen is manufactured industrially by the steam reforming of natural gas, and by the electrolysis Of water.

The manufacture of hydrogen on an industrial scale involves the reaction between steam and iron. Spongy iron from the reduction of spathic iron ore (ferrous carbonate) is heated to redness and steam passed over it.

$$3\ Fe + 4\ H_2O \Longrightarrow Fe_3O_4 + 4\ H_2$$

The hot ferrosoferric oxide, Fe3O4, is then reduced with water gas:

$$Fe_2O_4 + 4\ H_2 \Longrightarrow 3\ Fe + 4\ H_2O$$

$Fe_2O_4 + 4CO \Longrightarrow 3\ Fe + 4\ CO_2$ Water gas is made by passing steam over red hot carbon and it consists of a mixture of carbon monoxide and hydrogen, with a smaller amount of carbon dioxide:

$$C + H_2O \xrightarrow[\text{heat}]{\text{bright-red}} CO + H_2$$

$$C + 2\ H_2O \xrightarrow[\text{heat}]{\text{dull-red}} CO_2 + 2\ H_2$$

Properties

Hydrogen is

- a colourless odourless gaseous element,
- sparingly soluble in water and the solubility is not much affected by change of temperature,
- does not support respiration although it is not poisonous. When hydrogen is breathed mixed with some air for a short time, it weakens the voice and raises its pitch,
- a better conductor of heat than other gases, its conductivity being about five times that of air, and
- forms compounds with a large number of elements. In many cases, these compounds are formed by the direct combination of the elements.
- Chemically, hydrogen reacts with most elements.

Combustion of Hydrogen

- Hydrogen burns in oxygen or air to form water.

$$2\ H_2 + O_2 \Longrightarrow 2\ H_2O$$

- Oxygen will also burn in hydrogen.
- Hydrogen does not itself support combustion, as may be shown by passing a lighted taper into an inverted jar of hydrogen, when the taper is extinguished.

A mixture of hydrogen with oxygen or air explodes violently when kindled, provided either gas is not present in too large excess.

Reaction with Non-Metals

Hydrogen readily combines with fluorine and chlorine, less readily with bromine, iodine, sulphur, phosphorous, nitrogen, and carbon.

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H2   +   F2   ==>   2 HF
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Hydrogen burns in chlorine gas and a mixture of hydrogen and chlorine explodes violently when kindled or exposed to bright sunlight.

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H2   +   Cl2   ==>   2 Hcl
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Hydrogen combines with nitrogen on sparking or in presence of a catalyst, forming ammonia.

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N2   +   3 H2   ==>   2 NH3
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Hydride Formation

Hydrogen forms hydrides, (e.g. NaH) with a number of metals, including lithium, sodium and calcium.

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H2   +  2 Na   ==>   2 NaH
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These hydrides when pure are white salt-like compounds rapidly decomposed by water.

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NaH   +   H2O   ==>   NaOH   +   H2
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The hydrogen atom in these hydrides behaves to some extent like a halogen or electronegative element. For example, on the electrolysis of fused lithium hydride, the hydrogen is liberated at

the positive electrode (i.e. a negatively charged hydrogen ion is discharged), and not the negative electrode as is the case when water is electrolysed.

Hydrogen is also evolved at the anode in the electrolysis of a solution of calcium hydride, in fused mixture of potassium chloride and lithium chloride. This indicates that the ionic structure of the lithium hydride is Li(+)H(-).

Reducing Properties

When hydrogen is passed over many heated metallic oxides (e.g. copper oxide, iron oxide, or lead oxide), they are reduced to the metals.

CuO + H2 ==> Cu + H2O

Uses

Hydrogen is used

- in the reduction of oxide ores,
- in the refining of petroleum,
- in the production of hydrocarbons from coal,
- to fill balloons and airships, as it is the least dense gas known (i.e. it is lighter than air). Previously, coal gas was often used for the same purpose, as it contains a high percentage of hydrogen. However, because the flammable nature of hydrogen makes it dangerous for such use, this use of hydrogen has been to replaced by helium,
- in the Synthesis of ammonia,
- as a fuel in Oxy-Hydrogen blowpipes,
- for the hardening of vegetable or animal oils (i.e. to convert them into saturated fats which are solids), and
- for the hydrogenating petroleum fractions, coal and other organic compounds.

Principal Compounds

Hydrogen is widely distributed in industrially important compounds and is present

1. in a wide range of inorganic compounds, including

   Ammonia
   Hydrogen Sulphide
   Water

2. in the strong acids, including

   Sulphuric Acid
   Nitric Acid
   Hydrochloric Acid
   Hydrobromic Acid
   Hydrofluoric Acid

   and

3. in almost all organic compounds.

   Alkanes
   Alkenes
   Alkynes
   Alcohols
   etc.

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