HYDROGEN & ITS COMPOUNDS

Preface

The study of ‘Hydrogen & Its compounds is necessary concerning the aspect of chemistry. Hydrogen is produced is much more reactions of chemistry.

After successful completion of the topic you will be able to know about Position of hydrogen, methods of preparation & physical properties, Chemical reactions of hydrogen, Different forms of H_2 Isotopes of hydrogen, hydrides & its compounds, Properties of water, heavy water.

This book consists of theoritical & practical explanations of all the concepts involved in the chapter. Each article followed by a ladder of illustration. At the end of the theory part, there are miscellaneous solved examples which involve the application of multiple concepts of this chapter.

Students are advised to go through all these solved examples in order to develope better understanding of the chapter and to have better grasping level in the class.

Total number of Questions in **Hydrogen & It’s compounds** are :

In Chapter Examples 05

Solved Examples 05

Total no. of questions 10

HYDROGEN & ITS COMPOUNDS

1. HYDROGEN

1.1 Position of hydrogen in periodic table

It resembles with alkali metals as well as with halogens. So it show both type of character.

1.2 Preparation of di hydrogen (H_2)

(A) Lab method :

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

(B) By the Action of hydrolith on water :

$$CaH_2 + 2H_2O \xrightarrow{Fe_2O_3 \, or \, Cr_2O_3} Ca(OH)_2 + 2H_2.$$

(C) By electrolysis of water :

Water containing sulphuric acid - Ions are H^+, OH^- & SO_4^{-2}. On passing electricity H^+ ions move towards cathode while OH^- & SO_4^{-2} ions move towards anode.

At cathode $2H^+ + 2e^- \rightarrow 2H \rightarrow H_2$

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

$4OH \rightarrow 2H_2O + O_2$

Imp.- SO_4^{-2} ions are not discharged on anode as their discharge potential is higher than that of OH^- ions.

(D) Hydrogen from acids -

(i) $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

(ii) $Mg + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2$

(E) Hydrogen from alkalies - (Zn, Al, Sn, Pb, Si)

$Zn + 2NaOH \rightarrow \underset{\text{Sod. Zincate.}}{Na_2ZnO_2} + H_2\uparrow$

$2Al + 2NaOH + 2H_2O \rightarrow \underset{\text{Sod. meta aluminate.}}{2NaAlO_2} + 3H_2$

(F) From natural gas -

$$CH_4 + H_2O \xrightarrow{Ni \, or \, Cr} CO + 3H_2.$$

(G) Lane's Process -

$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2.$

(H) Bosch process - Reacting CO with steam in presence of iron chromate as catalyst

$CO_{(g)} + H_2O_{(g)} \rightarrow CO_{2(g)} + H_{2(g)}$

1.3 Physical Properties

(i) It's critical temperature is very low (–236.9°C) so difficult to liquefy.

(ii) It is adsorbed by certain metals like Fe, Au, Pt & Pd. Palladium in the powdered state can occlude nearly 1000 times its own volume of hydrogen. This property is used for the purification of hydrogen because only pure hydrogen is adsorbed by these metals and is given out when they are heated in vaccum.

Adsorption - It is a process of soaking up only on the surface while absorption is a process of soaking up through the entire mass.

1.4 Chemical Reactions

(i) Reaction with metals -

(a) $2Na + H_2 \rightarrow NaH$

(b) $Ca + H_2 \rightarrow CaH_2$

(c) $Be + H_2 \rightarrow$ No reaction

(ii) Reaction with non metals - F combine with H_2 readily even of low temperature & in dark. While the combustion with chlorine takes place in presence of sunlight. Similarly with bromine combines on heating while iodine combines when heated in presence of a catalyst.

$H_2 + X_2 \rightarrow 2HX$

(iii) Reducing nature -

(a) $CuO + H_2 \rightarrow Cu + H_2O$

(b) $Fe_3O_4 + 4H_2 \rightarrow 3Fe + 4H_2O$

(c) $\underset{\text{(Oil)}}{\text{Unsaturated fat}} + H_2 \xrightarrow{Ni} \underset{\text{(Vanaspati Ghee)}}{\text{Saturated fat}}$

(iv) Synthetic petrol - Petrol substitute are obtained by subjecting a paste of powdered coal in crude oil to the action of hydrogen under pressure and in presence of catalyst.

(v) Oxyhydrogen flame - It produces a temperature of 2800°C while oxy - atomic hydrogen flame produced a temperature of 4000°C. The heat generated is used for melting substances having very high melting points. Such as Quartz, Pt etc. & also for welding.

1.5 Different forms of H_2

(i) NASCENT HYDROGEN - (Newly Born)

(a) Preparation - $Zn + H_2SO_4 \rightarrow ZnSO_4 + 2H$

(b) Property - This hydrogen is more reactive & powerful reducing agent than ordinary hydrogen.

(A) It decolourises yellow colour of $FeCl_3$ (aq.)

$$(H) + \underset{\text{(yellow)}}{FeCl_3} \rightarrow \underset{\text{Colourless}}{FeCl_2 + HCl}$$

(B) Decolourise violet colour of $KMnO_4$.

(C) Turns $K_2Cr_2O_7$ (orange) solution to green.

$$\underset{\text{(orange)}}{K_2Cr_2O_7} + 4H_2SO_4 + 6H \rightarrow K_2SO_4 + \underset{\text{(green)}}{Cr_2(SO_4)_3} + 7H_2O$$

(ii) ADSORBED HYDROGEN- Hydrogen on bubbling at the surface of Pt black, get adsorbed there and becomes capable of bringing out many chemical changes such as reduction and hydrogenation. This type of hydrogen is named as adsorbed hydrogen. While hydrogen occluded on Pd is very strong reducing agent and combines with halogens in dark. Occlusion decreases with rise in temperature.

(iii) ATOMIC HYDROGEN -

(a) Atomic hydrogen is best produced by passing ordinary hydrogen through an electric arc.

$H_2 \xrightarrow[(200°C)]{\text{Electric Arc}} 2H$; $\Delta H = +104.5$ Kcal. (Endothermic)

(b) Life period of atomic hydrogen is only one third of a second.

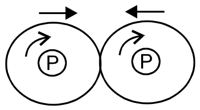
(c) This form of hydrogen is very - very reactive as it has the excited state of hydrogen atom.

(iv) ORTHO AND PARA HYDROGEN -

(a) Bonhoeffer & Hartech have shown that ordinary hydrogen is a mixture of two forms of ortho & para.

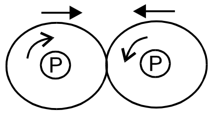
(b) A hydrogen molecule consists of two atoms. Each atom having one proton & one electron. Both electron & proton have the property to spin about their own axis.

(A) Ortho hydrogen - Spin of protons or nucleus are in same direction



ortho hydrogen

(B) Para hydrogen - Spin of proton or nucleus are in opposite direction.



(C) At room temperature about 75% of ortho & 25% para means 3 : 1. At low temperature para form increases.

(d) Difference between para & ortho form -

(i) Ortho is more stable than para.

(ii) Ortho & para hydrogen are called as nuclear spin isomers because they are different w.r.t their nuclear spins.

(iii) Conductivity of ortho is less than para.

(iv) Magnetic moment of para is zero while ortho has twice that of proton.

1.6 Hydrides

Compounds of hydrogen with less electronegative elements are called hydrides.

(a) Ionic hydrides or saline hydrides - These are formed by combination of hydrogen with IA & II A (Highly reactive metals)

eg. LiH, NaH, KH, MgH_2, CaH_2 etc.

CaH_2 → Hydrolith → Rich source of hydrogen

(b) Covalent hydrides -

Compounds of hydrogen with less electronegative non metals like B & Si.

eg. SiH_4, B_2H_6

(c) Interstitial hydrides -

Hydrogen + Transition metal

Hydrogen is held by vander waal force. These hydrides are non stoichiometric

Ti : H_2

1 : 1.67

1.7 Isotopes of hydrogen

Protium	Deuterium	Tritium
(a) $_1H^1$ or H	$_1H^2$ or D	$_1H^3$ or T
(b) p = 1, e = 1, n = 0	p =1, e =1, n = 1	p = 1, e = 1 n = 2
(c) Abudance - 99%	.01%	10^{-15} %
(d) Ordinary hydrogen	Heavy hydrogen	Radioactive used as tracer to study r × n mechanism

Examples based on

Hydrogen

Ex.1 Deuterium, an isotope of hydrogen is-

(A) Radioactive (B) Nonradioactive

(C) Heaviest (D) Lightest

Ans. [B]

Sol. For, $_1D^2$, the $\frac{n}{p} = \frac{1}{1} = 1$. Hence it is a stable nucleus.

Ex.2 The difference between ortho & para hydrogen is-

(A) Ortho is more stable than para

(B) Conductivity of ortho is more than para

(C) Magnetic moment of ortho is zero

(D) All of these

Ans. [A]

Sol. At room temp. ratio of o-H_2 & p-H_2 is 3 : 1.

2. HYDROGEN PEROXIDE (H_2O_2)

2.1 Methods of preparation of Hydrogen peroxide (H_2O_2)

Discovered by **L.J.Thenard**

(a) Lab method of preparation of H_2O_2 - H_2O_2 obtained by passing a current of CO_2 through a cold pasty solution of BaO_2 in water.

$BaO_2 + CO_2 + H_2O \rightarrow H_2O_2 + BaCO_3$

(b) Treating Na_2O_2 with H_2SO_4 -

(A) $Na_2O_2 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O_2$

(B) Also by small amount of Na_2O_2 added to ice cold water.

$$Na_2O_2 + 2H_2O \rightarrow 2NaOH + H_2O_2$$

(c) Industrial process - By electrolysis of 50% H_2SO_4 at 0°C using Pt electrod.

$$2H_2SO_4 \rightarrow 2H^+ \quad + 2HSO_4^-$$

At cathode (Cu) - $2H^+ + 2e^- \rightarrow H_2$

At anode (Pt) - $2HSO_4^- \rightarrow H_2S_2O_8 + 2e^-$

$$H_2S_2O_8 + 2H_2O \rightarrow H_2O_2 + 2H_2SO_4$$

(d) Electrolysis of ammonium hydrogen sulphate : In the electrolysis of ammonium hydrogen sulphate, ammonium per sulphate is formed. It is separated and distilled with dil. H_2SO_4 to give 30 - 40% H_2O_2 (aqueous solution)

$$NH_4HSO_4 \Leftrightarrow NH_4SO_4^- + H^+$$

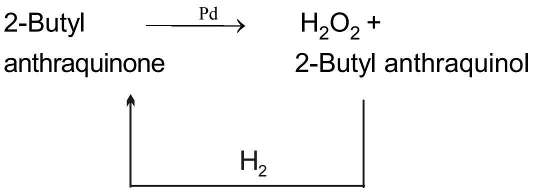
At cathode : $2H^+ + 2e^- \rightarrow H_2$(reduction)

At anode : $2NH_4SO_4^- \rightarrow (NH_4)_2S_2O_8 + 2e^-$ (oxidation)

Distillation :

$$(NH_4)S_2O_8 + 2H_2O \xrightarrow{H_2SO_4} 2NH_4HSO_4 + H_2O_2$$

(e) Auto - oxidation of 2-butyl anthraquinol : This is the most modern method and needs H_2, atmospheric oxygen and water as the major raw material.



First and foremost 2-butyl anthraquinone is catalytically reduced to 2-butyl anthraquinol in organic solvent by H_2 and Pd (catalyst).

Secondly , 2-butyl anthraquinol is oxidised by air to 2-butyl anthraquinone. H_2O_2 obtained in the process is extracted with water to give 20% H_2O_2 solution.

2-butyl anthraquinone is thus reused. The process is repeated , thus it is a cyclic process.

2.2 Physical Properties of H_2O_2

(a) Pure H_2O_2 is weak acidic in nature and exist as associated liquid due to hydrogen bonding.

(b) Smell of H_2O_2 resembles like nitric acid.

(c) It causes blisters on skin.

(d) Stored in plastic containers after addition of stabilizers.

(e) A dilute solution of H_2O_2 is concentrated by vaccum distillation or by distillation under pressure.

2.3 Chemical Reaction

(a) Decomposition : $2H_2O_2 \rightarrow 2H_2O + O_2$

Pt, Au, Ag accelerates its decomposition while acetanilide, alcohol acts as negative catalyst to retard the decomposition of H_2O_2.

(b) H_2O_2 acts as oxidising and reducing agent in acidic as well as alkaline medium :

(i) Oxidising action

(1) Black lead sulphide to white lead sulphide

$$\underset{\text{(Black)}}{Pbs + 4H_2O_2} \rightarrow \underset{\text{(White)}}{PbSO_4} + 4H_2O$$

(2) Acidified potassium dichromate is oxidised to blue peroxide of chromium, confirmatory test of H_2O_2.

$$K_2Cr_2O_7 + H_2SO_4 + 4H_2O_2 \rightarrow 2CrO_5 + K_2SO_4 + 5H_2O$$

(Blue colour)

(3) Bleaching action -

Coloured material + (O) → Colourless

It bleaches materials like silk, hair, cot ton, wool etc.

(ii) Reducing Action -

(1) It reduces Ag_2O to silver -

$$Ag_2O + H_2O_2 \rightarrow 2Ag + H_2O + O_2$$

(2) Acidified $KMnO_4$ is decolourised by H_2O_2

$$2KMnO_4 + 3H_2SO_4 + 5H_2O_2 \rightarrow K_2SO_4 + 2MnSO_4 + 8H_2O + 5O_2$$

(3) It reduces pot. ferricyanide to pot. ferrocyanide

$$2K_3[Fe(CN)_6] + 2KOH + H_2O_2 \rightarrow 2K_4[Fe(CN)_6] + 2H_2O + O_2$$

2.4 Uses of Hydrogen peroxide

(1) As germicide and antiseptic due to its oxidising property.

(2) As fuel for rocket

(3) In refreshing old oil paintings due to formation of black PbS. H_2O_2 converts it into white $PbSO_4$.

$$\underset{\text{(White)}}{PbO} + H_2S \rightarrow \underset{\text{(Black)}}{PbS} + H_2O$$

$$PbS + 4H_2O_2 \rightarrow \underset{\text{(White)}}{PbSO_4} + 4H_2O$$

2.5 Test for H_2O_2

(1) An acidified solution of titanium salt when treated with H_2O_2, a yellow or orange colour is developed due to formation of pertitanic acid.

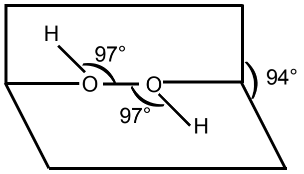
$Ti(SO_4)_2 + H_2O_2 + 2H_2O \rightarrow H_2TiO_4 + 2H_2SO_4$

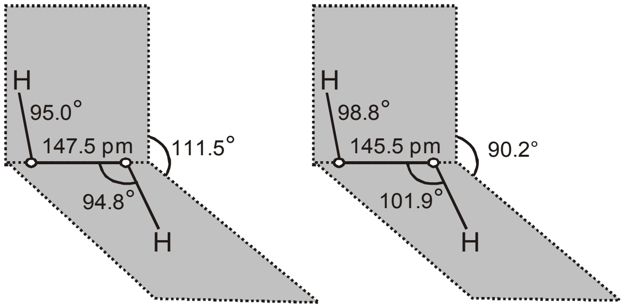
(2) It liberates iodine from KI solution which give blue colour with starch solution

(3) H_2O_2 on shaking with acidified $K_2Cr_2O_7$ with little ether, blue colour is produced.

2.6 Structure of H_2O_2

All four atoms in H_2O_2 are non planar. Structure of H_2O_2 has open book structure having two leaves at 90°, the H-atoms are placed one on each core. The H - O making an angle of 101.5° with O - O bond.





(a) Gas phase (b) Solid phase

Examples based on

Hydrogen Peroxide

Ex.3 Structure of H_2O_2 is -

(A) asymmetrical
(B) Symmetrical
(C) planar
(D) Straight chain

Ans. [A]

Sol. H_2O_2 has a open book like Structure.

Ex.4 H_2O_2 can be prepared by -

(A) Oxidation of 2-Ethylanthraquinol
(B) Passing CO_2 in paste of BaO_2 in water
(C) Electrolysis of H_2SO_4
(D) Any of these

Ans. [D]

Sol. All methods are suitable for preparation of H_2O_2

3 SOFT AND HARD WATER

(i) water which gives foams easily with soap is known as soft water. The other which gives with difficulty is known as hard water.

(ii) The hardness of water is due to the dissolved Ca, Mg salt of bicarbonate, chloride, sulphate etc.

(iii) Normal soaps are sodium salt of fatty acid (RCOONa). On dissolving in hard water soap reacts with soluble impurities to give insoluble fatty acid salt of Ca & Mg. Therefore foaming properties of soap are developed only when soluble impurities in hard water are completely removed. Thus hard water consumes more soap.

$RCOONa + CaCl_2 \rightarrow (RCOO)_2Ca + 2NaCl$

(iv) Hardness of water is of two types -

(A) Temporary hardness -

(i) Due to soluble bicarbonates of Ca and Mg

(ii) It can be removed by boiling or adding calculated quantity of slaked lime.

$Ca(HCO_3)_2 \xrightarrow{\Delta} CaCO_3 + H_2O + CO_2$

Clark's method -

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

(B) Permanent hardness

(i) Due to soluble sulphates, chlorides, nitrates of Ca and Mg.

(ii) It can be removed by

(a) By Permutit Process -

Permutit is sodium alumino silicate ($Na_2Al_2SiO_3$. x H_2O) or sodium zeolite (Na_2Z) where Z is Al_2 SiO_3. xH_2O. It is insoluble in water & has the property to exchange basic radical which helps in softening water.

$Na_2Z + CaSO_4 \rightarrow CaZ + Na_2SO_4$

(b) By washing soda (Na_2CO_3) -

$MgCl_2 + Na_2CO_3 \rightarrow MgCO_3 + 2NaCl$

$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$

It place of sodium carbonate, caustic soda or sodium phosphate can also be used.

$MgCl_2 + 2NaOH \rightarrow \underset{\text{Insoluble}}{Mg(OH)_2} + 2NaCl$

$3MgSO_4 + 2Na_3PO_4 \rightarrow$

$Mg_3(PO_4)_2 + 3Na_2SO_4$

(c) Calgon's method : Sodium hexametaphosphate ($Na_6P_6O_{18}$), commercially called 'calgon', when added to hard water, the following reactions take place.

$N_6P_6O_{18} \rightarrow 2Na^+ + Na_4P_6O_{18}^{2-}$ (M = Mg, Ca)

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

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

(d) Synthetic resins method : Nowadays hard water is softened by using synthetic cation exchangers. This method is more efficient than zeolite process. Cation exchange resins contain large organic molecule with - SO_3H group and are water insoluble, Ion exchange resin (RSO_3H) is changed to RNa by treating it with NaCl. The resin exchanges Na^+ ions with Ca^{2+} and Mg^{2+} ions present in hard water to make $2RNa(s) + M^{2+}(aq) \rightarrow R_2M(s) + 2Na^+(aq)$

The resin can be regenerated by adding aqueous NaCl solution. Pure de-mineralised (de-ionized) water free from all soluble mineral salts is obtained by passing water successively through a cation exchange (in the H^+ form) and an anion exchange (in the OH^-) resins :

$$2RH\ (s) + M^{2+}\ (aq) \rightleftharpoons MR_2\ (s) + 2H^+\ aq).$$

In this cation exchange process, H^+ exchange for Na^+, Ca^{2+}, Mg^{2+} and other cations present in water. This process results in proton release and thus makes the water acidic. In the anion exchange process :

$$RNH_2\ (s) + H_2O\ (l) \rightleftharpoons RNH_3^+.OH^-(s)$$

$$RNH_3^+.OH^-(s) + X^-(aq) \rightleftharpoons RNH_3^+.X^-(s) + + OH^-(aq)$$

OH^- exchange for anions like Cl^-, HCO_3^-, SO_4^{2-} etc. present in water. OH^- ions, thus, liberated neutralize the H^+ ions set free in the cation exchange.

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

The exhausted cation and anion exchange resin beds are regenerated by treatment with dilute acid and alkali solution respectively.

Examples based on Hardness of Water

Ex.5 Calgon, a water softer is -

(A) Sodium aluminosilicate
(B) Sodium hexametaphosphate
(C) Sodium zeolite
(D) Sodium bicarbonate

Ans. [B]

Sol. Calgon removes Ca and Mg ions from hard water by forming a soluble complex.

$$\underset{\text{hard water}}{2Ca^{++}} + \underset{\text{Calgon}}{Na_2[Na_4(PO_3)_6]} \rightarrow \underset{\text{Soluble complex}}{Na_2[Ca_2(PO_3)_6]} + 2Na^+$$

SOLVED EXAMPLES

Q.1 Which can adsorb largest volumes of hydrogen gas -

(A) Colloidal solution of palladium

(B) Finely divided nickel

(C) Colloidal ferric hydroxide

(D) Finely divided platinum

Sol. **[A]**

Acc. to amount to hydrogen occluded metal in decreasing order are -

Colloidal Pd > Pd > Pt > Au > Ni

Q.2 Ionic hydrides react with water to give -

(A) Acidic solutions (B) Basic solutions

(C) Hydride ion (D) Protons

Sol. **[B]**

S block elements form ionic hydrides which form basic hydroxide with water. Ex - NaOH

Q.3 H_2O_2 reduces $K_3[Fe(CN)_6]$ in -

(A) Neutral solution

(B) Acidic solution

(C) Alkaline solution

(D) Non-polar medium

Sol. **[C]**

$$2\,K_3[Fe(CN)_6] + 2\,KOH + H_2O_2 \rightarrow 2K_4[Fe(CN)_6] + 2H_2O + O_2$$

Q.4 The exhausted permutit is is generally regenerated by percolating through it a solution of -

(A) Sodium chloride

(B) Calcium chloride

(C) Magnesium chloride

(D) Potassium chloride

Sol. **[A]**

$CaZ + 2NaCl \rightarrow Na_2Z + CaCl_2$

Q.5 Permanent hardness of water can be removed by adding calgon $(NaPO_3)_n$.This is an example of -

(A) Adsorption (B) Exchange iof ion

(C) precipitation (D) None of these

Sol. **[B]**

$(NaPO_3)$n is used in calgon process, it form soluble complex with Ca^{2+} and Mg^{2+} ions.