9 Hydrogen

I. Multiple Choice Questions (Type-I)

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?
   (*i*) Its tendency to lose an electron to form a cation.
   (*ii*) Its tendency to gain a single electron in its valence shell to attain stable electronic configuration.
   (*iii*) Its low negative electron gain enthalpy value.
   (*iv*) Its small size.

Ans. (*ii*)

Explanation: Like halogens (with ns^2np^5 configuration belonging to the seventeenth group of the periodic table), it is short by one electron to the corresponding noble gas configuration, helium ($1s^2$).

2. Why does H^+ ion always get associated with other atoms or molecules?
   (*i*) Ionisation enthalpy of hydrogen resembles that of alkali metals.
   (*ii*) Its reactivity is similar to halogens.
   (*iii*) It resembles both alkali metals and halogens.
   (*iv*) 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. (*iv*)

Explanation: Loss of the electron from hydrogen atom results in nucleus (H^+) of 1.5×10^{-3} pm size. This is extremely small as compared to normal atomic and ionic sizes of 50 to 200 pm. As a consequence, H^+ does not exist freely and is always associated with other atoms or molecules.

3. Metal hydrides are ionic, covalent or molecular in nature. Among LiH, NaH, KH, RbH, CsH, the correct order of increasing ionic character is
   (*i*) LiH > NaH > CsH > KH>RbH
   (*ii*) LiH < NaH < KH < RbH < CsH
   (*iii*) RbH > CsH > NaH > KH > LiH
   (*iv*) NaH > CsH > RbH > LiH > KH

Ans. (*ii*)

Explanation: In ionic hydrid,e as it is formed by s-Block element, down the group, electropositive character increases.

4. Which of the following hydrides is electron-precise hydride?
   (*i*) B_2H_6 (*ii*) NH_3
   (*iii*) H_2O (*iv*) CH_4

Ans. (*iv*)

Explanation: These hydrides have the required number of electrons to write their conventional Lewis structures.

5. Radioactive elements emit α, β and γ rays and are characterised by their half-lives. The radioactive isotope of hydrogen is

(*i*) Protium (*ii*) Deuterium

(*iii*) Tritium (*iv*) Hydronium

Ans. (*iii*)

Explanation: The tritium concentration is about one atom per 10^{18} atoms of protium. Of these isotopes, only tritium is radioactive and emits low energy beta particles.

6. Consider the reactions:

(A) $H_2O_2 + 2HI \rightarrow I_2 + 2H_2O$

(B) $HOCl + H_2O_2 \rightarrow H_3O^+ + Cl^- + O_2$

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

(*i*) an oxidising agent in both (A) and (B)

(*ii*) an oxidising agent in (A) and reducing agent in (B)

(*iii*) a reducing agent in (A) and oxidising agent in (B)

(*iv*) a reducing agent in both (A) and (B)

Ans. (*ii*)

Explanation: In A, iodine is oxidized from –1 to zero whereas in B, chlorine get reduced from +1 to –1.

7. The oxide that gives H_2O_2 on treatment with dilute H_2SO_4 is—

(*i*) PbO_2 (*ii*) $BaO_2.8H_2O + O_2$

(*iii*) MnO_2 (*iv*) TiO_2

Ans. (*ii*)

Explanation: Acidifying barium peroxide and removing excess water by evaporation under reduced pressure gives hydrogen peroxide.

8. Which of the following equations depicts the oxidising nature of H_2O_2?

(*i*) $2MnO_4^- + 6H^+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$

(*ii*) $2Fe^{3+} + 2H^+ + H_2O_2 \rightarrow 2Fe^{2+} + 2H_2O + O_2$

(*iii*) $2I^- + 2H^+ + H_2O_2 \rightarrow I_2 + 2H_2O$

(*iv*) $KIO_4 + H_2O_2 \rightarrow KIO_3 + H_2O + O_2$

Ans. (*iii*)

Explanation: Iodine gets oxidized from –1 to zero.

9. Which of the following equations depicts reducing nature of H_2O_2?

(*i*) $2[Fe(CN)_6]^{4-} + 2H^+ + H_2O_2 \rightarrow 2[Fe(CN)_6]^{3-} + 2H_2O$

(*ii*) $I_2 + H_2O_2 + 2OH^- \rightarrow 2I^- + 2H_2O + O_2$

(*iii*) $Mn^{2+} + H_2O_2 \rightarrow Mn^{4+} + 2OH^-$

(*iv*) $PbS + 4H_2O_2 \rightarrow PbSO_4 + 4H_2O$

Ans. (*ii*)

Explanation: Iodine gets reduced from zero to –1.

10. Hydrogen peroxide is _____.

(*i*) an oxidising agent

(*ii*) a reducing agent

(*iii*) both an oxidising and a reducing agent

(*iv*) neither oxidising nor reducing agent

Ans. (*iii*)

Explanation: It acts as an oxidising as well as reducing agent in both acidic and alkaline media.

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

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

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

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

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

Ans. (*iii*)

Explanation: The production of dihydrogen can be increased by reacting carbon monoxide of syngas mixtures with steam in the presence of iron chromate as catalyst.

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

(*i*) sodium sulphate and water

(*ii*) sodium sulphate and oxygen

(*iii*) sodium sulphate, hydrogen and oxygen

(*iv*) sodium sulphate and hydrogen peroxide

Ans. (*iv*)

Explanation: $Na_2O_2 + \text{dil. } H_2SO_4 \rightarrow Na_2SO_4 + H_2O_2$

13. Hydrogen peroxide is obtained by the electrolysis of _____.

(*i*) water (*ii*) sulphuric acid

(*iii*) hydrochloric acid (*iv*) fused sodium peroxide

Ans. (*ii*)

Explanation: $2HSO_4^-(aq) \xrightarrow{\text{electrolysis}} HO_3SOOSO_3H(aq) \xrightarrow{\text{hydrolysis}} 2HSO_4^-(aq) + 2H^+(aq) + H_2O_2(aq)$

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

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

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

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

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

Ans. (*iv*)

Explanation: The reaction shown in equation(*iv*) shows the synthesis of methanol from water gas.

15. Which of the following ions will cause hardness in water sample?
(*i*) Ca^{2+} (*ii*) Na^{+}
(*iii*) Cl^{-} (*iv*) K^{+}

Ans. (*i*)

Explanation: Presence of calcium and magnesium salts in the form of hydrogencarbonate, chloride and sulphate in water makes water **'hard'**.

16. Which of the following compounds is used for water softening?
(*i*) $Ca_3(PO_4)_2$ (*ii*) Na_3PO_4
(*iii*) $Na_6P_6O_{18}$ (*iv*) Na_2HPO_4

Ans. (*iii*)

Explanation: Sodium hexametaphosphate ($Na_6P_6O_{18}$), commercially called 'calgon', is used to remove hardness from water.

17. Elements of which of the following group(s) of periodic table do **not** form hydrides?
(*i*) Groups 7, 8, 9 (*ii*) Group 13
(*iii*) Groups 15, 16, 17 (*iv*) Group 14

Ans. (*i*)

Explanation: The metals of group 7, 8 and 9 do not form hydrides.

18. Only one element of _____ forms hydride.
(*i*) group 6 (*ii*) group 7
(*iii*) group 8 (*iv*) group 9

Ans. (*i*)

Explanation: From group 6, only chromium forms CrH.

II. Multiple Choice Questions (Type-II)

In the following questions two or more options may be correct.

19. Which of the following statements are **not** true for hydrogen?
(*i*) It exists as diatomic molecule.
(*ii*) It has one electron in the outermost shell.
(*iii*) It can lose an electron to form a cation which can freely exist.
(*iv*) It forms a large number of ionic compounds by losing an electron.

Ans. (*iii*) and (*iv*)

Explanation: H^{+} does not exist freely and is always associated with other atoms or molecules. Unlike alkali metals, it has a very high ionization enthalpy and does not possess metallic characteristics under normal conditions.

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 _____.
(*i*) Water gas (*ii*) Syngas
(*iii*) Producer gas (*iv*) Industrial gas

Ans. (*i*) and (*ii*)

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

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

(*i*) Heavy water is used as a moderator in nuclear reactor.
(*ii*) Heavy water is more effective as solvent than ordinary water.
(*iii*) Heavy water is more associated than ordinary water.
(*iv*) Heavy water has lower boiling point than ordinary water.

Ans. (*i*) and (*iii*)

Explanation: Heavy water is used as moderator in nuclear reactors and in exchange reaction and due to its higher mass it is more associated with water.

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

(*i*) Hydrogen has three isotopes of which protium is the most common.
(*ii*) Hydrogen never acts as cation in ionic salts.
(*iii*) Hydrogen ion, H^+, exists freely in solution.
(*iv*) Dihydrogen does not act as a reducing agent.

Ans. (*i*) and (*ii*)

Explanation: Loss of the electron from hydrogen atom results in nucleus (H^+) of ~1.5×10^{-3} pm size. This is extremely small as compared to normal atomic and ionic sizes of 50 to 200 pm. As a consequence, H^+ does not exist freely and is always associated with other atoms or molecules.

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

(*i*) Water is known to be a universal solvent.
(*ii*) Hydrogen bonding is present to a large extent in liquid water.
(*iii*) There is no hydrogen bonding in the frozen state of water.
(*iv*) Frozen water is heavier than liquid water.

Ans. (*iii*) and (*iv*)

Explanation: The unusual properties of water in the condensed phase (liquid and solid states) are due to the presence of extensive hydrogen bonding between water molecules. This leads to high freezing point, high boiling point, high heat of vaporisation and high heat of fusion in comparison to H_2S and H_2Se.

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

(*i*) Chlorides of Ca and Mg in water
(*ii*) Sulphates of Ca and Mg in water
(*iii*) Hydrogencarbonates of Ca and Mg in water
(*iv*) Carbonates of alkali metals in water

Ans. (*i*) and (*ii*)

Explanation: Presence of calcium and magnesium salts in the form of hydrogencarbonate, chloride and sulphate in water makes water 'hard'.

25. Which of the following statements is correct?

(*i*) Elements of group 15 form electron deficient hydrides.
(*ii*) All elements of group 14 form electron precise hydrides.

(*iii*) Electron precise hydrides have tetrahedral geometries.
(*iv*) Electron rich hydrides can act as Lewis acids.

Ans. (*ii*) and (*iii*)

Explanation: Electron precise hydrides have the required number of electrons to write their conventional Lewis structures. All elements of group 14 form such compounds (*e.g.*, CH_4) which are tetrahedral in geometry.

26. Which of the following statements is correct?
(*i*) Hydrides of group 13 act as Lewis acids.
(*ii*) Hydrides of group 14 are electron deficient hydrides.
(*iii*) Hydrides of group 14 act as Lewis acids.
(*iv*) Hydrides of group 15 act as Lewis bases.

Ans. (*i*) and (*iv*)

Explanation: All elements of group 13 forms electron-deficient compounds and thus acts as Lewis acids. Electron-rich hydrides have excess electrons which are present as lone pairs. Elements of group 15-17 form such compounds. (NH_3 has 1–lone pair, H_2O – 2 and HF –3 lone pairs). Thus they act as Lewis bases.

27. Which of the following statements is correct?
(*i*) Metallic hydrides are deficient of hydrogen.
(*ii*) Metallic hydrides conduct heat and electricity.
(*iii*) Ionic hydrides do not conduct electricity in solid state.
(*iv*) Ionic hydrides are very good conductors of electricity in solid state.

Ans. (*i*), (*ii*) and (*iii*)

Explanation: Ionic hydrides are crystalline, non-volatile and non-conducting in solid state.

III. Short Answer Type

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

Ans. $\underset{\text{Water gas}}{CO + H_2} + \underset{\text{Steam}}{H_2O} \xrightarrow[770\ K]{Fe_2O_3/Cr_2O_3} CO_2 + 2H_2$

This reaction is called water gas shift reaction.

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

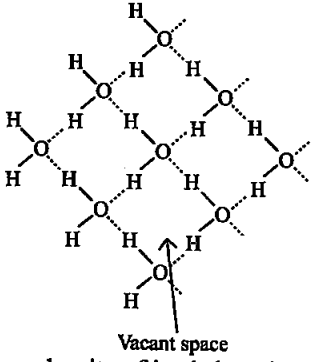
Ans. These are formed by many *d*-block and *f*-block elements. However, the metals of group 7, 8 and 9 do not form hydride. Unlike saline hydrides, they are almost always non-stoichiometric, being deficient in hydrogen. For example, LaH 2.87, YbH 2.55, TiH 1.5–1.8, ZrH 1.3–1.75. Dihydrogen forms molecular compounds with most of the *p*-block elements. Most familiar examples are CH_4, NH_3, H_2O and HF.

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

Ans. NaH belongs to Saline hydrides and B_2H_6 and H_2O belong to molecular hydrides.

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. Ice has a highly ordered 3D hydrogen bonded structure. Each oxygen atom is surrounded tetrahedrally by four other oxygen atoms at a distance of 276 pm.



Because of structure, density of ice is less than water.

32. Complete the following equations:

(*i*) $PbS(s) + H_2O_2(aq) \rightarrow$ (*ii*) $CO(g) + 2H_2(g) \xrightarrow[\text{catalyst}]{\text{cobalt}}$

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

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

33. Give reasons:

(*i*) Lakes freeze from top towards bottom.

(*ii*) Ice floats on water.

Ans. (*i*) During winter, the temperature of lake water keeps on decreasing. Since cold water is heavier, it moves towards bottom.

(*ii*) Density of ice is less than that of water that is why it floats on the surface of water.

34. What do you understand by the term 'autoprotolysis of water'? What is its significance?

Ans. Self ionization of water is known as autoprotolysis of water.

$$\underset{\text{acid-1 (acid)}}{H_2O(l)} + \underset{\text{base-2 (base)}}{H_2O(l)} \rightarrow \underset{\text{acid-2 (conjugate acid)}}{H_3O^+(aq)} + \underset{\text{base-1 (conjugate base)}}{OH^-(aq)}$$

Significance: Due to autoprotolysis, water has the ability to act as an acid as well as a base. Thus, it behaves as an amphoteric substance.

$$H_2O(l) + NH_3(aq) \rightleftharpoons OH^-(aq) + NH_4^+(aq)$$
$$H_2O(l) + H_2S(aq) \rightleftharpoons H_3O^+(aq) + HS^-(aq)$$

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

Ans. **Demineralisation of water by organic ion exchange or synthetic resins (ion exchange resins):**

(*a*) Synthetic resins are the insoluble polymeric solids having giant hydrocarbon network containing reactive acidic or basic groups.

These are superior to Zeolite because they can remove all types of cations as well as anions present in water. This resulting water is known as demineralised or deionised water.

(*b*) These are of two types:

- **Cation exchange resins:** They have acidic groups such as COOH or SO_3H. They may be represented as **resin—H^+.**

$$\underset{\text{In hard water}}{Mg^{2+}} + \underset{\text{Cation exchanger}}{2H\text{–resin}} \rightarrow Mg(\text{resin})_2 + 2H^+$$

$$\underset{\text{Hard water}}{Ca^{2+}} + \underset{\text{Cation exchanger}}{2H\text{–resin}} \rightarrow Ca(\text{resin})_2 + 2H^+$$

- **Anion exchange resins:** They have basic groups such as OH^- or NH_2. They may be represented as **resin—OH^- or resin $NH_3^+OH^-$.**

$$\underset{\text{Hard water}}{SO_4^{2-}} + \underset{\text{Anion exchanger}}{2HO\text{–resin}} \rightarrow SO_4\text{–resin}_2 + 2OH^-$$

$$\underset{\text{Hard water}}{Cl^-} + \underset{\text{Anion exchanger}}{HO\text{–resin}} \rightarrow Cl\text{–resin} + OH^-$$

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

Ans. (*a*) **Electron deficient:** The hydrides which do not have sufficient number of electrons to form normal covalent bonds are called electron deficient hydrides. For example, hydrides of group 13 (BH_3, AlH_3, etc.).

(*b*) **Electron precise:** The hydrides which have sufficient number of electrons required for forming covalent bonds are called electron precise hydrides. For example, hydrides of group 14 (CH_4, SiH_4, GeH_4, SnH_4, PbH_4 etc.). They have tetrahedral geometry.

(*c*) **Electron rich hydrides:** The hydrides which have excess electrons as required to form normal covalent bonds are called electron rich hydrides. For example, hydrides of group 15 to 17 (NH_3, PH_3, H_2O, H_2S, H_2Se, H_2Te, HF etc.).

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

Ans. Heavy water can be prepared by exhaustive electrolysis of water or as a by-product in some fertilizer industries. It is used for the preparation of other deuterium compounds.

Physical Properties of H_2O and D_2O

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	—
Temp of max. density/K	276.98	284.2
Density (298 K)/g cm^{-3}	1.0000	1.1059
Viscosity/centipoise	0.8903	1.107
Dielectric constant/$C^2/N.m^2$	78.39	78.06
Electrical conductivity (293 K/ohm^{-1} cm^{-1})	5.7×10^{-8}	—

38. Write one chemical reaction for the preparation of D_2O_2.

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

$$2HSO_4^-(aq) \xrightarrow{\text{Electrolysis}} HO_3SOOSO_3(aq)H \xrightarrow{\text{Hydrolysis}} 2HSO_4^-(aq) + 2H^+(aq) + H_2O_2(aq)$$

This method is now used for the laboratory preparation of D_2O_2.

$$K_2S_2O_8(s) + 2D_2O(l) \rightarrow 2KDSO_4(aq) + D_2O_2(l)$$

39. Calculate the strength of 5 volume H_2O_2 solution.

Ans. $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

5 volume H_2O_2 means 1L of H_2O_2 will give 5L of O_2 at STP.

On the basis of equation it is clear that 22.7 L of O_2 is produced by 68 g of H_2O_2.

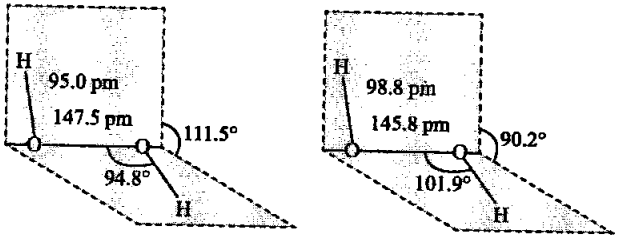
$$5L \text{ of } O_2 \text{ is produced by} = \frac{68g \times 5L}{22.7\,L} = \frac{3400}{227} g\ H_2O_2 = 14.9\ g \approx 15g\ H_2O_2$$

i.e., 15 g H_2O_2 dissolved in 1 L solution will give 5 L oxygen or 1.5 g H_2O_2/100 mL solution will give 500 mL oxygen. Thus 15 g/L or 1.5% solution is known as 5V solution of H_2O_2.

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*)



(*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*) In H_2O_2 oxygen is in –1 oxidation state which has tendency to become –2 that is why it is better oxidising agent than water.

41. Melting point, enthalpy of vapourisation 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 vapourisation 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?

Ans. D_2O has greater intermolecular force of attraction.

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. Dihydrogen reacts with dioxygen to form water. The reaction is highly exothermic.

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

$$\Delta H^{\ominus} = -285.9 \text{ kJ mol}^{-1}$$

The isotope of hydrogen which has one proton and one neutron is deuterium. When it reacts with O_2 it forms Deuterium oxide (D_2O). Deuterium reacts in a similar way but the reactivity will be lesser than hydrogen because of high bond dissociation enthalpy of D_2 as compared to hydrogen.

43. Explain why HCl is a gas and HF is a liquid.

Ans. Because of hydrogen bonding HF is liquid whereas HCl is gas as there is lack of hydrogen bonding in HCl.

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 compound is water which undergo self ionization.

The autoprotolysis (self-ionization) of water takes place as follows:

$$\underset{\substack{\text{acid-1}\\\text{(acid)}}}{H_2O(l)} + \underset{\substack{\text{base-2}\\\text{(base)}}}{H_2O(l)} \rightarrow \underset{\substack{\text{acid-2}\\\text{(conjugate acid)}}}{H_3O^+(aq)} + \underset{\substack{\text{base-1}\\\text{(conjugate base)}}}{OH^-(aq)}$$

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 given compound is H_2O_2.

(*ii*) It is employed in the industries as a bleaching agent for textiles, paper pulp, leather, oils, fats, etc. It acts as an oxidising as well as reducing agent in both acidic and alkaline media. It is, therefore, stored in wax-lined glass or plastic vessels in dark. Urea can be added as a stabiliser. It is kept away from dust because dust can induce explosive decomposition of the compound.

46. Give reasons why hydrogen resembles alkali metals?

Ans. Hydrogen has electronic configuration $1s^1$. On one hand, its electronic configuration is similar to the outer electronic configuration (ns^1) of alkali metals, which belong to the first group of the periodic table. Hydrogen, therefore, has resemblance to alkali metals, which lose one electron to form unipositive ions.

47. Hydrogen generally forms covalent compounds. Give reason.

Ans. Because of ionization enthalpy, hydrogen resembles more with halogens, $\Delta_i H$ of Li is 520 kJ mol^{-1}, F is 1680 kJ mol^{-1} and that of H is 1312 kJ mol^{-1}. Like halogens, it forms a diatomic molecule, combines with elements to form hydrides and a large number of covalent compounds.

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

Ans. In sodium the last shell electron is in $3s^1$ after loosing that electron, it can acquire the configuration of Ne. Whereas in hydrogen, the electron is in *s*-orbital.

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. Hydrogen economy (Hydrogen as fuel):

(*i*) The electricity cannot be stored to run automobiles. It is not possible to store and transport nuclear energy. Hydrogen is an alternative source of energy and hence called as 'hydrogen economy'. Hydrogen has some advantages as fuel.

(*ii*) Available in abundance in combined form as water.

(*iii*) On combustion produces H_2O. Hence pollution free.

(*iv*) H_2-O_2 fuel cell give more power.

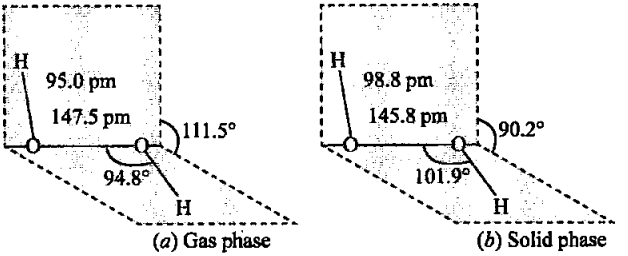
(*v*) Excellent reducing agent. Therefore, can be used as substitute of carbon in reduction for processes in industry.

50. What is the importance of heavy water?

Ans. Heavy water can be used as a moderator in nuclear reactors and in exchange reactions for the study of reaction mechanisms. It can be prepared by exhaustive electrolysis of water or as a by-product in some fertilizer industries.

51. Write the Lewis structure of hydrogen peroxide.

Ans. (*i*)



(*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°

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. (*i*) Oxidising action in acidic medium:

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

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

(*ii*) Reducing action in acidic medium:

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

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

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

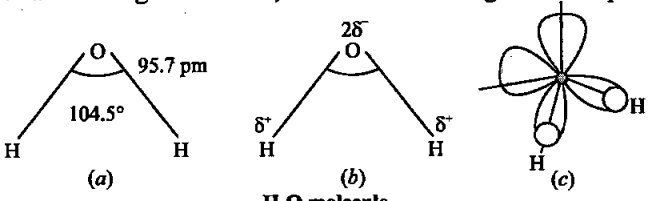
Ans. H_2O_2 decomposes slowly on exposure to light.

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

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.

54. Why is water molecule polar?

Ans. Water molecule is polar because in the gas phase water is a bent molecule with a bond angle of 104.5°, and O–H bond length of 95.7 pm.



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.

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

Ans. Because of hydrogen bonding water has high boiling point than H_2S as in H_2S hydrogen bonding is absent.

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

Ans. Hydrogen peroxide cannot be concentrated by heating as it can cause burns on heating. It can be 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.

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

Ans. Hydrogen peroxide is stored in wax lined bottles because H_2O_2 decomposes slowly on exposure to light.

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

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

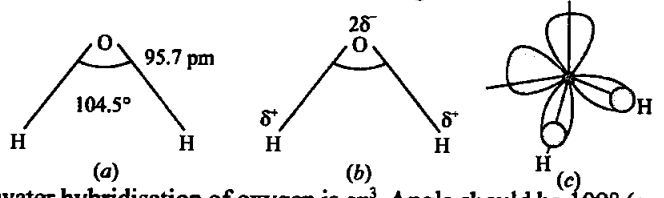
Ans. Hard water forms scum/precipitate with soap. Soap, containing sodium stearate ($C_{17}H_{35}COONa$), reacts with hard water to precipitate out Ca/Mg stearate. It is, therefore, unsuitable for laundry. It is harmful for boilers as well, because of deposition of salts in the form of scale.

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

Ans. Because H_2SO_4 can activate the decomposition of H_2O_2.

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

Ans.



In water hybridisation of oxygen is sp^3. Angle should be 109° (approx.) but due to LP – LP repulsion bond angle reduce to 104.5°.

61. Write redox reaction between fluorine and water.

Ans. $2F_2(g) + 2H_2O \rightarrow 4H^+(aq) + 4F^-(aq) + O_2(g)$

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

Ans. $H_2O(l) + NH_3(aq) \rightarrow OH^-(aq) + NH_4^+(aq)$

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

IV. Matching Type

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
(*i*) Synthesis gas	(*a*) $Na_2[Na_4(PO_3)_6]$
(*ii*) Dihydrogen	(*b*) Oxidising agent
(*iii*) Heavy water	(*c*) Softening of water
(*iv*) Calgon	(*d*) Reducing agent
(*v*) Hydrogen peroxide	(*e*) Stoichiometric compounds of *s*-block elements

(*v*) Salt like hydrides	(*f*) Prolonged electrolysis of water
	(*g*) Zn + NaOH
	(*h*) Zn + dil. H_2SO_4
	(*i*) Synthesis of methanol
	(*j*) Mixture of CO and H_2

Ans. (*i*) → (*j*); (*ii*) → (*h*); (*iii*) → (*f*); (*iv*) → (*a*); (*v*) → (*b*); (*vi*) → (*e*)

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

Column I	Column II
(*i*) H	(*a*) Used in the name of perhydrol.
(*ii*) H_2	(*b*) Can be reduced to dihydrogen by NaH.
(*iii*) H_2O	(*c*) Can be used in hydroformylation of olefin.
(*iv*) H_2O_2	(*d*) Can be used in cutting and welding.

Ans. (*i*) → (*d*); (*ii*) → (*b*); (*iii*) → (*c*); (*iv*) → (*a*)

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

Column I	Column II
(*i*) Electrolysis of water produces	(*a*) atomic reactor
(*ii*) Lithium aluminium hydride is used as	(*b*) polar molecule
(*iii*) Hydrogen chloride is a	(*c*) recombines on metal surface to generate high temperature
(*iv*) Heavy water is used in	(*d*) reducing agent
(*v*) Atomic hydrogen	(*e*) hydrogen and oxygen

Ans. (*i*) → (*e*); (*ii*) → (*d*); (*iii*) → (*b*); (*iv*) → (*a*); (*v*) → (*c*)

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

Column I	Column II
(*i*) Hydrogen peroxide is used as a	(*a*) zeolite
(*ii*) Used in Calgon method	(*b*) perhydrol
(*iii*) Permanent hardness of hard water is removed by	(*c*) sodium hexametaphosphate
	(*d*) propellant

Ans. (*i*) → (*b*); (*ii*) → (*c*); (*iii*) → (*a*)

V. Assertion and Reason Type

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

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.

(*i*) Statements A and R both are correct and R is the correct explanation of A.

(*ii*) A is correct but R is not correct.

(*iii*) A and R both are correct but R is not the correct explanation of A.

(*iv*) A and R both are false.

Ans. (*i*) R is the correct explanation of A.

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.

(*i*) Statements A and R both are correct and R is the correct explanation of A.

(*ii*) A is correct but R is not correct.

(*iii*) A and R both are correct but R is not the correct explanation of A.

(*iv*) A and R both are false.

Ans. (*i*) R is the correct explanation of A.

VI. Long Answer Type

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

Ans. Atomic hydrogen is very reactive whereas molecular hydrogen are quite stable. The chemical behaviour of dihydrogen (and for that matter any molecule) is determined, to a large extent, by bond dissociation enthalpy. The H–H bond dissociation enthalpy is the highest for a single bond between two atoms of any element. As a result, molecular hydrogen reacts only with a few elements.

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. D_2O can be prepared by prolonged electrolysis of water. Due to high molecular mass D_2O differ from water.

$$NaOH + D_2O \rightarrow NaOD + HOD$$

$$HCl + D_2O \rightarrow DCl + HOD$$

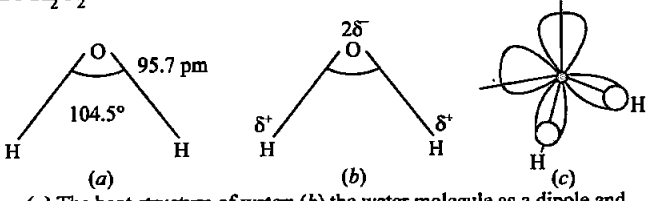
$$NH_4Cl + D_2O \rightarrow NH_3DCl + HOD$$

Physical Properties of H_2O and D_2O

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	—
Temp of max. density/K	276.98	284.2
Density (298 K)/g cm^{-3}	1.0000	1.1059
Viscosity/centipoise	0.8903	1.107
Dielectric constant/$C^2/N.m^2$	78.39	78.06
Electrical conductivity (293 K/ohm^{-1} cm^{-1})	5.7×10^{-8}	—

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



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

(*i*) As an antiseptic it is solid in market as perhydrol.

(*ii*) It is used to manufacture chemicals like sodium perborate and per-carbonate. It is employed in the industries as a bleaching agent for textiles.

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*) **Industrial preparation:** H_2O_2 is prepared by the auto-oxidation of 2-alkylanthraquinols.

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

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

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

(*ii*) (*a*) Reducing action in acidic medium

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

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

(*b*) Oxidising action in basic medium

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

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

(*c*) $I_2 + H_2O_2 + 2OH^- \rightarrow 2I^- + 2H_2O + O_2$

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

73. What mass of hydrogen peroxide will be present in 2 litres of a 5 molar solution? Calculate the mass of oxygen which will be liberated by the decomposition of 200 mL of this solution.

Ans. Mass of H_2O_2 = 68 g.

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

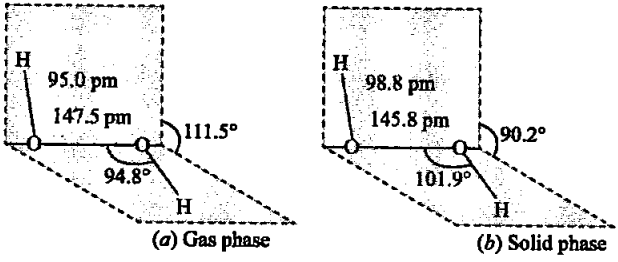
Mass of oxygen produced = 3.2g

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. (*i*) A is H_2O_2. Structure of H_2O_2 is given below.



(*a*) Gas phase (*b*) Solid phase

(*ii*) $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

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. Lithium hydride is rather unreactive at moderate temperatures with O_2 or Cl_2.

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

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. Saline hydrides react violently with water producing dihydrogen gas.

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

Their melts conduct electricity and on electrolysis liberate dihydrogen gas at anode, which confirms the existence of H^- ion.

$$2H^-(\text{melt}) \xrightarrow{\text{anode}} H_2(g) + 2e^-$$

❑❑❑