9 Hydrogen

Facts that Matter

• Electronic Configuration of Hydrogen $1s^1$

Position of hydrogen in the periodic table: Position of hydrogen in periodic table is not justified because it resembles both alkali metals as well as halogens.

• Resemblance of Hydrogen with Alkali Metals

(*i*) **Electronic Configuration:** Hydrogen has one electron in its valence shell like alkali metals.

For example, H_Atomic No. (1) = $1s^1$

L*i*_Atomic No. (3) = $1s^2\,2s^1$

Na_Atomic No. (11) = $1s^2\,2s^2\,2p^6\,3s^1$

(*ii*) Both hydrogen and alkali metals form unipositive ions.

For example, $Na \longrightarrow Na^+ + e^-$

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

(*iii*) Hydrogen and alkali metals both shows +1 oxidation state.

(*iv*) Hydrogen as well as other alkali metals acts as reducing agents.

(*v*) Both have affinity for electronegative element

For example, Na_2O, NaCl, H_2O, HCl.

• Resemblance with Hologens

(*i*) **Electronic configuration:** Hydrogen and halogen family both require one electron to fulfil the inert gas configuration

For example, $H + e^- \longrightarrow H^-$ $(1s^2)$

$F + e^- \longrightarrow F^-$

$(1s^2\,2s^2\,sp^5)$ $(1s^2\,2s^2\,2p^6)$

(*ii*) Ionisation energy of hydrogen is almost similar to halogens.

(*iii*) Hydrogen as well as halogens are Diatomic in nature.

(*iv*) Many compounds of hydrogen as well as of halogens are of covalent nature.

For example, CH_4, SiH_4, CCl_4, $SiCl_4$

• Occurrence of Hydrogen

Hydrogen is the most abundant element in the universe. It is present in combined state as water, coal, animal and vegetable matter. All organic compounds contain hydrogen as an essential constituent.

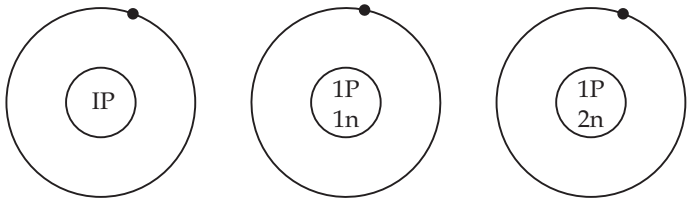
• Isotopes of Hydrogen

Hydrogen has three isotopes.

Protium, $^{1}_{1}H$

Deuterium, $^{2}_{1}H$

Tritium, $^{3}_{1}H$



	Atomic No.	Mass No.
Protium –	1	1
Deuterium –	1	2
Tritium –	1	3

• Preparation of Dihydrogen, H_2

Laboratory Preparation of Dihydrogen

(*i*) It is prepared by the reaction of granulated zinc with dil HCl.

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$

(*ii*) It is prepared by the action of zinc with aqueous alkali.

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

• Properties of Dihydrogen

Physical properties

(*i*) Dihydrogen is a colourless, odourless and tasteless gas.
(*ii*) It is a combustible gas.
(*iii*) It is insoluble in water.
(*iv*) It is lighter than air.

Chemical properties

Reaction with halogens: It reacts with halogens, X_2 to give hydrogen halides. HX.

(X = F, Cl, Br, I)

$$H_2(g) + X_2(g) \longrightarrow 2HX(g)$$

(F can react with hydrogen in dark also, iodine requires a catalyst)

Reaction with dioxygen:

$$2H_2(g) + O_2(g) \xrightarrow{\text{heating}} 2H_2O(l)$$

$$\Delta H^{\ominus} = -92.6 \text{ kJ mol}^{-1}.$$

The reaction is highly exothermic.

Reaction with dinitrogen: With dinitrogen to form ammonia

$$3H_2(g) + N_2(g) \xrightarrow[Fe]{673\ K,\ 200\ atm} 2NH_3(g)$$

$$\Delta H^{\ominus} = -92.6\ kJ\ mol^{-1}$$

Reaction with metals:

$$H_2(g) + 2M(s) \longrightarrow 2MH(s)$$

where (M = alkali metal)

• Hydrides

The hydrides are classified into three types:

(*i*) Ionic or saline or salt like hydrides
(*ii*) Covalent or molecular hydrides
(*iii*) Metallic or non-stoichiometric hydrides.

• Ionic or Saline Hydrides

Hydrides formed between hydrogen and electropositive element of group I and II belonging to s-block. These are known as stoichiometric compounds.

Properties of saline or ionic hydrides:

(*i*) The hydrides of lighter elements like Li, Be, Mg etc. have significant covalent character.
(*ii*) Ionic hydrides are crystalline, non-volatile and non-conducting in solid state.
(*iii*) They conduct electricity in molten state and liberate hydrogen at anode.

• Covalent or Molecular Hydrides

These are binary compounds of hydrogen with non-metals belonging to p-block.
For example, NH_3, CH_4, H_2O, HF They are mostly volatile compounds with low boiling points. They are classified as:

(*i*) **Electron-Deficient Molecular Hydride:** Molecular hydrides in which central atom does not have octet are called electron deficient hydrides *e.g.*, BH_3, MgH_2, BeH_2.
(*ii*) **Electron precise hydrides:** Those hydrides in which the central atom has its octet complete *e.g.*, group 14 hydrides. They are tetrahedral in geometry.
(*iii*) **Electron rich hydrides:** Those metal hydrides which contain lone pair of electrons are called electron rich hydrides. *e.g.*, NH_3, PH_3, H_2O and H_2S.
NH_3 and PH_3 has 1 lone pair and H_2O and H_2S have 2 lone pairs of electrons.

• Metallic or Non-Stoichiometric Hydrides

These hydrides are also known as interstitial hydrides. Transition metals group 3, 4 and 5 form metallic hydrides. In group 6, chromium alone has a tendency to form CrH. Metals of 7, 8 and 9 do not form hydrides. This is called as hydride gap.
Latest study shows that only N*i*, *Pd*, Ce and Ac are interstitial in nature, that means they can occpy hydrogen atom in the interstitial sides. The hydrides are generally non-stoichiometric and their composition varies with temperature and pressure, for example, T*i* $H_{1.73}$, $CeH_{2.7}$, $LaH_{2.8}$ etc.
These hydrides have metallic lock and their properties are closely related to those of the parent metal. They are strong reducing agents in most of the cases due to the presence of free hydrogen atom in the metal lattice.

• Water

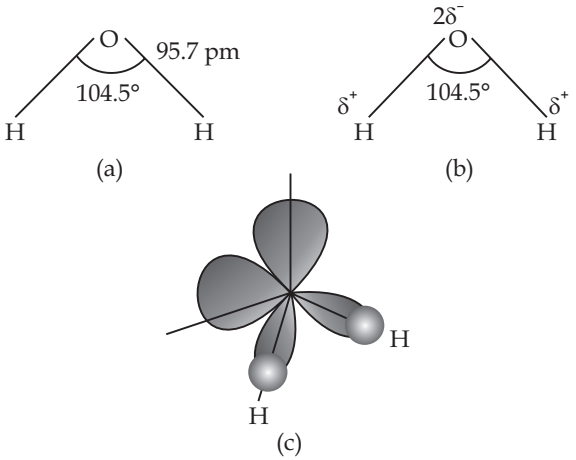
Human body has about 65% and some plants have nearly 95% water.

Physical properties of water:

(*i*) Freezing point of water is 273.15 K and boiling point 373.15 K.
(*ii*) Maximum density of water at 4°C is 1 gm cm^{-3}
(*iii*) It is a colourless and tasteless liquid.
(*iv*) Due to hydrogen bonding with polar molecules, even covalent compounds like alcohol and carbohydrates dissolve in water.

Structure of Water:

In gas phase, it is a bent molecule with HOH bond angle 104.5° and O—H bond length of 95.7 pm. It is highly polar in nature. Its orbital overlap picture is also shown below.



H_2O molecule

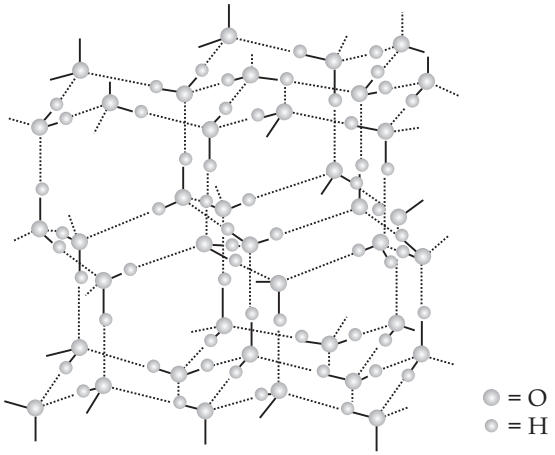
(a) The bent structure of water; (b) the water molecule as a dipole and (c) the orbital overlap picture in water molecule.

Water in Crystalline Form:

Ice is the crystalline form of water. At atmospheric pressure ice crystallise in the hexagonal form. At low temperature it condenses to cubic form.

Density of ice is less than that of water. Therefore, ice cubes can float on water.

Structure of ice:



The structure of ice

Chemical Properties of Water:

(*i*) **Amphoteric nature:** It behaves like an amphoteric substance because it can act as an acid as well as base.

$$H_2O(l) + NH_3(aq) \rightleftharpoons OH^-(aq) + NH_4^+(aq)$$
$$H_2O(l) + H_2S(aq) \rightleftharpoons H_3O(\overset{+}{a}q) + HS^-(aq)$$

Autoprotolysis of water also accounts for its amphoteric nature according to Bronsted-Lowry concept.

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O(\overset{+}{a}q) + OH^-(aq)$$

*p*H of water is 7. And it is neutral towards pH.

(*ii*) **Oxidising and Reducing Nature:** Water can act as an oxidising as well as reducing agent.

As an oxidising agent:

$$2H_2O + 2Na \longrightarrow 2NaOH + H_2$$
$$2H_2O + 2e^- \longrightarrow 2OH^- + H_2$$

As reducing agent:

$$2F_2 + 2H_2O \longrightarrow 4HF + O_2$$

(*iii*) **Hydrolysis Reaction:** It has a very strong hydrating tendency. It can hydrolyse a large number of compounds such as oxides, halides, carbides etc.

$$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$$
$$P_4O_{10}(s) + 6H_2O(l) \longrightarrow 4H_3PO_4(aq)$$
$$CaH_2 + 2H_2O \longrightarrow Ca(OH)_2 + C_2H_2$$
$$CaC_2 + 2H_2O \longrightarrow Ca(OH)_2 + C_2H_2$$
$$SO_2 + H_2O \longrightarrow H_2SO_3$$

• Hydrates Formation

From aqueous solutions many salts can be crystallised as hydrated salts.
Hydrates are of three types:

(*i*) **Coordinated water**
For example: $[Ni(H_2O)_6]^{2+}\ (NO_3^-)_2$ and $[Cr(H_2O)_6]^{3+}\ 3Cl^-$

(*ii*) **Interstitial water**
For example: $BaCl_2 \cdot 2H_2O$

(*iii*) **Hydrogen bonded water**
For example: $[Cu(H_2O)_4]^{2+}\ SO_4^{2-} \cdot H_2O$ in $CuSO_4 \cdot 5H_2O$

• Hard and Soft Water

Hard water: Water which does not produce lather with soap easily is called hard water. Presence of calcium and magnesium salts in the form of hydrogen carbonate, chloride and sulphate in water makes the water hard.

Types of Hardness of Water:

(*i*) **Temporary hardness:** It is due to the presence of bicarbonates of calcium and magnesium in water. It is known as temporary because it can be easily removed by simple boiling of hard water.

(*ii*) **Permanent hardness:** It is due to the presence of chlorides and sulphates of calcium and magnesium. It cannot be removed on boiling water. Permanent hardness of water can be removed by chemical methods.

Soft water: Water which readily forms lather with soap is called soft water.
For example: rain water, distilled water.

• Hydrogen Peroxide (H_2O_2)

Preparation:

(*i*) **From Barium peroxide**

$$BaO_2 \cdot 8HO(s) + H_2SO_4(aq) \longrightarrow BaSO_4(s) + H_2O_2(aq) + 8H_2O(l)$$

(*ii*) **By electrolysis of 50% H_2SO_4:** Electrolysis of a cold 50% solution of H_2SO_4 at high current density in an electrolytic cell using pe as anode and graphite as cathode.

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

At Cathode:

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

At Anode

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

peroxodisulphuric acid formed around anode is withdrawn and then distilled with water under reduced pressure.

$$\underset{\text{peroxodisulphuric acid}}{H_2S_2O_8} + H_2O \longrightarrow \underset{\text{peroxomonodisulphuric acid}}{H_2SO_5}$$

$$\underset{\text{peroxodisulphuric acid}}{H_2SO_5} + H_2O \longrightarrow H_2SO_4 + H_2O_2$$

Storage: Hydrogen peroxide is stored in wax lined flow or plastic vessels in dark. Because it decomposes slowly on exposure to light.

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

Uses of H_2O_2:

(*i*) It is used as a mild disinfectant. It is marketed as perhydrol (an Antiseptic).
(*ii*) It is used in the manufacture of high quality detergents.
(*iii*) It is used in the synthesis of hydroquinone tartaric acid and certain food products and pharmaceuticals.
(*iv*) It is used as bleaching agent for textilies, paper pulp etc.
(*v*) It is used for pollution control treatment of domestic and industrial effluents.
(*vi*) 93% H_2O_2 is used as an oxidant for rocket fuel.

• Heavy Water (D_2O)

It is used in the preparation of other deuterium compounds.

$$CaC_2 + 2D_2O \longrightarrow C_2D_2 + Ca(OD)_2$$

$$SO_3 + D_2O \longrightarrow D_2SO_4$$

$$Al_4C_3 + 12D_2O \longrightarrow 3CD_4 + 4Al(OD)_3$$

Uses of D_2O:

(*i*) It is used as moderator in nuclear reactors.
(*ii*) It is used in the exchange reaction study of reaction mechanisms.

• Hydrogen as a Fuel

Hydrogen Economy: The basic principle of hydrogen economy is the transportation and storage of energy in the form of liquid or gaseous dihydrogen. Advantage is that energy is transmitted in the form of dihydrogen and not as electric power.

Advantage as a fuel:

- It is used as fuel cells for the generation of electric power.
- One major advantage of combustion of hydrogen is that it produces very little pollution and there is not any emission of unburnt carbon particles in the form of smoke.
- It is evident from the study that dihydrogen in the gaseous state as well as in liquefied form releases more energy on combustion as compared to the other fuel commonly used.
- 5% of dihydrogen is mixed in CNG for use in four wheeler vehicles.

NCERT TEXTBOOK QUESTIONS SOLVED

Q1. *Justify the position of hydrogen in the periodic table on the basis of its electronic configuration.*

Ans. Hydrogen has been placed at the top of the alkali metal in group, but it is not a member of the group.

Its position is not justified properly because of its electronic configuration as ($1s^1$). It can be placed with alkali metals because it also has similar configuration (ns^1) as alkali metals.

However, it can also be placed along with halogen in group 17 since just like halogen it can acquire inert gas configuration by accepting one electron.

Q2. *Write the names of isotopes of hydrogen. What is the mass ratio of these isotopes?*

Ans. Protium – ^1_1H

Deuterium – ^2_1H or D

Tritium – ^3_1H or T

Mass ratio of Protium : Deuterium : Tritium

= 1 : 2 : 3

Q3. *Why does hydrogen occur in a diatomic form rather than in a monoatomic form under normal conditions?*

Ans. In diatomic form, the K-shell of hydrogen is complete ($1s^2$) and so it is quite stable.

Q4. *How can the production of dihydrogen obtained from 'Coal gasification' be increased?*

Ans. The production of dihydrogen in coal gasification can be increased by reacting CO(g) present in syngas with steam in the presence of iron chromate catalysts.

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

With the removal of CO_2 the reaction shifts in the forward direction and thus, the production of dihydrogen will be increased.

Q5. *Describe the bulk preparation of dihydrogen by electrolytic method. What is the role of an electrolyte in this process?*

Ans. In bulk, hydrogen can be produced by electrolysis of acidified water using Pt electrodes.

$$2H_2O(l) \xrightarrow[\text{traces of acid or base}]{\text{Electrolysis}} 2H_2(g) + O_2(g)$$

Electrolyte is added to increase the dissociation of water.

Q6. *Complete the following reactions.*

(i) $H_2(g) + MnO_3(s) \xrightarrow{\Delta}$

(ii) $CO(g) + H_2(g) \xrightarrow[Catalyst]{\Delta}$

(iii) $C_3H_8(g) + 3H_2O(g) \xrightarrow[Catalyst]{\Delta}$

(iv) $Zn(s) + NaOH(aq) \xrightarrow{heat}$

Ans. (*i*) $3H_2(g) + MnO_3(s) \xrightarrow{heat} Mn(s) + 3H_2O$

(*ii*) $CO(g) + 2H_2(g) \xrightarrow[Catalyst]{\Delta} CH_3OH(l)$

(*iii*) $C_3H_8(g) + 3H_2O(g) \xrightarrow[Catalyst]{1270K} 3CO(g) + 7H_2(g)$

(*iv*) $Zn\ (s) + 2NaOH(aq) \xrightarrow{\Delta} \underset{\text{Sodium Zincate}}{Na_2ZnO_2(s)} + H_2(g)$

Q7. *Discuss the consequences of high enthalpy of H–H bond in terms of chemical reactivity of dihydrogen.*

Ans. This is due to its small atomic size and also small bond length (74 pm) of H–H bond.

Q8. *What do you understand by (i) Electron-deficient (ii) Electron-precise (iii) Electron-rich compounds of hydrogen? Provide justification with suitable examples.*

Ans. (*i*) **Electron deficient hydrides:** Compounds in which central atom has incomplete octet, are called electron deficient hydrides. For example, BeH_2, BH_3 are electron deficient hydrides.

(*ii*) **Electron precise hydrides:** Those compounds in which exact number of electrons are present in central atom or the central atom contains complete octet are called precise hydrides *e.g.,* CH_4, SiH_4, GeH_4 etc. are precise hydrides.

(*iii*) **Electron rich hydrides:** Those compounds in which central atom has one or more lone pair of excess electrons are called electron rich hydrides. *e.g.,* NH_3, H_2O.

Q9. *What characteristics do you expect from an electron-deficient hydride with respect to its structure and chemical reaction?*

Ans. It is expected to be a Lewis acid. They are likely to accept electrons to become stable. They can form coordinate bond with electron rich compound.

$$2NaH(s) + B_2H_6(g) \xrightarrow{\text{Diethyl ether}} \underset{\text{Sod. borohydride}}{2Na^+\ [BH_4]^-(s)}$$

Q10. *Do you expect the carbon hydride of type $C_n H_{2n+2}$ to act as 'Lewis' acid or base? Justify your answer.*

Ans. Carbon hydrides of the type $C_n H_{2n+2}$ are electron precise hydrides. Because they have atom with exact number of electrons to form covalent bonds.

Thus, they do not behave as Lewis acid or base. Since they have no tendency to accept or lose electrons.

Q11. *What do you understand by the term 'non-stoichiometric hydrides'? Do you expect this type of hydrides to be formed by alkali metals? Justify your answer.*

Ans. Those hydrides which do not have fix composition are called non-stoichiometric hydrides, and the composition varies with temperature and pressure. This type of hydrides are formed by *d* and *f* block elements. They cannot be formed by alkali metals because alkali metal hydrides form ionic hydrides.

Q12. *How do you expect the metallic hydrides to be useful for hydrogen storage? Explain.*

Ans. In metallic hydrides, hydrogen is adsorbed as H-atoms. Due to the adsorption of H atoms the metal Lattice expands and become unstable. Thus, when metallic hydride is heated, it decomposes to form hydrogen and finely divided metal. The hydrogen evolved can be used as fuel.

Q13. *How does the atomic hydrogen or oxy-hydrogen torch function for cutting and welding purposes? Explain.*

Ans. When hydrogen is burnt in oxygen the reaction is highly exothermic, it produces very high temperature nearly 4000°C which is used for cutting and welding purposes.

Q14. *Among NH_3, H_2O and HF, which would you expect to have highest magnitude of hydrogen bonding and why?*

Ans. HF is expected to have highest magnitude of hydrogen bonding since, '*F*' is most electronegative. Therefore, HF is the most polar.

Q15. *Saline hydrides are known to react with water violently producing fire. Can CO_2, a well known fire extinguisher, be used in this case? Explain.*

Ans. No. Because if saline hydrides react with water the reaction will be highly exothermic thus the hydrogen evolved in this case can catch fire. CO_2 cannot be used as fire extinguisher because CO_2 will get absorbed in alkali metal hydroxides.

Q16. *Arrange the following:*

(i) CaH_2, BeH_2 and TiH_2 in order of increasing electrical conductance.

(ii) LiH, NaH and CsH in order of increasing ionic character.

(iii) H – H, D – D and F – F in order of increasing bond dissociation enthalpy.

(iv) NaH, MgH_2 and H_2O in order of increasing reducing property.

Ans. (*i*) $BeH_2 < TiH_2 < CaH_2$

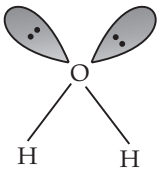
(*ii*) LiH < NaH < CsH

(*iii*) F – F < H – H < D – D

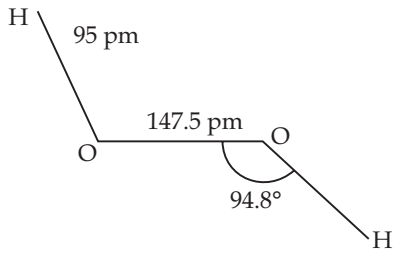
(*iv*) $H_2O < MgH_2 < NaH$

Q17. *Compare the structures of H_2O and H_2O_2.*

Ans. In water, O is sp^3 hybridized. Due to stronger lone pair-lone pair repulsions than bond pair-bond pair repulsions, the HOH bond angle decreases from 109.5° to 104.5°. Thus water molecule has a bent structure.



H_2O_2 has a non-planar structure. The O—H bonds are in different planes. Thus, the structure of H_2O_2 is like an open book.



Q18. *What do you understand by the term 'auto-protolysis' of water? what is its significance?*

Ans. Auto-protolysis means self-ionisation of water. It may be represented as

$$\underset{\text{Acid 1}}{H_2O(l)} + \underset{\text{Base 2}}{H_2O(l)} \rightleftharpoons \underset{\text{Acid 2}}{H_3O^+(aq)} + \underset{\text{Base 1}}{OH^-(aq)}$$

Due to auto-protalysis water is amphoteric in nature. *i.e.,* it can act as an acid as well as base.

Q19. *Consider the reaction of water with F_2 and suggest, in terms of oxidation and reduction, which species are oxidised/reduced?*

Ans.

$$\underset{\text{(oxidant)}}{2F_2(g)} + \underset{\text{(Reductant)}}{2H_2O(l)} \longrightarrow O_2(g) + 4H^+(aq) + 4F^-(aq)$$

In this reaction water acts as a reducing agent and itself gets oxidised to O_2 while F_2 acts as an oxidising agent and hence itself reduced to F^- ions.

Q20. *Complete the following chemical reactions.*

(i) $PbS(s) + H_2O_2\,(aq) \rightarrow$

(ii) $MnO_4^-\,(aq) + H_2O_2\,(aq) \rightarrow$

(iii) $CaO(s) + H_2O(g) \rightarrow$

(iv) $AlCl_3(g) + H_2O(l) \rightarrow$

(v) $Ca_3\,N_2(s) + H_2O(l) \rightarrow$

Classify the above into (a) hydrolysis, (b) redox and (c) hydration reactions.

Ans. (*i*) $PbS(s) + 4H_2O_2(aq) \longrightarrow PbSO_4(s) + 4H_2O(l)$

(*ii*) $2MnO_4^-(aq) + H_2O_2(aq) + 6H^+(aq) \longrightarrow 2Mn^4(aq) + 8H_2O(l) + 5O_2(g)$

(*iii*) $CaO(s) + H_2O(g) \longrightarrow Ca(OH)_2(aq)$

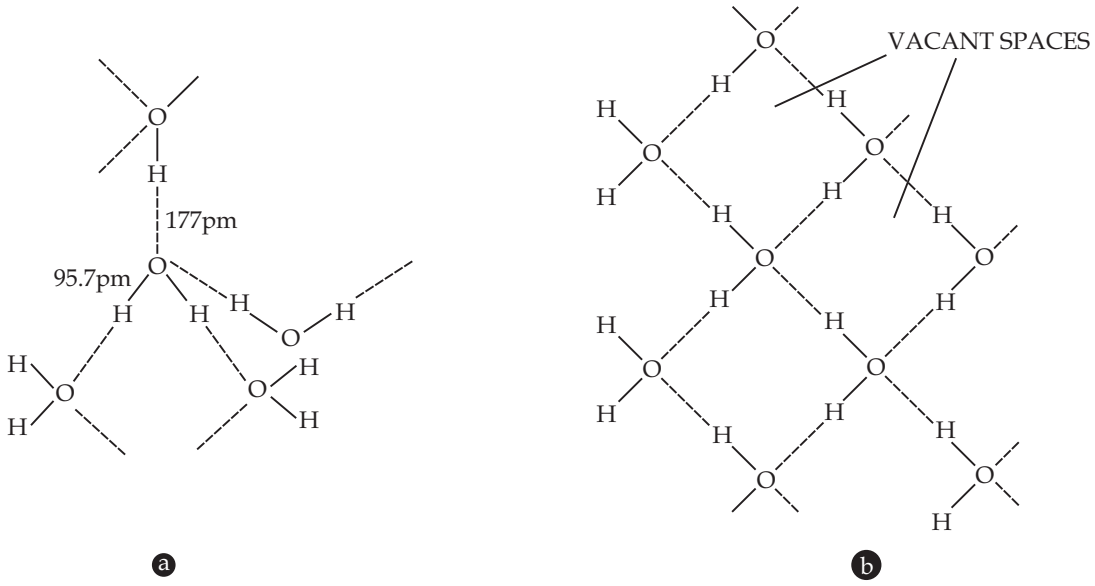
(*iv*) $AlCl_3(g) + 3H_2O(l) \longrightarrow Al(OH)_3(s) + 3HCl(aq)$

(*v*) $Ca_3N_2(s) + H_2O(l) \longrightarrow 3Ca(OH)_2(aq) + 2NH_3(aq)$

(*a*) Hydrolysis reactions. (*iii*) (*iv*) and (*v*)

(*b*) Redox reactions (*i*) and (*ii*)

Q21. *Describe the structure of common form of ice.*



(a) Structure of water in the liquid state
(b) Tetrahedral arrangement of oxygen atoms in ice.

Ans. Ice crystallizes in the normal hexagonal form. However, at very low temperatures it condenses in cubic form. In the normal hexagonal ice each oxygen atom is tetrahedrally surrounded by four other hydrogen atoms.

Q22. *What causes the temporary and permanent hardness of water?*

Ans. Temporary hardness of water is due to the presence of bicarbonates of calcium and magnesium in water i.e., $Ca(HCO_3)_2$ and $Mg(HCO_3)$ in water. Permanent hardness of water is due to the presence of soluble chlorides and sulphates of calcium and magnesium *i.e.,* $CaCl_2$, $CaSO_4$, $MgCl_2$ and $MgSO_4$.

Q23. *Discuss the principle and method of softening of hard water by synthetic ion-exchange resins.*

Ans. Cation exchange resins have large organic molecule with SO_3H group which are insoluble in water. Ion exchange resin (RSO_3H) is changed to RNa on treatment with NaCl. The resin exchange Na^+ ions with Ca^{2+} and Mg^{2+} ions present in hard water and make it soft.

$$2RNa(s) + M^{2+}(aq) \longrightarrow R_2M(s) + 2Na^+(aq)$$

where, M = Mg, Ca.

The resins can be regenerated by adding aqueous NaCl solution.

Q24. *Write chemical reaction to show the amphoteric nature of water.*

Ans. Water is amphoteric in nature because it acts as an acid

$$\underset{\text{Base 1}}{H_2O(l)} + \underset{\text{Acid 2}}{H_2S(aq)} \longrightarrow \underset{\text{Acid 1}}{H_3O^+(aq)} + \underset{\text{Base 2}}{HS^-(aq)}$$

$$\underset{\text{Acid 1}}{H_2O(l)} + \underset{\text{Base 2}}{NH_3(aq)} \longrightarrow \underset{\text{Acid 2}}{NH_4^+(aq)} + \underset{\text{Base 1}}{OH^-(aq)}$$

Q25. *Write chemical reactions to justify that hydrogen peroxide can function as an oxidising as well as reducing agent.*

Ans. **As an oxidising agent**

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

As a reducing agent

$$I_2(s) + H_2O_2\,(aq) + 2OH^-\,(aq) \longrightarrow 2I^-\,(aq) + 2H_2O(l) + O_2(g)$$

Q26. *What is meant by 'demineralised water' and how can it be obtained?*

Ans. Demineralised water is free from all soluble mineral salts which is obtained by passing water successively through a cation exchange (in the form of H^+) and an anion exchange in the form of OH^- resins.

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

H^+ exchanges for Na^+, Ca^{2+}, Mg^{2+} and other cations present in water. This process results in release of proton which makes the water acidic.

$$\overset{+}{R}NH_2(s) + H_2O \rightleftharpoons \overset{+}{R}N H_3OH^-$$

$$\overset{+}{R}N H_3OH^-(s) + X^- \rightleftharpoons \overset{+}{R}NH_3\,X^- + OH^-(aq)$$

OH^- exchanges, for anions like Cl^-, HCO_3^-, SO_4^{2-} etc.

OH^- ions thus liberated neutralize the H^+ ions set free in the cation exchange process.

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

Q27. *Is demineralised or distilled water useful for drinking purposes? If not, how can it be made useful?*

Ans. No, demineralised water is not fit for drinking purposes. It can be made useful by adding required amount of ions which are useful for our body.

Q28. *Describe the usefulness of water in biosphere and biological systems.*

Ans. (*i*) Major part of all living system is made of water.
(*ii*) It constitutes about 65 – 70% of body weights of animals and plants.
(*iii*) Some properties of water like high specific heat, thermal conductivity, surface tension, high polarity allow water to play a major role in biosphere.
(*iv*) Because of high heat of vaporisation it is responsible ro regulate temperature of living beings.
(*v*) It is an excellent fluid for the transportation of minerals and nutrients in plants.
(*vi*) It is also required for photosynthesis in plants.

Q29. *What properties of water make it useful as a solvent? What types of compound can it (i) dissolve (ii) hydrolyse?*

Ans. Water is highly polar in nature thats why it has high dielectric constant and high dipole moment. Because of these properties, water is a universal solvent.
It can hydrolyse many oxides metallic or non-metallic, hydrides, carbides, nitrides etc.

Q30. *Knowing the properties of H_2O and D_2O, do you think D_2O can be used for drinking purpose.*

Ans. No, D_2O is injurious to human beings, plants and animals.

Q31. *What is the difference between the terms 'hydrolysis' and 'hydration'?*

Ans. Hydrolysis is a chemical reaction in which a substance reacts with water under neutral, acidic or alkaline conditions.

$$\underset{\text{Salt 1}}{Na_2CO_3} + 2H_2O \longrightarrow \underset{\text{Base 2}}{2NaOH} + \underset{\text{Acid 1}}{H_2CO_3}$$

Hydration on the other hand is the property of a chemical compound to take up molecules of water of crystallisation and get hydrated.

$$\underset{\text{colorless}}{CuSO_4(s)} + 5H_2O(l) \longrightarrow \underset{\text{(Blue)}}{CuSO_4\,5H_2O(s)}$$

Q32. *How can saline hydrides remove traces of water from organic compounds?*

Ans. Saline hydrides (*i.e,* CaH_2, NaH etc.) react with water and form the corresponding metal hydroxide with the liberation of H_2 gas. Thus, these hydrides can be used to remove traces of water from the organic compounds.

$$NaH(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$$
$$CaH_2(s) + 2H_2O(l) \longrightarrow Ca(OH)_2(aq) + H_2(g)$$

Q33. *What do you expect the nature of hydrides is, if formed by elements of atomic numbers 15, 19, 23 and 44 with dihydrogen? Compare their behaviour towards water.*

Ans. Atomic No. 15 is of phosphorus. The hydride is PH_3 and its nature is covalent.

Atomic No. (Z = 19) is of potassium. The hydride is KH and it is ionic in nature.

Atomic No. (Z = 23) is of vanadium. The hydride is VH. It is interstitial or metallic.

Atomic No. 44 is of ruthenium, its hydride is interstitial or metallic.

Q34. *Do you expect different products in solution when aluminium (III) chloride and potassium chloride treated separately with (i) normal water (ii) acidified water (iii) alkaline water? Write equation wherever necessary.*

Ans. (*i*) In normal water

$$AlCl_3 + 3H_2O \longrightarrow Al(OH)_3 + 3HCl$$

KCl will dissolve in water and ions will get hydrated.

(*ii*) KCl will be unaffected in acidified water. While in acidic water H^+ ion react with Al $(OH)_3$ to form Al^{3+} (*aq*) ions and H_2O. Thus in acidic water $AlCl_3$ exists as

Al^{3+} (*aq*) and Cl^- (*aq*) ions

$$AlCl_3(s) \xrightarrow{\text{Acidified}} Al^{3+}(aq) + 3Cl^- (aq)$$

(*iii*) In alkaline water since the aqueous solution of KCl is neutral therefore, it is unaffected.

$Al(OH)_3$ reacts to form soluble tetrahydroxoaluminate complex or meta-aluminate.

$$AlCl_3(s) \xrightarrow[\text{water}]{\text{Alkaline}} Al^+[(OH)_4]^- + 3Cl^- OH^-$$
$$\downarrow$$
$$AlO_2^-(aq)\ \ 2H_2O(l) + 3Cl^-(aq)$$

Q35. *How does H_2O_2 behave as a bleaching agent?*

Ans. Bleaching action of H_2O_2 is due to the oxidation of colouring matter by nascent oxygen.

$$H_2O_2(l) \longrightarrow H_2O(l) + O(g)$$

Q36. *What do you understand by the terms:*
(i) Hydrogen economy (ii) hydrogenation (iii) syngas (iv) water-gas shift reaction (v) fuel-cell?

Ans. (*i*) **Hydrogen economy:** The basic principle of hydrogen economy is the storage and transportation of energy in the form of liquid or gaseous dihydrogen.

(*ii*) **Hydrogenation:** Hydrogenation means addition of hydrogen across double and triple bonds in presence of catalyst to form saturated compounds.

$$\text{Vegetable oil} + H_2 \xrightarrow{\text{Ni, 437K}} \text{Vegetable Ghee}$$

(*iii*) **Syngas:** The mixture of CO and H_2 are called synthesis or syngas. It can be produced by the reaction of steam on hydrocarbon or coke at high temperature in the presence of nickel catalyst

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

The process of producing syngas from coal is called 'Coal gasification'.

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

(*iv*) **Water-gas shift reaction:** The amount of hydrogen in the syngas can be increased by the action of CO of syngas mixture with steam in the presence of iron chromate as catalyst.

$$C(s) + H_2O(g) \xrightarrow[FeCrO_4]{673K} CO(g) + H_2(g)$$

This is called water-gas shift reaction.

(*v*) **Fuel-Cell:** It is a cell which converts chemical energy of fuel directly into electrical energy.

MORE QUESTIONS SOLVED

I. VERY SHORT ANSWER TYPE QUESTIONS

Q1. *Which isotope of hydrogen is radioactive?*

Ans. Tritium.

Q2. *What is the importance of heavy water with regard to nuclear power generation?*

Ans. It is used as a moderator and helps to control the nuclear reaction.

Q3. *What is zeolite?*

Ans. It is hydrated sodium aluminium silicate, $Na_2Al_2Si_2O_8.xH_2O$.

Q4. *What is water gas? How is it prepared?*

Ans. Mixture of CO and H_2 in the ratio of 1 : 1 is called water gas.

It is prepared by passing steam over red hot coke.

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

Q5. *Write two uses of interstitial hydrides.*

Ans. (*i*) In the storage of H_2.

(*ii*) Catalyst for hydrogenation reaction.

Q6. *Give an example of an ionic hydride and a covalent hydride:*

Ans. NaH is an ionic hydride and B_2H_6 is a covalent hydride.

Q7. *Give two advantages of using hydrogen over gasoline as a fuel.*

Ans. (*i*) High heat of combustion

(*ii*) It is pollution free.

Q8. *What type of elements form interstitial hydrides?*

Ans. *d*-block and *f*-block elements.

Q9. *What is perhydrol?*

Ans. Perhydrol is the trade name of H_2O_2. It is used as an antiseptic.

Q10. *What is meant by hard water?*

Ans. Water which does not produce lathers with soap is known as hard water. Hardness is due to the presence of bicarbonates, sulphates and chlorides of Ca^{2+} and Mg^{2+}.

Q11. *Which gas is evolved when Mg_3N_2 (Magnesium nitride) is treated with H_2O? Give chemical reaction.*

Ans. NH_3 gas is evolved.

$$Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$$

Q12. *Which compounds cause temporary hardness of water?*

Ans. $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$

Q13. *Which isotope of hydrogen does not have neutron?*

Ans. ${}_1^1H$ does not have neutron. It is called protium.

Q14. *Name a substance which can oxidise H_2O_2.*

Ans. Acidified $KMnO_4$.

Q15. *Which type of hydrides are generally non-stoichiometric in nature?*

Ans. Interstitial hydrides are non-stoichiometric in nature.

Q16. *What is the cause of bleaching action of H_2O_2?*

Ans.

$$H_2O_2(l) \longrightarrow H_2O(l) + O(g)$$

Nascent oxygen produced is responsible for bleaching action.

Q17. *What is the use of hydrogen in the manufacture of Vanaspati Ghee?*

Ans. H_2 is used as reducing agent to convert vegetable oil into vegetable ghee.

Q18. *Name the phenomenon of adsorption of hydrogen on metal surface.*

Ans. Occlusion.

II. SHORT ANSWER TYPE QUESTIONS

Q1. *Show how H_2O_2 functions both as a reducing and as an oxidising agent.*

Ans. **As oxidising agent.**

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

As reducing agent.

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

Q2. *What are interstitial hydrides? Give two examples.*

Ans. Many transition and inner-transition metals absorb hydrogen into the interstices of their lattices to yield metal like hydrides also called the interstitial hydrides. These hydrides are generally non-stoichiometric and their composition vary with temperature and pressure.

For example, $T_iH_{1.73}$, $CeH_{2.7}$

Q3. *The aqueous solution of H_2O_2 is acidic in nature. Explain with the help of example. Name two substances which catalyse the decomposition reaction of H_2O_2.*

Ans. The aqueous solution of H_2O_2 is weakly acidic in nature.

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

It gives two types of salts with alkalies, peroxides and hydroperoxides.

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

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

MnO_2 and finely divided metals like *Pt* and *Fe* catalyse the decomposition of H_2O_2.

Q4. *Complete the following reactions:*

(i) $SiCl_4 + LiAlH_4 \longrightarrow$

(ii) $Mg_3N_2 + H_2O \longrightarrow$

(iii) $NaH + CO \longrightarrow$

Ans. (*i*) $SiCl_4 + LiAlH_4 \longrightarrow SiH_4 + LiCl + AlCl_3$

(*ii*) $Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$

(*iii*) $NaH + 2CO \longrightarrow HCOONa + C$

Q5. *Explain the following:*

(i) Temporary hardness can remove by boiling

(ii) Soft water lathers with soap but hard water not.

Ans. (*i*) On boiling, the bicarbonates of calcium and magnesium decompose to insoluble carbonate which can be removed by filteration.

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

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

(*ii*) Because of the presence of Ca^{2+} and Mg^{2+} ions in hard water which exchange with Na^+ ions of the soap to form corresponding calcium and magnesium salts that form insoluble ppt.

$$\underset{\text{Soap}}{RCOONa} + \underset{\text{Hardwater}}{Ca^{2+}} \longrightarrow \underset{\text{ppt.}}{(RCOO)_2Ca} + 2Na^+$$

$$\underset{\text{Soap}}{RCOONa} + \underset{\text{(Hardwater)}}{Mg^{2+}} \longrightarrow \underset{\text{ppt.}}{(RCOO)_2Mg} + 2Na^+$$

Q6. *(a) How is dihydrogen prepared from water by using a reducing agent?*

(b) Give the industrial use of dihydrogen which depends upon heat liberated when it burns.

Ans. (*a*) Dihydrogen is prepared from water by the action of alkali metals like Na and K which is a strong reducing agent.

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

$$2K + 2H_2O \longrightarrow 2KOH + H_2$$

(*b*)For welding purposes.

$$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(g) + \text{heat}$$

Q7. *Water molecule is bent, not linear. Explain?*

Ans. In water molecule, O is sp^3 hybridized. Due to stronger lone pair-lone pair repulsion than bond pair-bond pair repulsions, the HOH bond angle decreases from 109.5° to 104.5°. Thus water is bent molecule.

Q8. *Account for the following:*

(i) dihydrogen gas is not preferred in balloons.

(ii) Conc. H_2SO_4 cannot be used for drying H_2.

Ans. (*i*) Dihydrogen is the lighest gas but due to its highly combustible nature it is not preferred in balloons.

(*ii*) Conc. H_2SO_4 on absorbing H_2O forms moist H_2 produces so much heat that hydrogen catches fires.

Q9. *Calculate the volume strength of a 3% solution of H_2O_2.*

Ans. 100 ml of H_2O_2 solution contain H_2O_2 = 3g.

$$\therefore \text{ 1000 ml of } H_2O_2 \text{ solution will contain } = \frac{3}{100} \times 1000 = 30\text{g}$$

Q10. *Complete the following reactions:*

(i) $CO(g) + H_2(g) \xrightarrow{\Delta}$

(ii) $Zn(s) + NaOH\ (aq) \xrightarrow{heat}$

(iii) $C_3H_8(g) + 3H_2O(g) \xrightarrow[Catalyst]{\Delta}$

Ans. (*i*) $CO(g) + 2H_2(g) \xrightarrow[\text{Catalyst}]{\Delta} CH_3OH(l)$ methanol

(*ii*) $Zn(s) + 2NaOH(aq) \xrightarrow{\text{heat}} Na_2ZnO_2(s) + H_2(g)$

(*iii*) $C_3H_8(g) + 3H_2O \xrightarrow{Ni\ 1270K} 3CO(g) + 7H_2(g)$

III. MULTIPLE CHOICE QUESTIONS

1. Hydrogen gas is generally prepared by the

(*a*) reaction of granulated zinc with dilute H_2SO_4

(*b*) reaction of zinc with conc. H_2SO_4

(*c*) reaction of pure zinc with dil. H_2SO_4

(*d*) action of steam on red hot coke

2. Hydrogen peroxide is used as

(*a*) an oxidizing agent (*b*) a reducing agent

(*c*) a bleaching agent (*d*) all of the above

3. Water may be softened using

(*a*) sodium aluminium silicate (*b*) Graham's salt

(*c*) an ion exchange resin (*d*) trisodium phosphate

(*e*) all of the above

4. On treatment of hard water with zeolite, sodium ions get exchanged with

(*a*) Ca^{2+} ions (*b*) Mg^{2+} ions

(*c*) H^+ ions (*d*) OH^-

5. Calgon, which is used as a water softener, has the formula

(*a*) $Na_4 [Na_2 (PO_3)_6]$ (*b*) $Na_2 [Na_4 (PO_3)_6]$

(*c*) $Na_2 [Na_4 (PO_4)_5]$ (*d*) $Na_2 [Na_2 (PO_4)_6]$

6. The higher density of water than that of ice is due to

(*a*) dipole-dipole interaction (*b*) dipole-induced dipole interaction

(*c*) hydrogen bonding (*d*) all of these

7. Hydrogen is obtained as a by-product in the

(*a*) electrolysis of water (*b*) manufacture of caustic soda

(*c*) Bosch process (*d*) Lane process

8. Zeolite is

(*a*) hydrated sodium aluminium silicate – $Na_2Al_2Si_2O_8 \cdot xH_2O$

(*b*) hydrated ferric oxide

(*c*) sodium hexametaphosphate

(*d*) sodium tetraborate

9. Water undergoes self-ionization to a small extent to give

(*a*) H^+ and OH^- (*b*) OH^+ and H^-

(*c*) H_3O^+ and OH^- (*d*) none of the above

10. The decomposition of H_2O_2 is retarded by

(*a*) acetanilide (*b*) glycerol

(*c*) sodium bicarbonate (*d*) oxalic acid

Ans. 1. (*a*) 2. (*d*) 3. (*e*) 4. (*a*) and (*b*) 5. (*b*)
6. (*c*) 7. (*b*) 8. (*a*) 9. (*c*) 10. (*a*) and (*b*)

IV. HOTS QUESTIONS

Q1. *Account for the following:*

(a) Can phosphorus with electronic configuration $3s^2\ 3p^3$ form PH_5?

(b) Water is responsible for moderation of body temperature. How?

(c) Hard water is not suitable for boilers as well as for laundary.

Ans. (*a*) High $\Delta_a H$ value of dihydrogen and less negative value of $\Delta_{eg} H$ of hydrogen do not favour to exhibit highest oxidation state of P and consequently the formation of PH_5, although P exhibit +3, +5 oxidation states.

(*b*) Because of high heat of vapourisation and high heat capacity.

(*c*) Hard water form precipitate with soap and deposition of salts in the form of scales.

Q2. *Can we use concentrated sulphuric acid and pure zinc in the preparation of dihydrogen? Write the chemical reactions to show the amphoteric nature of water. Why is hydrogen peroxide stored in wax-lined plastic coloured bottles?*

Ans. (*a*) Conc. H_2SO_4 cannot be used because it acts as an oxidizing agent also and gets reduced to SO_2.

$$Zn + 2H_2SO_4 \text{ (Conc.)} \rightarrow ZnSO_4 + 2H_2O + SO_2$$

Pure Zn is not used because it is non-porous and reaction will be slow. The impurities in Zn help in constitute of electrochemical couple and speed up reaction.

(*b*) Water is amphoteric in nature and it behaves both as an acid as well as base. With acids stronger than itself (e.g., H_2S) it behaves as a base and with bases stronger than itself (e.g., NH_3) it acts as an acid.

(*i*) As a base: $H_2O(l) + H_2S(aq) \rightarrow H_3O(aq) + HS^-(aq)$

(*ii*) As an acid: $H_2O(l) + NH_3(aq) \rightarrow OH^-(aq) + NH_4^+(aq)$

(*c*) The decomposition of H_2O_2 occurs readily in the presence of rough surface (acting as catalyst). It is also decomposed by exposure of light. Therefore, waxlined smooth surface and coloured bottles retard the decomposition of H_2O_2.

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