Hydrogen

Element	Hydrogen
Electronic Configuration	$1s^1$
Atomic Number	1
Electronegativity	2.1

Position of hydrogen in the periodic table :

Position for hydrogen is not fixed in the periodic table due to following reasons :

(1) Hydrogen resembles group 1 elements. (Alkali metals).

(2) Hydrogen resembles group 17 elements. (Halogens).

(3) Hydrogen exhibits other properties which different from both alkali metals and halogens.

Types of hydrogen :

(1) Atomic Hydrogen :

$$H-H \xrightarrow[200°C]{\text{Electric spark}} 2H \text{ (Atomic hydrogen)}$$

, $\Delta H = +104.5$ Kcal.

- When hydrogen gas is passed through an electric arc between two tungsten filaments, hydrogen s dissociated into atoms.
- Used for welding purpose.

(2) Nascent Hydrogen : When hydrogen is passed through acidified potassium permanganate solution or $FeCl_3$ solution neither of them is reduced however when Zn pieces are added both gets reduced.

$$Zn + H_2SO_4 \text{ (dil.)} \rightarrow ZnSO_4 + \underset{\text{Nascent hydrogen}}{2[H]}$$

Concept Ladder

The name hydrogen comes from Greek words “Hydro (meaning water) and genes (Meaning creator). It was named by French Chemist Antoine Lavoisier because when it burns it creates water.

Previous Year’s Question

The ionization of hydrogen atom would give rise to **[AIPMT]**

(1) Hydride ion
(2) Hydronium ion
(3) Proton
(4) Hydroxyl ion

Concept Ladder

Process of dissociation and recombination of hydrogen is utilized in oxy-hydrogen torch.

$$H_2 \xrightarrow{\text{Electric arch}} \underset{\text{(Atomic hydrogen)}}{2H}$$

$H + H \rightarrow H_2 + \text{energy}$

$KMnO_4 + H_2SO_4 + H_2 \rightarrow$ No reaction

Ordinary Hydrogen → $KMnO_4/H_2SO_4$ (Purple coloured solution) —Zn pieces→ Decolourisation occurs i.e. liberated Hydrogen Reduces Acidified $KMnO_4$

$KMnO_4/H_2SO_4$ (Purple coloured solution) → No change in colour as reduction doesn't occurs

Similarities of hydrogen with alkali metals :

(i) Electronic configuration : Alkali metals and hydrogen has only one electron in their outer shell.

(ii) Electropositive character : Like the alkali metals hydrogen has a tendency to lose its electron to form unipositive ion.

$H \longrightarrow H^+ + e^-$;

$Li \longrightarrow Li^+ + e^-$

$Na \longrightarrow Na^+ + e^-$

(iii) Oxidation state : Hydrogen, like alkali metals have +1 oxidation state.

(iv) Affinity for non-metals : H_2 as well as alkali metals (Na, K, Rb etc.) have a strong affinity towards non-metals.

Non-Metal	Hydrogen	Alkali Metal Compounds	
Chlorides	**HCl**	**NaCl**	**KCl**
Oxides	H_2O	Na_2O	K_2O
Sulphides	H_2S	Na_2S	K_2S

(v) Valency : Alkali metals as well as hydrogen show electrovalency of +1.

(vi) Reducing nature : Hydrogen-like alkali metals, acts as reducing agent.

Concept Ladder

- About 10% of the weight of living organism is hydrogen mainly in water, proteins and fats.
- H_2 is believed to be one of three elements produced in the Big Bang. The others are He and Li.

Rack your Brain

Why hydrogen is not termed as s-block element despite it is placed in Ist group?

Difference of hydrogen with alkali metals :

(i) Non-metallic character : Hydrogen is a non–metal while alkali metal are metalic.

(ii) Nature of oxide : Nature of oxide of hydrogen is neutral while oxides of alkali metals are basic in nature.

(iii) Atomicity : Hydrogen is diatomic in nature (H_2) while alkali metals are monoatomic.

(iv) Nature of compounds : Nature of compounds of hydrogen with halogens (HCl, HBr, HF, HI) are low boiling covalent compound while halides of alkali metals are low melting ionic solids (LiF, NaCl, KBr, etc.)

(v) Ionisation energy : Ionisation energy of hydrogen is very high in comparison to alkali metals.

Concept Ladder

Hydrogen shows dual nature. It behaves as electropositive element like alkali metals as it can lose the planetary electron. It also behaves as an electronegative element like halogens as it can gain one more electron to saturate 1s subshell.

Element	Hydrogen	Lithium	Sodium	Potassium
IE (kJ mol^{-1})	1312	520	495	418

Similarities of hydrogen with halogens :

(i) Electronic configuration : Electronic configuration of hydrogen resembles the halogens in having one electron less than the next inert gas in its atom.

(ii) Diatomic nature : Like-hydrogen halogens are also diatomic. (H_2, F_2, Cl_2, Br_2)

(iii) Non-metallic character : Hydrogen as well as halogens are non-metallic.

(iv) Electro-negative nature : Hydrogen as well as halogens can gain an-electron to form negative ion.

$H + e^- \longrightarrow H^-$; $Cl + e^- \longrightarrow Cl^-$

(v) Oxidation state : Hydrogen like halogens show –1 oxidation state.

Previous Year's Question

One would expect proton to have very large **[AIPMT]**

(1) Charge

(2) Ionization potential

(3) Hydrotion energy

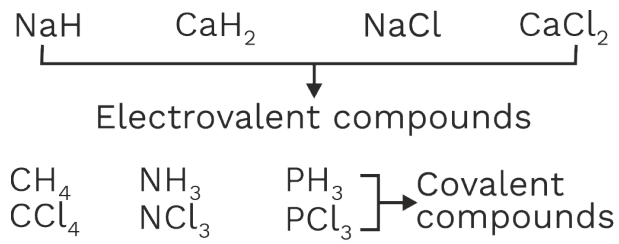
(4) Radius

Compound	NaH	NaCl	NaBr	NaI
Oxidation No.	–1	–1	–1	–1

(vi) Ionisation potential :

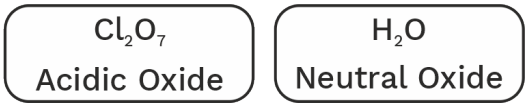
Element	H	F	Cl	Br	I
Ionization potential (eV)	13.5	17.4	13.0	11.82	10.43

(vii) Nature of compounds :



Differences with halogens :

(i) Nature of oxide :

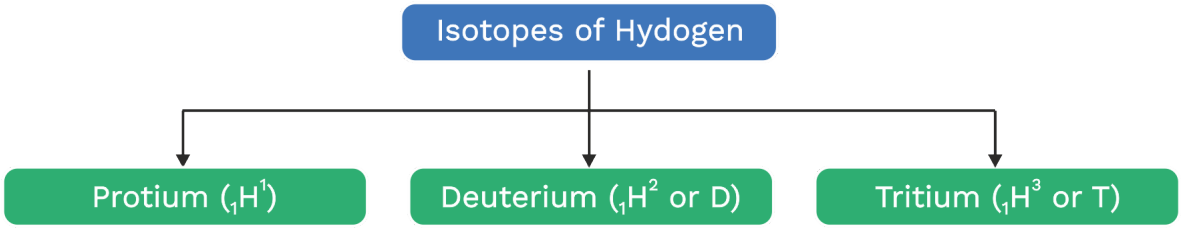


(ii) Absence of lone pair of electrons :

(iii) Less electro-negative : Hydrogen is less electro-negative than halogens.

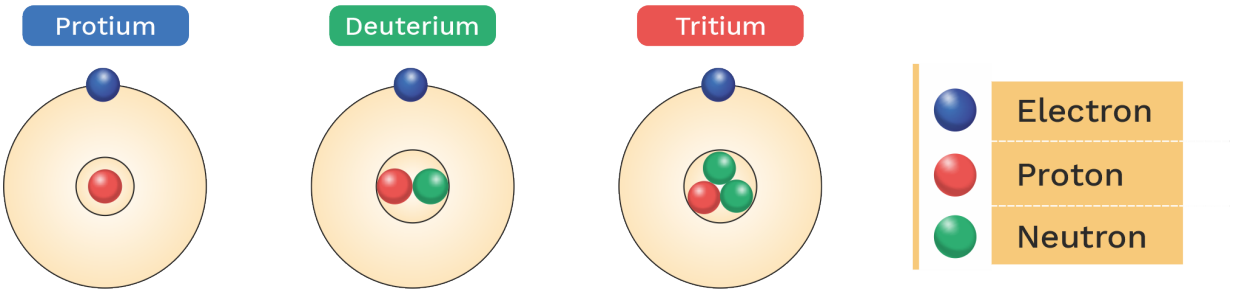
Concept Ladder

- Every hydrogen atom in our body is likely 13.5 billion years old because they were created at the birth of the universe.
- Hydrogen is about 14 times lighter than air.



Note :

	Protium	Deuterium	Tritium
	Ordinary H	Heavy H	Radioactive H
Representation	$^{1}_{1}H$	$^{2}_{1}D$	$^{3}_{1}T$
Neutrons	0	1	2
Occurrence	99.98%	0.16%	10^{-15} %



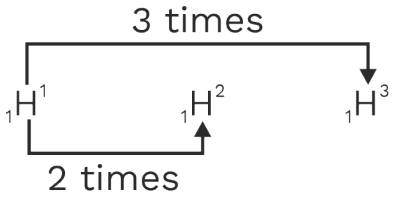
Isotopic Effect :

- In Isotopic effect minimum changes occurs in chemical properties like state of chemical reaction etc. and maximum changes occurs in physical properties like boiling point, bond energy, melting point while

Concept Ladder

The bond energy of H–H bond is least and hence it is most reactive among the isotopes of hydrogen.
Bond energy $H_2 < D_2 < T_2$

- The Isotopic effect is found only in hydrogen isotopes ($_1H^1$, $_1D^2$, $_1D^3$). Because there is large difference in mass.



While in other isotopes like $_7N^{14}$, $_7N^{15}$; only a fractional mass is increased and similarly in case of carbon ($_6C^{14}$, $_6C^{13}$, $_6C^{12}$) But in case of hydrogen mass increased by 2 to 3 times in their isotopes.

Definitions

isotopes can be defined as the variants of chemical elements that possess the same number of proton and electrons, but a different number of neutrons.
Ex. ^1_1H (Protium), ^2_1D (Deuterium), ^3_1T (Tritium)

Q.1 Isotopic effect is found in :
(1) H (2) N (3) C (4) All

A.1 (1)
Protium, Deutorium and Tritium are the Isotopes of hydrogen.

Q.2 Which of the following reaction is fast and why?
(i) $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$
(ii) $CD_4 + Cl_2 \rightarrow CD_3Cl + DCl$

A.2 (i) because C-H bond energy is less in comparison to C-D bond energy.

Q.3 Nascent hydrogen consists of :
(1) Hydrogen ions in excited state
(2) Hydrogen ions with excess energy
(3) Solvated protons
(4) Hydrogen atoms with excess energy

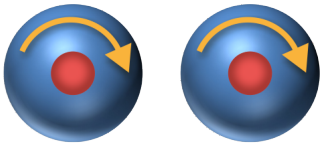
A.3 (4)
Hydrogen atom 'H' is termed nascent hydrogen when it has excess of energy.

Ortho and Para Hydrogen :

- Hydrogen molecule contains two hydrogen atoms, each atom has one proton in the nucleus with an electron. Like electron, proton is also spinning about its axis.
- If two protons in the hydrogen molecule have spins in the same direction then the form is termed as ortho hydrogen and if the protons spins are in opposite direction, the form is known as para hydrogen.

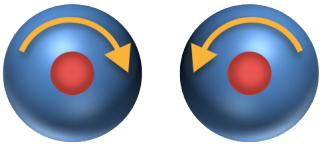
Definitions

Ortho hydrogen molecules are those in which the spins of both the nuclei are in the same direction. Molecules of hydrogen in which the spins of both the nuclei are in the opposite direction are called Para hydrogen



Ortho Hydrogen

(i) Parallel nuclear spin.
(ii) Nuclear spin = ½ + ½ = 1
(iii) More stable at room temperature.



Para Hydrogen

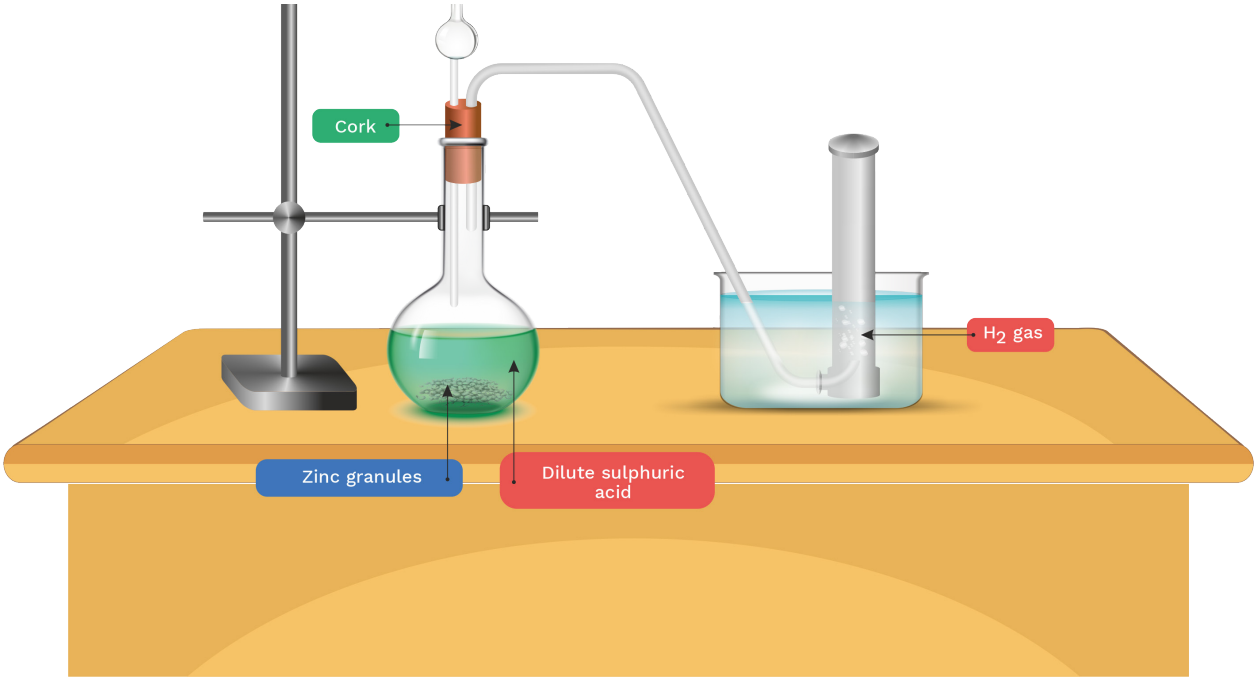
(i) Antiparallel nuclear spin
(ii) Nuclear spin = ½ – ½ = 0
(iii) More stable at low temperatı

Q.4 Ortho- and para-hydrogen differ in :
(1) Atomic number
(2) Mass number
(3) Electron spin in two atoms
(4) Nuclear spin in two atoms

A.4 (4)
Factual statement

Method of preparation of hydrogen :

Lab method :



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

(2) $Mg + 2HCl \rightarrow MgCl_2 + H_2$

(3) $Zn + 2NaOH \rightarrow Na_2ZnO_2 + H_2$
(Sodium zincate)

(4) $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$
(Sodium metaaluminate)

Industrial preparation:

(1) **Lane's process :** In Lane's process steam is passed over hot iron, also known as gassing reaction.

$$3Fe + \underset{\text{(Steam)}}{4H_2O} \xrightarrow{1027K-1073K} Fe_3O_4 + 4H_2$$

- Iron is generated by reducing magnetic oxide with water gas ($CO + H_2$). This reaction is called vivifaction.

$$Fe_3O_4 + 4CO \longrightarrow 3Fe + 4CO_2$$
$$Fe_3O_4 + 4H_2 \longrightarrow 3Fe + 4H_2O$$

Vivification Reaction

Concept Ladder

Pure zinc is not used as it is non-porous in nature so impure granulated zinc is used which becomes porous. Concentrated sulphuric acid cannot be used as it gives SO_2 and not hydrogen.
$Zn + \text{conc. } H_2SO_4 \rightarrow ZnSO_4 + SO_2 + 2H_2O$

Q.5 What is false about Lane's process ?
(1) Method is used for manufacture of dihydrogen
(2) It involves the oxidation of iron by steam
(3) It involves the reduction of $H_2O_{(g)}$ by iron
(4) It involves the oxidation of water gas

A.5 (4) Factual statement

(2) Bosch process:

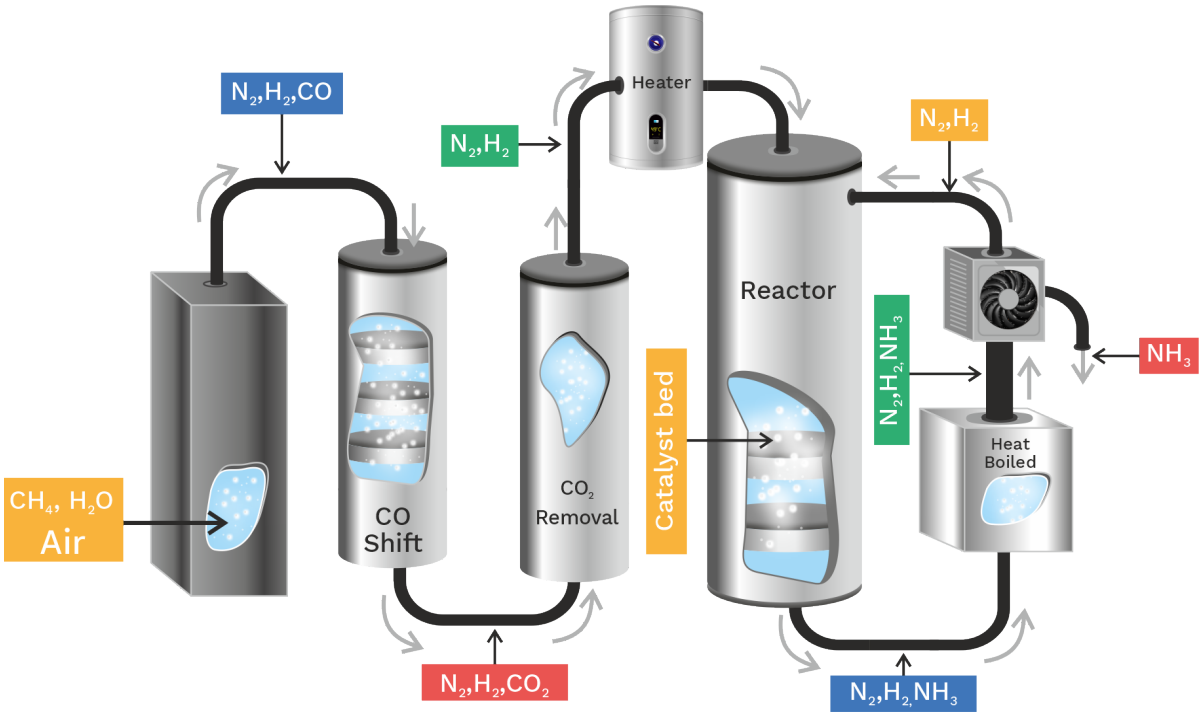
$$C + H_2O \xrightarrow{1000°C} \underbrace{CO + H_2}_{\text{Water gas}}$$

- **Water shift reaction :** Water gas is mixed with steel and passed over catalytic mixture of Fe_2O_3 and Cr_2O_3 at 450°C.

$$\underbrace{CO + H_2}_{\text{Water gas}} \xrightarrow{450°C,\ H_2O} CO_2 + 2H_2$$

Concept Ladder

- Hydrogen is the only atom for which Schrodinger explain has an exact solution
- Hydrogen reacts explosively with elements oxygen, chlorine and fluorine: O_2, Cl_2, F_2.



Coal gasification :

$$C_{(s)} + H_2O_{(g)} \xrightarrow{1270\ K} \underset{\text{(Syn- gas)}}{CO_{(g)} + H_{2(g)}}$$

Electrolysis of NaCl :

$$NaCl_{(aq)} + 2H_2O_{(l)} \longrightarrow Cl_{2(g)} + H_{2(g)} + 2Na^+_{(aq)} + 2OH^-$$

From hydrocarbons :

$$CH_{4(g)} + H_2O_{(g)} \xrightarrow{1270\ K,\ Ni} \underset{\text{(Water gas or Syn- gas)}}{CO_{(g)} + 3H_{2(g)}}$$

- Syn gas is also known as synthetic gas.

Previous Year's Question

Water gas is produced by **[AIPMT]**

(1) passing steam through a red hot coke

(2) Saturating hydrogen with moisture

(3) Mixing oxygen and hydrogen in the ratio of 1 : 2

(4) Heating a mixture of CO_2 and CH_4 in petroleum refineries.

Properties of hydrogen :

Physical properties : Hydrogen gas is colourless, odourless and tasteless.

S.No.	Property	
1	Solubility	Soluble in water
2	Density	313 kcal mol^{-1}
3	Ionisation potential	17.3 kcal mol^{-1}
4	Electronegativity	2.1
5	Bond energy, (H–H)	436 kJ mol^{-1}
6	Bond length, (H–H)	**74** Pm

Hydrides :

Types of hydrides :

(A) Ionic or saline or salt like hydrides.
(B) Covalent or molecular hydrides.
(C) Metallic or interstitial hydrides.

(A) **Ionic hydrides :** Ex : LiH, NaH, KH, RbH, CaH_2, BaH_2 etc.

- Formed by s-block elements. (Highly electropositive) except Be and Mg.
- Ionic hydrides have high melting and boiling point.
- Stability of hydrides : LiH > NaH > KH > RbH > CsH Similarly

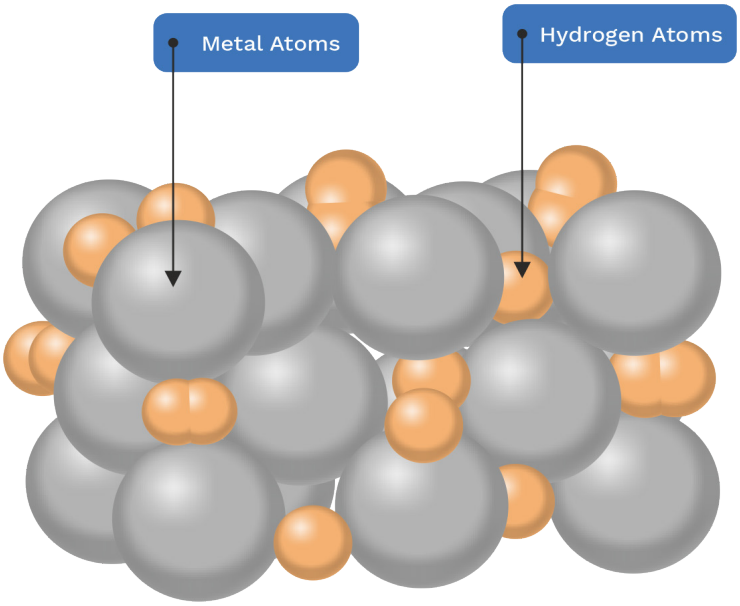
$$CaH_2 > SrH_2 > BaH_2$$

- Ionic hydrides are non-volatile and non-conducting in solid states but conduct electricity in molten state.

$$LiH_{(s)} + H_2O_{(l)} \longrightarrow H_{2(g)} + LiOH_{(aq)}$$

During electrolysis ionic hydrides liberated hydrogen gas.

$$2H^+ (melt) \xrightarrow{Anode} H_{2(g)} + 2e^-$$



Concept Ladder

During the preparation of hydrides, the metal should be hydrogenated in the presence of a surface active agent in kerosene or some form of agitation should be used to prevent the decomposition of surface film of hydride on the metal which leads to incomplete conversion

Rack your Brain

Out of methane, germane and plumbane which hydride has low thermal stability?

Q.6 When electric current is passed through an ionic hydride in molten state :
(1) Hydrogen is liberated at anode
(2) Hydrogen is liberated at cathode
(3) Hydride ion migrates towards cathode
(4) Hydride ion remains in solution

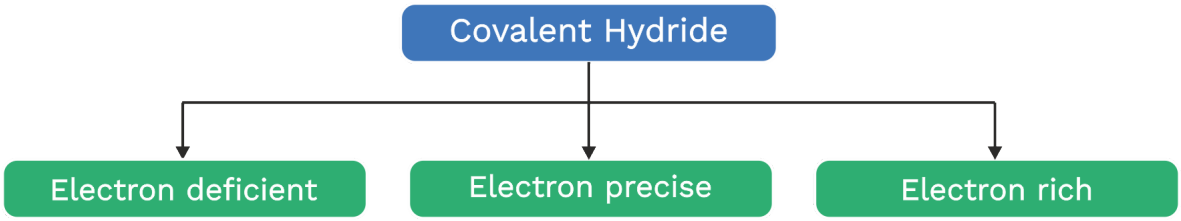
A.6 (1)
At anode : $2H^{\ominus} \rightarrow H_2 + 2e^{\ominus}$

Uses :
- Used as reducing agents.
- As a solid fuel.

Covalent hydrides :
Formed by p-block elements (Except noble gases)
Ex : NH_3, H_2O, H_2O_2, HF etc.

Concept Ladder

- BeH_2, MgH_2, LiH have covalent nature and covalent polymeric structure.
- Thermal stability of such hydrides decreases down the group.
- CaH_2 is known as hydrolith.



Electron deficient covalent hydrides :
- Elements of group 13th form electron deficient covalent hydrides.
- They acts as Lewis acids i.e. electron acceptors.
- Generally exist in polymeric form. Ex : B_2H_6, B_4H_{10}, $(AlH_3)_n$ etc.

Electron precise covalent hydrides :
- Formed by group 14th elements.
- All these hydrides are tetrahedral.

Ex : CH_4, $SiCl_4$ etc.

Previous Year's Question

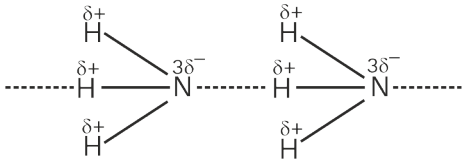
The number of hydrogen bonded water molecule(s) associated with $CuSO_4 . 5H_2O$ is **[NEET]**
(1) 3 (2) 1
(3) 2 (4) 5

Electron rich covalent hydrides :

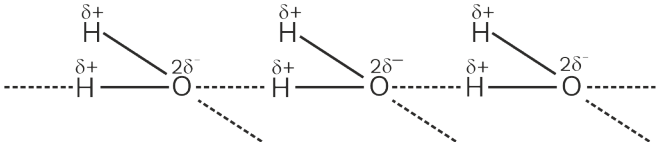
- Group 15th, 16th, 17th form electron rich covalent hydrides.
- Presence of 1, 2 and 3 lone pair of electrons with highly electronegative element-like O, N and F.
- These hydrides form hydrogen bonding.

Ex : NH_3, H_2O etc.

Ex-(1)



Ex-(2)



Properties :

- These hydrides are held together by weak van der Waal's forces and in some cases by hydrogen bonding.
- These hydrides are volatile in nature having low electrical conductivity.
- The thermal stability of 15th group hydrides are $NH_3 > PH_3 > AsH_3 > SbH_3 > BiH_3$.

Uses :

- Boron hydrides are used as energy fuel and propellants.
- Phosphine (PH_3) is used for Holme's singal.
- HF is used for etching of glass.
- Act as Lewis base.
- Acidic character increases from left to right.

NH_3	H_2O	HF
Basic	Neutral	Acidic

Concept Ladder

Hydrides of group 13 like AlH_3, B_2H_6 being electrophiles behave like lewis acids.

Rack your Brain

Why boron hydrides are used as high energy fuels and propellants?

Concept Ladder

Hydrogen is also used as a rocket fuel where liquid hydrogen is combined with liquid oxygen to produce a powerful explosion. Hydrogen can be used as a clean fuel alternative to gasoline.

- Hydrides of group 13th are electron deficient.

$B_2H_6 + 2NH_3 \longrightarrow 2[H_3N \longrightarrow BH_3]$

- Elements of group 14th, 15th and 16th form polynuclear halides.

Ex : C_2H_6, C_3H_8, C_4H_{10} for carbon
Si_2H_6, Si_3H_8, Si_4H_{10} for silicon
N_2H_4, N_3H, C_4H_{10} for nitrogen
H_2O_2, H_2O_3 for oxygen

Metallic Interstitial Halides :

- The hydrogen atoms occupy the interstitial spaces of transition elements.
- Metallic hydrides show electric conductivity. They are non–nonstoichiometric in nature.

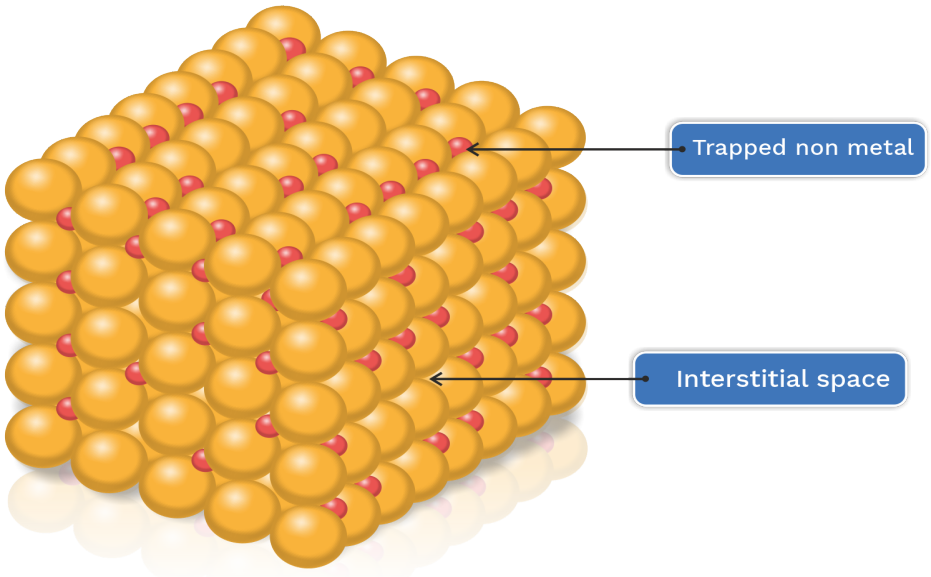
Ex : LaH_3, TiH_2, ZrH_2, HfY_2, VH, VH_2

Concept Ladder

d & f block elements have variable valencies but formation of VH_2, VH_3, CrH_2 are not possible.

Rack your Brain

Which compound on reaction with water evolves H_2 gas and gives alkaline solution?



Interstitial compound

Properties :

- Black powdery, metallic lustre and magnetic property.
- They are good conductors of electricity Conductivity decreases with increase in temperature.
- Density of hydrides is lower than those of metals from which are formed since crystal lattice expands due to absorption of hydrogen.
- High thermal conductivity.
- These generally undergo reversible decomposition into H_2 gas and metal.

Concept Ladder

- Group-7, 8, 9 do not form hydrides (Group 6 to 9 is referred to the hydride gap). Also in 6^{th} group only Cr from hydride.

$$\text{Red Hot Metal} + H_2 \xrightarrow[\text{Occlusion}]{\text{Coal}} \text{Interstitial Hydride} \xrightarrow{\text{Strong Heating}} \text{Metal} + H_2$$

Q.7 Which is not correct statement :
(1) s-block elements, except Be and Mg, form ionic hydride
(2) Interstitial hydride are non-stoichiometric in nature
(3) p-block elements form covalent hydride
(4) d, f-block elements form ionic hydride

A.7 (4)
Hydrogen atoms occupy the interstitial spaces of d & f-block elements and they form interstitial hydrides.

Q.8 Which of the following easily reacts with water producing hydrogen ?
(1) PH_3 (2) B_2H_6 (3) CH_4 (4) H_2S

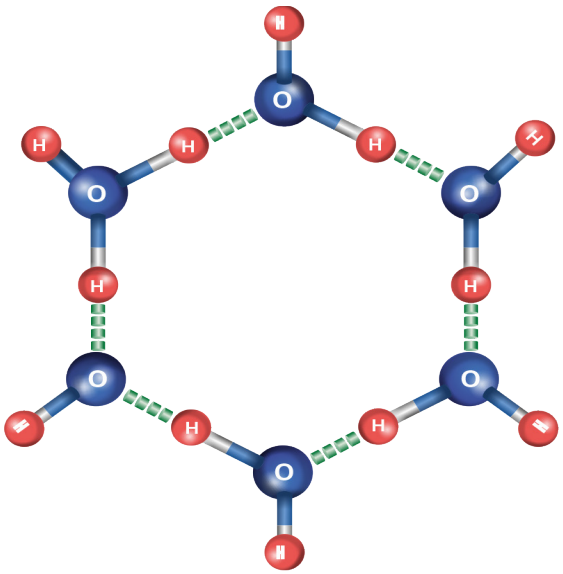
A.8 (2)
$B_2H_6 + 6H_2O \rightarrow 2B(OH)_3 + 6H_2$

Water :

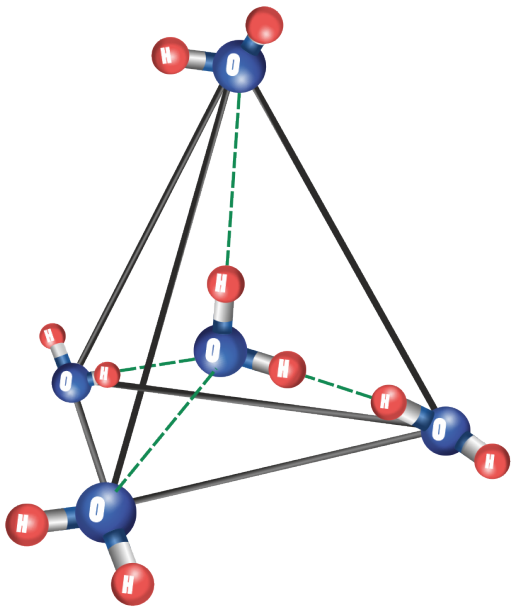
- Water is a universal solvent, exists as a solid below 0°C temperature and as a gas above 100°C temperature.
- Pure form of H_2O is bad conductor of electricity due to very low degree of ionization.
- Maximum density of water is 4°C.

Previous Year's Question

Which of the following is electron-deficient? **[NEET]**
(1) $(BH_3)_2$ (2) PH_3
(3) $(CH_3)_2$ (4) $(SiH_3)_2$



Hexagonal honey comb structure of ice



open-cage structure (water)

Definitions

Ice has definite 3D structure formed by H-bonds. It is lighter then H_2O.

Concept Ladder

(i) H_2O is colourless, odourless, tasteless liquid.

(ii) H_2O has M.P. of 273K and B.P. of 373K.

Rack your Brain

Why water extinguishes most fires, but it does not extinguish petrol fires?

Q.9 Explain, why the density of ice is less than water ?

A.9 Maximum density of H_2O is at 4°C. Ice floats on water because of density is less than that of water which in turn is due to the empty space in its crystal structure. Crystal structure of ice is regular hexagon with empty space at the centre. The crystal structure of ice is partly broken at 4°C.

Q.10 What is deionized water ?

A.10 Water free from all types of cations and anions is called deionized water.

Preparation :

$$2H_2 + O_2 \xrightarrow{\text{Electric spark}} 2H_2O$$

Properties : Pure water is colourless, tasteless, odourless.

S.No.	Property	Value
1	Freezing point	0°C
2	Boiling point	100°C
3	Density	1.0g cm^{-3} at 4°C
4	Polarity	Polar
5	Bond angle	104.5°
6	Geometry	Tetrahedral

7	Shape	Bent or V-shape
8	Enthalpy of vaporization	40.06 kJ/mol.
9	Enthalpy of formation	–285.9 kJ/mol.

Chemical Properties :

- pH = 7, in pure water $[H^+] = [OH^-] = 10^{-7}$ at 25°C.

Reaction with metals :

$$2Na + 2H_2O \longrightarrow 2NaOH + H_2$$

$$Ca + 2H_2O \longrightarrow Ca(OH)_2 + H_2$$

$$\underset{\text{Hot Red}}{Zn} + \underset{\text{Steam}}{H_2O} \longrightarrow ZnO + H_2$$

$$\underset{\text{Red Hot}}{3Fe} + \underset{\text{Steam}}{4H_2O} \longrightarrow Fe_3O_4 + 4H_2$$

Reaction with non-metals :

$$2F_2 + \underset{\text{Cold}}{3H_2O} \longrightarrow 3H_2F_2 + O_3\,(\text{Oznonised oxygen})$$

Action with non-metallic oxide :

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$SO_2 + H_2O \longrightarrow H_2SO_3$$

Action with metallic oxide :

$$Na_2O + H_2O \longrightarrow 2NaOH$$

Action on metal hydrides :

$$CaH_2 + 2H_2O \longrightarrow Ca(OH)_2 + H_2$$

Rack your Brain

Why Ag, Au, Hg and Pt metals do not decompose H_2O?

Concept Ladder

B.P, M.P and Enthalpy of vaporisation is maximum among chalcogen hydrides due to association by H-bond.

Rack your Brain

Why density of D_2O is greater than H_2O?

Q.11 What happens when hydrolith is treated with water.

Q.11 Hydrolith, i.e. CaH_2 on hydrolysis gives calcium hydroxide, $Ca(OH)_2$ with the evolution of dihydrogen gas, H_2.

$$CaH_2 + 2H_2O \rightarrow Ca(OH)_2 + H_2$$

Hydrolysis :

$$CH_3COONa + H_2O \rightleftharpoons CH_3COOH + NaOH$$

Halides of non-metals are decomposed by water:

$$PCl_5 + 4H_2O \longrightarrow H_3PO_4 + 5HCl$$

Decomposition :

$$2H_2O \longrightarrow 2H_2 + O_2$$

Water of crystallization : $CuSO_4.5H_2O$, $MgSO_4.7H_2O$, $FeSO_4.7H_2O$

Tests of water :

$$\underset{\text{White colour}}{CuSO_4} + 5H_2O \longrightarrow \underset{\text{Blue}}{CuSO_4} . \underset{\text{Coloured}}{5H_2O}$$

$$CaC_2 + H_2O \longrightarrow \underset{\substack{\text{Burns in}\\ \text{Bright Blue}\\ \text{Flame}}}{C_2H_2} + CaO$$

Concept Ladder

NO_2 and N_2O_4 are mixed anhydrides becasue they form two different acids with water.

Previous Year's Question

At its melting point, ice is lighter than water because **[1992]**

(1) H_2O molecules are more closely packed in solid state.

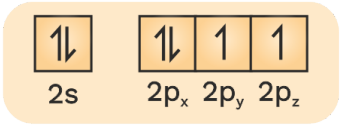
(2) ice crystals have hollow hexagonal arrangement of H_2O molecules

(3) On melting of ice the H_2O molecules shrinks in size

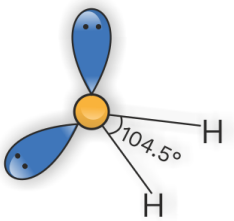
(4) ice forms mostly heavy water on first melting

Structure of H_2O :

Oxygen atom



sp^3 Hybridisation



Hard and soft water :

- A water is soft if it produces sufficient lather with soap and water is described as being hard. It forms insoluble scum before a lather with soap.
- The hardness of natural water is generally caused by presence of bicarbonates and sulphates of calcium and magnesium but all soluble salts form a scum with soap cause hardness.

Concept Ladder

Hard water can not form leather with soap ($C_{17}H_{35}COONa$). It forms $(C_{17}H_{35}COO)_2Ca$ in ppt form after reacting with $Ca^{2+}$when react with Ca^{+2}.

$$Ca^{2+}_{(aq)} + 2C_{17}H_{35}COO^-_{(aq)} \longrightarrow (C_{17}H_{35}COO)_2Ca \quad \text{or}$$

$$Mg^{2+}_{(aq)} + 2C_{17}H_{35}COO^-_{(aq)} \longrightarrow (C_{17}H_{35}COO)_2Mg$$

- Hardness of water is of two types.
  (A) Temporary hardness
  (B) Permanent hardness

(A) Temporary Hardness :

- Due to presence of $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$.
- Rain water dissolves small quantities of CO_2 from atmosphere forming a very dilute solution of carbonic acid.

Rack your Brain

How temporary hardness of water can be removed?

$$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (Carbonic acid)}$$

$$CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2 \text{ (Calcium bi-carbonate)}$$

- Temporary hardness is easily removed by boiling.

$$Ca(HCO_3)_2 \longrightarrow \underset{\text{Insoluble}}{CaCO_3\downarrow} + H_2O + CO_2\uparrow$$

$$Mg(HCO_3)_2 \xrightarrow{\text{Boil}} \underset{\text{Insoluble}}{MgCO_3\downarrow} + H_2O + CO_2\uparrow$$

- Temporary hardness is also removed by **Clark's process** which involves the addition of slaked lime [$Ca(OH)_2$].

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

$$Mg(HCO_3)_2 + 2Ca(OH)_2 \longrightarrow \underbrace{2CaCO_3\downarrow + Mg(OH)_2\downarrow}_{\text{Insoluble}} + 2H_2O$$

Previous Year's Question

Which method used to remove temporary hardness of water is **[NEET]**

(1) Synthetic resins method
(2) Calgon's method
(3) Clark's method
(4) Ion-exchange method

- Only calculated amount of $Ca(OH)_2$ used because excess of $Ca(OH)_2$ cause artificial hardness.

Q.12 Soft water lathers with soap, but not hard water. Why ?

A.12 Hard water contains Ca and Mg salts. These react with soap to form insoluble Ca and Mg salts of fatty acids. i.e. form scum and not lather.

$$2RCOONa + Ca^{2+} \rightarrow (RCOO)_2 Ca + 2Na^+$$

$$2RCOONa + Mg^{2+} \rightarrow (RCOO)_2 Mg + 2Na^+$$

Permanent Hardness :

- Permanent hardness due to presence of sulphates or chloride or both of calcium and magnesium.
- The various method to remove permanent hardness are :
  (a) Washing soda method
  (b) Permutit method
  (c) Calgon method
  (d) Ion exchange resins method

(a) Washing soda ($Na_2CO_3.10H_2O$) :
It removes both temporary and permanent hardness.

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2NaCl$$

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3 + Na_2SO_4$$

$$Ca(HCO_3)_2 + Na_2CO_3 \longrightarrow \underset{\text{Insoluble}}{CaCO_3} + 2\underset{\text{Soluble}}{NaHCO_3}$$

Caustic soda/Sodium phosphate can also be used to this purpose.

$$MgCl_2 + 2NaOH \longrightarrow Mg(OH)_2 + 2NaCl$$

$$3MgSO_4 + 2Na_3PO_4 \longrightarrow \underset{\text{Insoluble}}{Mg_3(PO_4)_2} + 3\underset{\text{Soluble}}{Na_2SO_4}$$

Concept Ladder

Permanent hardness is not removed by boiling or addition of slaked lime the substances used to remove the hardness of water are known as water softners.

Previous Year's Question

Which of the following groups of ions makes the water hard? **[AIPMT]**

(1) Sodium and bicarbonate ions
(2) Magnesium and chloride ions
(3) Potassium and sulphate ions
(4) Ammonium and chloride ions

(b) Permutit :

- Permutit is the hydrated silicates of aluminium and sodium ($Al_2Na_2Si_2O_8.xH_2O$) obtained by fusing sodium carbonate, china clay, silica or quartz. The crystalline sodium aluminosilicates (sodium zeolite) formed exchange sodium ions with calcium and magnesium ions.

$$Na_2Al_2Si_2O_8.xH_2O + Ca^{2+} \longrightarrow CaAl_2Si_2O_8.xH_2O + 2Na^+$$

$$\text{or } Na_2Al_2Si_2O_8.xH_2O + Mg^{2+} \longrightarrow MgAl_2Si_2O_8.xH_2O + 2Na^+$$

- These ions can be re-exchanged by treating it with brine (NaCl) solution.

$$CaAl_2Si_2O_8.xH_2O + 2NaCl \longrightarrow Na_2Al_2Si_2O_8.xH_2O + CaCl_2$$

Note :

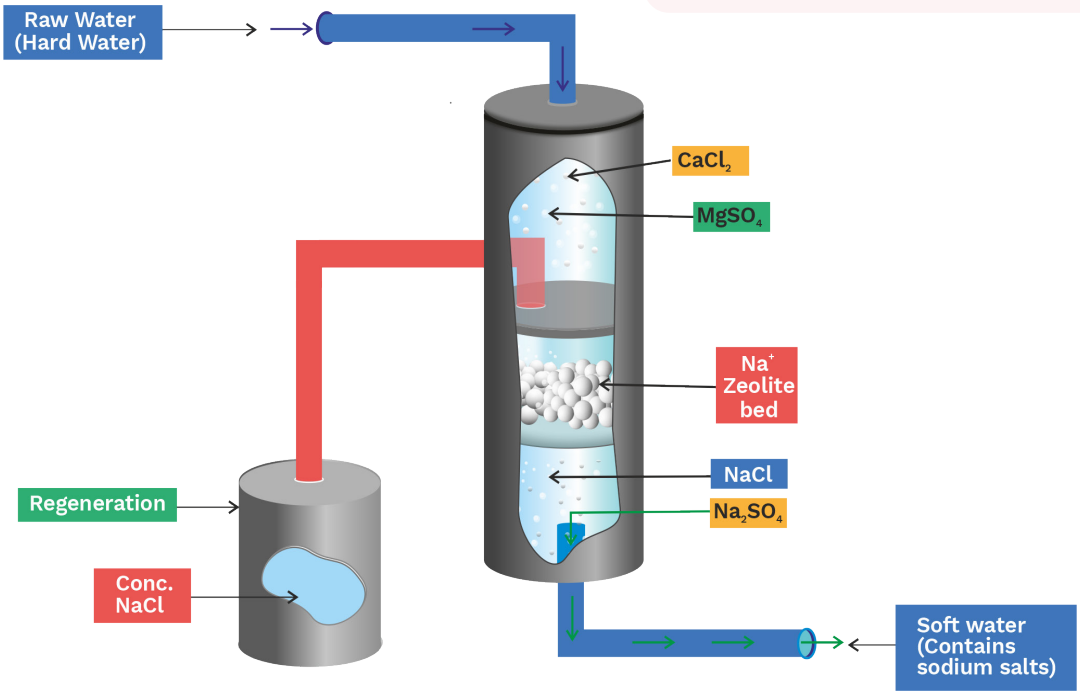
This method is useful for removal of both temporary and permanent hardness.

Concept Ladder

Permutit method is also termed as zeolite method. It is regenerated by treating NaCl.

Rack your Brain

Name the compounds used with Na^+ zeolite bed?



Q.13 The exhausted permutit is generally regenerated by percolating through it a solution of

(1) Sodium chloride (2) Calcium chloride

(3) Magnesium chloride (4) Barium chloride

A.13 (1)

Factual statement

Q.14 When zeolite, which is hydrated sodium aluminium silicate is treated with hard water, the sodium ions ($Na^{Å}$) are exchanged with :

(1) $H^{Å}$ ions (2) Ca^{2+} ions

(3) SO^{2-}_{4} ions (4) OH^{-} ions

Q.14 (2)

Factual statement

(c) Calgon method :

- complex salt of sodium hexametaphosphate $(NaPO_3)_6$ and metaphosphoric acid is called as Calgon. It is represented as $Na_2[Na_4(PO_3)_2]$ calcium and magnesium salts present in hard water with Calgon to give complex salts.

Concept Ladder

Calgon method is specially used in softening of water for boiler use.

$$2CaSO_4 + Na_2[Na_4(PO_3)_6] \longrightarrow Na_2[Ca_2(PO_3)_6] + 2Na_2SO_4$$

$$2MgSO_4 + Na_2[Na_4(PO_3)_6] \longrightarrow Na_2[Mg_2(PO_3)_6] + 2Na_2SO_4$$

Q.15 Calgon is an industrial name given to :

(1) Normal sodium phosphate (2) Sodium meta-aluminate

(3) Sodium hexametaphosphate (4) Hydrated sodium aluminium silicate

Q.15 (3)

Factual statement

(d) By ion exchange resins :

- Resins are synthetic substances the cation exchange consists of granular insoluble organic acid resin having gaint molecules with sulphonic group or carboxylic groups while the anion exchange contains giant organic molecules with basic groups derived from amines.
- Ion exchange resins remove all soluble minerals from water. The hard water is first passed through a bed of cation exchanger which removes the cations like Na^+, Mg^{2+}, Ca^{2+} and other by exchange with H^+ ions.

$$\underset{\text{Resin}}{2RH} + Ca^{2+} / Mg^{2+} / Na^{+} \longrightarrow (R)_2Ca + 2H^{+}$$

- H2O coming from cation exchanger is acidic in presence of free hydrogen ions. This H2O is then passed through another bed containing anion exchanger this exchanger removes anions like Cl^-, SO_4^{2-}, SO_4^{2-}, NO_3^- by exchange with OH^- ions.

$$\underset{\text{Resin}}{R-NH_3OH} + Cl^- \longrightarrow R-NH_3Cl + OH^-$$

- The OH^- ions neutralise the free H^+ ion produced by the cation exchanger.

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

- This process gives distilled H_2O can be used in laboratories.
- Cation exchanger is regenerated by action of an acid and anion exchanger by pouring a solution of a suitable sodium through it.

Concept Ladder

Hard water : Water that contain high amount of dissolved minerals or ions such as calcium, magnesium etc.

Soft water: Soft water is surface water that contains very low concentration of ions r minerals, e.g., Rainwater and distilled water.

Previous Year's Question

Some statements about heavy water are given below. **[AIPMT]**

(i) Heavy water is used as a moderator in nuclear reactors.

(ii) Heavy water is more associated than ordinary water.

(iii) Heavy water is more effective solvent than ordinary water.

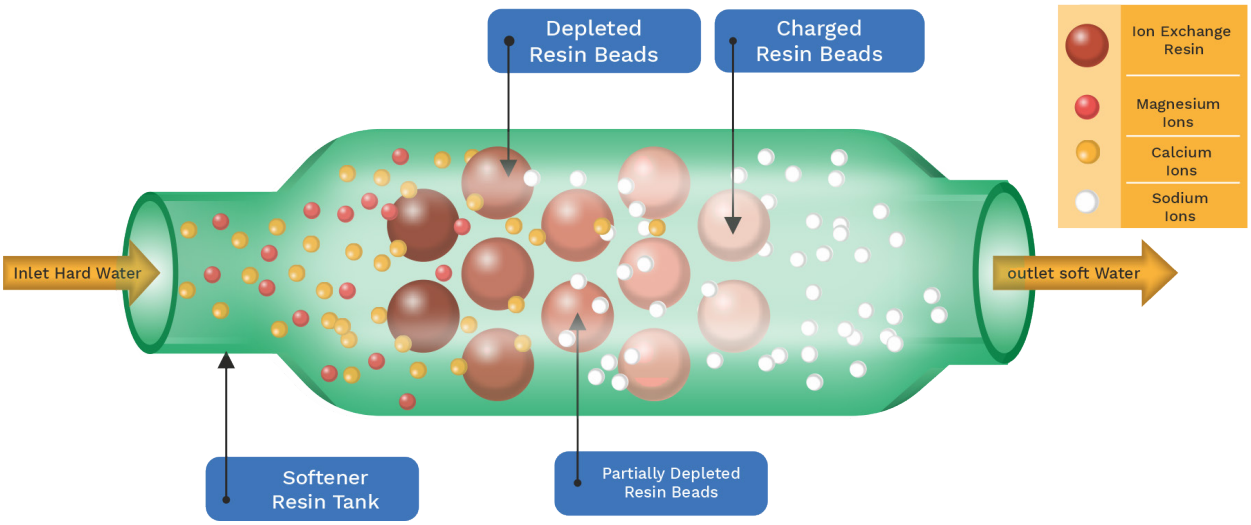
Which of the above statement are correct?

(1) (i) and (ii)

(2) (i), (ii) and (iii)

(3) (ii) and (iii)

(4) (i) and (iii)



Disadvantages of hard water :

(1) Not fit for domestic use because it spoils lustre of utensils.

(2) Not fit for industrial use because it contain Ca^{2+}/Mg^{2+} ions in H_2O.

(3) Not fit for boiler use because it causes rusting.

(4) Corrosion

$MgCl_2 + H_2O \rightarrow Mg(OH)Cl + HCl$

HCl attacks metal surface of boiler and thereby shortens its life by rusting.

(5) Not fit for washing the clothes because it forms scum.

Rack your Brain

Explain the process of rusting by attack of HCl?

Degree of hardness :

$$\text{Equivalent of } CaCO_3 = \frac{\text{Mass of hardness producing substance} \times \text{Chemical equivalent of } CaCO_3}{\text{Chemical equivalent of hardness producing substance}}$$

$$= \frac{\text{Mass of hardness producing substance} \times 50}{\text{Chemical equivalent of hardness producing}}$$

Q.16 A sample of hard water contains 1 mg $CaCl_2$ and 1 mg $MgCl_2$ per litre. Calculate the hardness of water in terms of $CaCO_3$ present in per 10^6 parts of water.
(1) 2.5 ppm (2) 1.95 ppm (3) 2.15 ppm (4) 195 ppm

Q.16 (2)

Molecular weight of $CaCl_2$ = 111.0 g
Molecular weight of $CaCO_3$ = 100 g
Molecular weight of $MgCl_2$ = 95.0 g
$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$
$MgCl_2 + Na_2CO_3 \rightarrow MgCO_3 + 2NaCl$

(i) 111.0 g $CaCl_2$ = 100 g $CaCO_3$

1 mg $CaCl_2 = \frac{100}{111}$ mg $CaCO_3 = 0.9$ mg $CaCO_3$]

(ii) 95.0 g $MgCl_2$ = 100 g $CaCO_3$

1 mg $MgCl_2 = \frac{100}{95}$ mg $CaCO_3 = 1.05$ mg $CaCO_3$

Hardness of $CaCO_3$ ppm $= \frac{(0.9 + 1.05) \times 10^{-3} \text{ g} \times 10^6 \text{ mL}}{10^3 \text{ mL}}$

= 1.95 ppm

Q.17 Find the degree of hardness of a sample of water containing 12 mg of $MgSO_4$ (Molecular Mass 12) per kg of water.

Q.17 12 mg of $MgSO_4$ is present in 10^3 g of water.
Thus, 10^6 g of water contains = 12000 mg of $MgSO_4$
120 g $MgSO_4$ º 100 g of $CaCO_3$

So, 12000 mg of $MgSO_4 = \frac{100}{120} \times \frac{12000}{1000} = 10$ g $CaCO_3$

Hardness of water = 10 ppm.

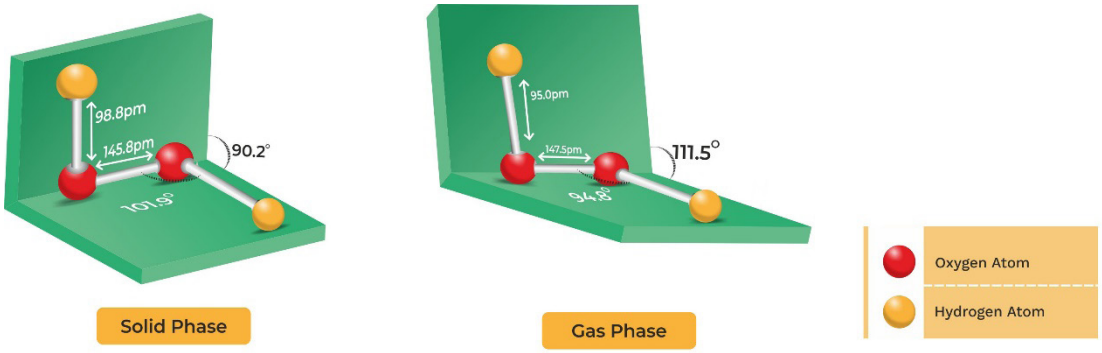
Hydrogen peroxide H_2O_2 :

H_2O_2 traces occurs in air, rain, snow some natural water and juices of certain plants.

Rack your Brain

In some tooth pastes hydrogen peroxide is used. What is role of H_2O_2 in it?

Structure of H_2O_2 :



Preparation :

$$Na_2O_2 + \underset{\text{Cold water}}{2H_2O} \longrightarrow 2NaOH + H_2O_2$$

$$Na_2O_2 + \underset{20\%}{H_2SO_4} \longrightarrow Na_2SO_4 + H_2O_2$$

$$BaO_2.8H_2O + \underset{\text{(Dilute)}}{H_2SO_4} \xrightarrow{0°C} BaSO_4 + H_2O_2 + 8H_2O$$

- The use of H_2SO_4 has a disadvantage as it catalyses the decomposition of H_2O_2.
- In place of sulphuric acid weak acids like H_3PO_4, H_2CO_3 acids are preferred.

$$3BaO_2 + 2H_3PO_4 \longrightarrow \underset{\text{ppt}}{Ba_3(PO_4)_2} + 3H_2O_2$$

Merck's Process :

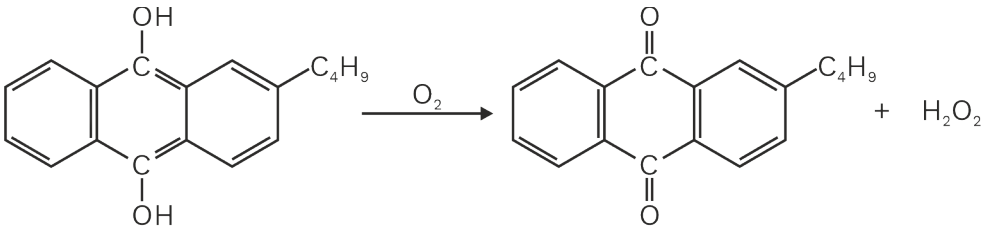
$$BaO_2 + CO_2 + H_2O \longrightarrow \underset{\text{ppt}}{BaCO_3} + H_2O_2$$

H_2O_2 can be obtained by passing a current of CO_2 through a cold pasty solution of barium peroxide in H_2O.

Concept Ladder

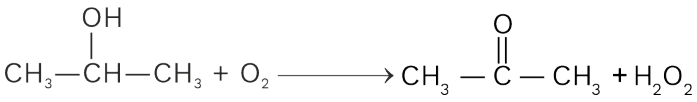
H_2O_2 is unstable liquid and decomposes easily into H_2O and O_2. A small amount of phosphoric acid, acetanilide or glycerol is added to check its decomposition (negative catalyst)

By oxidation of 2-Butylanthraquinol



2-Butylanthraquinol

By oxidation of isopropyl alcohol :



Electrolytic Process :

- In this process, the electrolysis of 50% H_2SO_4 is carried out at low temperature using platinum electrodes and a current of high density. Peroxy disulphuric acid is formed.

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

$2HSO_4^- \longrightarrow H_2S_2O_8 + 2e^-$ At anode

Again $H_2S_2O_8 + 2H_2O \longrightarrow 2H_2SO_4 + H_2O_2$ (30%)

Concept Ladder

Peroxide and Superoxide form H_2O_2 with H_2O, dil.HCl or dil. H_2SO_4.

Properties of H_2O_2 :

- Pure H_2O_2 syrupy liquid, colourless, odourless, specific gravity 1.45 at 0°C.
- Soluble in H_2O, ether and alcohol, bitter taste, injurious to skin, boils at 152°C, freezes at –0.89°C, begain to decompose on boiling, shows hydrogen bonding, having dipole movement (μ) = 2.1 D

Rack your Brain

Which compound is formed when H_2O_2 is react with dil. H_2SO_4?

Chemical properties :

1. Decomposition :

- Pure hydrogen peroxide is an unstable liquid

and decomposes into water and oxygen on long standing or heating.

$$2H_2O_2 \longrightarrow 2H_2O + O_2;\ \Delta H = -196.0\ kJ$$

It is an example of auto-oxidation and auto-reduction.

- The decomposition is further accelerated by the presence of certain metal ions e.g. Fe^{2+}, metal powders (Co, Au, Ag, Pt etc.), and metal oxides (e.g. MnO_2). Even carbon, rough surfaces and light also catalyse its decomposition.

2. Acidic Nature :

- Pure hydrogen peroxide turns blue litmus red but its dilute solution is neutral to litmus.
- Its dissociation constant is 1.55×10^{-12} at 293 K which is only slightly higher than that of water (1.0×10^{-12}).
- Thus, hydrogen peroxide is only a slightly stronger acid than water.

$$2NaOH + H_2O_2 \longrightarrow \underset{\text{Sodium Hydroperoxide}}{Na_2O_2} + 2H_2O$$

$$NaOH + H_2O_2 \longrightarrow \underset{\text{Sodium Peroxide}}{NaHO_2} + H_2O$$

$$Ba(OH)_2 + H_2O_2 \longrightarrow BaO_2 + 2H_2O$$

3. Oxidising and reducing character :

- H_2O_2 behaves as an oxidising as well as a reducing agent in both acidic and alkaline solutions.

(a) Oxidising character : Hydrogen peroxide acts as an oxidising agent both in acidic as well as in alkaline medium.

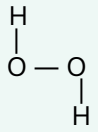
In acidic medium: $H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$

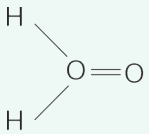
In Basic Medium: $H_2O_2 + 2e^- \longrightarrow 2OH^-$

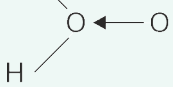
Previous Year's Question

Which of the following is the true structure of H_2O_2? **[AIPMT]**

(1) H — O — O — H

(2)


(3)


(4)


Concept Ladder

H_2O_2 shows bleaching by oxidation process, this process is parmanent.

$H_2O_2 \longrightarrow H_2O + O$

The product O is termed as nascent 'O' which makes it colourless.

(i) It oxidises acidified ferrous sulphate to ferric sulphate :

$$2FeSO_4 + H_2SO_4 + H_2O_2 \longrightarrow Fe_2(SO_4)_3 + 2H_2O$$

(ii) It oxidises acidified potassium ferrocyanide to potassium ferricyanide :

$$2K_4[Fe(CN)_6] + H_2SO_4 + H_2O_2 \longrightarrow 2K_3[Fe(CN)_6] + K_2SO_4 + 2H_2O$$

(iii) It liberates iodine form acidified potassium iodide solution :

$$2KI + H_2SO_4 + H_2O_2 \longrightarrow K_2SO_4 + 2H_2O + I_2$$

Concept Ladder

H_2O_2 acts as a O.A and R.A. in acidic and basic medium.

(iv) Hydrogen peroxide oxidses ice-cold acidified potassium dichromate solution (containing ether) to chromium pentoxide which dissolves in ether producing a blue colouration.

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

(v) Hydrogen peroxide oxidises lead sulphide to lead sulphate :

$$PbS + 4H_2O_2 \longrightarrow PbSO_4 + 4H_2O$$

(vi) Hydrogen peroxide oxidies H_2S to sulphur :

$$H_2S + H_2O_2 \longrightarrow 2H_2O + S$$

Previous Year's Question

The strucutre of H_2O_2 is **[AIPMT]**
(1) Spherical
(2) Non-planar
(3) Planar
(4) Linear

(vii) It oxidies arsenites to arsenates respectively.

$$Na_3AsO_3 + H_2O_2 \longrightarrow Na_3AsO_4 + H_2O$$

(viii) It oxidises manganese salts to manganese dioxide in alkaline medium.

$$MnSO_4 + H_2O_2 + 2NaOH \longrightarrow Na_2SO_4 + MnO_2 + 2H_2O$$

(ix) It oxidises chromium salts to chromates in alkaline medium.

$$Cr_2(SO_4)_3 + 3H_2O_2 + 10NaOH \longrightarrow 2Na_2CrO_4 + 3Na_2SO_4 + 8H_2O$$

(x) It oxidises formaldehyde to formic acid

$$HCHO + H_2O_2 \longrightarrow HCOOH + H_2O$$

(xi) It oxidises benzene to phenol

$$C_6H_6 + H_2O_2 \longrightarrow C_6H_5OH + H_2O$$

(xii) It oxidises mercury to mercuric oxide in acidic medium

$$Hg + H_2O \xrightarrow{H_2SO_4\,(dil.)} HgO + H_2O$$

(b) Reducing character : In presence of strong oxidising agents, hydrogen peroxide behaves as a reducing agent both in acidic as well as alkaline medium.

$$\underset{\text{From oxidising agent}}{H_2O_2} + [O] \longrightarrow H_2O + O_2$$

Acidic medium $H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$

Alkaline medium $H_2O_2 + 2OH^- \rightarrow 2H_2O + O_2 + 2e^-$

(i) It reduces acidified potassium permanganate solution. As a result of this reaction, the pink colour of $KMnO_4$ disappears.

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

(ii) It reduces acidified potassium dichromate solution. As a result of this reaction, the orange colour of $K_2Cr_2O_7$ changes to green due to the formation of chromium salt.

$$K_2Cr_2O_7 + 4H_2SO_4 + 3H_2O_2 \longrightarrow K_2SO_4 + Cr_2(SO_4)_3 + 7H_2O + 3O_2$$

(iii) It reduces manganese dioxide to manganese sulphate in presence of dil. H_2SO_4.

$$MnO_2 + H_2SO_4 + H_2O_2 \longrightarrow MnSO_4 + 2H_2O + O_2$$

(iv) It reduces ozone to dioxygen.

$$H_2O_2 + O_3 \longrightarrow H_2O + 2O_2$$

(v) Chlorine and bromine are reduced to HCl and HBr respectively. This property is called Antichlor.

Previous Year's Question

The O—O—H bond angle in H_2O_2 is **[AIPMT]**

(1) 106° (2) 109°28'

(3) 120° (4) 97°

Concept Ladder

Decomposition of H_2O_2 is example of redox reaction.

$$\overset{-1}{2H_2O_2} \longrightarrow \overset{-2}{2H_2O} + \overset{0}{O_2}$$

Reduction

Oxidation

Rack your Brain

How H_2O_2 react with MnO_2 in presence of dil. H_2SO_4?

$H_2O_2 + Cl_2 \longrightarrow 2HCl + O_2$ and
$H_2O_2 + Br_2 \longrightarrow 2HBr + O_2$

(vi) It reduces alkaline potassium ferricyanide to potassium ferrocyanide

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

(vii) It reduces metal oxides to metals, i.e., silver oxide to silver in the alkaline medium.
$Ag_2O + H_2O_2 \rightarrow 2Ag + H_2O + O_2$

(viii) It reduces hypohalites to halide.

$$NaOBr + H_2O_2 \longrightarrow NaBr + H_2O + O_2$$
$$CaOCl_2 + H_2O_2 \longrightarrow CaCl_2 + H_2O + O_2$$

4. Bleaching Action :

- The bleaching action of H_2O_2 is due to the nascent oxygen which liberates on decomposition.

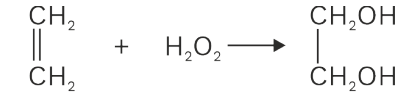
$$H_2O_2 \longrightarrow H_2O + [O] \text{ (nascent oxygen)}$$

- The nascent oxygen (O) combines with colouring matter which, in turn, gets oxidised. It's used for bleaching of delicate materials like silk, ivory, wool, feather etc.

Colouring matter + [O] $\longrightarrow$ Colourless matter

5. Addition Reactions :

- Hydrogen peroxide reacts with alkenes to form glycols.



Ethylene Ethylene glycol

Concept Ladder

H_2O_2 converts colour of old lead paint from black to white.

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

Rack your Brain

Explain how nascent O which is the product of H_2O_2, makes it colourless?

Previous Year's Question

Hydrogen peroxide molecules are **[AIPMT]**

(1) monoatomic and form X_2^{2-} ions
(2) diatomic and form X^- ions
(3) diatomic and form X_2^- ions
(4) monoatomic and form X^- ions

Uses of hydrogen peroxide :

(i) It is used as antichlor (to remove Cl_2) in textile industry to remove excess of chlorine after bleaching operations.

(ii) It is used in manufacture of many inorganic and organic (sodium perborate, epoxides) compounds.

(iii) It is used to restore the colour of lead paintings which have blackened due to the action of H_2S present in the air on lead paints.

(iv) It is used in the laboratory for detecting the presence of chromium, titanium and vanadium salts with which it 'yields peroxides of characteristic colours.

(v) It is used as an antiseptic under the name perhydrol (30% H_2O_2) for washing wounds, teeth and ears.

(vi) 93% H_2O_2 solution is used as an oxidant for rocket fuel and as a propellant for torpedoes and submarines.

Concentration of Hydrogen Peroxide Solution :

- Hydrogen prepared by any of the above methods is in the form of dilute aqueous solution. Quite often for a large number of reactions, we need a concentrated solution of H_2O_2. It cannot be concentrated simply by distillation since it decomposes much below its boiling point to give H_2O and O_2.

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

- Further, the process of decomposition is catalysed by the presence of heavy metal ion impurities, dust and rough surfaces. In view of these difficulties, concentration of H_2O_2 is carried out carefully in a number of stages.

Concept Ladder

H_2O_2 is used for bleaching delicate materials like hair, silk, wool, ivory, textile, wood and paper pulp.

Rack your Brain

Explain how H_2O_2 is used as an antiseptic for woulds?

Previous Year's Question

The reaction of H_2O_2 with H_2S is an example of ..... Reaction.

[AIPMT]

(1) addition (2) oxidation
(3) reduction (4) acidic

Storage of hydrogen peroxide :

The following precautions are taken while storing hydrogen peroxide solution.

(i) H_2O_2 cannot be stored in glass bottles since rough surface of glass, alkali metal oxides present in it, and exposure to light catalyse its decomposition. Therefore, H_2O_2 is usually stored in coloured paraffin wax coated or Teflon bottles.

(ii) Negative catalyst such as glycerine, acetanilide, phosphoric acid etc. must also be added to stabilize the H_2O_2.

Strength of hydrogen peroxide solution :

- Strength or concentration of H_2O_2 solution is expressed in the following ways :

(1) In terms of volume of O_2 gas : The commercial samples of H_2O_2 are marked as '10 volume', '20 volume', '30 volume', etc.

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

Meaning of 10 volume of O_2.

1 Volume of H_2O_2 on heating gives 10 volumes of O_2. Or 1 ml of H_2O_2 on heating gives 10 ml of O_2. Similarly 10 ml of H_2O_2 on heating gives 100 ml of O_2. Similarly; **10 ml of 20 volume of H_2O_2 on heating gives 20 × 10 = 200 ml of O_2.**

(2) In terms of weight :

50% H_2O_2 solution (w/v) means that 5 g of H_2O_2 is present in 100 mL of solution.

$$\underset{\substack{2(34)g \\ =68\ g}}{2H_2O_2} \xrightarrow{\Delta} 2H_2O + \underset{\substack{32g\ at\ STP \\ or\ 22400\ mL\ at\ STP}}{O_2}$$

∵ 22400 mL of O_2 gas is obtained at NTP from 68 g of H_2O_2.

∴ 10 mL of O_2 gas is obtained at NTP from

Concept Ladder

Hydrogen peroxide is biochemically formed in human boides and the bodies of other animals but it is actually toxic to cells.

Rack your Brain

Write the product formed when one mole of H_2O is mixed with $H_2S_2O_8$?

Concept Ladder

H_2O_2 is stored in the vessels of pure aluminium or in stone jars in dark.

$$\frac{68}{22400} \times 10 \text{ g of } H_2O_2 = 0.03035 \text{ g of } H_2O_2$$

1 mL of H_2O_2 contains 0.03035 g of H_2O_2
100 mL of H_2O_2 contains 0.3035 × 100 = 3.035 g of H_2O_2
Hence, concentration of '10 volume' of H_2O_2 solution is 3.035% (w/v) orconcentration or strength of '10 volume' of H_2O_2 solution is 3.035 × 10 = 30.35 g L^{-1}.

Rack your Brain

Calculate the strength of 10 volume solution of hydrogen peroxide.

3. **In terms of normality :** To know the normality, equivalent weight of H_2O_2 should be known, and this can be calculated as follows :

$$\underset{(2\times34)=68\text{ g}}{2H_2O_2} \longrightarrow 2H_2O + \underset{32\text{ g}}{O_2}$$

∵ 32 parts of weight of O_2 are obtained from 68 parts by weight of H_2O_2.

∴ 8 parts by weight of O_2 are obtained from $\frac{68 \times 8}{32}$ = 17 parts by weight of H_2O_2.

∴ Equivalent weight of H_2O_2 = 17.
$1N = 17gL^{-1}$

Concept Ladder

Pure H_2O_2 is a syrupy liquid. It is soluble in water, alcohol and ether. It is injurious to skin

Normality of 10 volume H_2O_2 solution

$$= \frac{\text{Strength of 10 volume } H_2O_2 \text{ soln in g } L^{-1}}{\text{Equivalent weight of } H_2O_2} = \frac{30.35}{17} = 1.785 \text{ N}$$

$$\underset{2\text{ mol}}{2H_2O_2} \longrightarrow 2H_2O + \underset{1\text{ mol}}{O_2}$$

2 mol of H_2O_2 = 22.4 L of O_2

1 mol of H_2O_2 = 11.2 L of O_2

1M H_2O_2 = 11.2 L of O_2

1 N H_2O_2 = 5.6 L of O_2 = 5.6 volume of O_2

Previous Year's Question

The volume strength of 1.5 N H_2O_2 solution is **[AIPMT]**

(1) 8.8 (2) 8.4
(3) 4.8 (4) 5.2

Q.18 In which group of the periodic table, hydrogen is placed?

A.18 No fixed position, sometimes placed in IA with alkali metals and sometimes in VIIA (or 17^{th}) group with halogens.

Q.19 Which metals react with H_2O or dilute HCl or dilute H_2SO_4 to evolve hydrogen?

A.19 Metals having positive oxidation potential values or placed above hydrogen in the electrochemical series evolve hydrogen with water or dilute HCl or dilute H_2SO_4.

Q.21 Why are the melting and boiling points of D_2O are higher than those of ordinary water?

A.21 D_2O has more molecular mass and greater degree of association than H_2O and thus shows higher m.pt and b.pt.

Q.22 Hydrogen peroxide acts as an oxidising agent as well as a reducing agent.

A.22 This is due to the following reaction.
Oxidation agent :

$$H_2O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O \text{ (acidic medium)}$$

$$H_2O_2 + 2e^- \longrightarrow 2OH^- \text{ (alkaline medium)}$$

Reducing agent:

$$H_2O_2 \longrightarrow 2H^+ + O_2 + 2e^-$$

Q.23 Hydrogen forms compounds with elements having atomic numbers: 9, 11, 12 and 17. What are their chemical formulas? Compare their chemical behaviour.

A.23

S. No.	Atomic Number	Element	Chemical formula of the hydride
1.	9	F	HF
2.	11	Na	NaH
3.	12	Mg	MgH_2
4.	17	Cl	HCl

The compounds formed are hydrides of s-and p-block elements. s-block hydrides (NaH and MgH_2) are also known as salt-like or ionic hydrides. These are non-volatile and non-conducting crystalline solids. MgH_2 has covalent polymer structure.

Q.24 Explain why hydrogen peroxide is stored in coloured plastic bottles?

A.24 H_2O_2 decomposes slowly on exposure to light.

$$2H_2O_{2(l)} \longrightarrow 2H_2O_{(l)} + O_{2(g)}$$

In the presence of metal surfaces of traces of alkali present in glass bottles, above decomposition reaction is catalysed. So, it is stored in coloured/ plastic bottles in dark. As a stabiliser, urea can be added. Dust also induces explosive decomposition..

Q.25 Discuss the importance of heavy water in nuclear reactors.

A.25 D_2O is used as a moderator in nuclear reactors because it slows down fast moving neutrons and therefore helps in controlling nuclear fission process. It has also been used as a tracer compound to study the mechanism of many chemical reactions.

Q.26 Ionic hydrides are frequently used to remove traces of water from organic compounds. What is the underlying basis of this process?

A.26 Electrolysis of solutions of ionic hydrides in molten alkalie halides produce hydrogen gas at the anode which confirms the existence of hydride, H– ion.

$$\underset{(\text{Melt})}{2H^-} \xrightarrow{\text{Anode}} H_{2(g)} + 2e^-$$

Since hydrides react explosively with water.

$$NaH_{(s)} + H_2O_{(aq)} \longrightarrow H_{2(g)} + NaOH_{(aq)}$$

H^- is a strong Bronsted base, which has high reactivity with water. The fire so produced can be extinguished by CO_2 as it gets reduced by the hot metal hydride.

Q.27 Why do lakes freeze from wate top towards bottom?

A.27 There are intermolecular hydrogen bonding in H_2O molecules. The density of water is greater than ice. It many be noted that at 4°C water has maximum density. In severe cold the upper layer of the sea water freezes and the heavier water (density more than that of ice) is present below the surface of ice. Due to this sea animals live safely in water.

Chapter Summary

1. Laboratory method of preparation of hydrogen (H_2)

$$Zn + dil.H_2SO_4 \longrightarrow ZnCl_2 + H_2$$

2. Commercial processes (for manufacture of hydrogen)

(i) Bosch process

$$C + H_2O \xrightarrow{\Delta} \underbrace{CO + H_2O}_{\text{Water gas}}$$

(ii) Lane's process

$$3Fe + \underset{\text{Stem}}{4H_2O} \xrightarrow[\Delta,\ 1000K]{Fe_2O+Cr_2O_3} CO_2 + 2H_2$$

(iii) From hydrocarbon

$$\text{Hydrocarbon} + H_2O \xrightarrow[\text{catalyst}]{1270K} CO + H_2$$

3. Uses of H_2

(i) Hydrogenation of oil.
(ii) haber's process for menufacture of Ammonia.
(iii) Liquid O_2 + liquid H_2 —rocket fuel in space research.
(iv) 85% He and 15% H_2 is used in filling of balloons.

4. Hydrides are compounds of hydrogen with other element.

Types of Hydrides

(i) Ionic or saline or salt like hydrides.
(ii) Covalent hydride.
(iii) Metallic or interstitial hydride.
(iv) Polynuclear hydride.

5. Soft and hard water :

Soft warter produces lather with soap and hard water does not.

Types of Hardness of Water

(i) Temporary hardness
  (a) Due to bicarbonates of Ca and Mg.
  (b) Removed by boiling, Clark's method.
(ii) Permanent hardness
  (a) Due to soluble chlorides and sulphates of Ca and Mg.
  (b) Removed by Soda lime method, Ion exchange method.

6. **Heavy water (H_2O_2) or Oxygenated water:** It was discovered by **Thennard.**

(i) Methods of preparation

(a) Lab emthod: By action of H_2SO_4 on hydrated barium peroxide ($BaO_2.8H_2O$)

$$BaO_2.8H_2O + H_2SO_4 \longrightarrow BaSO_4 + H_2O_2 + 8H_2O$$

(b) Merck's method

$$Na_2O_2 + H_2SO_4 \longrightarrow Na_2SO_4 + H_2O_2$$

(c) By electrolysis of 50% H_2SO_4

$$2H_2SO_4 \xrightarrow{\text{electricity}} 2H^+ + 2HSO_4^-$$

At cathode

$$2H^+ + 2e^- \longrightarrow H_2 \uparrow$$

At anode

$$2HSO_4^- \longrightarrow \underset{\text{Peroxodisulphuric acid}}{H_2S_2O_8} + 2e^-$$

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

(b) Properties

(i) Acidic in nature ($K_a = 1.55 \times 10^{-12}$ at 298k)

$$H_2O_2 + H_2O \longrightarrow H_3O^+ + HO_2^-$$

(ii) Bleaching action of H_2O_2 is due to oxidation

$$H_2O_2 \longrightarrow H_2O + [O]$$

(iii) Strong oxidising agent

$$H_2O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O \text{ (acidic medium)}$$

$$H_2O_2 + OH^- + 2e^- \longrightarrow 3OH^- \text{ (basic medium)}$$

It oxidises (in acidic medium)

(a) $Kl \longrightarrow I_2$

(b) $Fe^{2+} \longrightarrow Fe^{3+}$

(c) $PbS \longrightarrow PbSO_4$

(d) $K_3[Fe(CN)_6] \longrightarrow K_4[Fe(CN)_6]$

(e) $K_2Cr_2O_7 \longrightarrow Cr_2O_5$

(f) Sulphite $\longrightarrow$ Sulphate

In basic medium

(a) Mn salts $\longrightarrow MnO_2$

(b) Chromium salts to chromate

(c) $HCHO \longrightarrow HCOOH$

(iii) Uses of H_2O_2

(a) Bleaching of delicate material - hair, wool, feather.

(b) restoration of colour of lead painting (black PbS $\xrightarrow{H_2O_2}$ white $PbSO_4$)

(c) Perhydrol (trade name of 30% H_2O) used as antiseptic and germicide.

(d) As antichlore ($Cl_2 \longrightarrow HCl$)

(iv) Structure of H_2O_2 - Has open book structure

(v) Strength of H_2O solution

(a) When expressed as percentage means% of H_2O_2 in solution w/v.

(b) When expressed in volume strength means the volume of O_2(in L) obtained by decomposition of 1 L sample of H_2O_2.

(c) Volume strength of H_2O_2 = Normality × (Equivalent weight of H_2O_2 =17)

(d) Normality of $H_2O_2 = \frac{\text{percentage strength}}{\text{Eq. wt. of } H_2O_2} \times 10$

(vii) Test of H_2O_2

(a) Changes black PbS to white $PbSO_4$.

(b) $\underset{\text{(orange)}}{K_2Cr_2O_7} + H_2O_2 \longrightarrow \underset{\text{(blue)}}{Cr_2O_5}$