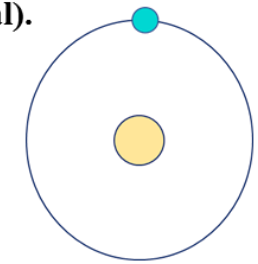
Hydrogen

A Hydrogen molecule is formed as a combination of two atoms with each hydrogen atom having one electron(1s orbital).



Hydrogen is the lightweight and most widely distributed element in the universe, it is colorless, odorless and tasteless gas.

It has the lowest density of all gases combined. It has atomic number of 1 and in elemental processing hydrogen is often generated.

Hydrogen is an important element for human life. It is spread in water and in almost all the molecules in organics material.

It is the most abundance gas in the universe. Hydrogen symbolized by H_2.

Hydrogen bonding is important in many chemical processes. Hydrogen bonding is responsible for water's unique solvent capabilities.

MIND MAP

Hydrogen

Hydrogen bonds hold complementary strands of DNA together, and they are responsible for determining the three-dimensional structure of folded proteins including enzymes and antibodies.

Applications

1. Nitrogen Dioxide Emission. Critics of hydrogen fuel cells argue that although these cells do not emit carbon after burning, they give out nitrogen dioxide and other emissions.
2. Storage Issues.

Hydrogen & it's Compounds

Hydrogen has electronic configuration $1s^1$.

On one hand, its electronic configuration is similar to the outer electronic configuration (ns^1) of alkali metals , which belongs to the first group of the periodic table.

Dihydrogen, H_2 Occurrence

Dihydrogen is the most abundant element in the universe (70% of the total mass of the universe) and is the principal element in the solar atmosphere.

Isotopes of Hydrogen

Hydrogen has three isotopes protium(P), deuterium(D) and tritium(T).

In the year 1934, an American Scientist, Harold C. Urey, got Nobel Prize for separating hydrogen isotope of mass number 2 by physical methods.

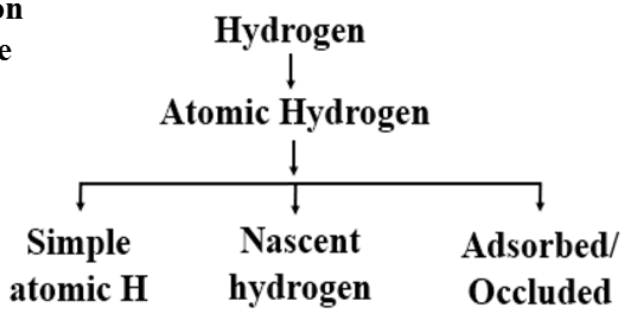
Different forms of Hydrogen

(a) Based on oxidation Number

There are three types of hydrogen

	H^+ Proton	H^- Hydride	H Atomic hydrogen
Number of electron	0	2	1
Oxidation number	+1	–1	1
Formation	$H \rightarrow H^+ + e^-$	$H + e^- \rightarrow H^-$	$H_2 \xrightarrow{\Delta} 2H$

(b) Based on reactivity



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Hydrogen

Atomic Hydrogen

(i) Simple atomic hydrogen

It is formed by simple dissociation of hydrogen.

$$H_2 \underset{}{\overset{3000\text{-}5000}{\rightleftharpoons}} 2H$$

Favourable condition – Favourable condition are high temp & low pressure.

(ii) Nascent hydrogen

Hydrogen at the moment of its birth is called Nascent hydrogen means which forms at the instant is known as Nascent hydrogen.

It is formed only by some specific chemical reaction.

(a) Acid + Metals

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + 2H$$

(b) Base + element

$$2NaOH + Be \longrightarrow Na_2BeO_2 + 2H$$

(c) C_2H_5OH + Alkali metal

$$2C_2H_5OH + 2Na \longrightarrow 2C_2H_5ONa + 2H$$

(iii) Adsorbed/Occluded hydrogen

Concentration of H is more

Adsorbed H is hydrogen present at the outer surface of metal.

Occlusion

The property of metal to adsorb any gas is called Occlusion.

(i) Reactivity order

Atomic hydrogen > Nascent hydrogen > Molecular hydrogen

Laboratory Preparation of Dihydrogen

(i) It is usually prepared by the reaction of granulated zinc with dilute hydrochloric acid.

$$Zn + 2H^+ \longrightarrow Zn^{2+} + H_2$$

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

$$Zn + 2NaOH \longrightarrow \underset{\text{Sodium zincate}}{Na_2ZnO_2} + H_2$$

Commercial Production of Dihydrogen

(i) Electrolysis of acidified water using platinum electrodes gives hydrogen.

$$2H_2O\,(\ell) \xrightarrow[\text{Trances of acid / base}]{\text{Electrolysis}} 2H_2(g) + O_2(g)$$

$$2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$$

at cathode

$$2H_2O(\ell) + 2e^- \longrightarrow H_2(g) + 2OH^-(aq)$$

The overall reaction is

$$2Na^+(aq) + 2Cl^-(aq) + 2H_2O(\ell) \longrightarrow Cl_2(g) + H_2(g) + 2Na^+(aq) + 2OH^-(aq)$$

(iv) Reaction of steam on hydrocarbons or coke at high temperatures in the presence of catalyst

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

The mixture of CO and H_2 is called water gas. As this mixture of CO and H_2 is used for the synthesis of methanol and a number of hydrocarbons, it is also called synthesis gas or 'syngas'.

Nowadays 'syngas' is produced from sewage, saw-dust, scrap wood, newspapers etc. The process of producing 'syngas' from coal is called 'coal gasification'.

$$C(s) + H_2O(g) \xrightarrow{1270\ K} CO(g) + H_2(g)$$

$$CO(g) + H_2O(g) \xrightarrow[\text{Catalyst}]{673\ K} \underset{H_2(g)}{CO_2(g) +}$$

This is called water-gas shift reaction /Bosch process. Carbon dioxide is removed by scrubbing with sodium arsenite solution.

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Hydrogen

Hydrides

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

The hydrides are classified into three categories

(i) Ionic or saline or saltlike hydrides

(ii) Covalent or molecular hydrides

(iii) Metallic or non-stoichiometric hydrides

Ionic or Saline Hydrides

These are stoichiometric compounds of dihydrogen formed with most of the s-block elements which are highly electropositive in character.

Saline hydrides react violently with water producing dihydrogen gas.

$NaH(s) + H_2O(aq) \longrightarrow NaOH(aq) + H_2(g)$

Lithium hydride is rather unreactive at moderate temperatures with O_2 or Cl_2. It is, therefore, used in the synthesis of other useful hydrides.

Covalent or Molecular Hydride

Dihydrogen forms molecular compounds with most of the p-block elements.

Metallic or Non-Stoichiometric (or Interstitial) Hydrides

These are formed by many d-block and f-block elements. However, the metals of group 7, 8 and 9 do not form hydride.

Even from group 6, only chromium forms CrH. These hydrides conduct heat and electricity though not as efficiently as their parent metals do.

Water

A major part of all living organisms is made up of water. Human body has about 65% and some plants have as much as 95% water. It is a crucial compound for the survival of all life forms.

Physical Properties of Water

It is a colourless and tasteless liquid.

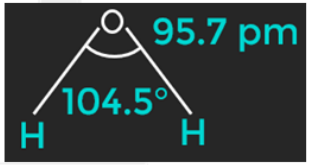
This leads to high freezing point, high boiling point, high heat of vaporisation and high heat of fusion in comparison to H_2S and H_2Se.

In comparison to other liquids, water has a higher specific heat, thermal conductivity, surface tension, dipole moment and dielectric constant, etc. These properties allow water to play a key role in the biosphere.

Due to hydrogen bonding with polar molecules, even covalent compounds like alcohol and carbohydrates dissolve in water.

Structure of Water

In the gas phase water is a bent molecule with a bond angle of 104.5° and O–H bond length of 95.7 pm .



The bent structure of water

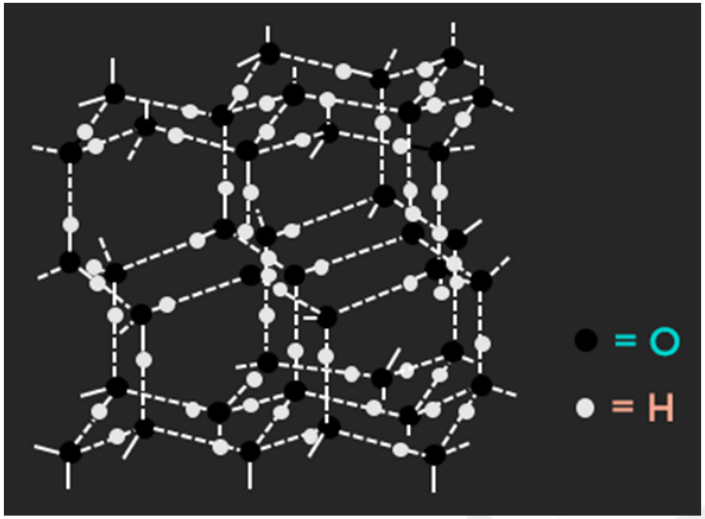
Structure of Ice

Ice has a highly ordered three dimensional hydrogen bonded structure .

Examination of ice crystals with X-rays shows that each oxygen atom is surrounded tetrahedrally by four other oxygen atoms at a distance of 276 pm.

MIND MAP

Hydrogen



The Structure of Ice

Chemical Properties of Water

Water reacts with a large number of substances. Some of the important reactions are as follow

$H_2O(\ell) + NH_3(aq) \longrightarrow OH^-(aq) + NH_4^+(aq)$

$H_2O(\ell) + H_2S(aq) \longrightarrow H_3O^+(aq) + HS^-(aq)$

The auto-protolysis (self-ionization) of water takes place as follows

$$\underset{\text{acid-1}}{H_2O(\ell)} + \underset{\text{base-2}}{H_2O(\ell)} \longrightarrow \underset{\text{acid-2}}{H_3O^+(aq)} + \underset{\text{base-1}}{OH^-(aq)}$$

(acid) (base) (conjugate acid) (conjugate base)

Redox Reactions Involving Water

Water can be easily reduced to dihydrogen by highly electropositive metals.

$2H_2O(\ell) + 2Na(s) \longrightarrow 2NaOH(aq) + H_2(g)$

$P_4O_{10}(s) + 6H_2O(\ell) \longrightarrow 4H_3PO_4(aq)$

$SiCl_4(\ell) + 2H_2O(\ell) \longrightarrow SiO_2(s) + 4HCl(aq)$

$N^{3-}(s) + 3H_2O(\ell) \longrightarrow NH_3(g) + 3OH^-(aq)$

Hard and Soft Water

Rain water is almost pure (may contain some dissolved gases from the atmosphere). Being a good solvent, when it flows on the surface of the earth, it dissolves many salts.

It is, therefore, unsuitable for laundry. It is harmful for boilers as well, because of deposition of salts in the form of scale. This reduces the efficiency of the boiler.

The hardness of water is of two types

(i) temporary hardness

(ii) permanent hardness

Temporary Hardness

Temporary hardness is due to the presence of magnesium and calcium hydrogen carbonates. It can be removed by following methods

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

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

(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 off.

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

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

Permanent Hardness

It is due to the presence of soluble salts of magnesium and calcium in the form of chlorides and sulphates in water. Permanent hardness is not removed by boiling. It can be removed by the following methods. By Washing soda

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

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

Permanent Hardness

(i) Calgon's method

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

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

(M = Mg,Ca)

The complex anion keeps the Mg^{2+} and Ca^{2+} ions in solution.

(ii) Ion-exchange method (By Zeolite)

This method is also called zeolite / permutit process.

$[Na_2Al_2Si_2O_8.\ xH_2O]$

$[Na_2O.Al_2O_3.2SiO_2.xH_2O]$

$$2NaZ(s) + M^{2+}(aq) \longrightarrow MZ_2(s) + 2Na^+(aq)$$

Reaction at cation exchanger

$$Ca^{2+} + 2RH \longrightarrow R_2Ca + 2H^+$$

$$Mg^{2+} + 2RH \longrightarrow R_2Mg + 2H^+$$

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Hydrogen

Reaction at Anion exchanger

$$ROH + Cl^- \longrightarrow RCl + OH^-$$

$$2ROH + SO_4^{2-} \longrightarrow R_2SO_4 + 2OH^-$$

Hydrogen Peroxide (H_2O_2)

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

Preparation

It can be prepared by the following methods.

(i) $Na_2O_2 + 2H_2O$ (ice cold water) $\longrightarrow$ $2NaOH + H_2O_2$

(ii) Acidifying barium peroxide and removing excess water by evaporation under reduced pressure gives hydrogen peroxide.

$$BaO_2.8H_2O(s) + H_2SO_4(aq) \longrightarrow BaSO_4(s) + H_2O_2(aq) + 8H_2O(\ell)$$

Instead of H_2SO_4, H_3PO_4 is added now-a-days because H_2SO_4 catalyses the decomposition of H_2O_2 whereas H_3PO_4 favours to restore it.

$$3BaO_2 + 2H_3PO_4 \longrightarrow Ba_3(PO_4)_2 + 3H_2O_2$$

$$Ba_3(PO_4)_2 + 3H_2SO_4 \longrightarrow 3BaSO_4 + 2H_3PO_4$$

(reused again)

(iii) Peroxodisulphate, obtained by electrolytic oxidation of acidified sulphate solutions at high current density, on hydrolysis yields hydrogen peroxide.

$$2H_2SO_4 \rightleftharpoons 2H^+ + 2HSO_4^-$$

$$2H_2SO_4^- \longrightarrow H_2S_2O_8 + 2H^+ + 2e$$

[At anode]

Physical Properties of Hydrogen Peroxide

Melting point/K	272.4	Density (liquid at 298K)/g cm^{-3}	1.44
Boiling point (exrapolated)/K	423	Viscosity (290 K)/centipoise	1.25
Vapour pressure (298K) mmHg	1.9	Dielectric constant (298K)/C^2/ N m^2	70.7
Density (solid at 268.5K)/g cm	1.64	Electrical conductivity (298K)/ W $^{-1}$ cm $^{-1}$	5.1 × 10^{-8}

Chemical Properties

It acts as an oxidising as well as reducing agent in both acidic and basic medium. Simple reactions are as follow

(i) Oxidising action in acidic medium

(a) $2Fe^{2+}(aq) + 2H^+(aq) + H_2O_2(aq) \longrightarrow 2Fe^{3+}(aq) + 2H_2O(\ell)$

(b) $PbS(s) + 4H_2O_2(aq) \longrightarrow PbSO_4(s) + 4H_2O(\ell)$

(ii) Reducing action in acidic medium

(a) $2MnO_4^- + 6H^+ + 5H_2O_2 \longrightarrow 2Mn^{2+} + 8H_2O + 5O_2$

(b) $HOCl + H_2O_2 \longrightarrow H_3O^+ + Cl^- + O_2$

MIND MAP

Hydrogen

(c) $CrO_4^{2-} + 2H^+ + 2H_2O_2 \longrightarrow CrO_5$ (Blue) $+ 3H_2O$

(d) $4CrO_5 + 12H^+ \longrightarrow 4Cr^{+3} + 7O_2 + 6H_2O$

Storage

H_2O_2 decomposes slowly on exposure to light.

$2H_2O_2(\ell) \longrightarrow 2H_2O(\ell) + O_2(g)$

In the presence of metal surfaces or traces of alkali (present in glass containers), the above reaction is catalysed.

Uses

Its wide scale use has led to tremendous increase in the industrial production of H_2O_2.Some of the uses are

(i) In daily life it is used as a hair bleach and as a mild disinfectant. As an antiseptic it is sold in the market as perhydrol.

(ii) As a rocket propellant

$NH_2.NH_2 + 2H_2O_2 \longrightarrow N_2 + 4H_2O$

[highly exothermic and large increase in volume]

Heavy Water, D_2O

It can be prepared by exhaustive electrolysis of water or as a by-product in some fertilizer industries.

Physical properties

(a) Heavy water is a colourless, odourless and tasteless liquid.

(b) Nearly all the physical constants are higher than the corresponding values of ordinary water.

Uses : It is extensively used as a moderator & coolant in nuclear reactors and in exchange reactions for the study of reaction mechanisms. As a neutron moderator Fission in uranium-235 is brought by slow speed neutrons.

It is for the first time in the history of India that a pilot project using dihydrogen as fuel was launched in October 2005 for running automobiles. Initially 5% dihydrogen has been mixed in CNG for use in four-wheeler vehicles.

It is expected that economically viable and safe sources of dihydrogen will be identified in the years to come, for its usage as a common source of energy.