# 9

# Hydrogen

## Multiple Choice Questions (MCQs)

**Q. 1** Hydrogen resembles halogens in many respects for which several factors are responsible. Of the following factors which one is most important in this respect?

(a) Its tendency to lose an electron to form a cation

(b) Its tendency to gain a single electron in its valence shell to attain stable electronic configuration

(c) Its low negative electron enthalpy value

(d) Its small size

**Ans.** *(b)* Hydrogen resembles halogens in many respects for which several factors are responsible. The most important is hydrogen like halogens accept an electron readily to achieve nearest inert gas configuration.

Inspite of the fact that hydrogen, to a certain extent resembles both with alkali metals and halogens.

**Q. 2** Why does $H^+$ ion always get associated with other atoms or molecules?

(a) Ionisation enthalpy of hydrogen resembles that of alkali metals

(b) Its reactivity is similar to halogens

(c) It resembles both alkali metals and halogens

(d) Loss of an electron from hydrogen atom results in a nucleus of very small size as compared to other atoms or ions. Due to small size it cannot exist free

**Ans.** *(d)* $H^+$ ion always get associated with other atoms or molecules. The reason is that loss of an electron from hydrogen atom results in a nucleus of very small size as compared to other atoms or ions. Due to small size it cannot exist free.

**Q. 3** Metal hydrides are ionic, covalent or molecular in nature. Among LiH, NaH, KH, RbH, CsH, the correct order of increasing ionic character is

(a) LiH > NaH > CsH > KH > RbH

(b) LiH < NaH < KH < RbH < CsH

(c) RbH > CsH > NaH > KH > LiH

(d) NaH > CsH > RbH > LiH > KH

**Ans.** *(b)* Metal hydrides are ionic, covalent or molecular in nature. Ionic character increases as the size of the atom increases or the electronegativity of the atom decreases. The correct order of increasing ionic character is

$$LiH < NaH < KH < RbH < CsH$$

**Q. 4** Which of the following hydrides is electron-precise hydride?

(a) $B_2H_6$ (b) $NH_3$ (c) $H_2O$ (d) $CH_4$

**Ans.** *(d)* Electron-precise hydrides contain exact number of electrons to form normal covalent bonds. *e.g.*, – $CH_4$ which has tetrahedral in geometry.

**Q. 5** Radioactive elements emit $\alpha$, $\beta$ and $\gamma$ rays and are characterised by their half-lives. The radioactive isotope of hydrogen is

(a) protium (b) deuterium (c) tritium (d) hydronium

**Thinking Process**

*To solve this problem, the point kept in mind that nucleids with n/p (neutron/proton) ratio > 1.5 are usually radioactive.*

**Ans.** *(c)* The radioactive isotope of hydrogen is tritium. For tritium ($n = 3$, $p = 1$), therefore $n/p$ ratio is 3.

**Q. 6** Consider the reactions

(i) $H_2O_2 + 2HI \longrightarrow I_2 + 2H_2O$

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

Which of the following statements is correct about $H_2O_2$ with reference to these reactions? Hydrogen peroxide is ......... .

(a) an oxidising agent in both (i) and (ii)

(b) an oxidising agent in (i) and reducing agent in (ii)

(c) a reducing agent in (i) and oxidising agent in (ii)

(d) a reducing agent in both (i) and (ii)

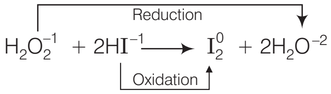
**Thinking Process**

*(i) Reducing agents are those substance (atoms, ions or molecules) which can readily lose electrons to other substance.*

*(ii) Oxidising agents are those substance (atoms, ions or molecules) which can readily accept electrons from other substance.*

**Ans.** *(b)*

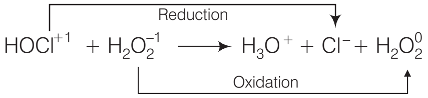
**(i)**



$$H_2O_2^{-1} + 2HI^{-1} \longrightarrow I_2^0 + 2H_2O^{-2}$$

Thus, here $H_2O_2$ oxidises HI into $I_2$ hence, it behaves as oxidising agent.

**(ii)**



$$HOCl^{+1} + H_2O_2^{-1} \longrightarrow H_3O^+ + Cl^- + H_2O_2^0$$

Here, $H_2O_2$ reduces HOCl to $Cl^{-1}$, thus, it acts as reducing agent.

**Q. 7 The oxide that gives $H_2O_2$ on treatment with dilute $H_2SO_4$ is**

| | |
|---|---|
| (a) $PbO_2$ | (b) $BaO_2.8H_2O + O_2$ |
| (c) $MnO_2$ | (d) $TiO_2$ |

**Ans.** ***(b)*** Oxides such as $BaO_2$, $Na_2O_2$ etc; which contain peroxide linkage (*i.e.,* – O – O or $O_2^{2-}$) on treatment with dilute $H_2SO_4$ give $H_2O_2$ but dioxides (O = *M* = O, where *M* is the metal atom) such as $PbO_2$, $MnO_2$, $TiO_2$ do not give $H_2O_2$ on treatment with dilute $H_2SO_4$.

$$\underset{\text{Hydrated barium peroxide}}{BaO_2 \cdot 8H_2O(s)} + H_2SO_4\,(aq) \longrightarrow BaSO_4(s) + \underset{\text{Hydrogen peroxide}}{H_2O_2(aq)} + 8H_2O(l)$$

**Q. 8 Which of the following equations depict the oxidising nature of $H_2O_2$?**

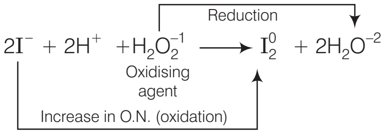
(a) $2MnO_4^- + 6H^+ + 5H_2O_2 \longrightarrow 2Mn^{2+} + 8H_2O + 5O_2$

(b) $2Fe^{3+} + 2H^+ + H_2O_2 \longrightarrow 2Fe^{2+} + 2H_2O + O_2$

(c) $2I^- + 2H^+ + H_2O_2 \longrightarrow I_2 + 2H_2O$

(d) $KIO_4 + H_2O_2 \longrightarrow KIO_3 + H_2O + O_2$

**Ans.** ***(c)*** The reaction in which $H_2O_2$ is reduced *i.e.,* oxidation state of oxygen decreases from –1 to –2 depicts the oxidising nature of $H_2O_2$. *e.g.,*



**Q. 9 Which of the following equation depicts reducing nature of $H_2O_2$?**

(a) $2[Fe(CN)_6]^{4-} + 2H^+ + H_2O_2 \longrightarrow 2[Fe\,(CN)_6]^{3-} + 2H_2O$

(b) $I_2 + H_2O_2 + 2OH^- \longrightarrow 2I^- + 2H_2O + O_2$

(c) $Mn^{2+} + H_2O_2 \longrightarrow Mn^{4+} + 2OH^-$

(d) $PbS + 4H_2O_2 \longrightarrow PbSO_4 + 4H_2O$

**Ans.** ***(b)*** $H_2O_2$ acts as an oxidising as well as reducing agent in alkaline media. *The given below reaction show the reducing action in basic medium*

$$I_2 + H_2O_2 + 2OH^- \longrightarrow 2I^- + 2H_2O + O_2$$

$$2MnO_4^- + 3H_2O_2 \longrightarrow 2MnO_2 + 3O_2 + 2H_2O + 2OH^-$$

**Q. 10 Hydrogen peroxide is ......... .**

(a) an oxidising agent

(b) a reducing agent

(c) both an oxidising and a reducing agent

(d) neither oxidising nor reducing agent

**Ans.** ***(c)*** Hydrogen peroxide acts as an oxidising as well as reducing agent in both acidic and alkaline media.

**Q. 11** Which of the following reactions increases production of dihydrogen from synthesis gas?

(a) $CH_4(g) + H_2O(g) \xrightarrow[\text{Ni}]{\text{1270 K}} CO(g) + 3H_2(g)$

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

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

(d) $C_2H_6 + 2H_2O \xrightarrow[\text{Ni}]{\text{1270 K}} 2CO + 5H_2$

**Ans.** ***(c)*** The process of producing syn gas or synthesis gas from coal is called 'coal gasification'.

$$\underset{\text{Coal}}{C(s)} + \underset{\text{Steam}}{H_2O(g)} \xrightarrow[\text{Ni}]{\text{1270 K}} \underbrace{CO(g) + H_2(g)}_{\text{Syn gas}}$$

The production of hydrogen can be increased by reacting carbon monoxide of the syn gas with steam in the presence of iron chromate as a catalyst at 673 K.

$$CO(g) + H_2O(g) \xrightarrow{FeCrO_4,\ 673\text{ K}} CO_2(g) + H_2(g)$$

$CO_2$ is removed by scrubbing with a solution of sodium arsenite.

**Q. 12** When sodium peroxide is treated with dilute sulphuric acid, we get ......... .

(a) sodium sulphate and water
(b) sodium sulphate and oxygen
(c) sodium sulphate, hydrogen and oxygen
(d) sodium sulphate and hydrogen peroxide

**Ans.** ***(d)*** When sodium peroxide is treated with dilute sulphuric acid, we get sodium sulphate and hydrogen peroxide

$$Na_2O_2 + \text{dil. } H_2SO_4 \longrightarrow Na_2SO_4 + H_2O_2$$

**Q. 13** Hydrogen peroxide is obtained by the electrolysis of ......... .

(a) water
(b) sulphuric acid
(c) hydrochloric acid
(d) fused sodium peroxide

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

$$2HSO_4^-(aq) \xrightarrow{\text{Electrolysis}} HO_3SOOSO_3H(aq) \xrightarrow{\text{Hydrolysis}} 2HSO_4^-(aq) + 2H^+(aq) + H_2O_2(aq)$$

**Q. 14** Which of the following reactions is an example of use of water gas in the synthesis of other compounds?

(a) $CH_4(g) + H_2O(g) \xrightarrow[\text{Ni}]{\text{1270 K}} CO(g) + H_2(g)$

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

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

(d) $CO(g) + 2H_2(g) \xrightarrow[\text{Catalyst}]{\text{Cobalt}} CH_3OH(l)$

**Ans.** *(d)* The water gas is the combination of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \xrightarrow[\text{Catalyst}]{\text{Cobalt}} CH_3OH(l)$$

It is an example of water gas used in the synthesis of methanol.

**Q. 15** Which of the following ions will cause hardness in water sample?

(a) $Ca^{2+}$ (b) $Na^+$ (c) $Cl^-$ (d) $K^+$

**Ans.** *(a)* Bicarbonates, chlorides and sulphates of Ca and Mg are responsible for the hardness of water.

**Note** *Hard water forms scum/precipitate with soap. Soap containing sodium stearate* ($C_{17}H_{35}COONa$) *reacts with hard water to precipitate out Ca/Mg stearate.*

$$2C_{17}H_{35}COONa\ (aq) + M^{2+}(aq) \longrightarrow (C_{17}H_{35}COO)_2M\downarrow$$
$$+\ 2Na^+(aq)\ (\text{where, } M = Ca/Mg)$$

*It is unsuitable for laundry and boilers.*

**Q. 16** Which of the following compounds is used for water softening?

(a) $Ca_3(PO_4)_2$ (b) $Na_3PO_4$ (c) $Na_6P_6O_{18}$ (d) $Na_2HPO_4$

**Ans.** *(c)* For water softening, sodium hexametaphosphate is used. The chemical formula is $Na_2[Na_4(PO_3)_6] = Na_6P_6O_{18}$. The trade name is calgon.

$$\underset{\text{(From hard water)}}{2CaCl_2} + \underset{\text{Sodium hexametaphosphate}}{Na_2[Na_4(PO_3)_6]} \rightarrow \underset{\text{Complex salt (soluble)}}{Na_2[Ca_2(PO_3)_6]} + 4NaCl$$

**Q. 17** Elements of which of the following group(s) of periodic table do not form hydrides?

(a) Groups 7, 8, 9 (b) Group 13

(c) Groups 15, 16, 17 (d) Group 14

**Ans.** *(a)* Dihydrogen forms molecular compounds with most of the *p*-block elements. Most familiar examples are $CH_4$, $NH_3$, $H_2O$ and HF. For convenience hydrogen compounds of non-metals have also been considered as hydrides.

**Q. 18** Only one element of ......... forms hydride.

(a) group 6 (b) group 7 (c) group 8 (d) group 9

**Ans.** *(a)* Only one element of group 6, *i.e.,* Cr forms hydride.

**Note** *Metallic (or interstitial) hydrides 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.*

## Multiple Choice Questions (More Than One Options)

**Q. 19** Which of the following statements are not true for hydrogen?

(a) It exists as diatomic molecule
(b) It has one electron in the outermost shell
(c) It can lose an electron to form a cation which can freely exist
(d) It forms a large number of ionic compounds by losing an electron

**Ans.** *(c, d)*

$H^+$ does not exist freely and is always associated with other atoms or molecules.

Like alkali metals, hydrogen forms oxides, halides and sulphides. However, unlike alkali metals, it has a very high ionisation enthalpy and does not possess metallic characteristics under normal conditions.

**Q. 20** Dihydrogen can be prepared on commercial scale by different methods. In its preparation by the action of steam on hydrocarbons, a mixture of CO and $H_2$ gas is formed. It is known as ......... .

(a) water gas (b) syn gas (c) producer gas (d) industrial gas

**Ans.** *(a, b)*

Dihydrogen can be prepared on commercial scale by different methods. Reaction of steam on hydrocarbons or coke at high temperatures in the presence of catalyst yield hydrogen.

$$C_nH_{2n+2} + nH_2O + 2 \xrightarrow[\text{Ni}]{1270\text{ K}} nCO_2 + (2n+1)H_2$$

*e.g.,*

$$CH_4(g) + H_2O(g) \xrightarrow[\text{Ni}]{1270\text{ K}} CO(g) + 3H_2(g)$$

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 'syn gas'.

**Q. 21** Which of the following statement(s) is/are correct in the case of heavy water?

(a) Heavy water is used as a moderator in nuclear reactor
(b) Heavy water is more effective as solvent than ordinary water
(c) Heavy water is more associated than ordinary water
(d) Heavy water has lower boiling point than ordinary water

**Ans.** *(a, c)*

Heavy water is used as moderator in nuclear reactor. Boiling point of heavy water is higher than ordinary water and it is not as effective in the form of solvent as water due to its low dielectric constant.

**Q. 22** Which of the following statements about hydrogen are correct?

(a) Hydrogen has three isotopes of which protium is the most common
(b) Hydrogen never acts as cation in ionic salts
(c) Hydrogen ion, $H^+$, exists freely in solution
(d) Dihydrogen does not act as a reducing agent

**Ans.** *(a, b)*

Among the three isotopes of hydrogen, protonium is the most common. In ionic salts, hydrogen exists as hydride ($H^-$).

**Q. 23** Some of the properties of water are described below. Which of them is/are not correct?

(a) Water is known to be a universal solvent

(b) Hydrogen bonding is present to a large extent in liquid water

(c) There is no hydrogen bonding in the frozen state of water

(d) Frozen water is heavier than liquid water

**Ans.** *(c, d)*

There is H-bonding even in frozen state of water, *i.e.,* ice is lighter than liquid water.

The crystalline form of water is ice. At atmospheric pressure, ice crystallises in the hexagonal form, but at very low temperatures it condenses to cubic form. Density of ice is less than that of water. Therefore, an ice cube floats on water.

**Q. 24** Hardness of water may be temporary or permanent. Permanent hardness is due to the presence of

(a) chlorides of Ca and Mg in water

(b) sulphates of Ca and Mg in water

(c) hydrogen carbonates of Ca and Mg in water

(d) carbonates of alkali metals in water

**Ans.** *(a, b)*

Permanent hardness 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.

**Q. 25** Which of the following statements is correct?

(a) Elements of group 15 form electron deficient hydrides

(b) All elements of group 14 form electron precise hydrides

(c) Electron precise hydrides have tetrahedral geometries.

(d) Electron rich hydrides can act as Lewis acids.

**Ans.** *(b, c)*

Electron precise compounds have the required number of electrons to write their conventional Lewis structures. All elements of group 14 forms electron-precise compounds (*e.g.,* $CH_4$) which are tetrahedral in geometry.

**Q. 26** Which of the following statements is correct?

(a) Hydrides of group 13 act as Lewis acids

(b) Hydrides of group 14 are electron deficient hydrides

(c) Hydrides of group 14 act as Lewis acids

(d) Hydrides of group 15 act as Lewis bases

**Ans.** *(a, d)*

All elements of group 13 will form electrondeficient compounds which acts as Lewis acids.

All elements of group 14 will form electronprecise compounds.

Electronrich hydrides have excess electrons which are present as lone pairs. Elements of group 15-17 forms such compounds. $NH_3$ has 1-lone pair, $H_2O$-2 and HF-3 lone pairs act as Lewis bases.

**Q. 27** Which of the following statements is correct?

(a) Metallic hydrides are deficient of hydrogen
(b) Metallic hydrides conduct heat and electricity
(c) Ionic hydrides do not conduct electricity in solid state
(d) Ionic hydrides are very good conductors of electricity in solid state

**Ans.** *(a, b, c)*

The ionic hydrides are crystalline, non-volatile and non-conducting in solid state. However, their molten state conduct electricity.

## Short Answer Type Questions

**Q. 28** How can production of hydrogen from water gas be increased by using water gas shift reaction?

**Ans.** Water gas is produced when superheated steam is passed over red hot coke or coal at 1270 K in presence of nickel as catalyst.

$$\underset{\text{Coke}}{C(s)} + \underset{\text{Steam}}{H_2O\,(g)} + 121.3\,\text{kJ} \xrightarrow[\text{Nickel}]{1270\text{ K}} \underbrace{CO\,(g) + H_2(g)}_{\text{Water gas}}$$

It is inconvinient to obtain pure $H_2$ from water gas as CO is difficult to remove. Hence, to increase the production of $H_2$ from water gas, CO is oxidised to $CO_2$ by mixing it with more steam and passing the mixture over $FeCrO_4$ catalyst at 673 K.

$$\underbrace{CO\,(g) + H_2(g)}_{\text{Water gas}} + \underset{\text{Steam}}{H_2O\,(g)} \xrightarrow[FeCrO_4]{673\text{ K}} CO_2(g) + 2H_2(g)$$

This is called water-gas shiff reaction. Carbon dioxide is removed by scrubbing with mixture of sodium arsenite solution or by passing the mixture through water under 30 atm pressure when $CO_2$ dissolves leaving behind $H_2$ which is collected.

**Q. 29** What are metallic/interstitial hydrides? How do they differ from molecular hydrides?

**Ans.** Metallic/interstitial hydrides are formed by many *d*-block and *f*-block elements. These hydrides conduct heat and electricity.

Unlike saline hydride, they are almost always non-stoichiometric, being deficient in hydrogen. *e.g.*, $LaH_{2.87}$, $YbH_{2.55}$, $TiH_{1.5-1.8}$, $ZrH_{1.3-1.75}$, $VH_{0.56}$, $NiH_{0.6\text{-}0.7}$, $PdH_{0.6\text{-}0.8}$ etc. In such hydrides, the law of constant composition does not hold good.

*Comparision between molecular and metallic hydrides*

| **Molecular hydrides** | **Metallic hydrides** |
|---|---|
| These are mainly formed by *p*-block elements and some *s*-block elements (Be and Mg). | These are formed by group 3, 4, 5 (Sc, Ti, V, Y, Zr, Nb, La, Hf, Ta, Ac etc.,) 10, 11, 12 (Pd, Cu, Zn etc.,) and *f*-block elements (Ce, Eu, Yb, Th, U etc.) |
| Those are usually volatile compounds having low melting and boiling point. | These are hard, have a metallic lustre. |
| It conduct electricity. | These do not conduct electricity. |

## Q. 30 Name the classes of hydrides to which $H_2O$, $B_2H_6$ and NaH belong.

**Ans.** $H_2O$ — Covalent or molecular hydride (electron rich hydride).

$B_2H_6$ — Covalent or molecular hydride (electron deficient hydride).

NaH — Ionic or saline hydride.

***Note*** *Molecular hydrides are further classified according to the relative number of electrons and bonds in their Lewis structures.*

*(i) Electron deficient hydride has too few electrons for writing its conventional Lewis structure.*

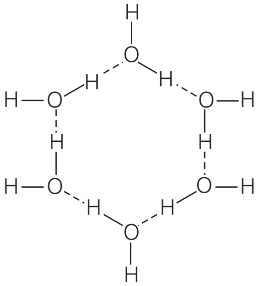
*(ii) Electron precise compounds have the required number of electrons to write their conventional Lewis structures.*

*(iii) Electron rich hydrides have excess electrons which are present as lone pairs.*

## Q. 31 If same mass of liquid water and a piece of ice is taken, then why is the density of ice less than that of liquid water?

**Ans.** In ice, molecules of $H_2O$ are not packed so closely as in liquid water. There exists vacant spaces in the crystal lattice. This results in larger volume and lower density (density = mass/volume).

In other words, density of ice is lower than liquid water and hence ice floats on water.



Hexagonal honey comb structure of ice

## Q. 32 Complete the following equations

(i) $PbS(s) + H_2O_2(aq) \longrightarrow$

(ii) $CO(g) + 2H_2(g) \xrightarrow[\text{catalyst}]{\text{Cobalt}}$

**Ans.** **(i)** When PbS react with hydrogen peroxide, then $PbSO_4$ and water are formed.

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

**(ii)** When carbon mono-oxide reacts with hydrogen in the presence of cobalt catalyst, then methanol is formed.

$$CO(g) + 2H_2(g) \xrightarrow[\text{catalyst}]{\text{Cobalt}} CH_3OH(l)$$

## Q. 33 Give reasons

(i) Lakes freeze from top towards bottom.

(ii) Ice floats on water.

**Ans.** **(i)** Density of ice is less than that of liquid water. During severe winter, the temperature of lake water keeps on decreasing. Since, cold water is heavier, therefore, it moves towards bottom of the lake and warm water from the bottom moves towards surface. This process continues. The density of water is maximum at 277 K.

Therefore, any further decrease in temperature of the surface water will decrease in density. The temperature of surface water keeps on decreasing and ultimately it freezes.

Thus, the ice layer at lower temperature floats over the water below it. Due to this, freezing of water into ice takes place continuously from top towards bottom.

**(ii)** Density of ice is less than that of liquid water, so it floats over water.

## Q. 34 What do you understand by the term 'auto-protolysis' of water? What is its significance?

**Ans.** Auto-protolysis means self ionisation of water.

$$\underset{\text{Acid}_1}{H_2O\,(l)} + \underset{\text{Base}_2}{H_2O\,(l)} \rightleftharpoons \underset{\text{Acid}_2}{H_3O^+(aq)} + \underset{\text{Base}_1}{OH^-(aq)}$$

Due to auto-protolysis, water is amphoteric in nature. It reacts with both acids and bases.

*e.g.,*

$$\underset{\text{Acid}_1}{H_2O(l)} + \underset{\text{Base}_2}{NH_3(aq)} \longrightarrow \underset{\text{Acid}_2}{NH_4^+(aq)} + \underset{\text{Base}_1}{OH^-(aq)}$$

$$\underset{\text{Base}_1}{H_2O(l)} + \underset{\text{Acid}_2}{H_2S(aq)} \longrightarrow \underset{\text{Acid}_1}{H_3O^+(aq)} + \underset{\text{Base}_2}{HS^-(aq)}$$

## Q. 35 Discuss briefly de-mineralisation of water by ion exchange resin.

**Ans.** Water which is free from all soluble minerals salts is called demineralised water. Demineralised water is obtained by passing water successively through a cation exchange and an anion exchange resins.

In cation exchanger, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ and other cations present in water are removed by exchanging them with $H^+$ ions while in anion exchanger, $Cl^-$, $HCO_3^-$, $SO_4^{2-}$, etc., present in water are removed by exchanging them with $OH^-$ ions.

$$\underset{\text{(Released in cation exchanger)}}{H^+} + \underset{\text{(Released in anion exchanger)}}{OH^-} \longrightarrow H_2O$$

Synthetic ion exchange resins are of two types.

Cation exchange resins contain large organic molecule with $SO_3H$ group and are water soluble. It is changed to $R$Na by treating it with NaCl. The resin $R$Na exchanges $Mg^{2+}$ and $Ca^{2+}$ ions present in hard water to make the water soft.

$$2RNa(s) + M^{2+}(aq) \longrightarrow R_2M(s) + 2Na^+(aq) \quad (M = Ca^{2+} \text{ or } Mg^{2+})$$

The resin can be regenerated by passing NaCl (aqueous solution) in it.

Pure demineralised (deionised) water is obtained by passing water successively through a cation exchange and anion exchange resins. In the cation exchange process,

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

(Cation exchange resin in the $H^+$ form)

$H^+$ exchanges for $Ca^{2+}$, $Mg^{2+}$ and other cations present in water.

This process results in proton release and thus, makes the water acidic. In the anion exchange process

$$RNH_2(s) + H_2O(l) \rightleftharpoons R\overset{+}{N}H_3 \cdot OH^-(s)$$

$R\overset{+}{N}H_3 \cdot OH^-$ is substituted ammonium hydroxide anion exchange resin.

$$R\overset{+}{N}H_3 \cdot OH^-(s) + X^-(aq) \rightleftharpoons R\overset{+}{N}H_3 \cdot X^-(s) + OH^-(aq)$$

## Q. 36 Molecular hydrides are classified as electron deficient, electron precise and electron rich compounds. Explain each type with two examples.

**Ans.** *Molecular hydrides are classified according to the relative numbers of electrons and bonds in Lewis structure as follow*

(i) **Electron deficient hydrides** These type of hydrides contain central atom with incomplete octet. These are formed by 13 group elements, *e.g.,* $BH_3$, $AlH_3$, etc. To complele their octet they generally exist in polymeric forms such as $B_2H_6$, $B_4H_{10}$, $(AlH_3)_n$ etc. These hydrides act as Lewis acids.

(ii) **Electron precise hydrides** These hydrides have exact number of electrons required to form normal covalent bonds. These are formed by 14 group elements, *e.g.,* $CH_4$, $SiH_4$, etc. These are tetrahedral in shape.

(iii) **Electron rich hydrides** These hydrides contain central atom with excess electrons, which are present as ione pairs.

These are formed by 15, 16 and 17 group elements, *e.g.,* $NH_3$, $H_2O$, HF, etc. These hydrides act as Lewis bases.

## Q. 37 How is heavy water prepared? Compare its physical properties with those of ordinary water.

**Ans.** Heavy water is prepared by prolonged electrolysis of water. *Comparison of physical properties of heavy water with those of ordinary water is as follows*

| **Property** | **$H_2O$** | **$D_2O$** |
|---|---|---|
| Molecular mass (g $mol^{-1}$) | 18.0151 | 20.0276 |
| Melting point (K) | 273.0 | 276.8 |
| Boiling point (K) | 373.0 | 374.4 |
| Enthalpy of formation (kJ $mol^{-1}$) | – 285.9 | – 294.6 |
| Enthalpy of vaporisation – 373 K (kJ $mol^{-1}$) | 40.66 | 41.61 |
| Enthalpy of fusion (kJ $mol^{-1}$) | 6.01 | — |
| Temperature of max. density (K) | 276.98 | 284.2 |
| Density at 298 K (g $cm^{-3}$) | 1.0000 | 1.1059 |
| Viscosity (centipoise) | 0.8903 | 1.107 |
| Dielectric constant ($C^2$ $/Nm^2$) | 78.39 | 78.06 |
| Electrical conductivity at 298 K ($ohm^{-1}$ $cm^{-1}$) | $5.7 \times 10^{-8}$ | — |

## Q. 38 Write one chemical reaction for the preparation of $D_2O_2$.

**Ans.** The one chemical reaction for the preparation of $D_2O_2$ is by the action of $D_2SO_4$ dissolved in water over $BaO_2$.

$$BaO_2 + D_2SO_4 \longrightarrow BaSO_4 + D_2O_2$$

## Q. 39 Calculate the strength of 5 volumes $H_2O_2$ solution.

**Ans.** By definition, 5 volumes $H_2O_2$ solution means that 1 L of this $H_2O_2$ solution on decomposition produces 5 L of $O_2$ at STP.

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$
$$2 \times 34 \text{ g} \longrightarrow 22.7 \text{ L at STP}$$

If 22.7 L $O_2$ at STP will be obtained from $H_2O_2$ = 68 g

$\therefore$ 5 L of $O_2$ at STP will be obtained from $H_2O_2 = \dfrac{68 \times 5}{22.7}$ g = 14.98 = 15 g

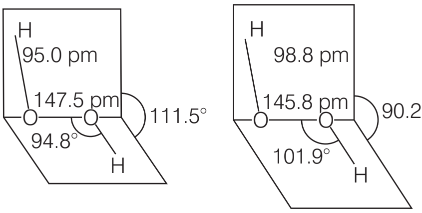
$\therefore$ Strength of $H_2O_2$ in 5 volume $H_2\ O_2$ solution = 15 g $L^{-1}$.

$\Rightarrow$ Percentage strength of $H_2O_2$ solution $= \dfrac{15}{1000} \times 100 = 1.5\%$

Therefore, strength of $H_2O_2$ in 5 volume $H_2O_2$ solution = 15 g/L = 1.5% $H_2O_2$ solution.

**Q. 40** (i) Draw the gas phase and solid phase structure of $H_2O_2$.
(ii) $H_2O_2$ is a better oxidising agent than water. Explain.

**Ans.** **(i)** $H_2O_2$ has a non-planar structure. *The molecular dimensions in the gas phase and solid phase are given below*



**(a) gas phase** **(b) solid phase**

(a) $H_2O_2$ structure in gas phase, dihedral angle is 111.5°.

(b) $H_2O_2$ structure in solid phase at 110 K, dihedral angle is 90.2°.

**(ii)** $H_2O_2$ is better oxidising agent than water as discussed below

(a) $H_2O_2$ oxidises an acidified solution of KI to give $I_2$ which gives blue colour with starch solution but $H_2O$ does not.

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

(b) $H_2O_2$ turns black PbS to white $PbSO_4$ but $H_2O$ does not.

$$PdS + 4H_2O_2 \rightarrow PbSO_4 + 4H_2O.$$

**Q. 41** Melting point, enthalpy of vaporisation and viscosity data of $H_2O$ and $D_2O$ is given below

| | $H_2O$ | $D_2O$ |
|---|---|---|
| Melting point/K | 373.0 | 374.4 |
| Enthalpy of vaporisation at (373 K)/kJ $mol^{-1}$ | 40.66 | 41.61 |
| Viscosity/centipoise | 0.8903 | 1.107 |

On the basis of this data explain in which of these liquids intermolecular forces are stronger?

**Thinking Process**

*The data given in the question shows that melting point, enthalpy of vaporisation and viscosity of $D_2O$ is more than that of $H_2O$. The intermolecular force is directly proportional to these three parameters.*

**Ans.** Given that,

| | $H_2O$ | $D_2O$ |
|---|---|---|
| Melting point/K | 373.0 | 374.4 |
| Enthalpy of vaporisation at (373 K)/kJ mol$^{-1}$ | 40.66 | 41.61 |
| Viscosity/centipose | 0.8903 | 1.107 |

From this data, it is concluded that the values of melting point, enthalpy of vaporisation and viscosity depend upon the intermolecular forces of attraction.

Since, their values are higher for $D_2O$ as compared to those of $H_2O$, therefore, intermolecular forces of attraction are stronger in $D_2O$ than in $H_2O$.

**Q. 42** Dihydrogen reacts with dioxygen ($O_2$) to form water. Write the name and formula of the product when the isotope of hydrogen which has one proton and one neutron in its nucleus is treated with oxygen. Will the reactivity of both the isotopes be the same towards oxygen? Justify your answer.

**Ans.** The isotope of hydrogen which contains one proton and one neutron is deuterium (D). Therefore, when dideuterium reacts with dioxygen, heavy water ($D_2O$) is produced.

$$\underset{\text{Dideuterium}}{2D_2(g)} + \underset{\text{Dioxygen}}{O_2(g)} \xrightarrow{\text{Heat}} \underset{\substack{\text{Deuterium oxide}\\\text{(Heavy water)}}}{2D_2O}$$

The reactivity of $H_2$ and $D_2$ towards oxygen will be different. Since, the D—D bond is stronger than H—H bond, therefore, $H_2$ is more reactive than $D_2$.

**Q. 43** Explain why HCl is a gas and HF is a liquid?

**Ans.** F is smaller and more electronegative than Cl, so it forms stronger H-bonds as compared to Cl. As the consequence, more energy is needed to break the H-bonds in HF than HCl and hence the boiling point of HF is higher than that of HCl.

That's why HF is liquid and HCl is a gas.

**Q. 44** When the first element of the periodic table is treated with dioxygen, it gives a compound whose solid state floats on its liquid state. This compound has an ability to act as an acid as well as a base. What products will be formed when this compound undergoes autoionisation?

**Ans.** The first element of the periodic table is hydrogen and its molecular form is dihydrogen ($H_2$). When $H_2$ reacts with $O_2$, water is formed. Water is a liquid at room temperature. When liquid water freezes, it expands to form ice.

Density of ice is lower than that of liquid water and hence ice floats over water. Water is amphoteric in nature. It acts as a base in presence of strong acids and as an acid in presence of strong bases.

$$\underset{\text{Base}_1}{H_2O\ (l)} + \underset{\text{Acid}_2}{H_2S\ (aq)} \longrightarrow \underset{\text{Acid}_1}{H_3O^+\ (aq)} + \underset{\text{Base}_2}{HS^-(aq)}$$

$$\underset{\text{Acid}_1}{H_2O\ (l)} + \underset{\text{Base}_2}{NH_3\ (aq)} \longrightarrow \underset{\text{Acid}_2}{NH_4^+\ (aq)} + \underset{\text{Base}_1}{OH^-\ (aq)}$$

Due to amphoteric character, water undergoes self ionisation as shown below

$$\underset{\text{Acid}_1}{H_2O\ (l)} + \underset{\text{Base}_2}{H_2O\ (aq)} \rightleftharpoons \underset{\substack{\text{Acid}_2\\\text{(Conjugate}\\\text{acid)}}}{H_3O^+\ (aq)} + \underset{\substack{\text{Base}_1\\\text{(Conjugate}\\\text{base)}}}{OH^-\ (aq)}$$

This self ionisation of water is called auto-protolysis or autoionisation.

**Q. 45** Rohan heard that instructions were given to the laboratory attendent to store a particular chemical, *i.e.,* keep it in the dark room, add some urea in it, and keep it away from dust. This chemical acts as an oxidising as well as a reducing agent in both acidic and alkaline media. This chemical is important for use in the pollution control treatment of domestic and industrial effluents.

(i) Write the name of this compound.

(ii) Explain why such precautions are taken for storing this chemical.

**Ans.** **(i)** The name of the compound is hydrogen peroxide, $H_2O_2$. It acts as an oxidising agent as well as reducing agent in both acidic and basic medium.

**(ii)** $H_2O_2$ decomposes slowly on exposure to light and dust particles. In the presence of metal surfaces or traces of alkali present in glass containers, the decomposition of $H_2O_2$ is catalysed.

It is, therefore, stored in wax lined glass or plastic vessels in dark. Urea is added as a negative catalyst or stabiliser to check its decomposition.

$$2\,H_2O_2(l) \xrightarrow{h\nu} 2\,H_2O\,(l) + O_2(g)$$

**Q. 46** Give reasons why hydrogen resembles alkali metals?

**Ans.** *Hydrogen resembles alkali metals, i.e.,* Li, Na, K, Rb, Cs *and* Fr *of* group I *of the periodic table in the following respects*

(i) Like alkali metals, hydrogen also contain one electron in its outermost (valence) shell and exhibit +1 oxidation state.

(ii) Like alkali metals, hydrogen also loses its only electron to form hydrogen ion, *i.e.,* $H^+$ (proton).

(iii) Like alkali metals, hydrogen combines with electronegative elements (non-metals) such as oxygen, halogens and sulphur forming their oxides, halides and sulphides respectively.

(iv) Like alkali metals, hydrogen also acts as a strong reducing agent.

**Q. 47** Hydrogen generally forms covalent compounds. Give reason.

**Ans.** Hydrogen has one electron which it can either lose or gain or share to acquire noble gas, *i.e.,* helium gas configuration.

Therefore, in principle, it can form either ionic or covalent bonds. But the ionisation enthalpy of hydrogen is very high (1312 kJ $mol^{-1}$) and its electron gain enthalpy is only slightly negative (–73 kJ $mol^{-1}$).

From this consequence, it does not have a high tendency to form ionic bonds but rather prefers to form only covalent bonds.

**Q. 48** Why is the ionisation enthalpy of hydrogen higher than that of sodium?

**Ans.** The ionisation enthalpy of hydrogen higher than that of sodium. Both hydrogen and sodium have one electron in the valence shell. But the size of hydrogen is much smaller than that of sodium and hence, the ionisation enthalpy of hydrogen is much higher (1312 kJ $mol^{-1}$) than that of sodium (496 kJ $mol^{-1}$).

**Q. 49** **Basic principle of hydrogen economy is transportation and storage of energy in the form of liquid or gaseous hydrogen. Which property of hydrogen may be useful for this purpose? Support your answer with the chemical equation if required.**

**Ans.** Basic principle of hydrogen economy is transportation and storage of energy in the form of liquid or gaseous hydrogen. Hydrogen is a gas at room temperature.

However, by cooling and applying high pressure, gaseous $H_2$ can be converted into liquid $H_2$ which has much smaller volume and hence can be transported easily. Thus, the basic property of hydrogen which is useful for hydrogen economy is that it can be converted into a liquid by cooling under high pressure.

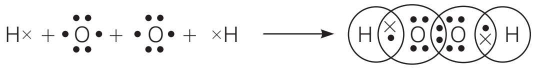
**Q. 50** **What is the importance of heavy water?**

**Ans.** *Following are the importance of heavy water*

(i) It is extensively used as a moderator in nuclear reactors.
(ii) It is used as a tracer compound in the study of reaction mechanism.
(iii) It is used for the preparation of other deuterium compounds such as $CD_4$, $D_2SO_4$, etc.

**Q. 51** **Write the Lewis structure of hydrogen peroxide.**

**Ans.** The Lewis structure of hydrogen peroxide is



Hydrogen peroxide

**Q. 52** **An acidic solution of hydrogen peroxide behaves as an oxidising as well as reducing agent. Illustrate it with the help of a chemical equation.**

**Ans.** *Following are the chemical equation of* $H_2O_2$ *in which it behaves as an oxidising as well as reducing agent*

(i) $H_2O_2$ oxidises acidified KI to iodine.

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

(ii) $H_2O_2$ reduces $KMnO_4$ to $MnO_2$ in alkaline medium.

$$2\,KMnO_4 + 3H_2O_2 \longrightarrow 2MnO_2 + 2KOH + 3O_2 + 2H_2O$$

**Q. 53** **With the help of suitable examples, explain the property of $H_2O_2$ that is responsible for its bleaching action?**

**Ans.** The bleaching action of hydrogen peroxide is due to the nascent oxygen which it liberates on decomposition.

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

The nascent oxygen combines with colouring matter, in turn, gets oxidised. Thus, the bleaching action of $H_2O_2$ is due to the oxidation of colouring matter by nascent oxygen. It is used for the bleaching of delicate materials like ivory, feathers, silk, wool etc.

$$\text{Colouring matter} + [O] \longrightarrow \text{Colourless matter}$$

**Q. 54** **Why is water molecule polar?**

**Ans.** Oxygen is more electronegative (EN=3.5) than hydrogen (EN = 2.1) hence, O — H bond is polar. In the water molecule, two polar O — H bonds are present which are held together at an angle of 104.5°. Due to the resultant of these two dipoles, water molecule is polar and has an dipole moment of 1.84 Debye.

### Q. 55 Why does water show high boiling point as compared to hydrogen sulphide? Give reasons for your answer.

**Ans.** Water show high boiling point as compared to hydrogen sulphide due to high electronegativity of oxygen (EN = 3.5). Water undergoes extensive H — bonding as a result of which water exists as associated molecule.

For breaking these hydrogen bond, a large amount of energy is needed and hence the boiling point of $H_2O$ is high.

In other words, due to lower electronegativity of S (EN = 2.5), hydrogen sulphide do not undergo H-bonding. Consequently, $H_2S$ exists as discrete molecule and hence its boiling point is much lower than that of $H_2O$. Thats why $H_2S$ is a gas at room temperature.

### Q. 56 Why can dilute solutions of hydrogen peroxide not be concentrated by heating? How can a concentrated solution of hydrogen peroxide be obtained?

**Ans.** Dilute solutions of $H_2O_2$ cannot be concentrated by heating because it decomposes much below its boiling point.

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

1% $H_2O_2$ is extracted with water and concentrated to ~ 30% (by mass) by distillation under reduced pressure. It can be further concentrated to ~ 85% by careful distillation under low pressure. The remaining water can be frozen out to obtain pure $H_2O_2$.

### Q. 57 Why is hydrogen peroxide stored in wax lined bottles?

**Ans.** Hydrogen peroxide is decomposed by rough surfaces of glass, alkali oxides present in it and light to form $H_2O$ and $O_2$.

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

To prevent this decomposition, hydrogen peroxide is usually stored in paraffin wax coated plastic or teflon bottles.

### Q. 58 Why does hard water not form lather with soap?

**Ans.** Hard water contains salts of calcium and magnesium ions. Hard water does not give lather with soap and forms scum/precipitate with soap. Soap containing sodium stearate ($C_{17}H_{35}COONa$) reacts with hard water to precipitate out as Ca/Mg stearate.

$$2C_{17}H_{35}COONa\,(aq) + M^{2+}\,(aq) \longrightarrow (C_{17}H_{35}COO)_2M\downarrow + 2Na^+\,(aq)$$

(where, $M$ is Ca/Mg)

It is therefore, unsuitable for laundry.

### Q. 59 Phosphoric acid is preferred over sulphuric acid in preparing hydrogen peroxide from peroxides. Why?

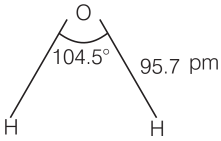
**Ans.** $H_2SO_4$ acts as a catalyst for decomposition of $H_2O_2$. Therefore, some weaker acids such as $H_3PO_4$, $H_2CO_3$ is preferred over $H_2SO_4$ for preparing $H_2O_2$ from peroxides.

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

**Q. 60** How will you account for 104.5° bond angle in water?

**Ans.** In water, oxygen has $sp^3$-hybridisation and the bond angle of HOH should have been 109°28′. In $H_2O$, the oxygen atom is surrounded by two shared pairs and two lone pairs of electrons. From VSEPR theory, lone pair - lone pair repulsions are stronger than bond pair–bond pair repulsions.

As a result, the bond angle of HOH in water slightly decreases from the regular tetrahedral angle of 109°. 28′ to 104.5°.



A bent structure of water

**Q. 61** Write redox reaction between fluorine and water.

**Ans.** Fluorine is a strong oxidising agent, it oxidises $H_2O$ to $O_2$ or $O_3$. *The reactions are as follows*

$$2\,F_2(g) + 2\,H_2O(l) \longrightarrow O_2(g) + 4H^+(aq) + 4F^-(aq)$$

$$3F_2(g) + 3\,H_2O(l) \longrightarrow O_3(g) + 6H^+(aq) + 6F^-(aq)$$

**Q. 62** Write two reactions to explain amphoteric nature of water.

**Ans.** Water has the ability to act as an acid as well as base, *i.e.*, it behaves as an amphoteric substance. From the Bronsted Lowry theory, it acts as an acid with $NH_3$ and a base with $H_2S$.

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

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

The auto - protolysis (self-ionisation) of water takes place. *The reaction are as follows*

$$\underset{\text{Acid}}{H_2O\ (l)} + \underset{\text{Base}}{H_2O\ (l)} \longrightarrow \underset{\text{Conjugate acid}}{H_3O^+\ (aq)} + \underset{\text{Conjugate base}}{OH^-\ (aq)}$$

## Matching The Columns

**Q. 63** Correlate the items listed in Column I with those listed in Column II. Find out as many correlations as you can.

| Column I | | Column II | |
|---|---|---|---|
| A. | Synthesis gas | 1. | $Na_2[Na_4(PO_3)_6]$ |
| B. | Dihydrogen | 2. | Oxidising agent |
| C. | Heavy water | 3. | Softening of water |
| D. | Calgon | 4. | Reducing agent |
| E. | Hydrogen peroxide | 5. | Stoichiometric compounds of *s*-block elements |
| F. | Salt like hydrides | 6. | Prolonged electrolysis of water |
| | | 7. | Zn + NaOH |
| | | 8. | Zn + dil. $H_2SO_4$ |
| | | 9. | Synthesis of methanol |
| | | 10. | Mixture of CO and $H_2$ |

**Ans.** **A.** → (9, 10) **B.** → (4, 5, 7, 8, 9) **C.** → (6) **D.** → (1, 3)
**E.** → (2, 4) **F.** → (5)

A. Synthesis gas — Synthesis of methanol
— Mixture of Co and $H_2$

B. Dihydrogen — Reducing agent
— Stoichiometric compounds of *s*-block elements
— Zn + NaOH
— Zn + dil. $H_2SO_4$
— Synthesis of methanol

C. Heavy water — Prolonged electrolysis of water

D. Calgon — $Na_2[Na_4(PO_3)_6]$
— Softening of water

E. Hydrogen peroxide — Oxidising agent
— Reducing agent

F. Salt like hydrides — Stoichiometric compounds of *s*-block elements.

**Q. 64** Match Column I with Column II for the given properties/applications mentioned therein.

| Column I | Column II |
|---|---|
| A. H | 1. used in the name of perhydrol. |
| B. $H_2$ | 2. can be reduced to dihydrogen by NaH. |
| C. $H_2O$ | 3. can be used in hydroformylation of olefin. |
| D. $H_2O_2$ | 4. can be used in cutting and welding. |

**A.** → (4) **B.** → (3) **C.** → (2) **D.** → (1)

A. Atomic hydrogen (H) can be used in cutting and welding.
B. Dihydrogen ($H_2$) can be used in hydroformylation of olefin.
C. Water ($H_2O$) can be reduced to dihydrogen by NaH.
D. Hydrogen peroxide ($H_2O_2$) used in the name of perhydrol.

**Q. 65** Match the terms in Column I with the relevant item in Column II.

| Column I | Column II |
|---|---|
| A. Electrolysis of water produces | 1. atomic reactor |
| B. Lithium aluminium hydride is used as | 2. polar molecule |
| C. Hydrogen chloride is a | 3. recombines on metal surface to generate high temperature |
| D. Heavy water is used in | 4. reducing agent |
| E. Atomic hydrogen | 5. hydrogen and oxygen |

**Ans.** **A.** → (5) **B.** → (4) **C.** → (2) **D.** → (1) **E.** → (3)

A. Electrolysis of water produce hydrogen and oxygen.
B. Lithium aluminium hydride is used as reducing agent.
C. Hydrogen chloride is a polar molecule.
D. Heavy water is used in atomic reactor as moderator.
E. Atomic hydrogen recombines on metal surface to generate high temperature.

**Q. 66** Match the items in Column I with the relevant item in Column II.

| Column I | | Column II | |
|---|---|---|---|
| A. | Hydrogen peroxide is used as a | 1. | zeolite |
| B. | Used in Calgon method | 2. | perhydrol |
| C. | Permanent hardness of hard water is removed by | 3. | sodium hexametaphosphate |
| | | 4. | propellant |

**Ans.** **A.** → (2, 4) **B.** → (3) **C.** → (1, 3)

A. Hydrogen peroxide is used as a perhydrol and propellant.

B. Sodium hexametaphosphate is used in Calgon method.

C. Permanent hardness of hard water is removed by zeolite and sodium hexametaphosphate.

## Assertion and Reason

*In the following questions a statement of Assertion* (A) *followed by a statement of Reason* (R) *is given. Choose the correct option out of the options given below in each question.*

**Q. 67** **Assertion** (A) Permanent hardness of water is removed by treatment with washing soda.

**Reason** (R) Washing soda reacts with soluble magnesium and calcium sulphate to form insoluble carbonates.

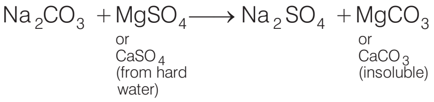
(a) Statements A and R both are correct and R is the correct explanation of A

(b) A is correct but R is not correct

(c) A and R both are correct but R is not the correct explanation of A

(d) A and R both are false

**Ans.** *(a)* Statements of assertion and reason both are correct and reason is the correct explanation of assertion.



$$Na_2CO_3 + \underset{\substack{\text{or}\\ CaSO_4\\ \text{(from hard}\\ \text{water)}}}{MgSO_4} \longrightarrow Na_2SO_4 + \underset{\substack{\text{or}\\ CaCO_3\\ \text{(insoluble)}}}{MgCO_3}$$

**Q. 68** **Assertion** (A) Some metals like platinum and palladium, can be used as storage media for hydrogen.

**Reason** (R) Platinum and palladium can absorb large volumes of hydrogen.

(a) Statements A and R both are correct and R is the correct explanation of A

(b) A is correct but R is not correct

(c) A and R both are correct but R is not the correct explanation of A

(d) A and R both are false

**Ans.** *(a)* Statements of assertion and reason both are correct and reason is the correct explanation of assertion. Since, metals like Pd and Pt adsorbs a large volume of hydrogen, hence, these are used as a storage media for it.

## Long Answer Type Questions

**Q. 69** **Atomic hydrogen combines with almost all elements but molecular hydrogen does not. Explain.**

**Ans.** Atomic hydrogen is highly unstable. Since, the electronic configuration of atomic hydrogen is $1s^1$, it needs one more electron to complete its configuration and gain stability. Therefore, atomic hydrogen is very reactive and combines with almost all the elements.

It, however, reacts in three different ways *i.e.,*

(i) by loss of its single electron to form $H^+$,

(ii) by gain of one electron to form $H^-$ and

(iii) by sharing its electron with other atoms to form single covalent bonds. In contrast, the bond dissociation energy form H—H bond is very high (435.88 kJ $mol^{-1}$). As a result, molecular hydrogen is almost inert at room temperature and hence reacts only with a few elements.

**Q. 70** **How can $D_2O$ be prepared from water? Mention the physical properties in which $D_2O$ differs from $H_2O$. Give at least three reactions of $D_2O$ showing the exchange of hydrogen with deuterium.**

**Ans.** **(i)** $D_2O$ can be prepared by prolonged electrolysis of water.

**(ii)** Physical properties

(a) $D_2O$ is colourless, odourless, tasteless liquid. It has maximum density – 1.1073 g $mL^{-1}$ at 11.6°C (Maximum density of water at 4°C).

(b) Solubility of salts in heavy water is less than in ordinary water because it is more viscous than ordinary water.

(c) Nearly, all physical constants of $D_2O$ are higher than $H_2O$. It is due to the greater nuclear mass of deuterium atom than H-atom and stronger H-bonding in $D_2O$ than $H_2O$.

**(iii)** Exchange reactions of hydrogen with deuterium

$$NaOH + D_2O \longrightarrow NaOD + HOD$$

$$HCl + D_2O \longrightarrow DCl + HOD$$

$$NH_4Cl + D_2O \longrightarrow NH_3DCl + HOD$$

**Q. 71** **How will you concentrate $H_2O_2$? Show differences between structures of $H_2O_2$ and $H_2O$ by drawing their spatial structures. Also mention three important uses of $H_2O_2$.**

**Ans.** **(i)** Industrially, $H_2O_2$ is prepared by the auto-oxidation of 2-alkylanthraquinols.

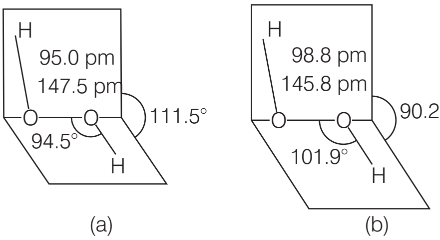
$$\text{2-ethylanthraquinol} \underset{H_2/Pd}{\overset{O_2/(air)}{\rightleftharpoons}} H_2O_2 + \text{Oxidised product}$$

In this case, 1% $H_2O_2$ is formed. It is extracted with water and concentrated to ~ 30% (by mass) by distillation under reduced pressure.

It can be further concentrated to ~ 85% by careful distillation under low pressure. The remaining water can be frozen out to obtain pure $H_2O_2$.

**(ii)** $H_2O_2$ has a non-planar structure.

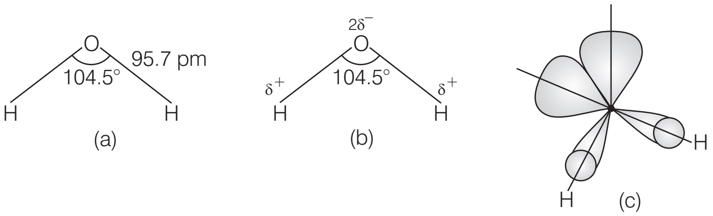
The molecular dimensions in the gas phase and solid phase are shown below



**(a) $H_2O_2$ structure in gas phase, dihedral angle is 111.5°**

**(b) $H_2O_2$ structure in solid phase at 110K, dihedral angle is 90.2°**

In the gas phase, $H_2O$ is a bent molecule with a bond angle of 104.5° and O—H bond length of 95.7 pm as shown below



**(a) The bent structure of water; (b) The water molecule as a dipole and (c) The orbital overlop picture in water molecule.**

**(iii)** *Following are the three important uses of* $H_2O_2$

(a) 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.

(b) It is used in the synthesis of hydroquinone, tartaric acid and certain food products and pharmaceuticals (cephalosporin) etc.

(c) It is employed in the industries as a bleaching agent for textiles, paper pulp, leather, oils, fats etc.

**Q. 72** (i) Give a method for the manufacture of hydrogen peroxide and explain the reactions involved therein.

(ii) Illustrate oxidising, reducing and acidic properties of hydrogen peroxide with equations.

**Ans.** **(i)** $H_2O_2$ is industrially manufactured by the auto-oxidation of 2alkylanthraquinols

$$\text{2-ethylanthraquinol} \underset{H_2/Pd}{\overset{O_2/(air)}{\rightleftharpoons}} H_2O_2 + \text{Oxidised product}$$

In this case, 1% $H_2O_2$ is formed. It is extracted with water and concentrated to ~ 30% (by mass) by distillation under reduced pressure. It can be further concentrated to ~ 85% by careful distillation under low pressure. The remaining water can be frozen out to obtain pure $H_2O_2$.

**(ii)** $H_2O_2$ acts as an oxidising as well as reducing agent in both acidic and alkaline media. *Following reactions are described below*

(a) Oxidising action in acidic medium

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

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

(b) Reducing action in acidic medium

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

$$HOCl + H_2O_2 \longrightarrow H_3O^+ + Cl^- + O_2$$

(c) Oxidising action in basic medium

$$2Fe^{2+} + H_2O_2 \longrightarrow 2Fe^{3+} + 2OH^-$$

$$Mn^{2+} + H_2O_2 \longrightarrow Mn^{4+} + 2OH^-$$

(d) Reducing action in basic medium

$$I_2 + H_2O_2 + 2OH^- \longrightarrow 2I^- + 2H_2O + O_2$$

$$2MnO_4 + 3H_2O_2 \longrightarrow 2MnO_2 + 3O_2 + 2H_2O + 2OH^-$$

**Q. 73** **(i) What mass of hydrogen peroxide will be present in 2 L of a 5 molar solution?**

**(ii) Calculate the mass of oxygen which will be liberated by the decomposition of 200 mL of this solution.**

**Ans.** **(i)** Molar mass of $H_2O_2 = 34\ g\ mol^{-1}$

1 L of 5 M solution of $H_2O_2$ will contain $34 \times 5$ g $H_2O_2$

2 L of 5 M solution of $H_2O_2$ will contain $34 \times 5 \times 2 = 340$ g $H_2O_2$

Mass of $H_2O_2$ present in 2 L of 5 molar solution = 340 g

**(ii)** 0.2 L (or 200 mL) of 5 M solution will contain

$$\frac{340 \times 0.2}{2} = 34\ g\ H_2O_2$$

$$\underset{2\times 34 = 68\ g}{2H_2O_2} \longrightarrow 2\ H_2O + \underset{2\times 16 = 32\ g}{O_2}$$

68 g $H_2O_2$ on decomposition will give 32 g $O_2$

$\therefore$ 34 g $H_2O_2$ on decomposition will give $\frac{32 \times 34}{68} = 16\ g\ O_2$

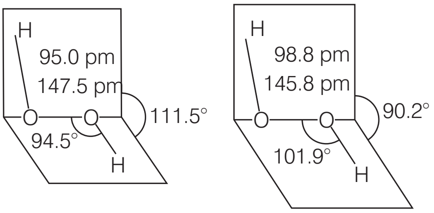
**Q. 74** **A colourless liquid '*A*' contains H and O elements only. It decomposes slowly on exposure to light. It is stabilised by mixing urea to store in the presence of light.**

**(i) Suggest possible structure of *A*.**

**(ii) Write chemical equations for its decomposition reaction in light.**

**Ans.** Since, a colourless liquid 'A' contains only hydrogen and oxygen and decomposes slowly on exposure to light but is stabilised by addition of urea, therefore, liquid *A* may be hydrogen peroxide.

**(i)** The structure of $H_2O_2$ is



(a) Gas phase (b) Solid phase

(a) $H_2O_2$ structure in gas phase, dihedral angle is 111.5°.

(b) $H_2O_2$ structure in solid phase at 110 K, dihedral angle is 90.2°.

**(ii)** $2H_2O_2 \xrightarrow[\text{Sunlight}]{h\nu} 2H_2O + O_2$

**Q. 75** An ionic hydride of an alkali metal has significant covalent character and is almost unreactive towards oxygen and chlorine. This is used in the synthesis of other useful hydrides. Write the formula of this hydride. Write its reaction with $Al_2Cl_6$.

**Ans.** It is LiH because it has significant covalent character due to the smallest alkali metal, Li. LiH is very stable. It is almost unreactive towards oxygen and chlorine.

It reacts with $Al_2Cl_6$ to form lithium aluminium hydride.

$$8LiH + Al_2Cl_6 \longrightarrow 2LiAlH_4 + 6LiCl$$

**Q. 76** Sodium forms a crystalline ionic solid with dihydrogen. The solid is non-volatile and non-conducting in nature. It reacts violently with water to produce dihydrogen gas. Write the formula of this compound and its reaction with water. What will happen on electrolysis of the melt of this solid?

**Ans.** Sodium reacts with dihydrogen to form sodium hydride which is a crystalline ionic solid.

$$2Na + H_2 \longrightarrow 2Na^+H^-$$

It reacts violently with water to produce $H_2$ gas

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

In solid state, NaH does not conduct electricity. On electrolysis, in its molten state it gives $H_2$ at anode and Na at cathode.

$$Na^+H^-(l) \xrightarrow{\text{Electrolysis}} \underset{\text{At cathode}}{2Na\,(l)} + \underset{\text{At anode}}{H_2\,(g)}$$