POSITION OF HYDROGEN IN PERIODIC TABLE

Hydrogen is the first element in the periodic table. However, its placement in the periodic table has been a subject of discussion in the past. As you know by now that the elements in the periodic table are arranged according to their electronic configurations. 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. On the other hand, 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 ($1s^2$). Hydrogen, therefore, has resemblance to alkali metals, which lose one electron to form unipositive ions, as well as with halogens, which gain one electron to form uninegative ion. Like alkali metals, hydrogen forms oxides, halides and sulphides. However, unlike alkali metals, it has a very high ionization enthalpy and does not possess metallic characteristics under normal conditions. In fact, in terms of ionization enthalpy, hydrogen resembles more with halogens, Δ_iH 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. However, in terms of reactivity, it is very low as compared to halogens.

Inspite of the fact that hydrogen, to a certain extent resembles both with alkali metals and halogens, it differs from them as well. Now the pertinent question arises as where should it be placed in the periodic table? Loss of the electron from hydrogen atom results in nucleus (H^+) of 1.510^{-3} pm size. This is extremely small as compared to normal atomic and ionic sizes of 50 to 200pm. As a consequence, H^+ does not exist freely and is always associated with other atoms or molecules. Thus, it is unique in behaviour and is, therefore, best placed separately in the periodic table.

DIHYDROGEN, H_2

Occurrence

Dihydrogen is the most abundant element in the universe (70% of the total mass of theuniverse) and is the principal element in the solar atmosphere. The giant planets Jupiter and Saturn consist mostly of hydrogen. However, due to its light nature, it is much less abundant (0.15% by mass) in the earth's atmosphere. Of course, in the combined form it constitutes 15.4% of the earth's crust and the oceans. In the combined form besides in water, it occurs in plant and animal tissues, carbohydrates, proteins, hydrides including hydrocarbons and many other compounds.

Isotopes of Hydrogen

Hydrogen has three isotopes: **protium**, ^1_1H, deuterium, ^2_1H or D and tritium, ^3_1Ho T.

These isotopes differ from one another in respect of the presence of neutrons. Ordinary hydrogen, protium, has no neutrons, deuterium (also known as heavy hydrogen) has one and tritium has two neutrons in the nucleus. In the year 1934, an American scientist, Harold C. Urey, got Nobel Prize for separating hydrogen isotope of mass number 2 by physical methods.

The predominant form is protium. Terrestrial hydrogen contains 0.0156% of deuterium mostly in the form of HD. The tritium concentration is about one atom per 1018 atoms of protium. Of these isotopes, only tritium is radioactive and emits low energy β^- particles.

Atomic and Physical Properties of Hydrogen

Property	Hydrogen	Deuterium	Tritium
Relative abundance (%)	99.985	0.0156	10^{-15}
Relative atomic mass (g mol^{-1})	1.008	2.014	3.016
Melting point / K	13.96	18.73	20.62
Boiling point / K	20.39	23.67	25.0
Density / gL^{-1}	0.09	0.18	0.27
Enthalpy of fusion/KJ mol^{-1}	0.117	0.197	–
Enthalpy of vaporization/kJ mol^{-1}	0.904	1.226	–
Enthalpy of bond dissociation/kJ mol^{-1} at 298.2K	435.88	443.35	–
Internuclear distance/pm	74.14	74.14	–
Ionization enthalpy.kJ mol^{-1}	13.12	–	–
Electron gain enthalpy/kJ mol^{-1}	–73	–	–
Covalent radius/pm	37	–	–
Ionic radius (H^-)/pm	208		

Since the isotopes have the same electronic configuration, they have almost the same chemical properties. The only difference is in their rates of reactions, mainly due to their different enthalpy of bond dissociation. However, in physical properties these isotopes differ considerably due to their large mass differences.

Different forms of Hydrogen:

Based on oxidation Number.

There are three types of hydrogen

H^+ H^- H

ProtonHydride

Atomic hydrogen

Number of electron 0 2 1

Oxidation number +1 –1 0

Formation $H \rightarrow H^+ + e^-$ $H + e^- \rightarrow H^-$ $H_2 \xrightarrow{\Delta} 2H$

Note : In the aqueous state proton (H^+) exist as $H^+ (H_2O)_n$Where n is a large number.

If n = 1→H_3O^+

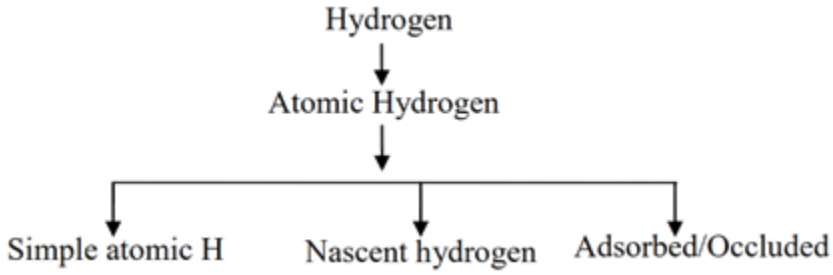
n = 2 → $H^+(H_2O)_2$

Q. In the eqeuous solution hydrogen ion exist as

(A)H_3O^+ (B) $H^+(H_2O)_2$ (C) $H^+(H_2O)_n$ (D) All

Ans. **(D)**

(B) Based on reactivity :



Atomic hydrogen :

(i) Simple atomic hydrogen – It is formed by simple dissociation of hydrogen.

$$H_2 \underset{}{\overset{3000-5000}{\rightleftharpoons}} 2H$$

Favourable condition – Favourable condition are high temp & low pressure.

(i) Nascent hydrogen – Hydrogen at the moment of its birth it called nascent hydrogen means which forms at the instant is known as nascent hydrogen.

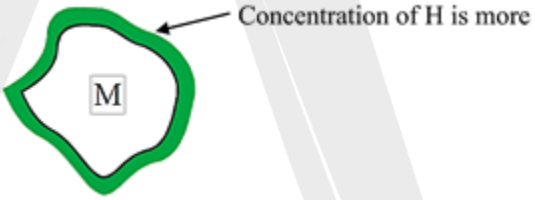
It is formed only by some specific chemical reaction.

(a) Acid + Metals $Zn + H_2SO_4 \rightarrow ZnSO_4 + 2H$

(b) Base + element $2NaOH + Be \rightarrow Na_2BeO_2 + 2H$

C_2H_5OH + Alkali Metal $C_2H_5OH + Na \rightarrow C_2H_5ONa + H$

(iii) Adsorbed/Occluded hydrogens

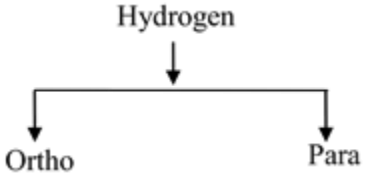


Adsorbed H is hydrogen present at the outer surface of metal. **Occlusion** - The property of metal to absorb any gas is called occlusion.

Reactivity Order

Atomic hydrogen > Nascent hydrogen > Molecular hydrogen

(IV) Based on Nuclear spin (Nuclear isomers)



(a) Ortho hydrogen - The molecular form of hydrogen having same spin of nucleus is called ortho hydrogen.

(b) Para hydrogen - The molecular form of hydrogen having opposite spin of nucleus is called para hydrogen.

In ortho hydrogen spin of nucleus is same, so they will repel each other & because of this repulsion, internal energy of ortho hydrogen increases. So ortho hydrogen has more internal energy.

Stability of ortho & para hydrogen

Stability of ortho & para hydrogen depends upon temperature condition.

At low temp : para hydrogen is more stable than ortho hydrogen while at high temp ortho hydrogen is more stable than para hydrogen.

$$P_{H_2} \underset{T\downarrow}{\overset{T\uparrow}{\rightleftharpoons}} O_{H_2}$$

	Ortho	Para
At room temperature	75%	25%
At absolute zero temp.	0	100%

Imp. Note : (i) We can obtain 100% pure para hydrogen at low temp but can't ortho because at high temp parahydrogen will dissociate into atomic hydrogen. (ii) Ortho & Para hydrogen differs only in physical properties but have same chemical properites.

PREPARATION OF DIHYDROGEN, H_2

There are a number of methods for preparing dihydrogen from metals and metal hydrides.

Laboratory Preparation of Dihydrogen

(i) It is usually prepared by the reaction of granulated zinc with dilute hydrochloric acid.

$Zn + 2H^+ \rightarrow Zn^{2+} + H_2$

(ii) It can also be prepared by the reaction of zinc with aqueous alkali.

$Zn + 2NaOH \rightarrow Na_2ZnO_2 + H_2$

Sodium zincate

Commercial Production of Dihydrogen

The commonly used processes are outlined below:

(i) Electrolysis of acidified water using platinum electrodes gives hydrogen.

$$2H_2O(\ell) \xrightarrow[\text{Trances of acid/base}]{\text{Electrolysis}} 2H_2(g) + O_2(g)$$

(ii) High purity ($> 99.95\%$) dihydrogen is obtained by electrolysing warm aqueous barium hydroxide solution between nickel electrodes.

(iii) It is obtained as a byproduct in the manufacture of sodium hydroxide and chlorine by the electrolysis of brine solution. During electrolysis, the reactions that take place are: at anode:

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

at cathode: $2H_2O(\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

The overall reaction is

$2Na^+(aq) + 2Cl^-(aq) + 2H_2O(\ell) \rightarrow Cl_2(g) + H_2(g) + 2Na^+(aq) + 2OH^-(aq)$

(iv) Reaction of steam on hydrocarbons or coke at high temperatures in the presence of catalyst yields hydrogen.

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

e. g.,

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

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 'syngas'. Nowadays 'syngas' is produced from sewage, saw-dust, scrap wood, newspapers etc. The process of producing 'syngas' from coal is called coal gasification.

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

The production of dihydrogen can be increased by reacting carbon monoxide of syngas mixtures with steam in the presence of iron chromate as catalyst (Fe_2O_3 and Cr_2O_3).

$$CO(g) + H_2O(g) \underset{\text{catalys}}{\overset{673\ K}{\longrightarrow}} CO_2(g) + H_2(g)$$

This is called water-gas shift reaction /Bosch process. Carbon dioxide is removed by scrubbing with sodium arsenite solution. Presently ~ 77% of the industrial dihydrogen is produced from petro-chemicals, 18% from coal, 4% from electrolysis of aqueous solutions and 1% from other sources.

PROPERTIES OF DIHYDROGEN

Physical Properties

Dihydrogen is a colourless, odourless, tasteless, combustible gas. It is lighter than air and insoluble in water. Its other physical properties alongwith those of deuterium are given in Table.

Chemical Properties

The chemical behavior 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. What inferences would you draw from this fact? It is because of this factor that the dissociation of dihydrogen into its atoms is only 0.081% around 2000 K which increases to 95.5% at 5000 K. Also, it is relatively inert at room temperature due to the high H – H bond enthalpy. Thus, the atomic hydrogen is produced at ahigh temperature in an electric arc or under ultraviolet radiations. Since its orbital is incomplete with $1\ s^1$ electronic configuration, it does combine with almost all the elements. It accomplishes reactions by (i) loss of the only electron to give H^+, (ii) gain of an electron to form H^-, and (iii) sharing electrons to form a single covalent bond. The chemistry of dihydrogen can be illustrated by the following reactions:

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

$H_2(g) + X_2(g) \rightarrow 2HX(g) (X = F, Cl, Br, I)$

While the reaction with fluorine occurs even in the dark, with iodine it requires a catalyst.

Reaction with dioxygen: It reacts with dioxygen to form water. The reaction is highly exothermic.

$2H_2(g) + O_2(g) \xrightarrow{\text{catalyst or heating}} 2H_2O(\ell); \Delta H^{\ominus} = -285.9 \text{ kJ mol}^{-1}$

Reaction with dinitrogen : With dinitrogen it forms ammonia.

$3H_2(g) + N_2(g) \xrightarrow[Fe]{673K/200atm} 2NH_3(g) \Delta H^{\ominus} = 92.6 \text{ kJ mol}^{-1}$

This is the method for the manufacture of ammonia by the Haber process.

Reactions with metals: With many metals it combines at a high temperature to yield the corresponding hydrides.

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

where M is an alkali metal

Reactions with metal ions and metal oxides: It reduces some metal ions in aqueous solution and oxides of metals (less active than iron) into corresponding metals.

$H_2(g) + Pd^{2+}(aq) \rightarrow Pd(s) + 2H^+(aq)$

$yH_2(g) + M_xO_y(s) \rightarrow xM(s) + yH_2O(\ell)$

Reactions with organic compounds: It reacts with many organic compounds in the presence of catalysts to give useful hydrogenated products of commercial importance. For example :

(i) Hydrogenation of vegetable oils using nickel as catalyst gives edible fats (margarine and vanaspati ghee)

(ii) Hydroformylation of olefins yields aldehydes which further undergo reduction to give alcohols.

$H_2 + CO + RCH = CH_2 \rightarrow RCH_2CH_2CHO$

$H_2 + RCH_2CH_2CHO \rightarrow RCH_2CH_2CH_2OH$

Problem-1

Comment on the reactions of dihydrogen with (i) chlorine, (ii) sodium, and (iii) copper (II) oxide

Solution

(i) Dihydrogen reduces chlorine into chloride (Cl^-)ion and itself gets oxidised to H^+ion by chlorine to form hydrogen chloride. An electron pair is shared between H and Cl leading to the formation of a covalent molecule.

(ii) Dihydrogen is reduced by sodium to form NaH. An electron is transferred from Na to H leading to the formation of an ionic compound, Na^+H^-.

(iii) Dihydrogen reduces copper (II) oxide to copper in zero oxidation state and itself gets oxidised to H_2O, which is a covalent molecule.

Uses of Dihydrogen

The largest single use of dihydrogen is in the synthesis of ammonia which is used in the manufacture of nitric acid and nitrogenous fertilizers.

Dihydrogen is used in the manufacture of vanaspati fat by the hydrogenation of polyunsaturated vegetable oils like soyabean, cotton seeds etc. It is used in the manufacture of bulk organic chemicals, particularly methanol.

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

It is widely used for the manufacture of metal hydrides.

It is used for the preparation of hydrogen chloride, a highly useful chemical.

In metallurgical processes, it is used to reduce heavy metal oxides to metals

Atomic hydrogen and oxy-hydrogen torches find use for cutting and welding purposes. Atomic hydrogen atoms (produced by dissociation of dihydrogen with the help of an electric arc) are allowed to recombine on the surface to be welded to generate the temperature of 4000 K.

It is used as a rocket fuel in space research.

Dihydrogen is used in fuel cells for generating electrical energy. It has many advantages over the conventional fossil fuels and electric power. It does not produce any pollution and releases greater energy per unit mass of fuel in comparison to gasoline and other fuels.

HYDRIDES

Dihydrogen, under certain reaction conditions, combines with almost all elements, except noble gases, to form binary compounds, called hydrides. If ' E ' is the symbol of an element then hydride can be expressed as EH_x (e.g., MgH_2) or E_mH_n (e.g., B_2H_6).

The hydrides are classified into three categories:

(i) Ionic or saline or saltlike hydrides

(ii) Covalent or molecular hydrides

(iii) Metallic or non-stoichiometric hydrides

Ionic or Saline Hydrides

These are stoichiometric compounds of dihydrogen formed with most of the s-block elements which are highly electropositive in character. The ionic hydrides are crystalline, non-volatile and nonconducting in solid state. However, their melts conduct electricity and on electrolysis liberate dihydrogen gas at anode, which confirms the existence of H^-ion.

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

Saline hydrides react violently with water producing dihydrogen gas.

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

Lithium hydride is rather unreactive at moderate temperatures with O_2 or Cl_2. It is, therefore, used in the synthesis of other useful hydrides, e.g.,

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

$2LiH + B_2H_6 \rightarrow 2LiBH_4$(Ionic hydride)

Covalent or Molecular Hydride

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 nonmetals have also been considered as hydrides. Being covalent, they are volatile compounds. Molecular hydrides are further classified according to the relative numbers of electrons and bonds in their Lewis structure into:

Covalent or Molecular Hydride

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 nonmetals have also been considered as hydrides. Being covalent, they are volatile compounds. Molecular hydrides are further classified according to the relative numbers of electrons and bonds in their Lewis structure into:

(i) electron-deficient, (ii) electron-precise, and (iii) electron-rich hydrides.

An electron-deficient hydride, as the name suggests, has too few electrons for writing its conventional Lewis structure. Diborane (B_2H_6) is an example. In fact all elements of group 13 will form electron deficient compounds. They act as Lewis acids i.e., electron acceptors. Electron-precise compounds 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.

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). They will behave as Lewis bases i.e., electron donors. The presence of lone pairs on highly electronegative atoms like N, O and F in hydrides results in hydrogen bond formation between the molecules. This leads to the association of molecules.

Note : BeH_2 & MgH_2 are covalent hydride

Problem -2

Would you expect the hydrides of N, O and F to have lower boiling points than the hydrides of their subsequent group members? Give reasons.

Solution

On the basis of molecular masses of NH_3, H_2O and HF, their boiling points are expected to be lower than those of the subsequent group member hydrides. However, due to higher electronegativity of N, O and F, the magnitude of hydrogen bonding in their hydrides will be quite appreciable. Hence, the boiling points NH_3, H_2O and HF will be higher than the hydrides of their subsequent group members.

Metallic or Non-stoichiometric (or Interstitial) Hydrides

These 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. Unlike saline hydrides, they are almost always nonstoichiometric, being deficient in hydrogen. For example, $LaH_{2.87}, YbH_{2.55}, TiH_{1.5-1.8}, ZrH_{1.3-1.75}, VH_{0.56}, NiH_{0.6-0.7}, PdH_{0.6-0.8}$ etc. In such hydrides, the law of constant composition does not hold good.

Earlier it was thought that in these hydrides, hydrogen occupies interstices in the metal lattice producing distortion without any change in its type. Consequently, they were termed as interstitial hydrides. However, recent studies have shown that except for hydrides of Ni, Pd, Ce and Ac, other hydrids of this class have lattice different from that of the parent metal. The property of absorption of hydrogen on transition metals is widely used in catalytic reduction / hydrogenation reactions for the preparation of large number of compounds. Some of the metals (e.g., Pd, Pt) can accommodate a very large volume of hydrogen and, therefore, can be used as its storage media. This property has high potential for hydrogen storage and as a source of energy.

Problem-3

Can phosphorus with outer electronic configuration $3s^2 3p^3$ form PH_5 ?

Solution

Although phosphorus exhibits +3 and +5 oxidation states, it cannot form PH_5. Besides some other considerations, high $\Delta_a H$ value of dihydrogen and $\Delta_{eg} H$ value of hydrogen do not favour to exhibit the highest oxidation state of P, and consequently the formation of PH_5.

LEARNER BOX-1

1. The catalyst used in Bosch process of manufacture of H_2 is :-

(A) Finely divided N (B) V_2O_5 (C) Pb (D) $Fe_2O_3 + Cr_2O_3$

2. In all its properties, hydrogen resembles:-

(A) Alkali metals only (B) Halogens only

(C) Both alkali metals and halogens (D) Neither alkali metals nor halogens

3. Hydrogen is :-

(A) Electropositive

(B) Electronegative

(C) Both electropositive as well as electro-negative

(D) Neither electropositive nor electronegative

4. Ortho and Para hydrogen differ :-

(A) In the number of protons (B) In the molecular mass

(C) In the nature of spins of nucleus (D) In the nature of spins of electrons

5. The adsorption of hydrogen by metals is called :-

(A) Dehydrogenation (B) Hydrogenation

(C) Occlusion (D) Adsorption

WATER

A major part of all living organisms is made up of water. Human body has about 65% and some plants have as much as 95% water. It is a crucial compound for the survival of all life forms. It is a solvent of great importance. The distribution of water over the earth's surface is not uniform. The estimated world water supply is given in Table.s

Estimated World Water Supply

Source	% of total
Oceans	97.33
Saline lakes and inland seas	0.008
Polar ice and glaciers	2.04
Ground water	0.61
Lakes	0.009
Soil moisture	0.005
Atmospheric water vapour	0.001
Rivers	0.001

Physical Properties of Water

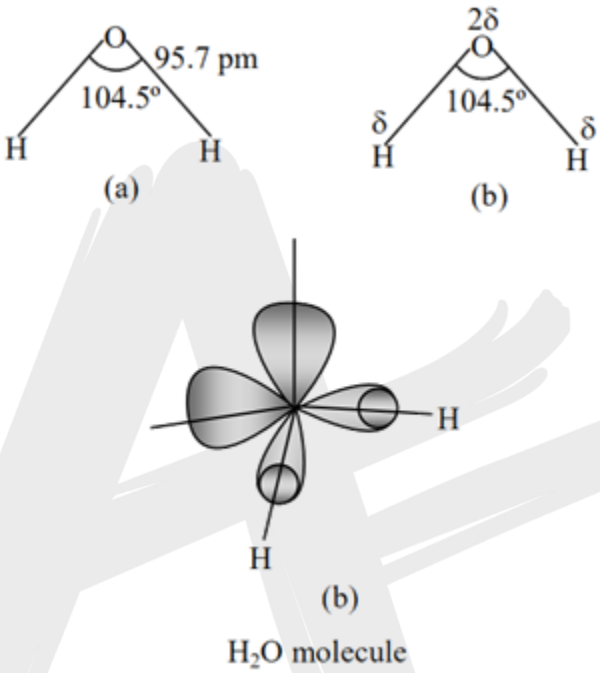
It is a colourless and tasteless liquid. Its physical properties are given in Table along with the physical properties of heavy water. The unusual properties of water in the condensed phase (liquid and solid states) are due to the presence of extensive hydrogen bonding between water molecules. This leads to high freezing point, high boiling point, high heat of vaporisation and high heat of fusion in comparison to H_2 S and H_2Se. In comparison to other liquids, water has a higher specific heat, thermal conductivity, surface tension, dipole moment and dielectric constant, etc. These properties allow water to play a key role in the biosphere.

Physical Properties of H_2O and D_2O

Property	H_2O	D_2O
Molecular mass ($gmol^{-1}$)	18.0151	20.0276
Melting point/K	273.0	276.8
Boiling point/K	373.0	374.4
Enthalpy of formation /$kJmol^{-1}$	-285.9	-294.6
Enthalpy of vaporisation (373 K)/$kJmol^{-1}$	40.66	41.61
Enthalpy of fusion /$kJmol^{-1}$	6.01	-
Temp of max. density/K	276.98	284.2
Density (298 K)/gcm^{-3}	1.0000	1.1059
Viscosity/centipoises	0.8903	1.107
Dielectric constant /$C^2/N \cdot m^2$	78.39	78.6
Electrical conductivity (293 K/ohm^{-1})cm^{-1}	5.7×10^{-8}	-

The high heat of vaporisation and heat capacity are responsible for moderation of the climate and body temperature of living beings. It is an excellent solvent for transportation of ions and molecules required for plant and animal metabolism. Due to hydrogen bonding with polar molecules, even covalent compounds like alcohol and carbohydrates dissolve in water.
Structure of Water

In the gas phase water is a bent molecule with a bond angle of 104.5°, and O – H bond length of 95.7pm as shown in Fig (a).



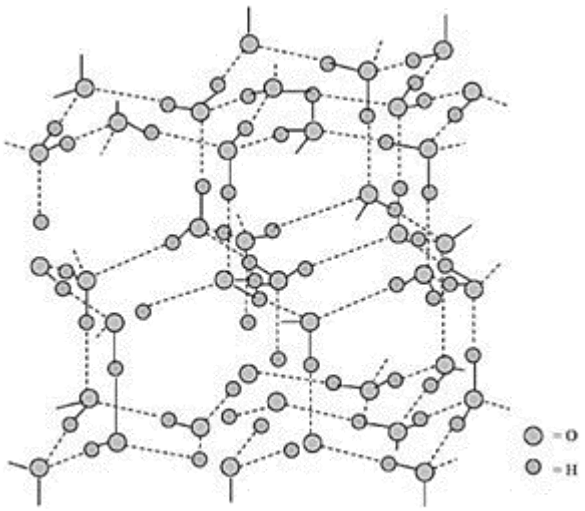
(a) The bent structure of water; (b) the water molecule as a dipole and (c) the orbital overlap picture in water molecule.

It is a highly polar molecule, (Fig (b)). Its orbital overlap picture is shown in Fig. (c). In the liquid phase water molecules are associated together by hydrogen bonds.

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. In winter season ice formed on the surface of a lake provides thermal insulation which ensures the survival of the aquatic life. This fact is of great ecological significance.

Structure of Ice

Ice has a highly ordered three dimensional hydrogen bonded structure as shown in Fig. Examination of ice crystals with X-rays shows that each oxygen atom is surrounded tetrahedrally by four other oxygen atoms at a distance of 276pm. Hydrogen bonding gives ice a rather open type structure with wide holes. These holes can hold some other molecules of appropriate size interstitially.



The structure of ice

Chemical Properties of Water

Water reacts with a large number of substances. Some of the important reactions are given below.

(1) **Amphoteric Nature:** It has the ability to act as an acid as well as a base i.e., it behaves as an amphoteric substance. In the Brönsted sense it acts as an acid with NH_3 and a base with H_2S.

$H_2O(\ell) + NH_3(aq) \rightarrow OH^-(aq) + NH_4^+(aq)$

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

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

$H_2O(\ell) + H_2O(\ell) \rightarrow H_3O^+(aq) + OH^-(aq)$

acid-1 base-2 acid-2 base-1

(acid) (base) (conjugate acid) (conjugate base)

(2) **Redox Reactions Involving Water:** Water can be easily reduced to dihydrogen by highly electropositive metals.

$2H_2O(\ell) + 2Na(s) \rightarrow 2NaOH(aq) + H_2(g)$

Thus, it is a great source of dihydrogen.

Water is oxidised to O_2 during photosynthesis.

$6CO_2(g) + 12H_2O(\ell) \rightarrow C_6H_{12}O_6(aq) + 6H_2O(\ell) + 6O_2(g)$

With fluorine also it is oxidised to O_2.

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

(3) **Hydrolysis Reaction:** Due to high dielectric constant, it has a very strong hydrating tendency. It dissolves many ionic compounds. However, certain covalent and some ionic compounds are hydrolysed in water.

$P_4O_{10}(s) + 6H_2O(\ell) \rightarrow 4H_3PO_4(aq)$

$SiCl_4(\ell) + 2H_2O(\ell) \rightarrow SiO_2(s) + 4HCl(aq)$

$N^{3-}(s) + 3H_2O(\ell) \rightarrow NH_3(g) + 3OH^-(aq)$

(4) Hydrates Formation: From aqueous solutions many salts can be crystallised as hydrated salts. Such an association of water is of different types viz.,

(i) coordinated water e.g., $[Cr(H_2O)_6]^{3+}3Cl^-$

(ii) interstitial water e.g., $BaCl_2 \cdot 2H_2O$

(iii) hydrogen-bonded water e.g., $[Cu(H_2O)_4]^{2+}SO_4^{2-} \cdot H_2O$ in $CuSO_4 \cdot 5H_2O$.

Problem -4

How many hydrogen-bonded water molecule(s) are associated in $CuSO_4 \cdot 5H_2O$?

Solution

Only one water molecule, which is outside the brackets (coordination sphere), is hydrogenbonded. The other four molecules of water are coordinated.

Hard and Soft Water

Rain water is almost pure (may contain some dissolved gases from the atmosphere). Being a good solvent, when it flows on the surface of the earth, it dissolves many salts. Presence of calcium and magnesium salts in the form of hydrogen carbonate, chloride and sulphate in water makes water 'hard'. Hard water does not give lather with soap. Water free from soluble salts of calcium and magnesium is called Soft water. It gives lather with soap easily.

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.

$2C_{17}H_{35}COONa(aq) + M^{2+}(aq) \rightarrow (C_{17}H_{35}COO)_2M \downarrow +2Na^+(aq)$; M is Ca/Mg

It is, therefore, unsuitable for laundry. It is harmful for boilers as well, because of deposition of salts in the form of scale. This reduces the efficiency of the boiler. The hardness of water is of two types:

(i) temporary hardness, and (ii) permanent hardness.

Temporary Hardness

Temporary hardness is due to the presence of magnesium and calcium hydrogencarbonates. It can be removed by :

(i) Boiling: During boiling, the soluble $Mg(HCO_3)_2$ is converted into insoluble $Mg(OH)_2$ and $Ca(HCO_3)_2$ is changed to insoluble $CaCO_3$. It is because of high solubility product of $Mg(OH)_2$ as compared to that of $MgCO_3$, that $Mg(OH)_2$ is precipitated. These precipitates can be removed by filtration. Filtrate thus obtained will be soft water.

$$Mg(HCO_3)_2 \xrightarrow{\text{Heating}} Mg(OH)_2 \downarrow +2CO_2 \uparrow$$

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

(ii) Clark's method: In this method calculated amount of lime is added to hard water. It precipitates out calcium carbonate and magnesium hydroxide which can be filtered off.

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

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

Permanent Hardness

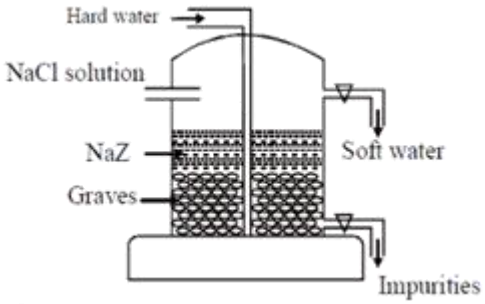
It is due to the presence of soluble salts of magnesium and calcium in the form of chlorides and sulphates in water. Permanent hardness is not removed by boiling. It can be removed by the following methods:

(i) Treatment with washing soda (sodium carbonate): Washing soda reacts with soluble calcium and magnesium chlorides and sulphates in hard water to form insoluble carbonates.

$MCl_2 + Na_2CO_3 \rightarrow MCO_3 \downarrow + 2NaCl (m + Mg, Ca)$

$MSO_4 + Na_2CO_3 \rightarrow MCO_3 \downarrow + Na_2SO_4$

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



$Na_6P_6O_{18} \rightarrow 2Na^+ + Na_4P_6O_{18}{}^{2-} (M = Mg. Ca)$

$M^{2+} + Na_4P_6O^{2-}{}_{18}[Na_2MP_6O_{18}]^{2-} + 2Na^+$

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

(iii) Ion-exchange method: This method is also called zeolite/ permutit process.

$[Na_2Al_2Si_2O_{8.} \cdot xH_2O]$

$[Na_2O \cdot Al_2O_3 \cdot 2SiO_2 \cdot xH_2O]$

Hydrated sodium aluminium silicate is zeolite/permutit. For the sake of simplicity, sodium aluminium silicate ($NaAlSiO_4$) can be written as NaZ. When this is added in hard water, exchange reactions take place.

$2NaZ(s) + M^{2+}(aq) \rightarrow MZ_2(s) + 2Na^+(aq) (M = Mg, Ca)$

Permutit/zeolite is said to be exhausted when all the sodium in it is used up. It is regenerated for further use by treating with an aqueous sodium chloride solution.

$Mz_2(s) + 2NaCl(aq) \rightarrow 2NaZ(s) + MCl_2(aq)$

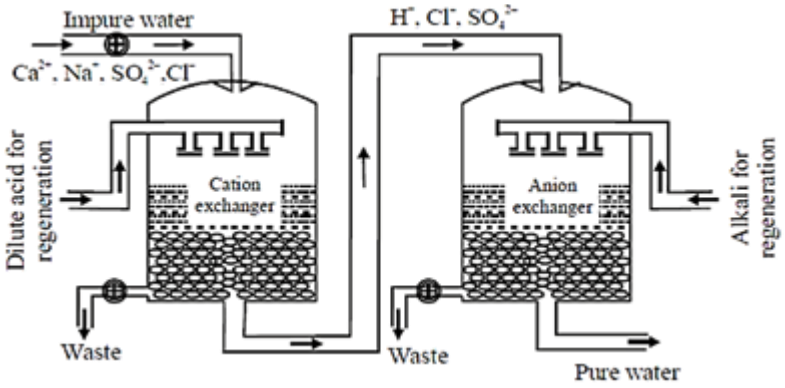
(iv) Synthetic resins method: Nowadays hard water is softened by using synthetic cation exchangers. This method is more efficient than zeolite process. Cation exchange resins contain large organic molecule with $-SO_3H$ group and are water insoluble. Ion exchange resin (RSO_3H) is changed to RNa by treating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

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

The resin can be regenerated by adding aqueous NaCl solution.

Pure de-mineralised (de-ionized) water free from all soluble mineral salts is obtained by passing water successively through a cation exchange (in the H^+form) and an anionexchange (in the OH^-form) resins:

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



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

$RNH_2(s) + H_2O(\ell) \rightarrow RNH_3{}^+OH^-(s)$

$RNH_3{}^+ \cdot OH^-(s) + X^-(aq) \rightarrow RNH_3{}^+ \cdot X(s) + OH^-(aq)$

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

$H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell)$

This water becomes soften but not used for drinking purpose because this water contain the impurity of acid. To remove anion of hardness this acidic water then passed through another bed containing anion exchanger. This exchanger removes anion like Cl^-, SO_4^{-2} & HCO_3^-.

$R-NH_3{}^+OH + H^+ + Cl^- \longrightarrow R-NH_3{}^+Cl^- + H^+OH$

This water is free from impurities & can be used for drinking purpose.

After some times when both resin gets exhausted process is stopped.

Regenration of resin :

(i) Cation exchange resin: We use dil acid.

$2H^+Cl^- + (R-COO)_2Ca \longrightarrow 2R^-COO^+H^+ + CaCl_2$

(ii) Anion exchange resin : We use dil NaOH solution

$R-NH_3^+Cl^- + Na^+OH^- \longrightarrow Na^+Cl^- + R-NH_3{}^+OH$

HYDROGEN PEROXIDE (H_2O_2)

Hydrogen peroxide is an important chemical used in pollution control treatment of domestic and industrial effluents.

Preparation

It can be prepared by the following methods.

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

$BaO_2 \cdot 8H_2O(s) + H_2SO_4(aq) \rightarrow BaSO_4(s) + H_2O_2(aq) + 8H_2O(\ell)$

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

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

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

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

(iii) Industrially it is prepared by the autooxidation of 2-alklylanthraquinols.

$$\text{2-ethylanthraquinol} \underset{H_2/pd}{\overset{O_2\ (air)}{\rightleftarrows}} H_2O_2 + \text{(oxidised product)}$$

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

Physical Properties

In the pure state H_2O_2 is an almost colorless (very pale blue) liquid. Its important physical properties are given in Table. H_2O_2 is miscible with water in all proportions and forms a hydrate $H_2O_2 \cdot H_2O$(mp221 K). A 30% solution of H_2O_2 is marketed as ' 100 volume' hydrogen peroxide. It means that one millilitre of $30\%H_2O_2$ solution will give 100 mL of oxygen at STP. Commercially marketed sample is 10 V, which means that the sample contains $3\%H_2O_2$.

Problem-5

Calculate the strength of 10 volume solution of hydrogen peroxide.

Solution

10 volume solution of H_2O_2 means that 1 L of this H_2O_2 solution will give 10 L of oxygen at STP

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

On the basis of above equation 22.7 L of O_2 is produced from 68 gH_2O_2 at STP 10 L of O_2 at STP is produced from

$$\frac{68 \times 10}{22.7} = 29.9\ g\ 30\ gH_2O_2$$

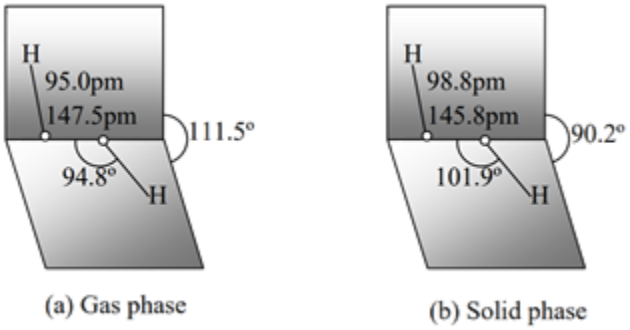
Therefore, strength of H_2O_2 in 10 volume H_2O_2 solution $= 30\ g/L = 3\%H_2O_2$ solution

Physical Properties of Hydrogen Peroxide

Melting point/K	272.4	Density (liquid at 298 K)/gcm^{-3}	1.44
Boiling point (extrapolated)/K	423	Viscosity (290 K)/ centipoise	1.25
Vapor pressure (298 K)mmHg	1.9	Dielectric constant (298 K)/C^2/Nm^2	70.7
Density (solid at 268.5 K)/gcm^{-3}	1.64	Electric conductivity (298 K)$^{-1}$ cm^{-1}	5.1×10^{-8}

Structure

Hydrogen peroxide has a non-planner structure. The molecular dimensions in the gas phase and solid phase are shown in Fig



(a) Gas phase (b) Solid phase

Fig. (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°.

Chemical Properties

It acts as an oxidising as well as reducing agent in both acidic and alkaline media. Simple reactions are described below.

(i) Oxidising action in acidic medium

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

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

(ii) Reducing action in acidic medium

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

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

(iii) Oxidising action in basic medium

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

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

(iv) Reducing action in basic medium

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

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

Storage

H_2O_2 decomposes slowly on exposure to light.

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

In the presence of metal surfaces or traces of alkali (present in glass containers), the above reaction is catalysed. 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.

Uses

Its wide scale use has led to tremendous increase in the industrial production of H_2O_2. Some of the uses are listed below:

(i) 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.

(ii) It is used to manufacture chemicals like sodium perborate and per-carbonate, which are used in high quality detergents.

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

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

(v) Nowadays it is also used in Environmental (Green) Chemistry. For example, in pollution control treatment of domestic and industrial effluents, oxidation of cyanides, restoration of aerobic conditions to sewage wastes, etc.

HEAVY WATER, D_2O

It can be prepared by exhaustive electrolysis of water or as a by-product in some fertilizer industries.

Physical properties : (a) Heavy water is a colorless, odorless and tasteless mobile liquid, (b) Nearly all the physical constants are higher than the corresponding values of ordinary water. It is used for the preparation of other deuterium compounds, for example:

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

$SO_3 + D_2O \rightarrow D_2SO_4$

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

Uses : It is extensively used as a moderator & coolant in nuclear reactors and in exchange reactions for the study of reaction mechanisms. As a neutron moderator : Fission in uranium-235 is brought by slow speed neutrons. The substances which are used for slowing down the speed of neutrons are called moderators. Heavy water is used for this purpose in nuclear reactors.

DIHYDROGEN AS A FUEL Dihydrogen releases large quantities of heat on combustion. The data on energy released by combustion of fuels like dihydrogen, methane, LPG etc. are compared in terms of the same amounts in mole, mass and volume, are shown in Table.

From this table it is clear that on a mass for mass basis dihydrogen can release more energy than petrol (about three times). Moreover, pollutants in combustion of dihydrogen will be less than petrol. The only pollutants will be the oxides of dinitrogen (due to the presence of dinitrogen as impurity with dihydrogen). This, of course, can be minimised by injecting a small amount of water into the cylinder to lower the temperature so that the reaction between dinitrogen and dioxygen may not take place. However, the mass of the containers in which dihydrogen will be kept must be

taken into consideration. A cylinder of compressed dihydrogen weighs about 30 times as much as a tank of petrol containing the same amount of energy. Also, dihydrogen gas is converted into liquid state by cooling to 20 K. This would require expensive insulated tanks. Tanks of metal alloy like $NaNi_5$, $Ti - TiH_2$, $Mg - MgH_2$ etc. are in use for storage of dihydrogen in small quantities. These limitations have prompted researchers to search for alternative techniques to use dihydrogen in an efficient way. In this view Hydrogen Economy is an alternative. The basic principle of hydrogen economy is the transportation and storage of energy in the form of liquid or gaseous dihydrogen. Advantage of hydrogen economy is that energy is transmitted in the form of dihydrogen and not as electric power. It is for the first time in the history of India that a pilot project using dihydrogen as fuel was launched in October 2005 for running automobiles. Initially 5% dihydrogen has been mixed in CNG for use in fourwheeler vehicles. The percentage of dihydrogen would be gradually increased to reach the optimum level.

Nowadays, it is also used in fuel cells for generation of electric power. It is expected that economically viable and safe sources of dihydrogen will be identified in the years to come, for its usage as a common source of energy.

The Energy Released by Combustion of Various Fuels in moles, Mass and Volume

Energy released on combustion in kJ state	Dihydrogen in gaseous state	Dehydrogen (in liquid)	LPG	CH4 gas	Octance (in liquid state)
Per mole	286	285	2220	880	5511
Per gram	143	142	50	53	41
Per liter	12	9968	25590	35	34005

LEARNER BOX-2

1. Both temporary and permanent hardness is removed on boiling water with :-
(A) $Ca(OH)_2$ (B) Na_2CO_3 (C) $CaCO_3$ (D) CaO

2. Hydrogen peroxide is not :-
(A) A reducing agent (B) An oxidising agent
(C) A dehydrating agent (D) A bleaching agent

3. H_2O_2 is :-
(A) An oxiding agent (B) Both oxidising and reducing agent
(C) Reducing agent (D) None of the above

4. Calgon is an industrial name given to :-
(A) Normal sodium phosphate (B) Sodium meta-aluminate
(C) Sodium hexametaphosphate (D) Hydrated sodium aluminium silicate

5. Water softening by Clarke's process uses :-
(A) Calcium bicarbonate (B) Sodium bicarbonate
(C) Potash alum (D) Calcium hydroxide

QUESTIONS

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

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

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

4. How can the production of dihydrogen, obtained from 'coal gasification', be increased?

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

6. Complete the following reactions:

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

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

(iii) $C_3H_8(g) + 3H_2O(g)$ catalyst $\xrightarrow[\text{catalyst}]{}$

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

7. Discuss the consequences of high enthalpy of $H-H$ bond in terms of chemical reactivity of dihydrogen.

8. What do you understand by (i) electron-deficient, (ii) electron-precise, and (iii) electron-rich compounds of hydrogen? Provide justification with suitable examples.

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

10. Do you expect the carbon hydrides of the type (C_nH_{2n+2}) to act as 'Lewis' acid or base? Justify your answer.

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

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

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

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

15. 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.

16. 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.

17. Compare the structures of H_2O and H_2O_2.

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

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

20. Complete the following chemical reactions.

(i) $PbS(s) + H_2O_2(aq) \rightarrow$ (ii) $MnO_4^-(aq) + H_2O_2(aq) \rightarrow$

(iii) $CaO(s) + H_2O(g) \rightarrow$ (v) $AlCl_3(g) + H_2O(\ell) \rightarrow$

(vi) $Ca_3N_2(s) + H_2O(\ell) \rightarrow$

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

21. Describe the structure of the common form of ice.

22. What causes the temporary and permanent hardness of water ?

23. Discuss the principle and method of softening of hard water by synthetic ionexchange resins.

24. Write chemical reactions to show the amphoteric nature of water.

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

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

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

28. Describe the usefulness of water in biosphere and biological systems.

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

30. Knowing the properties of H_2O and D_2O, do you think that D_2O can be used for drinking purposes?

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

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

33. 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 behavior towards water.

34. Do you expect different products in solution when aluminium (III) chloride and potassium chloride treated separately with

(i) normal water

(ii) acidified water, and

(iii) alkaline water? Write equations wherever necessary.

35. How does H_2O_2 behave as a bleaching agent?

36. What do you understand by the terms:

(i) hydrogen economy (ii) hydrogenation

(iii) 'syngas' (iv) water-gas shift reaction

(v) fuel-cell

EXERCISE # I

DEHYDRATION

1. Which of the following will not produce hydrogen gas :-

(A) Reaction between Fe and dil. HCl (B) Reaction between Zn and conc. H_2SO_4

(C) Reaction between Zn and NaOH (D) Electrolysis of NaCl in Nelson's cell

2. At high temperature Para hydrogen is :-

(A) Less stable than ortho hydrogen (B) More stable than ortho hydrogen

(C) As stable as ortho hydrogen (D) None of these

WATER (H_2O)

3. Temporary hardness is caused due to the presence of :-

(A) $CaSO_4$ (B) $CaCl_2$ (C) $CaCO_3$ (D) $Ca(HCO_3)_2$

4. High boiling point of water is due to :-

(A) Its high specific heat (B) Hydrogen bonding

(C) High dielectric constant (D) Low dissociation constant

HYDROGEN PEROXIDE (H_2O_2)

5. The bleaching properties of H_2O_2 are due to its :-

(A) Reducing properties (B) Oxidising properties

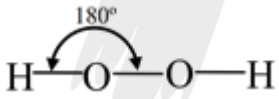
(C) Unstable nature (D) Acidic nature

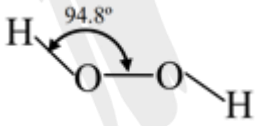
6. Hydrogen peroxide has a:-

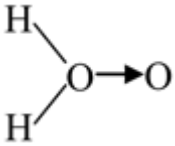
(A) Linear structure (B) Pyramidal structure

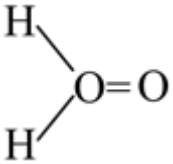
(C) Closed book type structure (D) Half open book type structure

7. Which of the following is a true structure of H_2O_2

(A) 

(B) 

(C) 

(D) 

8. H_2O_2 is :-

(A) Diamagnetic (B) Paramagnetic (C) Ferromagnetic (D) None of these

9. The hybridisation of the orbitals of oxygen in H_2O_2 is :-

(A) sp^3d (B) sp (C) sp^2 (D) sp^3

EXERCISE # II

1. Permutit is :-

(A) Hydrated sodium aluminium silicate (B) Sodium hexametaphosphate

(C) Sodium silicate (D) Sodium meta-aluminate

2. In Bosch's process which gas is utilised for the production of hydrogen :-

(A) Producer gas (B) Water gas (C) Coal gas (D) Natural gas

3. Which of the following produces hydrolith with dihydrogen :-

(A) Mg (B) Al (C) Cu (D) Ca

4. The lightest gas is :-

(A) Nitrogen (B) Helium (C) Oxygen (D) Hydrogen

5. Ionic hydrides are usually :-

(A) Good electrically conductors when solid

(B) Easily reduced

(C) Good reducing agents

(D) Liquid at room temperature

EXERCISE # III

1. Match List I with List II and select the correct answer using the codes given below the lists :-

List – I	**List II**
1. Heavy water	A. Bicarbonates of Mg and Ca in water
2. Temporary hard	B. No foreign ions in water
3. Soft water	C. D2O
4. Permanent hard	D. Sulphates and water chlorides of Mg and Cain water

2. Ortho-hydrogen and Para-hydrogen resembles in which of the following property:-

(A) Thermal conductivity (B) Magnetic properties

(C) Chemical properties (D) Heat capacity

3. Acidified solution of $K_2Cr_2O_7$ on treatment with H_2O_2 yields:-

(A) $CrO_3 + H_2O + O_2$ (B) $Cr_2O_2 + H_2O + O_2$

(C) $CrO_5 + H_2O + K_2SO_4$ (D) $H_2Cr_2O_7 + H_2O + O_2$

4. H_2O_2 restores the colour of old lead paintings, blackened by the action of H_2S gas by :-

(A) Converting PbO_2 to Pb (B) By oxidising PbS to $PbSO_4$

(C) Converting $PbCO_3$ to Pb (D) Oxidising $PbSO_3$ to $PbSO_4$

EXERCISE # IV

1. Which hydride is an ionic hydride :-

(A) NH_3 (B) H_2S (C) $TiH_{1.73}$ (D) NaH

2. The reaction, $H_2S + H_2O_2 \longrightarrow S + 2H_2O$ manifests:

(A) Acidic nature of H_2O_2 (B) Alkaline nature of H_2O_2

(C) Oxidising nature of H_2O (D) Reducing nature of H_2O_2

3. Calgon (a water softener) is :-

(A) $Na_2[Na_4(PO_3)_6]$ (B) $Na_4[Na_2(PO_3)]_6$

(C) $Na_2[Na_4(PO_4)]_6$ (D) $Na_4[Na_2(PO_4)_6]$

4. The hair dyes available in the market generally contain two bottles, one containing the dye and the other hydrogen peroxide. Before applying the dye, the two solutions are mixed. the hydrogen peroxide

(A) Is added to dilute the solution of the dye

(B) Oxidises the dye to give the desired colour

(C) Reduces the dye to give the the desired colour

(D) Acidifies the solution of the dye

5. When zeolite (hydrated sodium aluminium silicate) is treated with hard water, the sodium ions are exchanged with :-

(A) H^+ions (B) Ca^{2+} ions (C) SO_4^{2-} ions (D) OH^-ions

6. The hardness of water is due to.....metal ions

(A) Ca^{2+} and Na^+ (B) Mg^{2+} and K^+ (C) Ca^{2+} and Mg^{2+} (D) Zn^{2+} and Ba^{2+}

7. The formula of heavy water is :-

(A) H_2O^{18} (B) D_2O (C) T_2O (D) H_2O^{17}

8. Polyphosphates are used as water softening agent because they :-

(A) Form soluble complexes with anionic species

(B) Precipitate anionic species

(C) Form soluble complexes with cationic species

(D) Precipitate cationic species.

9. Which one of the following processes will produce hard water: -

(A) Saturation of water with $CaSO_4$ (B) Addition of Na_2SO_4 to water

(C) Saturation of water with $CaCO_3$ (D) Saturation of water with $MgCO_3$

10. Very pure hydrogen (99.9% can be made by which of the following processes ?**[AIEEE 2012]**

(A) Reaction of salt like hydrides with water

(B) Reaction of methane with steam

(C) Mixing natural hydrocarbons of high molecular weight

(D) Electrolysis of water

EXERCISE # JEE-MAINS

1. Which one of the following processes will produce hard water ? **[2007]**

(A) Saturation of water with $CaCO_3$. (B) Saturation of water with $CaSO_4$.

(C) Saturation of water with $MgCO_3$. (D) Addition of Na_2SO_4 to water.

2. In context with the industrial preparation of hydrogen from water gas $(CO + H_2)$, which of the following is the correct statement? **[2008]**

(A) CO is oxidized to CO_2 with steam in the presence of a catalyst followed by absorption of CO_2 in alkali.

(B) CO and H_2 are fractionally separated using differences in their densities.

(C) CO is removed by absorption in aqueous Cu_2Cl_2 solution.

(D) H_2 is removed through occlusion with Pd.

3. Very pure hydrogen (99.9%) can be made by which of the following processes ? **[2012]**

(A) Mixing natural hydrocarbons of high molecular weight

(B) Electrolysis of water.

(C) Reaction of salt like hydrides with water

(D) Reaction of methane with steam.

4. Hydrogen peroxide acts both as an oxidising and as a reducing agent depending upon the nature of the reacting species. In which of the following cases H_2O_2 acts as a reducing agent in acid medium? **[2014]**

(A) KI (B) $Cr_2O_7^{2-}$ (C) SO_3^{2-} (D) MnO_4^-

5. The molecular formula of a commercial resin used for exchanging ions in water softening is $C_8H_7SO_3Na$ (Mol. wt. 206). What would be the maximum uptake of Ca^{2+} ions by the resin when expressed in mole per gram resin? **[2015]**

(A) $\frac{2}{309}$ (B) $\frac{1}{412}$ (C) $\frac{1}{103}$ (D) $\frac{1}{206}$

6. Which physical property of dihydrogen is wrong ? **[2015]**

(A) Odourless gas (B) Tasteless gas

(C) Colourless gas (D) Non-inflammable gas

7. Which one of the following statements about water is FALSE? **[2016]**

(A) Water can act both as an acid and as a base.

(B) There is extensive intramolecular hydrogen bonding in the condensed phase.

(C)Ice formed by heavy water sinks in normal water.

(D) Water is oxidized to oxygen during photosynthesis.

8. Identify the incorrect statement regarding heavy water : **[2016]**

(A) It reacts with Al_4C_3 to produce CD_4 and $Al(OD)_3$.

(B) It is used as a coolant in nuclear reactors.

(C) It reacts with CaC_2 to produce C_2D_2 and $Ca(OD)_2$.

(D) It reacts with SO_3 to form deuterated sulphuric acid (D_2SO_4).

9. Identify the reaction which does not liberate hydrogen : **[2016]**

(A) Reaction of zinc with aqueous alkali.

(B) Electrolysis of acidified water using Pt electrodes

(C) Allowing a solution of sodium in liquid ammonia to stand.

(D) Reaction of lithium hydride with

10. In which of the following reactions, hydrogen peroxide acts as an oxidizing agent ? **[2017]**

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

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

(C) $+3H_2O_2 \rightarrow 2MnO_2 + 3O_2 + 2H_2O + 2OH^-$

(D) $PbS + 4H_2O_2 \rightarrow PbSO_4 + 4H_2O$

11. The strength of 11.2 volume solution of H_2O_2 is : [Given that molar mass of H = 1 g mol^{-1} and O = 16 g mol^{-1}] **[2019]**

(A) 3.4% (B) 1.7% (C) 13.6% (D) 34%

12. The total number of isotopes of hydrogen and number of radioactive isotopes among them, respectively, are: **[2019]**

(A) 3 and 1 (B) 3 and 2 (C) 2 and 1 (D) 2 and 0

13. The chemical nature of hydrogen peroxide is: **[2019]**

(A) Oxidising agent in acidic medium, but not in basic medium.

(B) Reducing agent in basic medium, but not in acidic medium.

(C) Oxidising and reducing agent in acidic medium, but not in basic medium.

(D) Oxidising and reducing agent in both acidic and basic medium.

14. 100 mL of a water sample contains 0.81 g of calcium bicarbonate and 0.73 g of magnesium bicarbonate. The hardness of this water sample expressed in terms of equivalents of $CaCO_3$ is: (molar mass of calcium bicarbonate is 162 g mol^{-1} and magnesium bicarboante is 146 g mol^{-1}) **[2020]**

(A) 5,000ppm (B) 1,000ppm (C) 100ppm (D) 10,000ppm

15. Which of the following statements are correct? **[2020]**

(I) On decomposition of H_2O_2, O_2 gas is released.

(II) 2-ethylanthraquinol is used in preparation of H_2O_2

(III) On heating $KClO_3$, $Pb(NO_3)_2$, $NaNO_3$, O_2 gas is released.

(IV) In the preparation of sodium peroxoborate, H_2O_2 is treated with sodium metaborate.

(A) I, II, IV (B) II, III, IV (C) I, II, III, IV (D) I, II, III

16. Hydrogen peroxide, in the pure state, is **[2020]**

(A) linear and blue in color (B) planar and blue in color

(C) linear and almost colorless (D) non-planar and almost colorless

17. In comparison to the zeolite process for the removal of permanent hardness, the synthesis resins method is: **[2020]**

(A) more efficient as it can exchange both cations as well as anions 4

(B) less efficient as it exchanges only anions

(C) more efficient as it can exchange only cations

(D) less efficient as the resins cannot be regenerated

18. Dihydrogen of high purity (> 99.95%) is obtained through **[2020]**

(A) the electrolysis of acidified water using Pt electrodes

(B) the electrolysis of warm $Ba(OH)_2$ solution using Ni electrodes

(C) the electrolysis of brine solution

(D) the reaction of Zn with dilute HCl

19. Statement about heavy water are given below **[2021]**

A. Heavy water is used in exchange reactions for the study of reaction mechanisms

B. Heavy water is prepared by exhaustive electrolysis of water

C. Heavy water has higher boiling point than ordinary water

D. Viscosity of H_2O is greater than D_2O

(A) A and B only (B) A and D only (C) A, B and C only (D) A and C only

20. Calgon is used for water treatment. Which of the following statement is NOT true about calgon? **[2021]**

(A) Calgon contains the 2^{nd} most abundant element by weight in the earth's crust.

(B) It is also known as Graham's salt.

(C) It is polymeric compound and is water soluble.

(D) It doesnot remove Cat ion by precipitation.

21. Given below are two statements: One is labelled as Assertion A and other is labelled as Reason R.

Assertion A : The dihedral angles in H_2O_2 in gaseous phase is 90.2° and in solid phase is 111.5°.

Reason R : The change in dihedral angle in solid and gaseous phase is due to the difference in the intermolecular forces. **[2021]**

Choose the most appropriate answer from the options given below for A and R.

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

(B) Both A and R are correct but R is not the correct explanation of A.

(C) Both A and R are correct and R is the correct explanation of A.

(D) A is not correct but R is correct.

22. Which one of the following statements is incorrect? **[2021]**

(A) Atomic hydrogen is produced when H_2 molecules at a high temperature are irradiated with UV radiation.

(B) At around 2000 K, the dissociation of dihydrogen into its atoms is nearly 8.1%.

(C) Bond dissociation enthalpy of H_2 is highest among diatomic gaseous molecules which contain a single bond .

(D) Dihydrogen is produced on reacting zinc with HCl as well as $NaOH_{(aq)}$.

23. **Statement -I:** The process of producing syn-gas is called gasification of coal.

Statement -II: The composition of syn-gas is $CO + CO_2 + H_2 (1:1:1)$

In the light of the above statements, choose the most appropriate answer from the options given below : **[2021]**

(A) Statement -I is false but Statement -II is true

(B) Statement -I is true but Statement - II is false

(C) Both Statement -I and Statement -II are false

(D) Both Statement -I and Statement -II are true

24. Which one of the following methods is most suitable for preparing deionized water? **[2021]**

(A) Synthetic resin method (B) Clark's method

(C) Calgon's method (D) Permutit method

25. The metal salts formed during softening of hardwater using Clark's method are : **[2022]**

(A) $Ca(OH)_2$ and $Mg(OH)_2$ (B) $CaCO_3$ and $Mg(OH)_2$

(C) $Ca(OH)_2$ and $MgCO_3$ (D) $CaCO_3$ and $MgCO_3$

26. Which one of the following reactions indicates the reducing ability of hydrogen peroxide in basic medium ? **[2022]**

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

(B) $PbS + 4H_2O_2 \rightarrow PbSO_4 + 4H_2O$

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

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

27. Decreasing order of the hydrogen bonding in following forms of water is correctly represented by **[2023]**

A. Liquid water B. Ice C. Impure water

(A) $A = B > C$ (B) $B > A > C$ (C) $C > B > A$ (D) $A > B > C$

28. Which of the given compounds can enhance the efficiency of hydrogen storage tank? **[2023]**

(A) Li/P_4 (B) SiH_4

(C) $NaNi_5$ (D) Di-isobutylaluminium hydride

29. The starting material for convenient preparation of deuterated hydrogen peroxide (D_2O_2) in laboratory is: **[2023]**

(A) $K_2 S_2O_8$ (B) 2-ethylanthraquinol

(C) BaO_2 (D) BaO

30. O-O bond length in H_2O_2 is X than the $O-O$ bond length in F_2O_2. The $O-H$ bond length in H_2O_2 is Y than that of the $O-F$ bond in F_2O_2. **[2023]**

Choose the correct option for X and Y from the given below.

(A) X-shorter, Y – shorter (B) X - shorter,Y - longer

(C) X - longer, Y – longer (D) X - longer, Y - shorter

EXERCISE # JEE-ADVANCED

1. The temporary hardness of water due to calcium bicarbonate can be removed by adding **[1979]**

(A) $CaCO_3$ (B) $Ca(OH)_2$ (C) $CaCl_2$ (D) HCl

2. The volume strength of 1.5 NH_2O_2 solution is **[1991]**

(A) 4.8 (B) 8.4 (C) 3.0 (D) 8.0

3. The oxide that gives hydrogen peroxide on treatment with a dilute acid is **[1985]**

(A) PbO_2 (B) Na_2O_2 (C) MnO_2 (D) TiO_2

4. Heavy water is **[1985]**

(A) $H_2\ ^{18}O$ (B) water obtained by repeated distillation

(C) D_2O (D) water at 4°C

5. The reagent(s) used for softening the temporary hardness of water is (are) **[2010]**

(A) $Ca_3(PO_4)_2$ (B) $Ca(OH)_2$ (C) Na_2CO_3 (D) NaOCl

6. The species that do not contain peroxide ions are **[1998]**

(A) PbO_2 (B) H_2O_2 (C) $Sr(O_2)_2$ (D) BaO_2

7. When zeolite, which is hydrated sodium aluminium silicate, is treated with hard water the sodium ions are exchanged with **[1990]**

(A) H^+ions (B) Ca^{++}ions (C) SO_4^{--}ions (D) Mg^{++}ions

8. Hydrogen peroxide in its reaction with KlO_4 and NH_2OH respectively, is acting as a **[2014]**

(A) Reducing agent, oxidising agent (B) Reducing agent, reducing agent

(C) Oxidising agent, oxidising agent (D). Oxidising agent, reducing agent

NCERT EXAMPLER - HYDROGEN

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 gain enthalpy value.

(D) Its small size.

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.

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

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

(A) B_2H_6 (B) NH_3 (C) H_2O (D) CH_4

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

(A) Protium (B) Deuterium (C) Tritium (D) Hydronium

6. Consider the reactions

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

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

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

(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)

7. The compound 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

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

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

(B) $2Fe^{3+} + 2H^+ + H_2O_2 \rightarrow 2Fe^{2+} + 2H_2O + O_3$

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

(D) $KIO_4 + H_2O_2 \rightarrow KIO_3 + H_2O + O_2$

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

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

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

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

(D) $PbS + 4H_2O_2 \rightarrow PbSO_4 + 4H_2O$

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

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

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

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

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

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

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

13. Hydrogen peroxide is obtained by the electrolysis of

(A) water (B) sulphuric acid

(C) hydrochloric acid (D) fused sodium peroxide

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

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

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

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

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

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

(A) Ca^{2+} (B) Na^{+} (C) Cl^{-} (D) K^{+}

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

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

18. Only one element of forms hydride.

(A) group 6 (B) group 7 (C) group 8 (D) group 9

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?

(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.

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) Syngas (C) Producer gas (D) Industrial gas

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.

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.

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.

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

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.

26. Which of the following statements is correct?
(A) Hydnides 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.

27. Which of the following statements is correct?
(A) Metallic hydrides are deficient of hydrogen.
(B) Metallic hydrides conduct heat and electricity.
(C) lonic hydrides do not conduct electricity in solid state.
(D) lonic hydrides are very good conductors of electricity in solid state.

III. Short Answer Type

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

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

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

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?

32. Complete the following equations:
(A) $PbS(s) + H_2O_2(aq) \rightarrow$
(B) $CO(g) + 2H_2(g) \xrightarrow[\text{Cobalt}]{\text{Catalyt}}$

33. Give reasons:
(A) Lakes freeze from top towards bottom.
(B) Ice floats on water.

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

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

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

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

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

39. Calculate the strength of 5 volume H_2O_2 solution.

40. (A) Draw the gas phase and solid phase structure of H_2O_2.

(B) H_2O_2 is a better oxidising agent than water. Explain.

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)/kJmol^{-1}	40.66	41.61
Viscosity/centipoise	0.8903	1.107

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

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.

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

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?

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.

(A) Write the name of this compound.

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

46. Give reasons why hydrogen resembles alkali metals?

47. Hydrogen generally forms covalent compounds. Give reason.

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

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.

50. What is the importance of heavy water?

51. Write the Lewis structure of hydrogen peroxide.

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.

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

54. Why is water molecule polar?

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

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

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

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

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

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

61. Write redox reaction between fluorine and water.

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

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**
(A) Synthesis gas	(i) $Na_2[Na_4(PO_3)_6]$
(B) Dihydrogen	(ii) Oxidising agent
(C) Heavy water	(iii) Used in softening of water
(D) Calgon	(iv) Reducing agent
(E) Hydrogen peroxide	(v) Stoichiometric compounds of s-block elements
(F) Salt like hydrides	(vi) Produced by prolonged electrolysis of water
	(vii) Zn + NaOH
	(viii) Zn + dil. H_2SO_4
	(ix) Synthesis of methanol
	(x) Mixture of CO and H_2

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

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

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

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

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	(i) zeolite
(B) Used in Calgon method	(ii) perhydrol
(C) Permanent hardness of water is removed by	(iii) hexametaphosphate
	(iv) propellant

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 the options 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.

(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.

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.

VI. Long Answer Type

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

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.

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.

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

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

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

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.

(A) Suggest possible structure of A.

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

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.

76. Sodium forms a crystalline ionic solid with dihydrogen. The solid is nonvolatile and nonconducting 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.

ANSWER KEY

LEARNER BOX–1

1. (D) **2.** (C) **3.** (C) **4.** (C) **5.** **(C)**

LEARNER BOX–2

1. (B) **2.** (C) **3.** (B) **4.** (C) **5.** (D)

EXERCISE # I

1. (B) **2.** (A) **3.** (D) **4.** (B) **5.** (B) **6.** (D) **7.** (B)
8. (A) **9.** (D)

EXERCISE # II

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

EXERCISE # III

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

EXERCISE # IV

1. (D) **2.** (C) **3.** (A) **4.** (B) **5.** (B) **6.** (C) **7.** (B)
8. (C) **9.** (A) **10.** (D)

EXERCISE # JEE-MAINS

1. (C) **2.** (A) **3.** (B) **4.** (D) **5.** (B) **6.** (D) **7.** (B)
8. (B) **9.** (D) **10.** (D) **11.** (A) **12.** (A) **13.** (D) **14.** (D)
15. (3) **16.** (D) **17.** (A) **18.** (B) **19.** (C) **20.** (A) **21.** (D)
22. (B) **23.** (B) **24.** (A) **25.** (B) **26.** (C) **27.** (B) **28.** (C)
29. (A) **30.** (D)

EXERCISE # JEE-ADVANCED

1. (B) **2.** (B) **3.** (B) **4.** (B) **5.** (B, C) **6.** (A, C) **7.** (B, D)
8. (A)

NCERT EXAMPLER – HYDROGEN

I. Multiple Choice Questions (Type-I)

1. (B) **2.** (D) **3.** (B) **4.** (D) **5.** (C) **6.** (B) **7.** (B)
8. (C) **9.** (B) **10.** (C) **11.** (C) **12.** (D) **13.** (B) **14.** (D)
15. (A) **16.** (C) **17.** (A) **18.** (A)

II. Multiple Choice Questions (Type-II)

19. (C,D) **20.** (A,B) **21.** (A,C) **22.** (A,B) **23.** (C,D) **24.** (A,B) **25.** (B,C)
26. (A,D) **27.** (A,B,C)

III. Short Answer Type

39. 5 volume H_2O_2 solution means that hydrogen peroxide contained in 1 volume of this solution will decompose to give 5 volumes of oxygen at STP i.e. if 1 L of this solution is taken, then 5 L of oxygen can be produced from this at STP. Chemical equation for the decomposition of H_2O_2 is $2H_2O_2(\ell) \rightarrow O_2(g) + H_2O(\ell)$.

It shows that 68 gH_2O_2 gives 22.7 L of O_2 at STP, so 5 L oxygen will be obtained from :

$$\frac{68 \text{ g} \times 5 \text{ L}}{22.7 \text{ L}} = \frac{3400}{227} \text{g}H_2O_2 = 14.9 \text{ g} \approx 15 \text{ g}H_2O_2$$

i.e., 15 gH_2O_2 dissolved in 1 L solution will give 5 L oxygen or 1.5 gH_2O_2/100 mL solution will give 500ml oxygen. Thus 15 g/L or 1.5% solution is known as 5 V solution of H_2O_2.

42. [Hint : Heavy water; Bond dissociation energy of dihydrogen is less than dideuterium]

44. [Hint : $H_2O + H_2O \rightarrow H_3O^+ + {}^-OH$]

45. (A) H_2O_2

IV. Matching Type

63. (A) → (ix), (x) ; (B) → (iv), (v), (vi), (vii), (viii) ;
(C) → (v), (vi) ; (D) → (i), (iii) ; (E) → (ii), (iv) ; (F) → (v)

64. (A) → (iv) ; (B) → (iii); (C) → (ii) ;(D) → (i)

65. (A) → (v) ; (B) → (iv) ; (C) → (ii) ;(D) → (i) ; (E) → (iii)

66. (A) → (ii), (iv) ; (B) → (iii) ; (C) → (i), (iii)

V. Assertion and Reason Type

67. (A)

68. (A)

VI. Long Answer Type

73. 68 g, 3.2 g

SOLUTION

EXERCISE-I

1. $Fe + \text{ dil } HCl \longrightarrow FeCl_2 + H_{2(g)}$

$Zn + \text{Canc.} H_2SO_4 \longrightarrow Fe(SO_4)_3 + SO_2 + H_2O$

$Zn + NaOH \longrightarrow Na_2ZnO_2 + H_{2(g)}$

2. At high temperature ortho hydrogen is more stable than fura hydrogen.

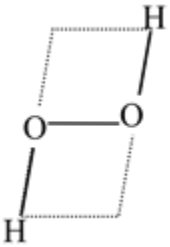
$$\left[P_{H_2} \underset{T\downarrow}{\overset{T\uparrow}{\rightleftharpoons}} O_{H_2}\right]$$

3. Temporary hardness is due to the presence of magnesium and calcium hydrogencarbonates.

4. High boiling point of water is due to hydrogen bonding.

5. The bleaching properties of H_2O_2 are due to it's oxidizing properties. It acts as bleaching agent due to the release of nascent oxygen.

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

6.  Half open book type strature

8. H_2O_2 is diamagnetic in nature

9.  hybridisation $\Rightarrow sp^3$

EXERCISE-II

1. Permit is hydrated sodium aluminium silicate having the formula $Na_2Al_2Si_2O_8 \cdot xH_2O$

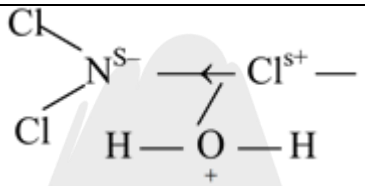
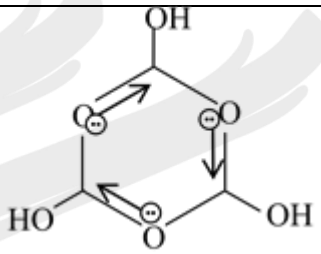
2. $C_{(s)} + H_2O_{(g)} \xrightarrow{1270K} CO_{(g)} + H_{2(g)}$

$CO_{(g)} + H_2O_{(g)} \xrightarrow[\text{Catlyst}]{673K} CO_{2(g)} + H_{2(g)}$

The mixture of CO & H_2 is called water gas.

3. CaH_2 is known as hydrolith used as a reducing agent.

4. Ionic hydrides are usually good reducing agents.

SN^1	SN^2	Silicis acid
$AB \longrightarrow A^+ + B^-$ NCl_3		Only compound in the syllabus, in which the surrounding atom undergoes hydrolysis.
$PCl_3 +$		

EXERCISE-III

2. Ortho & Para hydrogen have similar chemical properties.

EXERCISE-IV

1. Alkali metal hydrides are saline/ionic hydridation.

2. S^{-2} is converting into S^o which makes H_2O_2 an oxidizing agent.

3. Calgon : $Na[NaCl(PO_3)_6]$

4. $Na_2Al_2Si_2O_8 \cdot XH_2O$ is termed as zeolite (NaZ)

$NaZ + Ca^{+2}/Mg^{+2} \longrightarrow 2(CaZ_2/MgZ_2) + 2Na^+_{(aq.)}$

5. Heavy water : D_2O

6. Highly pure ($> 99.9\%$) H_2 gas is obtained by electrolysis of water.

EXERCISE # (JEE-MAINS)

12. There are three isotopes of H out of which only tritium is radioactive, which emits low energy β^- particles. Its half life is 12.33 years.

13. H_2O_2 acts as oxidising agent as well as reducing agent in both acidic and basic medium.

H_2O_2 acts as oxidant:

$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$ (acidic medium)

$H_2O_2 + 2e^- \rightarrow 2OH^-$ (basic medium)

H_2O_2 acts as reductant:-

$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$ (acidic medium)

$H_2O_2 + 2OH^- \rightarrow 2H_2O + O_2 + 2e^-$ (basic medium)

14. Moles of $Ca(HCO_3)_2 = \frac{0.81}{162} = 0.005$

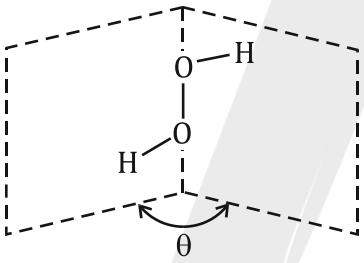
Moles of $Mg(HCO_3)_2 = \frac{0.73}{146} = 0.005$

Hardness in terms of $CaCO_3$ in ppm

$= \frac{(0.005+0.005)\times 100}{100} \times 10^6 = 10^4$ ppm

15. Theory based

16.



Open book like structure

- Non planar
- Almost colorless

18. To obtain H_2 of high purity ($> 99.95\%$) electrolysis of $Ba(OH)_2$ solution is done using Ni electrodes

20. $Na_6(PO_3)_6$ or $Na_6P_6O_{18}$

Order of abundance of element in earth crust is

$O > Si > Al > Fe > Ca > Na > Mg > K$

So second most abundant element in earth crust is Si not Ca.

22. Atomic hydrogen is produced at high temperature in an electric are or under ultraviolet radiations

The dissociation of dihydrogen at 2000 K is only 0.081%.

$H-H$ bond dissociation enthalpy is highest for a single bond for any diatomic molecule.

Dihydrogen can be produced on reacting Zn with dil. HCl as well as NaOH (aq.)

23. The process of producing syn-gas from coal is called gasification of coal.

Syn-gas having composition of $CO\&H_2$ in 1: 1

24. Pure demineralised (de-ionized) water free from all soluble mineral salts is obtained by passing water successively through a cation exchange (in the H form) and an anion exchange (in the OH^- form) resins.

25. Clark's Method Reaction

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

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

26. In option (A) and (C) reducing action of hydrogen peroxide is shown.

In option (A) it is in acidic medium, in option (B) it is in basic medium.

or

For reducing ability H_2O_2 changes to O_2, i.e. oxidize, so in option 'A' & ' $C'O_2$ is formed but 'A' is in acidic medium so option - C correct.

27. Ice > Liquid water > Impure water

Due to impurity extent of H-Bonding decreases

29. $(K_2\ S_2O_8(\ s) + 2D_2O(l) \rightarrow 2KDSO_4\ (aq.\ ) + D_2O_2$

30. According to bent rule more electronegative atom occupy less s-characters so bond length increases. $O-H$ bond will be short than $O-F$ bond due to small size of H than F.

SOLUTION

JEE ADVANCED

8. (a) $KIO_4 + H_2O_2 \rightarrow KIO_3 + H_2O + O_2$

Thus, H_2O_2 is acting as a reducing agent

$2NH_2OH + H_2O_2 \rightarrow N_2 + 4H_2O$

Here H_2O_2 is acting as an oxidising agent