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**UNIT 9**

**HYDROGEN**



***Hydrogen, the most abundant element in t e univer e and the third most abundant on the surface of t e globe, is being visualised as the major future source of energy.***



After studying this unit, you will be

able to

* present informed opinions on the position of hydrogen in the

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| **•** | periodic table; | | |  |  |  | Hydrogen has the simplest atomic structure among all the | | | | | |  |
| identify the modes of occurrence | | | | | | elements around s in Nat re. In atomic form it consists | | | | | |  |
|  | and preparation of dihydrogen on | | | | | | of only one proton and one electron. However, in elemental | | | | | |  |
|  | a small and commercial scale; | | | | | |  |
|  | form it exists as a diatomic (H2) molecule and is called | | | | | |  |
|  | describe isotopes of hydrogen; | | | | |  |  |
| **•** | explain how different elements | | | | | | dihydrog n. It forms more compounds than any other | | | | | |  |
| element. Do you know that the global concern related to | | | | | |  |
|  | combine with hydrogen to form | | | | | |  |
|  | ionic, molecular and non- | | | | | | ene gy can be ov rcome to a great extent by the use of | | | | | |  |
| **•** | stoichiometric compounds; | | | |  |  | hyd og n as a source of energy? In fact, hydrogen is of | | | | | |  |
| describe how an understanding of | | | | | | great indust ial importance as you will learn in this unit. | | | | | |  |
|  | its properties can lead to the | | | | | |  |
|  |  |  |  |  |  | 1 |  |
|  |  |  |  |  |  | be | | |  |  |  |  |
|  | production of useful substances, | | | | | | **9.1** | **POSITION OF HYDROGEN IN THE PERIODIC** | | | | |  |
| **•** | and new technologies; | | | |  |  |  | **TABLE** | |  |  |  |  |
| understand the structure of wat r | | | | | |  |  |  |  |  |
|  | Hydrogen is the first element in the periodic table. | | | | |  |
|  | and use the knowledge for | | | | | |  |  |
|  | explaining physical and chemical | | | | | | However, its placement in the periodic table has been a | | | | | |  |
| **•** | properties; | | |  |  |  | su | ject of discussion in the past. As you know by now | | | | |  |
| explain how envir nmental water | | | | | | that the elements in the periodic table are arranged | | | | | |  |
|  | quality depends n a variety f | | | | | |  |
|  | according to their electronic configurations. | | | | | |  |
|  | dissolved subs ances; difference | | | | | |  |
|  |  |  |  |  |  |  |  |
|  | between 'hard' and 's f ' wa er and | | | | | |  | Hydrogen has electronic configuration 1*s* . On one | | | | |  |
| not | | | | |  |  |  |  |  |  |  |  |  |
| **•** | learn about wa er s f ening; | | | |  |  | hand, its electronic configuration is similar to the outer | | | | | |  |
| acquire | | he knowledge about | | | |  |  |  |  |  | 1 |  |
|  |  |  |  |  |  |  | electronic configuration (*n*s ) of alkali metals , which belong | | | | | |  |
|  | NCERTheavy wa er and i s importance; | | | | | | |  |  |  |  |  |  |
| **•** | unders and | | | to | |  | to the first group of the periodic table. On the other hand, | | | | | |  |
| he structure of | | |  |  | 2 |  | 5 |  |  |
| © | hydr gen per xide, learn its | | | | | | like halogens (with *ns* | | | *np* |  | configuration belonging to the |  |
| preparat | | ry | methods | and | | seventeenth group of the periodic table), it is short by one | | | | | |  |
| pr | perties | | leading to | the | | electron to the corresponding noble gas configuration, | | | | | |  |
|  | ma ufacture of useful chemicals | | | | | | helium (1*s*2). Hydrogen, therefore, has resemblance to | | | | | |  |
| **•** | a | d clea | ing of environment; | | |  | alkali metals, which lose one electron to form unipositive | | | | | |  |
| u | dersta | d and use certain terms | | | |  |
| ions, as well as with halogens, which gain one electron to | | | | | |  |
|  | e.g., electron-deficient, electron- | | | | | |  |
|  | form uninegative ion. Like alkali metals, hydrogen forms | | | | | |  |
|  | precise, electron-rich, hydrogen | | | | | |  |
|  | economy, hydrogenation etc. | | | |  |  | oxides, halides and sulphides. However, unlike alkali | | | | | |  |

metals, it has a very high ionization enthalpy and does not

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| possess metallic characteristics under normal | | | | solar atmosphere. The giant planets Jupiter | | |  |
| conditions. In fact, in terms of ionization | | | | and Saturn consist mostly of hydrogen. | | |  |
| enthalpy, | hydrogen | resembles more | | However, due to its light nature, it is much less | | |  |
| with halogens, *i* *H* of Li is 520 kJ mol–1, F is | | | | abundant (0.15% by mass) in the earth’s | | |  |
| 1680 kJ mol–1 and that of H is 1312 kJ mol–1. | | | | atmosphere. Of course, in the combined form | | |  |
| Like halogens, it forms a diatomic molecule, | | | | it constitutes 15.4% of the earth's crust and | | |  |
| combines with elements to form hydrides and | | | | the oceans. In the combined form besides in | | |  |
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| a large number of covalent compounds. | | | | water, it occurs in plant and animal tissues, | | |  |
| However, in terms of reactivity, it is very low as | | | | carbohydrates, proteins, hydrides inclu ing | | |  |
| compared to halogens. | |  |  | hydrocarbons and many other compoun s. | | |  |
| Inspite of the fact that hydrogen, to a | | | | **9.2.2 Isotopes of Hydrogen** | |  |  |
| certain extent resembles both with alkali | | | |  |  | 1 |  |
| metals and halogens, it differs from them as | | | | Hydrogen has three isotopes: **protium**, 1H, | | |  |
|  | 2 | 3 |  |
| well. Now the pertinent question arises as | | | | **deuterium**,1H or D and **tritium**,1H or T. Can | | |  |
| you guess how these i otopes differ from each | | |  |
| where should it be placed in the periodic table? | | | |  |
| other ? These isotopes d ffer from one anot er | | |  |
| Loss of the electron from hydrogen atom | | | |  |
| in respect of the presence of neutrons. Ordinary | | |  |
| results in | nucleus (H+) of ~1.510–3 pm size. | | |  |
| hydrogen, protium, has no neutrons, | | |  |
| This is extremely small as compared to normal | | | | deuterium (also known as heavy hydrogen) has | | |  |
| atomic and ionic sizes of 50 to 200pm. As a | | | | one and tritium has two neutrons in the | | |  |
| consequence, H+ does not exist freely and is | | | | nucle s. | In the year 1934, an American | |  |
| always associated with other atoms or | | | | scientist, Harold C. Urey, got Nobel Prize for | | |  |
| molecules. Thus, it is unique in behaviour and | | | | separating hydrogen isotope of mass number | | |  |
| NCERT | | |  |  |  |  |  |
| is, therefore, best placed separately in the | | | | 2 by hysical methods. | |  |  |
| periodic table (Unit 3). | |  |  | The | redominant form | is protium. |  |
|  |  |  |  |  |
| **9.2 DIHYDROGEN, H2** | |  |  | T rr strial hydrogen contains 0.0156% of | | |  |
|  |  | d ut rium mostly in the form of HD. The | | |  |
| **9.2.1 Occurrence** | |  |  |  |
|  |  | t itium concentration is about one atom per | | |  |
|  |  | be | |  |
|  |  | 1018 atoms of protium. Of these isotopes, only | | |  |
| Dihydrogen is the most abundant element in | | | |  |
| the universe (70% of the | | total mass of the | | t itium is radioactive and emits low energy | | |  |
| universe) and is the principal el m nt in the | | | | β– particles (t , 12.33 years). | |  |  |

**Table 9.1 Atomic and Physical Properties of Hydrogen**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | **Property** | |  | **Hydrogen** | **Deuterium** | **Tritium** |  |
|  |  |  | | |  |  |  |  |  |
|  |  | Relative abundance (%) | | |  | 99.985 | 0.0156 | 10–15 |  |
|  |  | Relative atomic mass (g m l–1) | | |  | 1.008 | 2.014 | 3.016 |  |
|  |  | Melting point / K | | |  | 13.96 | 18.73 | 20.62 |  |
|  |  | Boiling poin / K | | |  | 20.39 | 23.67 | 25.0 |  |
|  |  | Densi y / gL –1 | |  |  | 0.09 | 0.18 | 0.27 |  |
|  |  | Enthalpy of fusion/kJ mol–1 | | |  | 0.117 | 0.197 | - |  |
| © |  |  |  | to |  |  |  |  |  |
|  | Enthalpy | f vaporization/kJ mol | | –1 | 0.904 | 1.226 | - |  |
|  |  |  |
|  | Enthalpy | f b nd | |  |  |  |  |  |
|  | diss ciati n/kJ mol–1 at 298.2K | | |  | 435.88 | 443.35 | - |  |
|  |  | I ter uclear distance/pm | | |  | 74.14 | 74.14 | - |  |
|  |  | Io ization enthalpy/kJ mol–1 | | |  | 1312 | - | - |  |
|  | not | | | |  |  |  |  |  |
|  | Electron gain enthalpy/kJ mol–1 | | | |  | –73 | - | - |  |
|  |  | Covalent radius/pm | | |  | 37 | - | - |  |
|  |  | Ionic radius(H– )/pm | | |  | 208 |  |  |  |

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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 (Table 9.1). However, in physical properties these isotopes differ considerably due to their large mass differences.

**9.3 PREPARATION OF DIHYDROGEN, H2**

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

**9.3.1 Laboratory Preparation of**

**Dihydrogen**

1. It is usually prepared by the reaction of granulated zinc with dilute hydrochloric acid.

Zn + 2H+ → Zn2+ + H2

1. It can also be prepared by the reaction of zinc with aqueous alkali.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Zn + 2NaOH → Na2ZnO2 | | | | | | | + H2 | | |  |  |  |  |
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|  |  |  |  |  |  | Sodium zincate | | | |  |  |  |  |  |
| **9.3.2 Commercial Production of** | | | | | | | | | | |  |  |  |  |
|  |  | **Dihydrogen** | | | | |  |  |  |  |  |  |  |  |
| The commonly used processes are outlined | | | | | | | | | | | | | |  |
| below: | |  |  |  |  |  | be | | | | | | |  |
| (i) | Electrolysis | | | | |  |  |
| of acidified | | water | | | using | | |  |
|  | platinum electrodes gives hydrog n. | | | | | | | | | | |  | g |  |
| 2H O l → 2H | | | | | | | | |  | g + O | |  |  |
|  |  | ( |  |  | lectrolysis | |  |  | 2 ( | ) |  | 2 ( ) | |  |
|  | 2 | )Traces of acid / base | | | |  |  |  |  |
| (ii) | High purity (>99.95%) dihydrog n is | | | | | | | | | | | | |  |
|  | obtained by electrolysing warm aqueous | | | | | | | | | | | | |  |
|  |  |  | – |  |  | to | |  | – |  |  |  |  |  |
|  | barium hydroxide solution | | | | | | | etween nickel | | | | | |  |
|  | electrodes. | | |  |  |  |  |  |  |  |  |  |  |  |
| (iii) It is obtained as a bypr | | | | | | | |  | duct | | in | | the |  |
| © | manufacture | | | | | f s dium hydroxide and | | | | | | | |  |
| not22 | | | | | | |  |  |  |  | brine | | |  |
|  | chlorine by | | | | | he elec rolysis of | | | | |  |
|  | solution. During elec rolysis, the reactions | | | | | | | | | | | | |  |
|  | that take place are: | | | | | |  |  |  |  |  |  |  |  |
| at an | | de: 2Cl (aq) | | | | → Cl2(g) + 2e | | |  |  |  |  |  |  |
| at cath de: 2H | | | | 2 | O (l) + 2e–→ H (g) + 2OH–(aq) | | | | | | | | |  |
|  | The | |  |  |  | 2 |  |  |  |  |  |  |  |
|  | verall reaction is | | | |  |  |  |  |  |  |  |  |

2Na+ (aq) + 2Cl–(aq) + 2H2O(l)

↓

Cl (g) + H (g) + 2Na+ (aq) + 2OH–(aq) (iv) Reaction of steam on hydrocarbons or coke

at high temperatures in the presence of catalyst yields hydrogen.

|  |  |  |  |
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| C n H 2n 2 nH 2 O | 1270K | nCO (2n 1)H2 |  |
| Ni |  |
| e.g., |  |  |  |

CH 4 ( g ) + H 2 O ( g ) →1270K CO ( g ) + 3H 2 ( g)

Ni

The mixture of CO and H2 is called *water* *gas*. As this mixture of CO and H2is used forrepublishedthesynthesisofmethanolandanumberof hydrocarbons, it is also called *synthesis gas*

*or* **'syngas'***.* Nowadays 'syngas' is pro ucfrom sewage, saw-dust, scrap woo , newspapers etc. The process of producing 'syngas' from coal is called *'coal gasification'*.

C ( s ) + H 2 O ( g ) →1270K CO ( g ) + H 2 ( g)

The production of d hydrogen can be increased by react ng carbon monoxide of syngas mixtures with steam n the presence of iron chromate as cata yst.

CO (g ) + H 2 O (g ) →673K CO 2 (g ) + H 2 (g)

catalyst

This is called *water-gas shift reaction*. Carbon dioxide is removed by scrubbing with sodium arsenite solution.

Pr s ntly ~77% of the industrial dihydrog n is produced from petro-chemicals, 18% from coal, 4% from electrolysis of aqueous solutions and 1% from other sources.

**9.4 PROPERTIES OF DIHYDROGEN**

**9.4.1 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 9.1.

**9.4.2 Chemical Properties**

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. 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 2000K which increases to 95.5% at 5000K. Also, it is relatively inert at room temperature due to the

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high H–H bond enthalpy. Thus, the atomic hydrogen is produced at a high 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 withhalogens, X2 to give hydrogen halides, HX,

H 2 ( g ) + X 2 ( g ) → 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 withdioxygen to form water. The reaction is highly exothermic.



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2H2(g) + O2 | (g) |  |  | 2H2O(l); |  |
|  |  |  |
| NCERT | | | | |  |
|  |  | *H*V | = –285.9 kJ mol–1 | |  |

***Reaction with dinitrogen:*** With dinitrogenit forms ammonia.

3H 2 (g ) + N 2 (g ) 673K,200atm → 2NH 3 (g ) ; Fe

V −

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

***Reactions with metals:*** With many m tals itcombines at a high temperature to yield the corresponding hydridesto(section 9.5)

*H* = −92.6 be kJ mol 1

H2(g) +2M(g) → 2MH(s);

where M is an alkali me al

© not ***Reactions wi h me al i ns and metal oxides:*** It reduces some me al ions in aqueoussolution and oxides of metals (less active than iron) into c rresp nding metals.

H 2 (g ) + Pd 2+ (aq ) → Pd (s ) + 2H + (aq )

yH 2 ( g ) + M x O y ( s ) → xM ( s ) + yH 2 O ( l )

***Reactio s with organic compounds:*** Itreacts with many organic compounds in the presence of catalysts to give useful hydrogenated products of commercial importance. For example :

1. Hydrogenation of vegetable oils using nickel as catalyst gives edible fats (margarine and vanaspati ghee)
2. Hydroformylation of olefins yields aldehydes which further undergo reduction to give alcohols.

republishedH2+CO+RCH=CH2→RCH2CH2CHO H2 + RCH2CH2CHO → RCH2CH2CH2OH

**Problem 9.1**

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

**Solution**

(i) Dihydrogen reduces chlorine into chloride (Cl–) ion and tse f gets oxidised to H+ ion y ch orine 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 H2O, which is a covalent molecule.

**9.4.3 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 ) cobalt →CH 3 OH ( l )

catalyst

* It is widely used for the manufacture of metal hydrides (Section 9.5)
* It is used for the preparation of hydrogen

chloride, a highly useful chemical.

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* 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.

**9.5 HYDRIDES**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Dihydrogen, under certain reaction conditions, | | | | | | | |  |
| combines with almost all elements, except | | | | | | | |  |
| noble gases, to form binary compounds, called | | | | | | | |  |
|  | NCERT | | | | | | |  |
| **hydrides**. If ‘E’ is the symbol of an element then | | | | | | | |  |
| hydride can be expressed as EHx (e.g., MgH2) | | | | | | | |  |
| or EmHn (e.g., B2H6). | | | | | |  |  |  |
|  |  | The hydrides are classified into th ee | | | | | |  |
| categories : | | | | |  |  |  |  |
| (i) |  | Ionic or saline or saltlike hydrides | | | | | |  |
| (ii) |  | Covalent or molecular hydrid s | | | | | |  |
| (iii) Metallic or non-stoichiometric hydrid s | | | | | | | |  |
| **9.5.1** | | | | **Ionic or Saline Hydrides** | | | |  |
| These are stoichiometric compounds of | | | | | | | |  |
|  |  |  |  |  | to | |  |  |
| dihydrogen formed with most of the *s*- lock | | | | | | | |  |
| elements which are highly electropositive in | | | | | | | |  |
| character. However, significantbecovalent | | | | | | | |  |
| character is found in | | | | | | he ligh er metal hydrides | |  |
| such as LiH, BeH2 and MgH2. In fact BeH2 and | | | | | | | |  |
|  | not | | | |  |  |  |  |
| MgH2 | | | | are polymeric in s ructure. The ionic | | | |  |
| hydrides are crys alline, non-volatile and non- | | | | | | | |  |
| conducting in s lid s a e. However, their melts | | | | | | | |  |
| conduct electricity and on electrolysis liberate | | | | | | | |  |
| ©dihydr gen gas at anode, which confirms the | | | | | | | |  |
| existe | | | | ce of H– ion. |  |  |  |  |
| 2H | | – | ( melt) → H2 ( g) + 2e | | | | − |  |
|  |  |  | anode |  |  |  |

Saline hydrides react violently with water producing dihydrogen gas.

NaH ( s ) + H 2 O ( aq ) → NaOH ( aq ) + H 2 ( g)

Lithium hydride is rather unreactive at moderate temperatures with O2 or Cl2. It is, therefore, used in the synthesis of other useful hydrides, e.g.,

8LiH + Al2Cl6 → 2LiAlH4 + 6LiCl 2LiH + B2H6 → 2LiBH4

republished An electron-deficient hydride, as the name suggests, has too few electrons for writing its

**9.5.2 Covalent or Molecular Hydride**

Dihydrogen forms molecular compoun s with most of the *p*-block elements. Most familiar examples are CH4, NH3, H2O and HF. For convenience hydrogen compounds of non-metals have also been considered as ydrid s. Being covalent, they are volatile compounds.

Molecular hydrides are furt er classified according to the re at ve numbers of electrons and bonds in their Lew tructure into :

**(i) electron-deficient, ( ) e ectron-precise, and (iii) electron-rich hydrides.**

conventional Lewis structure. Diborane (B2H6) is an exam le. In fact all elements of group 13 will form electron-deficient compounds. What do you x ect from their behaviour? They act as L wis acids i.e., electron acceptors.

El ctron-precise compounds have the equired number of electrons to write their conventional Lewis structures. All elements of group 14 form such compounds (e.g., CH4) 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. (NH3 has 1- lone pair, H2O – 2 and HF –3 lone pairs). What do you expect from the behaviour of such compounds ? 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.

**Problem 9.2**

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.

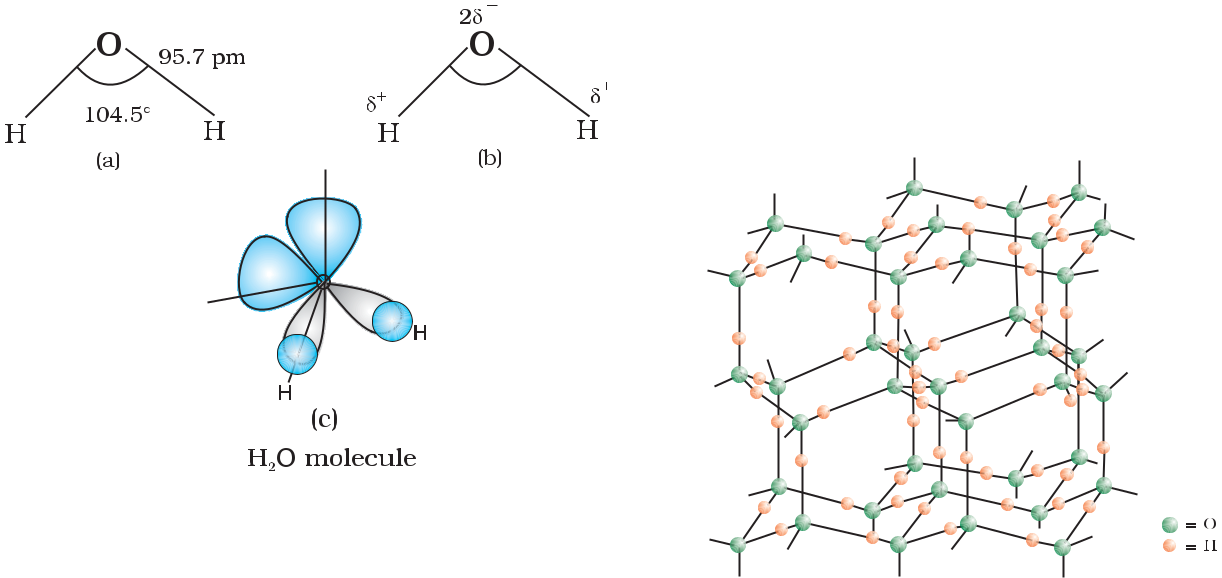
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|  |  | **Solution** | |  |  |  |  |  |  | **Solution** | |  |  |  |  |
|  |  | On the basis of molecular masses of NH3, | | | | | |  |  | Although phosphorus exhibits +3 and +5 | | | |  |  |
|  |  | H2O and HF, their boiling points are | | | | | |  |  | oxidation states, it cannot form PH | | | . |  |  |
|  |  | expected to be lower than those of the | | | | | |  |  |  |  | 5 |  |  |  |
|  |  |  |  | Besides some other considerations, high | | | |  |  |
|  |  | subsequent group member hydrides. | | | | | |  |  | a*H* value of dihydrogen and | | *egH* value | |  |  |
|  |  | However, due to higher electronegativity | | | | | |  |  | of hydrogen do not favour to exhibit the | | | |  |  |
|  |  | of N, O and F, the magnitude of hydrogen | | | | | |  |  | republished | | | |  |  |
|  |  |  |  | highest oxidation state of P, and | | | |  |  |
|  |  | bonding in their hydrides will be quite | | | | | |  |  | consequently the formation of PH5. | | |  |  |  |
|  |  | appreciable. Hence, the boiling points | | | | | |  |  |  |  |  |  |  |  |
|  |  | NH3, H2O and HF will be higher than the | | | | | |  |  | **9.6 WATER** | |  |  |  |  |
|  |  | hydrides of their subsequent group | | | | | |  |  |  |  |  |  |
|  |  | members. | | |  |  |  |  |  | A major part of all living organisms is made | | | | |  |
|  | **9.5.3** | | **Metallic or Non-stoichiometric** | | | | | |  | up of water. Human body has about 65% and | | | | |  |
| some plants have as much as 95% water. It is | | | | |  |
|  |  |  | **(or Interstitial ) Hydrides** | | | | |  |  | a crucial compound for the urvival of all life | | | | |  |
|  | These are formed by many *d*-block and *f*-block | | | | | | | | | forms. It is a solvent of great mportance. The | | | | |  |
|  | elements. However, the metals of group 7, 8 | | | | | | | | | distribution of water over the earth’s surface | | | | |  |
|  | and 9 do not form hydride. Even from group | | | | | | | | | is not uniform. The est mated world water | | | | |  |
|  | 6, only chromium forms CrH. These hydrides | | | | | | | | | supply is given in Ta e 9.2 | |  |  |  |  |
|  | conduct heat and electricity though not as | | | | | | | | | **Table 9.2 Estimated World Water Supply** | | | | |  |
|  | efficiently as their parent metals do. Unlike | | | | | | | | |  |  |  |  |  |  |
|  | saline hydrides, they are almost always non- | | | | | | | | | **Source** |  | **% of Total** | |  |  |
|  | stoichiometric, being deficient in hydrogen. For | | | | | | | | |  |  |  |  |  |  |
|  | Oceans |  | 97.33 |  |  |  |
|  | example, LaH2.87, YbH2.55, TiH1.5–1.8, ZrH1.3–1.75, | | | | | | | | |  |  |  |  |
|  | Saline lakes and inland seas |  | 0.008 |  |  |  |
|  | VH0.56, NiH0.6–0.7, PdH0.6–0.8 etc. In such | | | | | | | | |  |  |  |  |
|  | Polar ice and glaciers |  | 2.04 |  |  |  |
|  | hydrides, the law of constant composition does | | | | | | | | |  |  |  |  |
|  | G ound water |  | 0.61 |  |  |  |
|  | not hold good. | | | |  |  | be | | |  |  |  |  |
|  |  |  |  |  |  |  | Lakes |  | 0.009 |  |  |  |
|  |  | Earlier it was thought that in these | | | | | | | |  |  |  |  |
|  | hydrides, hydrogen occupies int rstic s in the | | | | | | | | | Soil moisture |  | 0.005 |  |  |  |
|  | metal lattice producing distortion without any | | | | | | | | | Atmospheric water vapour |  | 0.001 |  |  |  |
|  | change in its type. | | | | onsequently, th y w re | | | | | Rivers |  | 0.0001 |  |  |  |
|  | termed as interstitial hydrides. How v r, r c nt | | | | | | | | | **9.6.1 Physical Properties of Water** | | |  |  |  |
|  | studies have shown that except for hydrides | | | | | | | | |  |  |  |
|  | of | i, Pd, e and Ac, | | | ther hydrides of this class | | | | | It is a colourless and tasteless liquid. Its | | | | |  |
|  | have lattice different fr | | | | | | m hat f the parent | | | physical properties are given in Table 9.3 along | | | | |  |
|  | metal. The proper y | | | | f abs rpti n of hydrogen | | | | | with the physical properties of heavy water. | | | | |  |
|  | on transition me als is widely used in catalytic | | | | | | | | | The unusual properties of water in the | | | | |  |
|  | reduction / hydrogena ion reactions for the | | | | | | | | |  |
|  |  |  |  |  |  |  |
|  |  | not | | |  |  |  |  |  | condensed phase (liquid and solid states) are | | | | |  |
|  | preparationNCERTof large number of compounds. | | | | | | | | |  |
|  | due to the presence of extensive hydrogen | | | | |  |
|  | Some | | f | to | | | |  |  |  |
|  | he me als | | | (e.g., Pd, Pt) can | | | bonding between water molecules. This leads | | | | |  |
|  | acc mm da e a very large volume of hydrogen | | | | | | | | |  |
|  | to high freezing point, high boiling point, high | | | | |  |
|  | a | d, theref | | re, can be used as its storage | | | | | |  |
|  | heat of vaporisation and high heat of fusion in | | | | |  |
| © | |  |  |  |  |  |  |  |  |  |
|  | media. This pr perty has high potential for | | | | | | | | | comparison to H2S and H2Se. In comparison | | | | |  |
|  | **hydrogen storage** and as a **source of energy**. | | | | | | | | |  |
|  | to other liquids, water has a higher specific | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  | **Problem 9.3** | | |  |  |  |  |  | heat, thermal conductivity, surface tension, | | | | |  |
|  |  |  |  |  |  |  | dipole moment and dielectric constant, etc. | | | | |  |
|  |  | Can phosphorus with outer electronic | | | | | |  |  |  |
|  |  |  |  | These properties allow water to play a key role | | | | |  |
|  |  |  |  | 2 |  | 3 |  |  |  |  |
|  |  | configuration 3*s* | | | 3*p* |  | form PH5 ? |  |  | in the biosphere. | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |

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| --- | --- | --- | --- | --- | --- | --- | --- |
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|  |  |  | **Table 9.3 Physical Properties of H2O and D2O** | | | |  |
|  | **Property** | |  |  | **H2O** | **D2O** |  |
|  | 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 | | | republished | | |  |
|  | –285.9 | | –294.6 |  |
|  | Enthalpy of vaporisation (373K)/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 (298K)/g cm–3 | | | 1.0000 | | 1.1059 |  |
|  | Viscosity/centipoise | | | 0.8903 | | 1.107 |  |
|  | Dielectric constant/C2/N.m2 | | | 78.39 | | 78.06 |  |
|  | Electrical conductivity (293K/ohm–1 cm–1) | | | 5.7 10–8 | | - |  |
|  | The high heat of vaporisation and heat | | | polar molecule, (Fig 9.1( )). Its orbital overlap | | |  |
| capacity are responsible for moderation of the | | | | picture is shown in Fig. 9.1(c). In the liquid | | |  |
| climate and body temperature of living beings. | | | | phase water molec | | les are associated together |  |
| It is an excellent solvent for transportation of | | | | by hydrogen | onds. | |  |
| ions and molecules required for plant and | | | | The crystalline form of water is ice. At | | |  |
|  | NCERT | | |  |  |  |  |
| animal metabolism. Due to hydrogen bonding | | | | atmos heric | ress | re ice crystallises in the |  |
| with polar molecules, even covalent | | | | hexagonal form, but at very low temperatures | | |  |
| compounds like alcohol and carbohydrates | | | | it cond nses to cubic form. Density of ice is | | |  |
| dissolve in water. | | |  | l ss than that of water. Therefore, an ice cube | | |  |
| **9.6.2 Structure of Water** | | | | floats on water. In winter season ice formed | | |  |
| on the surface of a lake provides thermal | | |  |
|  |  |  | be |  |
|  |  |  |  |  |  |  |
| In the gas phase water is a bent molecule with | | | | insulation which ensures the survival of the | | |  |
| a bond angle of 104.5°, and O–H bond l ngth | | | |  |
| aquatic life. This fact is of great ecological | | |  |
| of 95.7 pm as shown in Fig 9.1(a). It is a highly | | | |  |
| significance. |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  | **9.6.3 Structure of Ice** | | |  |
|  |  |  | to | Ice has a highly ordered three dimensional | | |  |
|  |  |  | hydrogen bonded structure as shown in | | |  |
|  |  |  |  |  |
|  |  |  |  | Fig. 9.2. Examination of ice crystals with | | |  |
| © | not | |  |  |  |  |  |
|  |  |  |  |  |  |
| ***Fig. 9.1*** | | *(a) The bent structure of water; (b) the* | |  |  |  |  |
|  |  | *water molecule as a dipole and* | |  |  |  |  |
|  |  | *(c) the orbital overlap picture in water* | |  |  |  |  |
|  |  | *molecule.* |  | ***Fig. 9.2*** *The structure of ice* | | |  |



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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HYDROGEN | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 283 | |  |
| X-rays shows that each oxygen atom is | | | | | | | | | | | | | |  |  | N 3− ( s ) + 3H 2 O ( l ) → NH 3 ( g ) + 3OH − ( aq ) | | | | | | | | | | | | | | | | | | |  |
| surrounded tetrahedrally by four other oxygen | | | | | | | | | | | | | |  | ***(4) Hydrates Formation:*** From aqueous | | | | | | | | | | | | | | | | | | | |  |
| atoms at a distance of 276 pm. | | | | | | | | | |  |  |  |  |  |  |
|  |  |  |  |  | solutions many salts can be crystallised as | | | | | | | | | | | | | | | | | | | |  |
|  | Hydrogen bonding gives ice a rather open | | | | | | | | | | | | |  |  |
|  |  | hydrated salts. Such an association of water | | | | | | | | | | | | | | | | | | | |  |
| type structure with wide holes. These holes can | | | | | | | | | | | | | |  |  |
|  | is of different types viz., | | | | | | | | | | | | | | | |  |  |  |  |  |
| hold some other molecules of appropriate size | | | | | | | | | | | | | |  |  |  |  |  |  |
|  | (i) | | coordinated water e.g., | | | | | | | | | | | | | | |  |  |  |  |
| interstitially. | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | republished | | | | | | | | | | | | | | | | | | | | | |  |
| **9.6.4 Chemical Properties of Water** | | | | | | | | | | | |  |  |  |  | Cr | | ( | | H | | 2 | O | |  | 3+ 3Cl | | – |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | )6 | | |  |  |  |  |  |  |  |  |
| Water reacts with a large number of | | | | | | | | | | | | | |  | (ii) | | interstitial water e.g., BaCl 2 .2H 2 O | | | | | | | | | | | | | | | |  |  |  |
| substances. Some of the important reactions | | | | | | | | | | | | | |  | (iii) hydrogen-bonded water e.g., | | | | | | | | | | | | | | | | | |  |  |  |
| are given below. | | | | | |  |  |  |  |  |  |  |  |  |  | Cu | | | ( | | H | |  | O | | )4 | 2+ SO2– | | .H | O | in CuSO 4 .5H 2O, | | | |  |
| ***(1) Amphoteric Nature:*** It has the ability to | | | | | | | | | | | | | |  |  |  |  |  |  | 2 | |  |  |  | 4 | 2 |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| act as an acid as well as a base i.e., it behaves | | | | | | | | | | | | | |  |  |  | **Problem 9.4** | | | | | | | | | | |  |  |  |  |  |  |  |  |
| as an amphoteric substance. In the Brönsted | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | How many hydrogen-bonded water | | | | | | | | | | | | | | | | |  |  |
| sense it acts as an acid with NH3 and a base | | | | | | | | | | | | | |  |  |  |  |  |
|  |  |  | molecule(s) | | | | | | | | | | | are | |  | a | ociated | in |  |  |
| with H2S. | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | CuSO4.5H2O? | | | | | | | | | | |  |  |  |  |  |  |  |  |
| H 2 O ( l ) + NH 3 ( aq ) | | | | | |  |  | OH – ( aq ) + NH 4+ ( aq) | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | **Solution** | | | | | | | | | |  |  |  |  |  |  |  |  |  |
| H 2 O ( l ) + H 2 S ( aq ) | | | | | |  |  | H 3 O + ( aq ) + HS – ( aq) | | | | |  |  |  |  | Only one water molecule, which is outside | | | | | | | | | | | | | | | | |  |  |
| The auto-protolysis (self-ionization) of water | | | | | | | | | | | | | |  |  |  | the brackets (coordination sphere), is | | | | | | | | | | | | | | | | |  |  |
|  |  |  | hydrogen-bonded. The other | | | | | | | | | | | | | | | | four |  |  |
|  | NCERT | | | | | | | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| takes place as follows : | | | | | | | | |  |  |  |  |  |  |  |  | molec | | | | | | | | les of water are coordinated. | | | | | | | |  |  |  |
| H 2 O ( l ) + H 2 O ( l ) | | | | | |  |  | H 3 O + ( aq ) + OH – ( aq) | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | **9.6.5 Hard and Soft Water** | | | | | | | | | | | | | | | | | |  |  |  |
| acid-1 | | base-2 | | | |  | acid-2 | |  |  | base-1 |  |  |  |  |  |  |
|  |  |  |  |  |  | Rain wat r is almost pure (may contain some | | | | | | | | | | | | | | | | | | | |  |
| (acid) | | (base) | | | | (conjugate | | | |  | (conjugate | |  |  |  |
|  |  |  | dissolv d gases from the atmosphere). Being a | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  | acid) |  |  | base) |  |  |  |  |
|  |  |  |  |  |  |  |  |  | be | | | |  |  | good solvent, when it flows on the surface of | | | | | | | | | | | | | | | | | | | |  |
| ***(2) Redox Reactions Involving Water:*** Water | | | | | | | | | | | | | |  |  |
| can be easily reduced to dihydrog n by highly | | | | | | | | | | | | | |  | the earth, it dissolves many salts. Presence of | | | | | | | | | | | | | | | | | | | |  |
| electropositive metals. | | | | | | | |  |  |  |  |  |  |  | calcium and magnesium salts in the form of | | | | | | | | | | | | | | | | | | | |  |
| 2H 2 O ( l ) + 2Na ( s ) → 2NaOH ( aq ) + H 2 ( g) | | | | | | | | | | | | |  |  | hydrogencarbonate, chloride and sulphate in | | | | | | | | | | | | | | | | | | | |  |
|  |  | water makes water **‘hard’**. **Hard water** does | | | | | | | | | | | | | | | | | | | |  |
| Thus, it is a great source of dihydrogen. | | | | | | | | | | | |  |  | not give lather with soap. Water free from | | | | | | | | | | | | | | | | | | | | |  |
| Water is oxidised to O2 during ph tosynthesis. | | | | | | | | | | | | | | soluble salts of calcium and magnesium is | | | | | | | | | | | | | | | | | | | | |  |
| called **Soft water**. It gives lather with soap | | | | | | | | | | | | | | | | | | | | |  |
| 6CO2 (g) + 12H2 O(l) → C6H12O6(aq) + 6H2O(l) | | | | | | | | | | | | |  |  |
|  | easily. | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| © |  |  |  |  |  |  |  |  |  |  | + 6O2(g) | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| not | | | | | | |  |  |  |  |  |  |  | Hard water forms scum/precipitate with | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |
| With fluorine also it is oxidised to O2. | | | | | | | | | | | |  |  |  |  |  |  |
|  |  | soap. Soap containing | | | | | | | | | | | | | | | | | | sodium stearate | | |  |
| 2F | (g) + 2H | |  | O(l) → | |  | + | |  | – | (aq) + O | (g) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | 4H (aq) + 4F | | | |  |  | (C17H35COONa) reacts with hard water to | | | | | | | | | | | | | | | | | | | | |  |
|  | 2 |  |  | to | | | | |  | 2 |  |  |  |
| ***(3) Hydr lysis Reaction:*** Due to high | | | | | | | | | | | | | |  | precipitate out Ca/Mg stearate. | | | | | | | | | | | | | | | | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| dielectric c | | | | | nstant, it has a very strong | | | | | | | | |  |  | 2C17 H 35COONa (aq ) + M | | | | | | | | | | | | | | | 2+ | (aq) → |  |  |  |
| hydrati | | g te | | | dency. It dissolves many ionic | | | | | | | | |  |  |  |  |  |  |
|  |  | ( C17 H 35COO )2 M ↓ +2Na + ( aq ); M is Ca / Mg | | | | | | | | | | | | | | | | | | |  |
| compou | | ds. However, certain covalent and | | | | | | | | | | | |  |  |  |
| some io | | ic compounds are hydrolysed in water. | | | | | | | | | | | |  |  |  | It is, therefore, unsuitable for laundry. It is | | | | | | | | | | | | | | | | | |  |
| P4 O10 ( s ) + 6H 2 O ( l ) → 4H 3 PO 4 ( aq ) | | | | | | | | | | | |  |  |  |  |  |  |
|  |  |  | harmful for boilers as well, because of | | | | | | | | | | | | | | | | | | | |  |
| SiCl 4 ( l ) + 2H 2 O ( l ) → SiO 2 ( s ) + 4HCl ( aq) | | | | | | | | | | | | |  |  | deposition of salts in the form of scale. This | | | | | | | | | | | | | | | | | | | |  |
|  |  | reduces the efficiency of the boiler. The | | | | | | | | | | | | | | | | | | | |  |

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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
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| hardness of water is of two types: (i) temporary | | | | | | | | | | | | | Na 6 P6 O18 → 2Na + + Na 4 P6 O182– | | | | | | |  |  |  |  |
| hardness, and (ii) permanent hardness. | | | | | | | | | | | |  |  |  |  |  |  |  | (M = Mg, Ca) | | |  |  |
| **9.6.6** | | **Temporary Hardness** | | | | | | |  |  |  |  | M 2 + | | + Na 4 P6 O182− → [ Na 2 MP6 O18 ]2− + 2Na+ | | | | | | | |  |
| Temporary hardness is due to the presence of | | | | | | | | | | | | | The complex anion keeps the Mg2+ and Ca2+ | | | | | | | | | |  |
| magnesium and calcium hydrogen- | | | | | | | | | | | | |  |
| carbonates. It can be removed by : | | | | | | | | | |  |  |  | ions in solution. | | | | | |  |  |  |  |  |
| ***(i) Boiling:*** During boiling, the soluble | | | | | | | | | | | | | ***(iii) Ion-exchange method:*** This method is | | | | | | | | | |  |
| Mg(HCO3)2 is converted into insoluble Mg(OH)2 | | | | | | | | | | | | | also called zeolite/permutit process. Hy rated | | | | | | | | | |  |
| and Ca(HCO3)2 is changed to insoluble CaCO3. | | | | | | | | | | | | | sodium aluminium silicate is zeolit /p rmutit. | | | | | | | | | |  |
| It is because of high solubility product of | | | | | | | | | | | | | For the sake of simplicity, sodium aluminium | | | | | | | | | |  |
| Mg(OH) | | | 2 | as compared to that of MgCO , that | | | | | | | | | silicate (NaAlSiO4) can be written as NaZ. W n | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  | 3 |  | this is added in hard water, exc | | | | | | | ange r actions | | |  |
| Mg(OH)2 is precipitated. These precipitates can | | | | | | | | | | | | |  |
| be removed by filtration. Filtrate thus obtained | | | | | | | | | | | | | take place. | | | |  |  |  |  |  |  |  |
| will be soft water. | | | | | |  |  | (OH)2 ↓ + 2CO2 ↑ | | | | | 2NaZ ( s ) + M 2+ ( aq ) → MZ 2 ( | | | | | | | ) + 2Na + ( aq) | | |  |
|  |  |  |  |  | Heating | |  |  |  |  |  |  |  |  | (M = Mg, Ca) | | |  |
| Mg ( HCO 3 )2→ Mg | | | | | | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  | Heating |  |  |  |  |  |  |  |  | Permutit/zeolite | | | | | s sa d to be exhausted | | | |  |
| Ca (HCO3 )2→ CaCO3 ↓ + H2 O + CO2 ↑ | | | | | | | | | | | | |  |  |
| ***(ii) Clark’s method:*** In this method calculated | | | | | | | | | | | | | when all the sodium in it is used up. It is | | | | | | | | | |  |
| regenerated for f rther use y treating with an | | | | | | | | | |  |
| amount of lime is added to hard water. It | | | | | | | | | | | | |  |
| aqueo | | | s sodi | | m chloride solution. | | | |  |  |
| precipitates out calcium carbonate and | | | | | | | | | | | | |  |  |
| MZ 2 ( s ) + 2NaCl ( aq ) → 2NaZ ( s ) + MCl 2 ( aq) | | | | | | | | | |  |
| magnesium hydroxide which can be filtered off. | | | | | | | | | | | | |  |
| Ca (HCO 3 )2 + Ca (OH )2 → 2CaCO 3 ↓ +2H 2 O | | | | | | | | | | | | | ***(iv) Synthetic resins method:*** Nowadays | | | | | | | | | |  |
| Mg ( HCO3 )2 + 2Ca ( OH )2 → 2CaCO3 ↓ | | | | | | | | | | | |  | hard wat r is softened by using synthetic | | | | | | | | | |  |
|  | cation | | | xchangers. This method is more efficient | | | | | | |  |
|  |  |  |  |  |  |  | + Mg ( OH ) | | |  | ↓ +2H2O | | than z olite process. Cation exchange resins | | | | | | | | | |  |
|  |  |  |  |  |  |  | 2 | contain large organic molecule with - SO3H | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **9.6.7** | | **Permanent Hardness** | | | | | | |  |  |  |  | g oup and are water insoluble. Ion exchange | | | | | | | | | |  |
|  |  |  |  | resin (RSO H) is changed to RNa by treating it | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | republished3 | | | | | | | | | | |  |
| It is due to the presence of soluble salts of | | | | | | | | | | | | | with NaCl. The resin exchanges Na | | | | | | | | + | ions with |  |
| magnesium and calcium in the form of | | | | | | | | | | | | |  |  |
| Ca | 2+ | and Mg | | 2+ | ions present in hard water to | | | | |  |
| chlorides and sulphates in water. P rman nt | | | | | | | | | | | | |  |  |  |
| make the water soft. Here R is resin anion. | | | | | | | | | |  |
| hardness is not removed by oiling. It can be | | | | | | | | | | | | |  |
| 2RNa ( s ) + M 2+ ( aq ) → R 2M ( s ) + 2Na + ( aq) | | | | | | | | | |  |
| removed by the foll wing meth ds: | | | | | | | | | |  |  |  |  |
| ***(i) Treatment wi h washing s da (sodium*** | | | | | | | | | | | | |  | The resin can be regenerated by adding | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  | be | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ***carbonate):*** Washing s da reacts with soluble | | | | | | | | | | | | | aqueous NaCl solution. | | | | | | |  |  |  |  |
| calcium and magnesium chl rides and | | | | | | | | | | | | |  |  |  |  |
|  | Pure de-mineralised (de-ionized) water free | | | | | | | | |  |
| sulphates in hard wa er | | | | | | | | o form insoluble | | | | |  |  |
| from all soluble mineral salts is obtained by | | | | | | | | | |  |
|  | NCERT | | | | | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| carb nates. | | | | | to | | | | |  |  |  | passing water successively through a cation | | | | | | | | | |  |
| MCl 2 + Na 2 CO 3 → MCO 3 ↓ + 2NaCl | | | | | | | | | | | |  | exchange (in the H+ form) and an anion- | | | | | | | | | |  |
|  |  |  |  |  |  |  | – |  |  |  |  |
| © |  |  |  |  |  |  |  |  | (M = Mg, Ca) | | | | exchange (in the OH form) resins: | | | | | | | |  |  |  |
|  |  |  |  |  |  |  |  | 2RH ( s ) + M 2+ ( aq ) | | | | | | MR 2 ( s ) + 2H + ( aq) | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| MSO 4 + Na 2 CO 3 → | | | | | | MCO 3 ↓ + Na 2 SO4 | | | | | |  |  |
|  | In this cation exchange process, H+ exchanges | | | | | | | | | |  |
| ***(ii) Calgo ’s method:*** Sodium hexameta- | | | | | | | | | | | | |  |
| for Na+, Ca2+, Mg2+ and other cations present | | | | | | | | | |  |
| phosphate (Na P O | | | | | | 18 | ), commercially called | | | | | | in water. This process results in proton release | | | | | | | | | |  |
| not6 6 | | | | | |  |  |  |  |  |  |  |
| ‘calgon’, when added to hard water, the | | | | | | | | | | | | | and thus makes the water acidic. In the anion | | | | | | | | | |  |
| following reactions take place. | | | | | | | | |  |  |  |  | exchange process: | | | | | |  |  |  |  |  |

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|  |  |
| --- | --- |
| HYDROGEN | 285 |

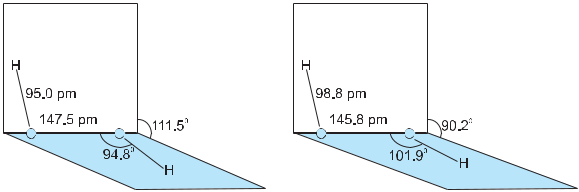
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | RNH2 ( s) | | | | | | + H2O ( l ) | RNH3.OH | | | | |  |  | ( s) | |  |  |  |  |  |  |  |  |  | → | |  |  |  |  |
|  |  |  |  |  |  |  |  |  | + | |  |  | − | |  |  |  |  |  |  |  |  |  |  |  | O 2 | ( air) |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 − ethylanthraquinol ← H 2 O2 + | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | H 2 | / Pd |  |  |  |  |
|  | RNH 3+ .OH – (s ) + X − (aq ) RNH 3+ .X − (s) | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  | ( oxidised product) | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  | + OH − ( aq) | | | | | | |  |  |  | In this case 1% H2O2 | | | | | is formed. It is | | | |  |
|  | oxidation of acidified sulphate solutions | | | | | | | | | | | | | | | | |  |  |  | extracted with water and concentrated to ~30% | | | | | | | | | |  |
|  | republishedat | | | | | | | | | | | | |  |
|  | OH–exchanges for anions like Cl–, HCO3–, SO42– | | | | | | | | | | | | | | | | | | |  | (by mass) by distillation under reduced | | | | | | | | | |  |
|  | etc. present in water. OH– ions, thus, liberated | | | | | | | | | | | | | | | | | | |  | pressure. It can be further concentrated to | | | | | | | | | |  |
|  | neutralise the H+ ions set free in the cation | | | | | | | | | | | | | | | | | | |  | ~85% by careful distillation under low | | | | | | | | | |  |
|  | exchange. | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | pressure. The remaining water can be froz n | | | | | | | | | |  |
|  |  |  | H + ( aq ) + OH − ( aq ) → H 2 O ( l ) | | | | | | | | | |  |  |  |  |  |  |  |  | out to obtain pure H2O2. | | | | | |  |  |  |  |  |
|  |  |  | The exhausted cation and anion exchange | | | | | | | | | | | | | | | | |  | **9.7.2 Physical Properties** | | | | | | |  |  |  |  |
|  |  |  |  | In the pure state H2O2 is an almost colourl ss | | | | | | | | | |  |
|  | resin beds are regenerated by treatment with | | | | | | | | | | | | | | | | | | |  |  |
|  | dilute acid and alkali solutions respectively. | | | | | | | | | | | | | | | | | |  |  | (very pale blue) liquid. Its important p | | | | | | | | ysical | |  |
|  |  |  | properties are given n Table 9.4. | | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **9.7** | | | **HYDROGEN PEROXIDE (H O )** | | | | | | | | | | | | | |  |  |  |  |  | H2O2 is | | | miscib e | w th water | | | in all | |  |
|  |  |  |  |  |  |  |  |  |  |  |  | **2** | |  |  | **2** |  |  |  |  | proportions and forms a hydrate H2O2.H2O | | | | | | | | | |  |
|  | Hydrogen peroxide is an important chemical | | | | | | | | | | | | | | | | | | |  |  |
|  |  | (mp 221K). A 30% so ut on of H2O2 is marketed | | | | | | | | | |  |
|  | used in pollution control treatment of domestic | | | | | | | | | | | | | | | | | | |  |  |
|  |  | as ‘100 volume’ hydrogen peroxide. It means | | | | | | | | | |  |
|  | and industrial effluents. | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | that one millilitre of 30% H2O2 solution will give | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | **9.7.1 Preparation** | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  | 100 mL of oxygen at STP. Commercially | | | | | | | | | |  |
|  | It can be prepared by the following methods. | | | | | | | | | | | | | | | | | | |  | marketed sample is 10 V, which means that | | | | | | | | | |  |
|  |  | the sam le contains 3% H2O2. | | | | | | |  |  |  |  |
|  |  | NCERT | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  | (i) Acidifying barium peroxide and removing | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  | excess water by evaporation under reduced | | | | | | | | | | | | | | | | | | |  | **Problem 9.5** | | | | |  |  |  |  |  |  |
|  | pressure gives hydrogen peroxide. | | | | | | | | | | | | |  |  |  |  |  |  |  | Calculate the strength of 10 volume | | | | | | | | |  |  |
|  | BaO 2 .8H 2 O ( s ) + H 2 SO 4 ( aq ) → BaSO 4 ( s ) + | | | | | | | | | | | | | | | | | | |  | solution of hydrogen peroxide. | | | | | | |  |  |  |  |
|  |  | **Solution** | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | ( aq ) | | | + 8H 2 O ( l ) | | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | H2O2 | |  |  | 10 volume solution of H2O2 means that | | | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  | be | | | | | | | | | |  | 2 | |  |  |  |  | 2 2 |  |  |  |  |
|  | (ii) Peroxodisulphate, obtained by | | | | | | | | | | | |  |  | l ctrolytic | | | | |  | 1L of this H2O2 solution will give 10 L of | | | | | | | | |  |  |
|  |  |  |  | oxygen at STP | | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | high current density, on hydrolysis yi lds | | | | | | | | | | | | | | | | | | |  | 2H 2 O 2 ( l ) → O 2 ( g ) + H 2 O ( l ) | | | | | | |  |  |  |  |
|  | hydrogen peroxide. | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  | 234 g | | |  | 22.7 L at STP | | |  |  |  |  |
|  | 2HSO4 (aq) →HO3 SOOSO3H(aq) | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  |  |  |  | 68 g | | |  |  |  |  |  |  |  |  |
|  |  |  | − |  |  |  | Electrolysis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | → 2HSO4 ( aq) | | | | | | | + 2H | + | ( aq ) + H2O2 ( aq) | | | | | | | | | |  | On the basis of above equation 22.7 L of | | | | | | | | |  |  |
|  |  | O is produced from 68 g H O | | | | | | | at STP | |  |  |
|  |  | Hydrolysis | | | |  | − |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| © | |  | This method is n w used f r the laboratory | | | | | | | | | | | | | | | | |  | 10 L of O2 at STP is produced from | | | | | | | | |  |  |
|  | preparation of D2 O2. | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 68 10 |  | g = 29.9 g | | 30 g H2 O2 | | |  |  |  |
|  | K | S O | | ( | s | ) | + 2D O l → 2KDSO | | | | | aq | |  | ) | + D O | | l | ) |  | 22.7 | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | Therefore, strength of H2O2 in 10 volume | | | | | | | | |  |  |
| 2 | |  | 2 8 |  | 2 (to) | | | | 4 ( |  |  |  |  | 2 2 | ( |  |  |  |
|  | (iii) Indus rially it is prepared by the auto- | | | | | | | | | | | | | | | | | | |  | H2O2 solution = 30 g/L **=** 3% H2O2 | | | | | | | | |  |  |
|  | oxidati | | |  |  |  | f 2-alklylanthraquinols. | | | | | | | | |  |  |  |  |  | solution | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | | | | |  | | | | | | | | |  | | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  | **Table 9.4** | | | | | **Physical Properties of Hydrogen Peroxide** | | | | | | | | | | | | | | |  |  |  |  |  |
|  |  | | |  | | | |  |  |  |  |  |  |  | | | |  |  | |  |  |  | | | |  |  | |  |  |
|  | Melti | | | g poi t/K | | | |  |  |  |  |  |  | 272.4 | | | |  | Density (liquid at 298 K)/g cm–3 | | | | | | | |  | 1.44 | |  |  |
|  | Boiling point(exrapolated)/K | | | | | | | | |  |  |  | 423 | | | |  |  | Viscosity (290K)/centipoise | | | | | | |  |  | 1.25 | |  |  |
|  | not | | | | | | | | | | |  |  |  |  |  | |  |  | |  | | | | | | |  | |  |  |
|  | Vapour pressure(298K)/mmHg | | | | | | | | | | |  |  |  |  | 1.9 | |  | Dielectric constant (298K)/C2/N m2 | | | | | | | | | 70.7 | |  |  |
|  | Density (solid at 268.5K)/g cm–3 | | | | | | | | | | | |  |  |  | 1.64 | |  | Electrical conductivity (298K)/Ω–1 | | | | | | | | cm–1 | 5.1 10–8 | |  |  |

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**9.7.3 Structure**

Hydrogen peroxide has a non-planar structure. The molecular dimensions in the gas phase and solid phase are shown in Fig 9.3



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.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | **9.7.6** | | **Uses** |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Its wide scale use has led to tremen ous | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | increase in the industrial production of H2O2. | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Some of the uses are listed below: | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | (i) | In daily life it is used as a hair bl ach and | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | as a mild disinfectant. As an antis ptic it is | | |  |
| ***Fig. 9.3*** | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | sold in the market as per | | ydrol. |  |
|  | *(a) H2O2 structure in gas phase, dihedral* | | | | | | | | | | | | | | | | | | | | | |  |  |
|  | (ii) | It is used to manufacture c emicals like | | |  |
|  |  |  |  |  |  |  |  | *angle is 111.5°. (b) H2O2 structure in solid* | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  | sodium perborate and per-carbonate, | | |  |
|  |  |  |  |  |  |  |  | *phase at 110K, dihedral angle is 90.2°.* | | | | | | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | which are used in h gh qual ty detergents. | | |  |
| **9.7.4** | | | | |  | **Chemical Properties** | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  | (iii) It is used in the synthe | | | of hydroquinone, |  |
| It acts as an oxidising as well as reducing agent | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | tartaric acid and certa n food products and | | |  |
| in both acidic and alkaline media. Simple | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | pharmaceutica s (cepha osporin) etc. | | |  |
| reactions are described below. | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  | (iv) It is employed in the industries as a | | | |  |
| (i) Oxidising action in acidic medium | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  | bleaching agent for textiles, paper pulp, | | |  |
| 2Fe 2 + ( aq ) + 2H + ( aq ) + H 2 O 2 ( aq) → | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  | leather, oils, fats, etc. | |  |  |
|  |  |  | (v) Nowadays it is also used in Environmental | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2Fe 3+ ( aq ) + 2H 2 O ( l ) | | | | | | | | | | |  | (Gr | n) Chemistry. For example, in | |  |
| PbS ( s ) + 4H 2 O 2 ( aq ) → PbSO 4 ( s ) + 4H 2 O ( l ) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  | ollution control treatment of domestic and | | |  |
|  | industrial effluents, oxidation of cyanides, | | |  |
| (ii) Reducing action in acidic medium | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  | storation of aerobic conditions to sewage | | |  |
|  |  |  | wastes, etc. | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2MnO – | | | | | | | + 6H+ | | | | | | + 5H O → 2Mn 2+ + 8H O + 5O | | | | | | | | | | | | | | | | |  |  |  |  |  |
|  |  |  |  |  | 4 | |  |  |  |  |  |  |  |  |  |  | 2 | 2 |  |  |  |  |  |  |  |  | 2 |  | 2 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | republished**9.8 HEAVY WATER, D O** | | | | |  |
| HOCl + H O → H O + | | | | | | | | | | | | | | | | | | + Cl − + O | | | | |  |  |  |  |  |  |  |  |  | **2** |  |  |
|  |  |  |  |  |  |  | It is extensively used as a moderator in nuclear | | | |  |
|  |  |  |  |  |  |  |  |  | 2 2 | |  |  |  |  |  |  | 3 |  |  |  |  | 2 | |  |  |  |  |  |  |  |
| (iii) Oxidising action in basic medium | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  | reactors and in exchange reactions for the | | | |  |
|  |  | study of reaction mechanisms. It can be | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | 2Fe 2 + + H 2 O 2 → 2Fe 3 + + 2OH − | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  | prepared by exhaustive electrolysis of water or | | | |  |
|  |  |  | Mn 2 + + H | | | | | | | |  | O | |  |  | → Mn 4 + + 2OH − | | | | | | | | |  |  |  |  |  | as a by-product in some fertilizer industries. | | | |  |
|  |  |  |  | 2 | |  |  |  |  |  | Its physical properties are given in Table 9.3. | | | |  |
|  |  |  |  |  |  |  |  |  | 2 | | |  |  |  |  |  |  |  |  |  | be | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | It is used for the preparation of other deuterium | | | |  |
| (iv) Reducing ac ion in basic medium | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |
| I |  |  | + H | |  | O | |  | + 2OH− → 2I− + 2H | | | | | | | | | | | |  | O + O | | | | |  |  |  | compounds, for example: | | |  |  |
| 2 | | 2 | 2 | 2 | 2 |  |  |  |  |  |  |  |
|  |  |  | NCERT | | | | | | | | | | | | | | | | | | | | | | | | |  |  | CaC 2 + 2D 2 O → C 2 D 2 + Ca ( OD)2 | | | |  |
| 2MnO | | | | | | – | + 3H | | | |  |  | O | | → 2MnO + 3O | | | | | | | | | |  | + |  |  |  |  |
| 4 | 2 | | 2 |  |  |  |  |
| © | | |  |  |  |  |  |  |  |  |  | 2 |  | to2 | | | | |  |  |  |  |  |  |  | SO3 + D2O → D2SO4 | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2H2O + 2OH | | | | | | | – |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Al 4 C 3 + 12D 2 O → 3CD 4 + 4Al ( OD)3 | | | |  |
|  |  |  | **St rage** | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **9.7.5** | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| H2O2 decomposes slowly on exposure to light. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | **9.9 DIHYDROGEN AS A FUEL** | | | |  |
| 2H 2 O 2 (l ) → 2H 2 O (l ) + O 2 (g) | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  | Dihydrogen releases large quantities of heat on | | | |  |
|  |  |  | not | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  | combustion. The data on energy released by | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | combustion of fuels like dihydrogen, methane, | | | |  |
| In the presence of metal surfaces or traces of | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| alkali (present in glass containers), the above | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | LPG etc. are compared in terms of the same | | | |  |



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|  |  |  |
| --- | --- | --- |
| HYDROGEN | 287 |  |
| amounts in mole, mass and volume, are shown | limitations have prompted researchers to |  |
| in Table 9.5. | search for alternative techniques to use |  |
| From this table it is clear that on a mass | dihydrogen in an efficient way. |  |
| for mass basis dihydrogen can release more | In this view **Hydrogen Economy** is an |  |
| energy than petrol (about three times). | alternative. The basic principle of hydrogen |  |
| Moreover, pollutants in combustion of | economy is the transportation and storage of |  |
| dihydrogen will be less than petrol. The only | energy in the form of liquid or gaseous |  |
| pollutants will be the oxides of dinitrogen (due | republished |  |
| dihydrogen. Advantage of hydrogen economy |  |
| to the presence of dinitrogen as impurity with | is that energy is transmitted in the form of |  |
| dihydrogen). This, of course, can be minimised | dihydrogen and not as electric pow r. It is for |  |
| by injecting a small amount of water into the | the first time in the history of India that a pilot |  |
| cylinder to lower the temperature so that the |  |
| project using dihydrogen as fuel was launc d |  |
| reaction between dinitrogen and dioxygen may |  |
| in October 2005 for running automobiles. |  |
| not take place. However, the mass of the |  |
| Initially 5% dihydrogen has been mixed in |  |
| containers in which dihydrogen will be kept |  |
| CNG for use in four-whee er ve icles. The |  |
| must be taken into consideration. A cylinder |  |
| percentage of dihydrogen would be gradually |  |
| of compressed dihydrogen weighs about 30 |  |
| increased to reach the opt mum level. |  |
| times as much as a tank of petrol containing |  |
| Nowadays, it is a so used in fuel cells for |  |
| the same amount of energy. Also, dihydrogen |  |
| generation of electric power. It is expected that |  |
| gas is converted into liquid state by cooling to |  |
| economically via le and safe sources of |  |
| 20K. This would require expensive insulated |  |
| dihydrogen will be identified in the years to |  |
| tanks. Tanks of metal alloy like NaNi5, Ti–TiH2, |  |
| NCERT | come, for its sage as a common source of |  |
| Mg–MgH2 etc. are in use for storage of |  |
| dihydrogen in small quantities. hese | energy. |  |

**Table 9.5 The Energy Released by Combustion of Various Fuels in Moles, Mass and Volume**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Energy released on** | |  | **Dihydrogen** | |  |  | **Dihyd og n** | **LPG** | **CH4 gas** | **Octane** |  |
|  |  | **combustion in kJ** | |  | **(in gaseous** | |  |  | **(in liquid)** |  |  | **(in liquid** |  |
|  |  | **state)** |  |  | **state)** | |  |  |  |  |  | **state)** |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | per mole |  |  |  | 286 |  |  | 285 | 2220 | 880 | 5511 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | per gram |  |  |  | 143 |  |  | 142 | 50 | 53 | 47 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | per litre |  |  |  | 12 |  |  | 9968 | 25590 | 35 | 34005 |  |
|  |  |  |  |  |  | be |  | **SUMMARY** | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Hydrogen is | he lightest atom with only one electron. Loss of this electron results in an | | | | | | | | | |  |
|  |  | elemen ary par icle, the proton. Thus, it is unique in character. It has three isotopes, | | | | | | | | | | |  |
| © | |  | to | | |  |  |  | 21H) and **tritium** (T or31H). Amongst these three, | | | |  |
| namely : **pr** | **ium** | (11H), **deuterium** (D or | | | | |  |
| ly tritium is radioactive. Inspite of its resemblance both with alkali metals and halogens, | | | | | | | | | | |  |
| it ccupies a separate position in the periodic table because of its unique properties. | | | | | | | | | | |  |
|  |  |  |
|  |  | Hydrogen is the most abundant element in the universe. In the free state it is almost | | | | | | | | | | |  |
|  |  | ot fou d in the earth’s atmosphere. However, in the combined state, it is the third most | | | | | | | | | | |  |
|  |  | abundant element on the earth’s surface. | | | | | | | |  |  |  |  |
|  | not | | |  |  |  |  |  |  |  |  |  |  |
|  |  | Dihydrogen on the industrial scale is prepared by the **water-gas shift** reaction from | | | | | | | | | | |  |



petrochemicals. It is obtained as a byproduct by the electrolysis of brine.

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The H–H **bond dissociation enthalpy** of dihydrogen (435.88 kJ mol–1) is the highest for a single bond between two atoms of any elements. This property is made use of in the atomic hydrogen torch which generates a temperature of ~4000K and is ideal for welding of high melting metals.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Though dihydrogen is rather inactive at room temperature because of very high | | | | | | | | | | |  |
|  | negative dissociation enthalpy, it combines with almost all the elements under appropriate | | | | | | | | | | | |  |
|  | conditions to form **hydrides.** All the type of hydrides can be classified into three categories: | | | | | | | | | | | |  |
|  | industrial and domestic efflu nts. | | | | | | |  | epublishedr | | | |  |
|  | ionic or saline hydrides, covalent or molecular hydrides and metallic or non-stoichiometric | | | | | | | | | | | |  |
|  | hydrides. Alkali metal hydrides are good reagents for preparing other hydride compounds. | | | | | | | | | | | |  |
|  | Molecular hydrides (e.g., B2H6, CH4, NH3, H2O) are of great importance in day-to-day life. | | | | | | | | | | | |  |
|  | Metallic hydrides are useful for ultrapurification of dihydrogen and as dihydrogen storage | | | | | | | | | | | |  |
|  | media. | |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Among the other chemical reactions of dihydrogen, **reducing reactions** leading to | | | | | | | | | | |  |
|  | the formation hydrogen halides, water, ammonia, methanol, vanaspati ghee, etc. are of | | | | | | | | | | | |  |
|  | great importance. In metallurgical process, it is used to reduce metal oxides. In pace | | | | | | | | | | | |  |
|  | programmes, it is used as a rocket fuel. In fact, it has promising potent al for u e as a | | | | | | | | | | | |  |
|  | non-polluting fuel of the near future **(Hydrogen Economy)**. | | | | | | | | | |  |  |  |
|  |  | Water is the most common and abundantly available substance. It | | | | | | | | | | of a great |  |
|  | chemical and biological significance. The ease with which water s transformed from | | | | | | | | | | | |  |
|  | liquid to solid and to gaseous state allows it to play a vital role in the **iosphere.** The | | | | | | | | | | | |  |
|  | water molecule is highly polar in nature due to its bent str ct | | | | | | | | | | re. This property leads to | |  |
|  | hydrogen bonding which is the maximum in ice and least in water vapour. The polar | | | | | | | | | | | |  |
|  | nature of water makes it: (a) a very good solvent for ionic and partially ionic compounds; | | | | | | | | | | | |  |
|  | NCERT | | | | | | |  |  |  |  |  |  |
|  | (b) to act as an amphoteric (acid as well as base) substance; and (c) to form hydrates of | | | | | | | | | | | |  |
|  | different types. Its property to dissolve many salts, | | | | | | | | | artic larly in large quantity, makes | | |  |
|  | it hard and hazardous for industrial use. Both t m | | | | | | | | | orary and | ermanent **hardness** can | |  |
|  | be removed by the use of zeolites, and synth tic ion- xchangers. | | | | | | | | | | |  |  |
|  |  | **Heavy water,** D2O is another impo tant compound which is manufactured by the | | | | | | | | | | |  |
|  | electrolytic enrichment of normal water. It is ss ntially used as a moderator in nuclear | | | | | | | | | | | |  |
|  | reactors. | |  |  |  |  |  |  |  |  |  |  |  |
|  |  | **Hydrogen peroxide,** H2O2has an int | | | | | | | sting non-polar structure and is widely used | | | |  |
|  | as an industrial bleach and in pharmac utical and pollution control treatment of | | | | | | | | | | | |  |
|  |  |  | to | |  |  |  | **EXERCISES** | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  | 9. 1 | Jus ify he p si i | | nbef hydrogen in the periodic table on the basis of its electronic | | | | | | | | |  |
|  |  | configura i n. | |  |  |  |  |  |  |  |  |  |  |
| not | | | | f is topes of hydrogen. What is the mass ratio of these isotopes? | | | | | | | | |  |
| © | 9.2 | Wri e | he names |  |
| 9. 3 | Why does hydrogen occur in a diatomic form rather than in a monoatomic form | | | | | | | | | | |  |
|  | under normal conditions? | | | | | |  |  |  |  |  |  |
| 9.4 | H w can he production of dihydrogen, obtained from ‘coal gasification’, be | | | | | | | | | | |  |
|  | increased? | |  |  |  |  |  |  |  |  |  |  |
| 9.5 | Describe the bulk preparation of dihydrogen by electrolytic method. What is the | | | | | | | | | | |  |
|  |  | role of an electrolyte in this process ? | | | | | | | |  |  |  |  |
|  | 9.6 | Complete the following reactions: | | | | | | | |  |  |  |  |
|  |  | (i) | H 2 ( g ) + M m O o ( s ) → | | | | | |  |  |  |  |  |
|  |  | (ii) | CO ( g ) + H | | 2 | ( g ) | → | | |  |  |  |  |
|  |  |  |  |  |  | catalyst | |  |  |  |  |  |



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|  |  |
| --- | --- |
| HYDROGEN | 289 |

(iii) C 3 H 8 ( g ) + 3H 2 O ( g) →



catalyst

1. Zn ( s ) + NaOH ( aq) heat →

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

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 9.8 | What do you understand by (i) electron-deficient, (ii) electron-precise, and (iii) | | | | | | |  |
|  | 9.19 | electron-rich compounds of hydrogen? Provide justification with suitable examples. | | | | | | |  |
|  | onsider the reaction of wat r withrepublishedF and suggest, in terms of oxidation and | | | | | | |  |
|  | 9.9 | What characteristics do you expect from an electron-deficient hydride with respect | | | | | | |  |
|  |  | to its structure and chemical reactions? | | | | | | |  |
|  | 9.10 | Do you expect the carbon hydrides of the type (CnH2n + 2) to act as ‘Lewis’ acid or | | | | | | |  |
|  |  | base? Justify your answer. | | | | |  |  |  |
|  | 9.11 | 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 answ r. | | | | | | |  |
|  | 9.12 | How do you expect the metallic hydrides to be useful for hydrogen torage? | | | | | | |  |
|  |  | Explain. | | |  |  |  |  |  |
|  | 9.13 | How does the atomic hydrogen or oxy-hydrogen torch funct on for cutt ng and | | | | | | |  |
|  |  | welding purposes ? Explain. | | | | |  |  |  |
|  | 9.14 | Among NH3, H2O and HF, which would you expect to have highest magnitude of | | | | | | |  |
|  |  | hydrogen bonding and why? | | | | |  |  |  |
|  | 9.15 | Saline hydrides are known to react with water violently prod cing fire. Can CO2, | | | | | | |  |
|  |  | a well known fire extinguisher, be used in this case? Explain. | | | | | | |  |
| NCERT3( )2 ( ) | | | | | | |  |  |  |
|  | 9.16 | Arrange the following | | | | |  |  |  |
|  |  | (i) CaH2, BeH2 | | | and | iH2 in order of increasing electrical conductance. | | |  |
|  |  | (ii) LiH, NaH and CsH in order of incr asing ionic character. | | | | | | |  |
|  |  | (iii) H–H, D–D and F–F in order of inc | | | | |  | asing bond dissociation enthalpy. |  |
|  |  | (iv) NaH, MgH2 | | | and H2O in order of inc | | | asing r ducing property. |  |
|  |  | (ii) |  | – | be | |  |  |  |
|  | 9.17 | Compare the structures of H 2O and H2O2. | | | | | | |  |
|  | 9.18 | What do you understand by the t m ’auto-protolysis’ of water? What is its | | | | | | |  |
|  |  | significance? | | |  |  |  |  |  |
|  |  |  |  |  |  |  | 2 |  |  |
|  |  | reduction, which speci s are oxidis d/reduced. | | | | | | |  |
|  | 9.20 | omplete the following chemical reactions. | | | | | | |  |
|  |  |  |  | 3to22 | |  |  |  |  |
|  |  | (i) Pb S ( s ) + H 2 O 2 ( aq ) → | | | | |  |  |  |
| © |  |  | MnO 4 ( aq ) + H 2O 2 ( aq ) → | | | |  |  |  |
|  | (iii) | CaO ( s ) + H 2 O ( g) → | | | |  |  |  |
|  |  |  |  |  |
|  | not | | |  |  |  |  |  |  |
|  |  | (v) | AlCl g + H O l | | | → |  |  |  |
|  |  | (vi) | Ca N ( s ) + H O ( l ) → | | | |  |  |  |
|  |  | Classify the above into (a) hydrolysis, (b) redox and (c) hydration reactions. | | | | | | |  |
|  | 9.21 | Describe the structure of the common form of ice. | | | | | | |  |
|  | 9.22 | What causes the temporary and permanent hardness of water ? | | | | | | |  |
|  | 9.23 | Discuss the principle and method of softening of hard water by synthetic ion- | | | | | | |  |
|  |  | exchange resins. | | | |  |  |  |  |
|  | 9.24 | Write chemical reactions to show the amphoteric nature of water. | | | | | | |  |
|  | 9.25 | Write chemical reactions to justify that hydrogen peroxide can function as an | | | | | | |  |
|  |  | oxidising as well as reducing agent. | | | | |  |  |  |

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9.26 What is meant by ‘demineralised’ water and how can it be obtained ?

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

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

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  | republished |  |
| 9.30 | Knowing the properties of H2O and D2O, do you think that D2O can be used for | | | |  |
|  | drinking purposes? | |  |  |  |
| 9.31 | What is the difference between the terms ‘hydrolysis’ and ‘hydration’ ? | | | |  |
| 9.32 | How can saline hydrides remove traces of water from organic compounds? | | | |  |
| 9.33 | 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 behaviour towards | | | |  |
|  | water. |  |  |  |  |
| 9.34 | Do you expect different products in solution when alumin um(III) c loride and | | | |  |
|  | potassium chloride treated separately with (i) normal water ( ) ac d f ed water, | | | |  |
|  | and (iii) alkaline water? Write equations wherever necessary. | | | |  |
| 9.35 | How does H2O2 behave as a bleaching agent? | | | |  |
| 9.36 | What do you understand by the terms: | | | |  |
|  | (i) hydrogen economy (ii) hydrogenation (iii) ‘syngas’ (iv) water-gas shift reaction | | | |  |
|  | (v) fuel-cell ? | |  |  |  |
| NCERT | | | |  |  |
|  |  | to | be |  |  |
| not | |  |  |  |
|  |  |  |  |

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