9 Hydrogen

LESSON AT A GLANCE

- **Position of hydrogen in the periodic table:** Position of hydrogen in periodic table is not justified because it resembles both alkali metals as well as halogens.
- **Occurrence of Hydrogen:** Hydrogen is the most abundant element in the universe. It is present in combined state as water, coal, animal and vegetable matter. All organic compounds also contain hydrogen as essential constituent.
- **Isotopes of Hydrogen:** Hydrogen has three isotopes.

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

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

  Tritium, $^{3}_{1}H$
- **Water:** Human body has about 65% and some plants have nearly 95% water.

  Physical properties of water:

  (*i*) Freezing point of water is 373.15 K and boiling point 373.15 K.

  (*ii*) Maximum density of water at 4°C is gm cm^{-3}.

  (*iii*) It is a colourless and tasteless liquid.

  (*iv*) Due to hydrogen bonding with polar molecules, even covalent compounds like alcohol and carbohydrates dissolve in water.
- **Hard and Soft Water**

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

Types of Hardness of Water:

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

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

- **Soft water:** Water which readily forms lather with soap is called soft water.

  For example: rain water, distilled water.
- **Storage:** Hydrogen peroxide is stored in wax lined flow or plastic vessels in dark. Because it decomposes slowly on exposure to light.
- **Hydrogen Economy:** The basic principle of hydrogen economy is the transportation and storage of energy in the form of liquid or gaseous dihydrogen. Advantage is that energy is transmitted in the form of dihydrogen and not as electric power.

TEXTBOOK QUESTIONS SOLVED

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

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

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

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

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

Ans. protium – ^1_1H

Deuterium – ^2_1H or D

Tritium – ^3_1H or T

ratio of mass of protium : Deutrium : Tritium

$$= 1 : 2 : 3$$

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

Ans. Draw the MO energy level diagram for H_2 molecule and find the bond order. Bond order one indicates that hydrogen occurs as H_2 rather than H form.

Alternatively, from the electronic configuration, $1s^1$ of H atom, one can infer that it is short of only one electron to give a stable inert gas configuration of He, $1s^2$. Therefore, it shares its single electron with other hydrogen atom to form a covalent bond forming H_2 molecule.

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

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

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

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

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

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

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

Electrolyte is added to increase the dissociation of water.

Q6. *Complete the following reactions:*

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

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

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

(*iv*) $Zn\,(s) + NaOH\,(aq) \xrightarrow[catalyst]{heat}$

Ans. (*i*) $oH_2 (g) + M_mO_o (s) \xrightarrow{\Delta} mM (s) + oH_2O (g)$

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

(*iii*) $C_3H_8 (g) + 3H_2O (g) \xrightarrow[catalyst]{\Delta} 3CO (g) + 7H_2 (g)$

(*iv*) $Zn (s) + 2NaOH (aq) \xrightarrow{heat} Na_2ZnO_2 (aq) + H_2 (g)$
Sod. zincate

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

Ans. High enthalpy of H–H bond makes H_2 gas inert or unreactive at room temperature.

However, at higher temperatures it reacts with many metals and non-metals alike.

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

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

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

(*iii*) **Electron rich hydrides:** Those compounds in which central atom has one or more lone pair of excess electrons are called electron rich hydrides. *e.g.*, NH_3H_2O etc.

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

Ans. Electron-deficient hydrides especially of boron and aluminium (*e.g.*, BH_3, AlH_3) cannot exist as such because they do not have sufficient electrons to form required number of covalent bonds in order to satisfy octet rule. Therefore, such hydrides exist in polymeric forms such as B_2H_6, B_4H_{10}, $(AlH_3)_n$ etc.

These structural features are quite unique, *e.g.*, for B_2H_6 two B atoms are linked by two hydrogen atoms acting as bridge atoms. These hydrides are very reactive towards metals, non-metals and their compounds. Examples are:

$$B_2H_6\,(g) + 3O_2\,(g) \longrightarrow B_2O_3\,(s) + 3H_2O\,(g)$$

$$B_2H_6\,(g) + 2NaH\,(s) \longrightarrow 2Na^+[BH_4]^-\,(s)$$

$$B_2H_6\,(g) + \underset{\text{Trimethylamine}}{2N(Me)_3} \longrightarrow 2[H_3B \leftarrow N(Me)_3]$$

Q10. *Do you expect the carbon hydrides of the type (C_nH_{2n+2}) to act as 'Lewis' acid or base? Justify your answer.*

Ans. For any compound to act as Lewis acid, its central atom must have vacant orbital in the valence shell. For Lewis base, the central atom should be able to donate a pair of electrons.

For carbon hydrides of the type C_4H_{2n+2}, *e.g.*, CH_4, C_2H_6, the octet of carbon atom is complete and their structures reveal that carbon atom has neither vacant orbital nor unpaired electrons. In other words, these are electron precise hydrides. Hence these hydrides do not act as Lewis acids or bases.

Q11. *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.*

Ans. Non-stoichiometric hydrides are formed by *d* or *f*-block elements when hydrogen atoms are trapped in the lattice holes of the element. When some lattice holes remain unoccupied, the hydrides are termed as non-stoichiometric, *i.e.*, the metal to hydrogen ratio is *not* stoichiometric, *e.g.*, $LaH_{2.76}$. Unlike NaH, where it is 1:1. Alkali metals are highly electropositive and with hydrogen they form ionic hydrides of the type M^+H^- by transferring their valence electrons to hydrogen. Their combining ratio is always 1:1 and thus they do not form non-stoichiometric hydrides.

(Also see that alkaline earth metals of Group 2 behave like alkali metals).

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

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

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

Ans. Molecular hydrogen gas, H_2, dissociate into atomic hydrogen, H, when it is passed through an electric arc produced by passing high current between tungsten electrodes:

$$H_2\,(g) \xrightarrow[3773-4273\text{ K}]{\text{electric arc}} 2H\,(g)$$

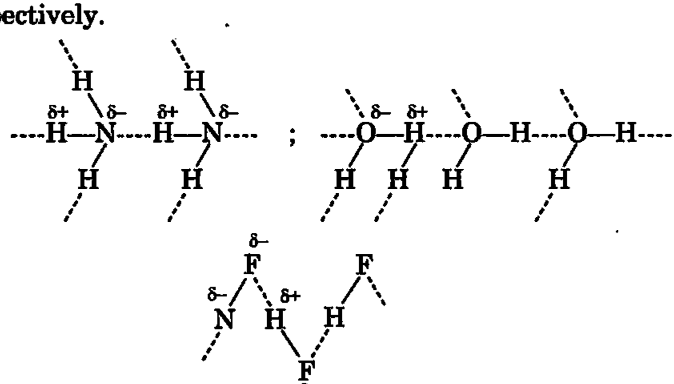
The lifetime of atomic hydrogen is about 0.3 sec. When it reconverts into molecular hydrogen, huge amount of heat energy is liberated which is used for cutting and welding purposes.

In the oxy-hydrogen torch, oxygen and hydrogen gases are ignited as done in gas welding torches producing a flame of very high temperature:

$$2H_2\,(g) + O_2\,(g) \longrightarrow 2H_2O\,(g) + \text{Heat}$$

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

Ans. All the three molecules have intermolecular hydrogen bonding due to the formation of dipoles between hydrogen atoms and N, O and F atoms. N, O and F are more electronegative than hydrogen and among themselves the order of electronegativity is F > O > N. Fluorine will thus form stronger hydrogen bonds because the dipole, $\overset{\delta+}{H}—\overset{\delta-}{F}$, will be the strongest in comparison to $\overset{\delta-}{O}—\overset{\delta+}{H}$ and $\overset{\delta-}{N}—\overset{\delta+}{H}$, respectively.



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

Ans. Saline hydrides react with water exhothermally. The high heat so produced is enough to ignite H_2 gas:

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

The fire so produced cannot be extinguished by CO_2 gas since any unreacted saline hydride will combine with CO_2 gas:

$$NaH\ (s) + CO_2\ (g) \longrightarrow \underset{\text{Sod. formate}}{HCOONa\ (s)}$$

In this case, sand may be used in place of CO_2 gas.

Q16. *Arrange the following:*

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

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

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

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

Ans. (*i*) The order of increasing electric conductance is:

$$BeH_2 < CaH_2 < TiH_2.$$

BeH_2 is a covalent hydride, CaH_2 is saline hydride but conducts electricity in fused or molten state while TiH_2 conducts electricity even at room temperature.

(*ii*) The increasing order of ionic character is:

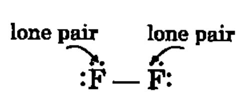
$$LiH < NaH < CsH.$$

It is due to the decrease in electronegativity within Group I from Li to Cs.

(*iii*) The increasing order of bond dissociation enthalpy is:

$$F—F < H—H < D—D.$$

The bond dissociation enthalpy of D_2 molecule is more than that of H_2 molecule because of the smaller size of D than H. For F_2 molecule, lone pair-lone pair repulsions make the dissociation enthalpy less:



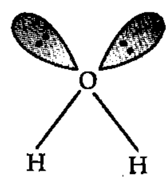
(*iv*) The reducing power of the hydrides is in the order:

$$NaH > MgH_2 > H_2O.$$

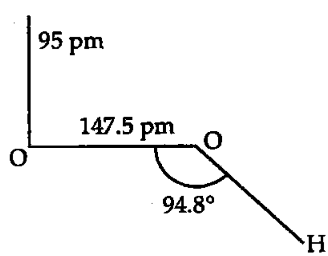
NaH is an ionic or saline hydride and so is a stronger reducing agent while MgH_2 and H_2O are both covalent hydrides. Among MgH_2 and H_2O, H_2O is more covalent and also possess higher dissociation enthalpy.

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

Ans. In water, O is SP^3 hybridized. Due to stronger lone pair-lone pair repulsions than bond pair-bond-pair repulsions the HOH bond angle decreases from 105.5 to 104.5°. Thus water molecule has a bent structure.



H_2O_2 has a non planner structure. The O—H bonds are different planes. Thus the structure of H_2O_2 is like open book.



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

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

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

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

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

Ans. Following two reactions of water with fluorine will occur:

(*i*) $2F_2\,(g) + 2H_2O\,(l) \longrightarrow O_2\,(g) + 4HF\,(aq)$

(*ii*) $3F_2\,(g) + 3H_2O\,(l) \longrightarrow O_3\,(g) + 6HF\,(aq)$

Using the oxidation number concept, it can be seen that in both the reactions, F_2 is acting as an oxidising agent while water as a reducing agent. Water is being oxidised while fluorine is reduced.

Q20. *Complete the following chemical reactions:*

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

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

(*iii*) $CaO\,(s) + H_2O\,(g) \longrightarrow$

(*iv*) $Ca_3N_2\,(s) + H_2O\,(l) \longrightarrow$

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

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

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

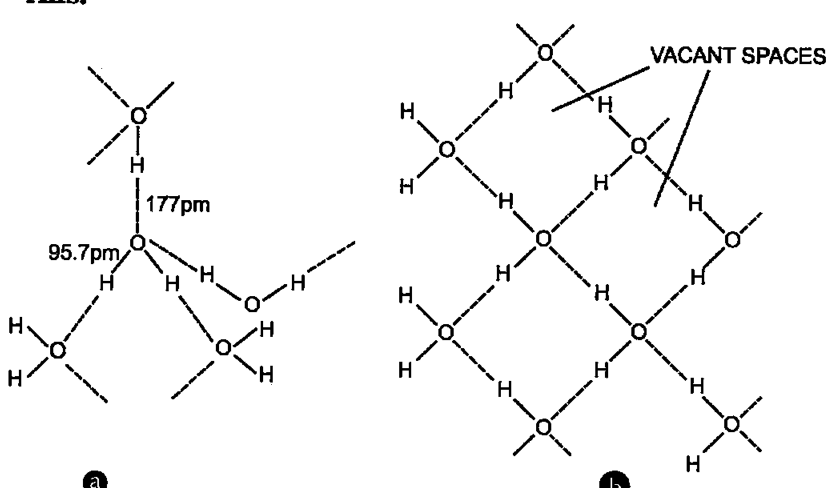
(*iii*) $CaO\,(s) + H_2O\,(g) \longrightarrow Ca(OH)_2\,(aq)$

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

(*v*) $Ca_3N_2\,(s) + 6H_2O\,(l) \longrightarrow 3Ca(OH)_2\,(aq) + 2NH_3\,(g)$

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

Ans.



(a) Structure of water in the liquid state

(b) Tetrahedral arrangement of oxygen atoms in ice.

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

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

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

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

Ans. Cation exchange resins having large organic molecule—SO_3H group which are insoluble in water. Ion exchange resin RSO_3H connected into RNa on treatment with NaCl. The resin exchange Na^+ and Hg^2 ions with Ca^{2+} ions present in hard water and make it soft.

$$2RNa(s) + M^{1+}(aq) \longrightarrow R_2M(s) + 2Na^+(aq)$$

where, M = Mg, Ca.

The resins can be regenerated by adding aqueous NaCl solution.

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

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

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

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

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

Ans. **As an oxidising agent**

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

As a reducing agent

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

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

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

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

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

$$RNH_2(s) + H_2O \rightleftharpoons RN^+ H_3OH^-$$

$$RN^+ H_3OH^-(s) + X^- \rightleftharpoons RNH^+_3 X^- + OH^-(aq)$$

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

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

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

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

Ans. Demineralised or distilled water does not contain any minerals and so it is not useful for drinking purposes. To make it drinkable or potable, proper minerals in required amounts should be added.

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

Ans. Water is essential for all forms of life. When compared to other liquids, it has relatively high boiling point, high heat capacity, high thermal conductivity, high surface tension, high dielectric constant and high dipole moment, etc. High dielectric constant of water makes it excellent solvent for ionic compounds.

Due to high dipole moment, it involves in extensive intermolecular hydrogen bonding making it high boiling. On cooling, it freezes and occupies more volume while reducing its density. Thus, solid water (ice) floats on water protecting aquatic life from extreme cold. Oxygen is set free from water in the process of photosynthesis.

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

Ans. Water is highly polar in nature that is why it has high dielectric constant and high dipole moment. Because of these properties water is a universal solvent.

It can hydrolyse many oxides metallic or non-metallic, hydrides, carbides, nitrides etc.

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

Ans. The chemical reactions shown by water and heavy water are nearly identical. However, due to differences in masses of hydrogen and deuterium, such reactions occur at different rates. Their equilibrium constants also vary. The rates of reactions involving heavy water are slower than those involving ordinary water. If heavy water is consumed, the enzyme catalysed biochemical reactions will occur slower than their optimum rate. Moreover, heavy water will tend to replace hydrogen attached to electronegative atoms in enzymes with deuterium. The enzyme may then lose its ability to catalyse a biochemical reaction. Thus, heavy water will interfere with regulatory mechanisms that control the biological processes and hence prove to be toxic.

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

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

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

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

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

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

Ans. Hydride ion is a strong Brönsted base and, therefore, can extract a proton easily from an acid. In presence of hydride ions, the water molecules, present as trace impurities in organic compounds, act as Brönsted acid. As the acid donates its proton (H^+) to the base (H^-), dihydrogen is formed.

$$H^- + H_2O \longrightarrow H_2 + OH^-$$

Thus, when an ionic hydride, for example sodium hydride, is added to an organic compound, it reacts with the trace water content as follows:

$$NaH\,(s) + H_2O\,(l) \longrightarrow NaOH\,(aq) + H_2\,(g)$$

As a result, the organic compound gets rid of water.

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

Ans. (*i*) Element with $Z = 15$ is P, a non-metal. It will form covalent hydride, PH_3. It is slightly soluble in water.

(*ii*) Element with $Z = 19$ is K, an alkali metal. It will form saline hydride K^+H^-. With water it releases H_2 gas.

(*iii*) Element with $Z = 23$ is V, a transition metal, and will form metallic hydride.

(*iv*) Element with $Z = 44$ is again a transition element, Ru, and can form metallic or interstitial hydride.

Q34. *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.*

Ans. KCl is an ionic salt of a strong acid and strong base and ionises in water as:

$$KCl\,(s) \longrightarrow K^+\,(aq) + Cl^-\,(aq)$$

Its aqueous solution is neutral, it is not affected by an acid or a base, the ions remain as such.

$AlCl_3$ is a salt of weak base, $Al(OH)_3$, and a strong acid, HCl. So, it undergoes hydrolysis as:

$$AlCl_3\,(s) + 3H_2O\,(l) \longrightarrow Al(OH)_3\,(s) + H^+\,(aq) + Cl^-\,(aq)$$

(*i*) When the solution is made acidic, $Al(OH)_3$ reacts with H^+ (aq) to give Al^{3+} (aq) ions and H_2O molecules:

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

or $$Al(OH)_3\,(s) \xrightarrow[H^+(aq)]{\text{acidic water}} Al^{3+}\,(aq) + H_2O\,(l)$$

(*ii*) When the solution is made alkaline, $Al(OH)_3$ reacts with OH^- ions as:

$$Al(OH)_3\,(s) + OH^-\,(aq) \longrightarrow \underset{\text{Tetrahydroxoaluminate (III) ion}}{[Al(OH)_4]^-\,(aq)}$$

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

Ans. The bleaching action of H_2O_2 is due to the production of nascent oxygen when it decomposes:

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

The oxygen so produced acts as a bleaching agent. It can bleach articles like hair, wool, silk, etc.

Q36. *What do you understand by the terms:*

(*i*) *hydrogen economy* (*ii*) *hydrogenation*
(*iii*) *'syngas'* (*iv*) *water-gas shift reaction*
(*v*) *fuel-cell?*

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

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

$$\text{Vegetable oil} + H_2 \xrightarrow{\text{Ni, 473K}} \text{Vegetable Ghee}$$

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

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

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

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

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

$$C(g) + H_2O(g) \xrightarrow[\text{FeCrO}_4]{673\text{ K}} CO(g) + H_2(g)$$

This is called water-gas shift reaction.

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

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