Date: 16/10/2021

Q1. What causes the temporary and permanent hardness of water?

Q2. Discuss the consequences of high enthalpy of H — H bond in terms of chemical reactivity of dihydrogen.

Q3. Why is ice less dense than water and what kind of attractive forces must be overcome to melt ice?

Q4. Why do lakes freeze from top towards bottom?

Q5. Although D_2O resembles H_2O chemically, yet it is a toxic substance. Example.

Q6. Give an example of each of an ionic hydride and a covalent hydride.

Q7. Elements with atomic number 17 and 20 form compounds with hydrogen. Write the formulae of these two compounds and compare their chemical behaviour in water.

Q8. How many allotropes of dihydrogen is known? What is their important?

Q9. Is it correct to say that hydrogen can behave as a metal? State the conditions under which such behabiour can be possible.

Q10. What is understood by hydrogen economy?

Q11. Discus the importance of heavy water in nuclear reactor.

Q12. Explain, why is hydrogen peroxide stored in coloured/plastic bottels?

Q13. What are metallic/interstitial hydrides? How do they differ from molecular hydrides?

Q14. Name the classes of hydrides to which H_2O, B_2H_6 and NaH belong.

Q15. How do you expect the metallic hydrides to be useful for hydrogen storage? Explain.

Q16. Knowing the properties of H_2O and D_2O, do you think that D_2O can be used for drinking purposes?

Q17. How does H_2O_2 behave as a bleaching agent?

Q18. Write one chemical reaction for the preparation of D_2O_2.

Q19. Is demineralised or distilled water useful for drinking purposes? If not, how can it be made useful?

Q20. Write the names of isotopes of hydrogen. What is the mass ratio of these isotopes?

Q21. How can the production of dihydrogen, obtained from coal gasification, be increased?

Q22. Discuss the consequences of high enthalpy of H — H bond in terms of chemical reactivity.

Q23. Why does hydrogen occur in a diatomic form rather than in a monoatomic form under normal conditions?

Q24. Complete the following reactions:

(a) $CaO(s) + H_2O(l) \longrightarrow$ (b) $Na_2O(s) + H_2O(l) \longrightarrow$

Q25. Hydrogen forms compounds with elements having atomic number 9, 11, 12 and 17. What are their chemical formulae? Compare their behavior.

Q26. How is heavy water prepared from normal water?

Q27. Explain why water has high boiling and melting points as compared to H_2S?

Q28. Compare the structure of H_2O and H_2O_2.

Q29. Explain the amphoteric nature of water.

Q30. Discuss the principle and method of softening of hard water by organic exchange resins.

Q31. Describe the structure of the common form of ice.

Q32. Explain the correct context in which the following terms are used:

(a) diprotium (b) dihydrogen (c) proton (d) hydron.

Q33. Name the isotopes of hydrogen. What is the importance of heavier isotopes of hydrogen?

Q34. Ionic hydrides are frequency used to remove traces of water form organic compounds. What is the underlying basis of this process?

Q35. Complete the following reaction:

(a) $CuO(s) + H_2(g) \longrightarrow$ (b) $Na_2O(s) + H_2(g) \longrightarrow$

Q36. Hydrogen forms three types of bonds in its compounds. Describe each type of bonding using suitable examples.

Q37. Name the class of hydrides to which, H_2O, B_2H_6, NaH and LaH_3 belong. What is understood *by* 'Hydride Gap'?

Q38. Complete the following reactions:

(a) $H_2(g) + M_mO_o(s) \xrightarrow{\Delta}$ (b) $CO(g) + H_2(g) \xrightarrow[\text{Catalyst}]{\Delta}$

(c) $C_3H_8(g) + 3H_2O(g) \xrightarrow[\text{Catalyst}]{\Delta}$ (d) $Zn(s) + NaOH(aq) \xrightarrow{\text{Heat}}$

Q39. What is the difference between the terms 'hydrolysis' and 'hydration'?

Q40. Consider the reaction of water with F_2 and suggest, in terms of oxidation and reduction, which species are oxidised/reduced.

Q41. What do you understand by the term 'auto-protolysis' of water? What is its significance?

Q42. Saline hydrides are known to react with water violently producing fire. Can CO_2 a wellknown fire extinguisher, be used in this case? Explain.

Q43. Among NH_3, H_2O and HF, which would you expect to have highest magnitude of hydrogen bonding and why?

Q44. 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.

Q45. Write chemical reactions to justify that hydrogen peroxide can function as an oxidising as well as a reducing agent.

Q46. 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.

Q47. What do you understand by the term "non-stoichiometric hydrides"? Do you expect this type of hydrides to be formed by alkali metals.? Justify your answer.

Q48. What do you understand by (a) electron-deficient, (b) electron-precise, and (c) electron rich compounds of hydrogen? Provide justification with suitable examples.

Q49. How does the atomic hydrogen or oxy-hydrogen used in torch function for cutting and welding purposes?

Q50. What properties of water make it useful as a solvent? What type of compounds can it (a) dissolve (b) hydrolyse?

Q51. How can saline hydrides remove traces of water from organic compounds?

Q52. What are the advantages in using hydrogen as a fuel?

Q53. Describe some unusual properties of water.

Q54. What is understood by "water gas shift reaction"? Discuss its use for the preparation of hydrogen.

Q55. Why is hydrogen best placed separately in the periodic table of elements?

Q56. Do you know expect different products in solution when aluminium (III) chloride and potassium chloride are treated separately with (a) normal water (b) acidified water, and (c) alkaline water?

Q57. Describe the industrial applications of hydrogen dependent of:

(a) The heat liberated when its atoms are made to combine on the surface of a metal.
(b) Its effect on unsaturated organic system in presence of a catalyst.
(c) Its ability of combine with nitrogen under specific conditions.

Q58. How is dihydrogen prepared:

(a) From water by using a reducting agent? (b) In the laboratory in pure form?
(c) From hydrocarbons?

Q59. Show by proper chemical reactions how hydrogen peroxide can function both as an oxidising and a reducing agent?

Q60. Complete the following chemical reactions.

(a) $PbS(s) + H_2O_2(aq) \longrightarrow$ (b) $MnO_4^-(aq) + H_2O_2(aq) \longrightarrow$
(c) $CaO(s) + H_2O(g) \longrightarrow$ (d) $AlCl_3(g) + H_2O(l) \longrightarrow$
(e) $Ca_3N_2(s) + H_2O(l) \longrightarrow$

Q61. Compute the following reactions:

(a) $H_2(g) + M_mO_n(s) \xrightarrow{\Delta}$ (b) $CO(g) + H_2(g) \xrightarrow[\text{Catalyst}]{\Delta}$
(c) $Zn(s) + NaOH(aq) \xrightarrow{\text{Heat}}$

Q62. Arrange the following:

(a) CaH_2, BeH_2 and TiH_2 in order of increasing electrical conductance.
(b) LiH, NaH and CsH in order of increasing ionic character.
(c) H — H, D — D and F — F in order of increasing bond dissociation enthalpy.
(d) NaH, MgH_2 and H_2O in order of increasing reducing property.

Q63. What do you understand by the term: (a) hydrogen economy (b) hydrogenation (c) syngas (d) water gas shift reaction and (e) fuel cell.

Q64. Give the chemical properties of H_2O_2.

Q65. Give the chemical properties of H_2O.

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S1. The temporary hardness is due to the presence of bicarbonates of calcium and magnesium *i.e.*, $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$ in water. On the other hand, permanent hardness is caused by the presence of chlorides and sulphates of calcium and magnesium i.e. $CaCl_2$, $CaSO_4$, $MgCl_2$, $MgSO_4$ in water.

S2. The bond dissociation enthalpy of H — H bond is very high (435.9 kJ mol^{-1}). Due to high bond enthalpy, it is not very reactive at room temperature. However, at high temperatures or in the presence of catalysts, hydrogen combines with many metals and non-metal to form hydrides.

S3. The structure of ice is open structure having a number of vacant spaces. Therefore the density of ice is less than water. When ice melts the hydrogen bonds are broken and the water molecules go in between vacant spaces in the structure. As a result the structure of liquid water is less open than structure of ice. Therefore ice is less dense than water. When ice melts, the force of attraction decreaes.

S4. There are intermolecular hydrogen bonding in H_2O molecule. The density of water is greater than ice. It may be noted that at 4°C water has maximum density. In severe cold the upper layer of the sea water freeze and the heavier water (density more than that of ice) is present below the surface of ice. Due to this sea animals can live safely in water.

S5. Chemically heavy water is deuterium oxide (D_2O). Like ordinary water it is odourless and tasteless liquid. The slower rate of D^+ compared to H^+ in reactions involved in enzymatic catalysis. Due to this the D_2O is toxic in nature. This also becomes toxic because it is produced by repeating electrolysis in electrolytic cell.

S6. **Ionic hydride:** LiH, NaH.

Covalent hydride: CH_4, NH_3 and H_2O.

S7. Elements with atomic number 17 is chlorine and 20 is calcium. They form compounds with hydrogen:

(a) HCl (b) CaH_2

Hydrogen forms molecular hydride with *p*-block elements. HCl is a compound which is covalent bonded and easily dissolves in water. While CaH_2 is salt like hydride and it get easily hydrolysed and produced H^+ ion which shows their ionic nature.

S8. There are two allotropes of hydrogen:

(a) Ortho hydrogen (ii) Para hydrogen.

The ortho and para hydrogen varies with temperature and have differences in their liquefication and stability.

S9. Hydrogen under very-very high pressures is expected to behave like a metal. Recent reports from America have confirmed this possibility.

S10. Use of hydrogen as an automobile fuel is known as hydrogen economy. The main aim of 'hydrogen economy' is to transmit energy, not as electric power but in the form of hydrogen.

S11. Heavy water is used as a moderator in nuclear reactors because it slows down the fast moving neutron and therefore helps in controlling the nuclear fission process. It has also been used as a tracer compound to study the mechanism of many chemical reaction.

S12. H_2O_2 decomposed by exposure to light. In glass bottles it decomposed readily and so it is stored in coloured bottle or plastic bottle.

S13. **Metallic hydrides:** These hydrides are formed by *d*-block and *f*-block elements (metals). They are non-stoichiometric and show electric conduction. Examples are $Sc.H_2$, YH_2, YH_3, LaH_2, LaH_3 etc.

S14. H_2O : Covalent or molecular hydride

B_2H_6 : Electron deficient molecular hydride

NaH : Ionic hydride.

S15. In some of the transition metal hydrides, hydrogen is absorbed as H-atoms. Due to the inclusion of H-atoms, the metal lattice expands and thus becomes less stable. Therefore, when such metallic hydride is heated, it decomposes to release hydrogen gas and very finely divided metal. The hydrogen evolved in this manner can be used as a fuel. Thus, transition metals or their alloys can act as sponge and can be used to store and transport hydrogen to be used as a fuel.

S16. Heavy water is injurious to plants, animals and human beings because it shows down the rates of reactions occuring in them. Thus, heavy water does not support life so as well as does ordinary water.

S17. The leaching action of H_2O_2 is due to the nascent oxygen whichit liberates on decomposition.

$$H_2O_2 \longrightarrow H_2O + O$$

The nascent oxygen oxidise the colouring matter to colourless products. It is used for the bleaching of delicate materials like ivory, feather, silk, wool, etc.

S18. D_2O_2 can be prepared by the reaction of D_2SO_4 dissolved in water over BaO_2.

$$BaO_2 + D_2SO_4 \longrightarrow BaSO_4 + D_2O_2$$

S19. Demineralised or distilled water is not useful for drinking purposes because it does not contain even useful minerals. Therefore, to make it useful for drinking purposes, useful minerals in proper amounts should be added to demineralised or distilled water.

S20. ${}_1^1H$ (Protium); ${}_1^2H$ or D (Deuterium); ${}_1^3H$ or T (Tritium)

The mass ratio of ${}_1^1H$: ${}_1^2H$: ${}_1^3H$ is 1 : 2 : 3.

S21. Coal gasification is the process of producing syngas from coal and steam

$$\underset{\text{Coal}}{C(s)} + \underset{\text{Steam}}{H_2O(g)} \xrightarrow[\text{Ni}]{1270\,K} \underbrace{CO(g) + H_2(g)}_{\text{Syngas}}$$

The production of hydrogen can be increased by reacting carbon monoxide of syngas with steam in presence of iron chromate as catalyst at 673 K when it is oxidised to CO_2

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

The CO_2 thus produced is removed by scrubbing with a solution of sodium arsenite.

S22. Due to high bond enthalpy of H — H bond, dihydrogen molecule (H_2) is quite unreactive at room temperature. However, at high temperature or in presence of catalysts, it combines with many metals and non-metals to form respective hydrides.

S23. Hydrogen atom has only one electron and thus, to achieve stable inert gas configuration of helium, it shares its single electron with electron of other hydrogen atom to form a stable diatomic molecule. The stability of H_2 is further confirmed by the fact, that formation of one mole of gaseous H_2 molecules results in the release of 435.9 kJ of energy

$$H(g) + H(g) \longrightarrow H_2(g); \qquad \Delta H = -435.9 \text{ kJ mol}^{-1}.$$

S24. (a) $CaO(s) + H_2O(l) \longrightarrow \underset{\text{(Calcium hydroxide)}}{Ca(OH)_2(l)}$

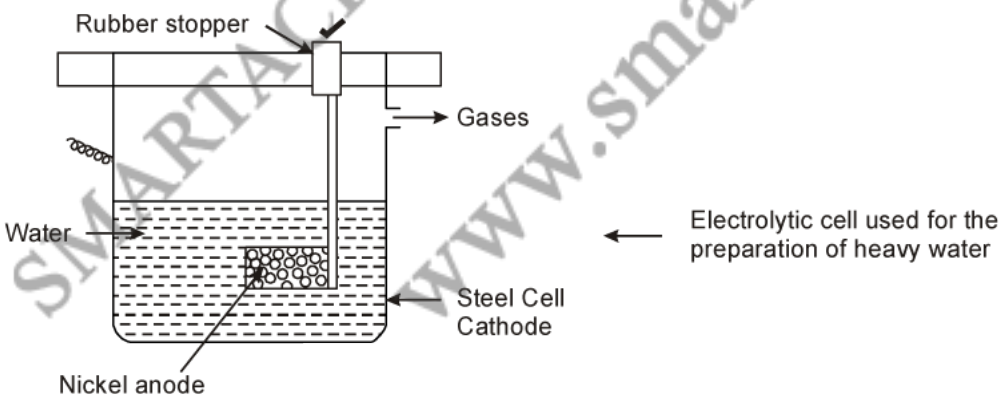
(b) $NaO(s) + H_2O(l) \longrightarrow \underset{\text{(Sodium hydroxide)}}{2NaOH(l)}$

S25. Formulae of their compounds:

(a) HF (b) NaH (c) MgH_2 (d) HCl

The compounds are hydrides of *s*-block and *p*-block elements. *s*-block hydride are volatile, non-conducting crystalline solids. They are also called salt like hydride. MgH_2 has convert polymer structure. *p*-block hydride are covalent, which are volatile molecular compounds. They are electron rich hydride and have higher boiling point. HF shows high hydrogen bonding.

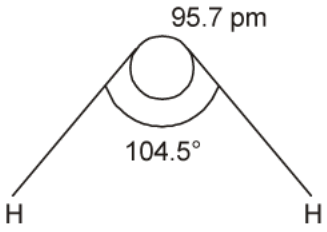
S26. Heavy water is isolated by exhaustive electrolysis of water. It is based on the fact that during electrolysis, protium (ordinary hydrogen) is liberated six times more readily than heavy hydrogen (deuterium).



The apparatus essentially consists of steel cell about 40 cm in length and 10 cm in diameter. The cell itself acts as a cathode while the naode consists of a perforated nickel sheet. A large number of cells are employed for electrolysis of water which is completed in a number of stages. The gases evolved from each stage are separately hunt and water so formed is returned to the previous stage. As a result, the conncentration of heavy water increases.

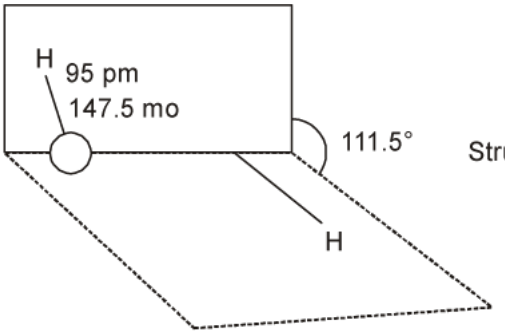
S27. Water is liquid due to the presence of strong intermolecular hydrogen bonding between H_2O molecules. Now to change the liquid into gaseous state more energy and hence heating to higher temperature is required. On the other hand, in H_2S there is no intermolecular hydrogen bonding between H_2S molecules. The H_2S molecules are held together by weak dipole-dipole interactions and weak van der Wasls' forces. Therefore, small thermal energy is required to cause the boiling to H_2S. Thus water has a high boiling point and high melting point compared to H_2S.

S28. **Structure of H_2O molecule:** Water in the gaseous form is a bent molecule with a HOH bond angle of 104.5° and OH bond length of 95.7 pm. It is polar in nature.



H_2O molecule.

Structure of H_2O_2 molecule: It has non-plannar structure. In gaseous phase the molecular dimensions, the dihedral angle is (115.5°) reduces to 92.2° on account of hydrogen bonding. The two oxygen atoms are joined by a single electron pair bond.



Structure of hydrogen peroxide in gas phase.

S29. Water each both as an acid and a base and is said to be amphoteric in nature. According to Lowry Bronsted concept, it can act as an acid by loosing a proton and as a base by accepting a proton, for example:

$$HCl + \underset{\text{(base)}}{H_2O} \rightleftharpoons Cl^- + H_3O^+ \qquad NH_3 + \underset{\text{(acid)}}{H_2O} \rightleftharpoons NH_4^+ + OH^-$$

However, water is neutral towards litmus and its P_H is 7. The auto-protolysis is water is represented by

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

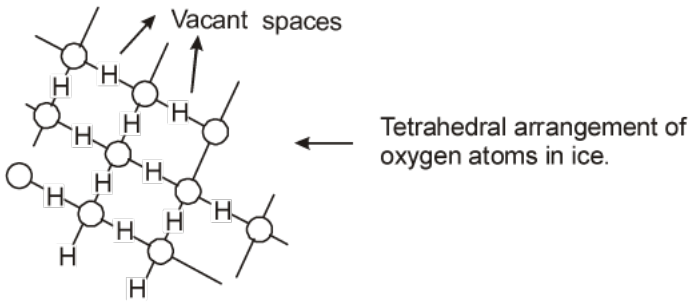
S30. **Ion-exchange method:** The common substance used for this porcess is zeolite which is hydrated sodium aluminium silicate $NaAl(SiO_2)$. The exchange occurs when on passing over the zeolite bed, sodium ions form zeolite are replaced by calcium and magnesium ions. Thus,

$$2NaZe + Ca^{2+} \longrightarrow (Ze)_2Ca + 2Na^+$$
$$2NaZe + Mg^{2+} \longrightarrow (Ze)_2Mg + 2Na^+$$

When all the sodium ions of the zeolite has been replaced, the zeolite is said to be exhausted. It can be regenerated by treatment with strong solution of sodium chloride.

$$2Na + (Ze)_2Ca \longrightarrow 2ZeNa + Ca^+$$

S31. In the normal hexagonal ice, each oxygen atom is tetrahedrally surrounded by four other oxygen atoms, *i.e.*, there is a hydrogen atom between each pair of oxygen atoms. This gives ice an open cage like structure. Form the figure, it is clear that each oxygen is surrounded by four hydrogen atoms, two by strong covalent bonds (shown by solid lines) and two by weak hydrogen bonds (shown by dotted lines). Since the H-bonds are longer than covalent bonds, the molecules of water are not closely packed in the crystal lattice.



S32. (a) **Diprotium:** It is used for the correct term for H_2.

(b) The term dihydrogen is used for the H_2 molecule white referring to the isotopic mixture with natural abundance for H and D.

(c) **Proton:** It is used for H^+.

(d) **Hydron:** It is used in relation to the isotopic mixture.

S33. Three isotopes of hydrogen are known:

(a) **Protium ($_1^1H$):** Its atomic mass is 1.008123. Its nucleus consists of one proton and one electron in 1s energy level. It constitutes 99.985% of natural hydrogen.

(b) **Deuterium ($_1^2H$ or D) or heavy hydrogen:** Its atomic mass is 2.014 amu. An atom of deuterium has one proton and one neutron in its nucleus, 0.015% exists in natural hydrogen.

(c) **Tritium ($_1^3H$ or T):** Its atomic mass is 3.01 amu. An atom of tritium has one proton and two neutrons in its nucleus. Tritium atoms are unstable and are radioactive whereas the former two are non-radioactive.

- **Imp:** It is found in the heavy water. Heavy water is used to control the nuclear reaction in nuclear reactor and helps in slow down the speed of neutrons.

S34. Electrolysis of solutions of ionic hydrides in molten alkali halides produce hydrogen gas at the anode which confirms the existence of hydride, H^+ ion.

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

Saline hydrides react explisively with water

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

H^+ is a strong bronsted base, which has high reactivity with water. The fire so produced can be extinguished by CO_2 as it gets reduced by the hot metal hydride.

S35. (a) $CuO(s) + H_2(g) \xrightarrow{\Delta} \underset{\text{(Copper)}}{Cu} + H_2O$

(b) $Na_2O(s) + H_2(g) \xrightarrow{\Delta} \underset{\text{(Sodium)}}{2Na} + H_2O$

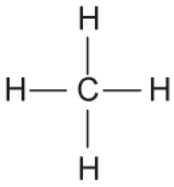
S36. (a) **Ionic bond:** The binary hydride of alkali metals (like LiH, NaH, KH etc.) form ionic bond. They on electrolysis give hydride ion H^+.

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

$$Na^+ + H \longrightarrow NaH$$

(b) **Metallic bond:** *d* and *f* block element (metals) forms metallic bond. Example: ScH_2, YH_2, LaH_3. etc.

(c) **Covalent bond:** With *p* block element hydrogen form covalent bond. For example:



(Methane)

CH_4

S37.
- H_2O and B_2H_6 are molecular hydride or covalent hydride.
- B_2H_6 is an electron deficient hydride.
- NaH is saline hydride or salt like hydride. They produce H^+ ion on electrolysis.
- LaH_3 is metallic hydride.

S38. (a) $H_2(g) + M_mO_o(s) \xrightarrow{\Delta} mM(s) + oH_2O(l)$

(b) $CO(g) + 2H_2(g) \xrightarrow[\text{Catalyst}]{\Delta} \underset{\text{Methanol}}{CH_3OH(l)}$

(c) $C_3H_8(g) + 3H_2O(g) \xrightarrow[\text{Catalyst}]{\Delta} 3CO(g) + 7H_2(g)$

(d) $Zn(s) + 2NaOH(aq) \xrightarrow{\text{Heat}} \underset{\text{Sodium zincate}}{Na_2ZnO_2(aq)} + H_2(g)$

S39. Hydrolysis is the interaction of H^+ and OH^- ions of water with the anion and cation of a salt respectively to form acid and base. For example,

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

Hydration is the interaction of water with the salts to forms coordinated or hydrated ions or hydrated salts.

$$Na^+Cl^-(s) + 2xH_2O \longrightarrow Na^+(H_2O)_x + Cl^-(H_2O)_x$$

$$Ni + 6H_2O(l) \longrightarrow Ni(H_2O)_6(aq)$$

$$CuSO_4(s) + 5H_2O(l) \longrightarrow \underset{\text{Hydrated salt}}{CuSO_4(s) \cdot 5H_2O}$$

S40.

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

or

$$\underset{\text{Oxidant}}{3F_2(g)} + \underset{\text{Reductant}}{3H_2O(l)} \longrightarrow O_3(g) + 6H^+(aq) + 6F^-(aq)$$

Water acts as a reducing agent and gets oxidised to O_2 or O_3.

F_2 acts as an oxidising agent and itself gets reduced to F^-.

S41. Auto-protolysis is a reaction in which two same molecules react to give ions with proton transfer. For example, in water, a proton from one water molecule is transferred to another water molecule leaving behind OH^- ions and forming H_3O^+ ion:

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

Because of auto-protolysis, water is amphoteric in nature i.e., it reacts with acids as well as bases. It acts as a base towards acids stronger than itself and as an acid towards bases stronger than itself. For example:

$$\underset{\text{acid}_1}{H_2O(l)} + \underset{\text{base}_2}{NH_3(aq)} \longrightarrow \underset{\text{acid}_2}{NH_4^+(aq)} + \underset{\text{base}_1}{OH^-(aq)}$$

$$\underset{\text{base}_1}{H_2O(l)} + \underset{\text{acid}_2}{H_2S(aq)} \longrightarrow \underset{\text{acid}_1}{H_3O^+(aq)} + \underset{\text{base}_2}{HS^-(aq)}$$

It helps to understand bronsted concept of conjugate acid-base pairs.

S42. Saline hydrides (*e.g.*, NaH, CaH_2 etc.) react with water violently to form corresponding metal hydroxide the evolution of dihydrogen as,

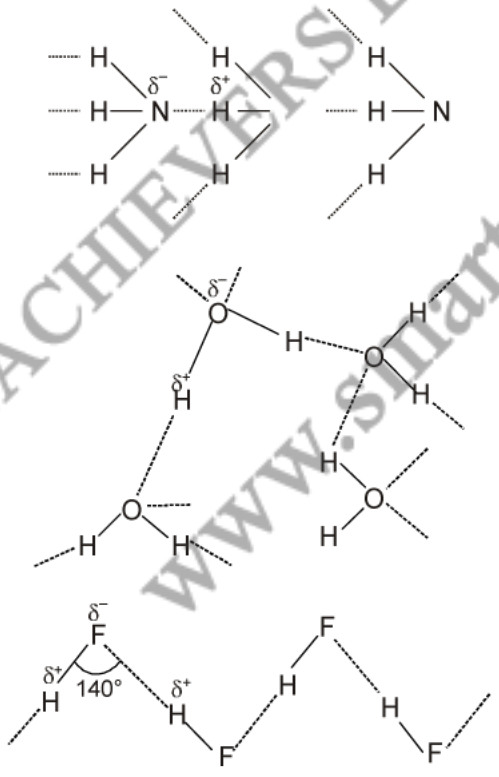
$$NaH(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$$
$$CaH_2(s) + 2H_2O(l) \longrightarrow Ca(OH)_2(aq) + 2H_2(g)$$

These reactions are very exothermic and the evolved H_2 catches fire. The fire produced cannot be extinguished by CO_2 because it gets reduced by hot metal hydride.

$$NaH + CO_2 \longrightarrow HCOONa$$

However, sand is used because it is highly stable solid.

S43. All these molecules undergo hydrogen bonding due to greater electronegativity of N, O and F.



Since, F is most electronegative and therefore, the magnitude of negative charge on F and positive charge on H will be highest andtherefore, H bonding will be strongest in HF.

S44. (a) Element with Z = 15 is a non-metal (*i.e.*, P) and hence form covalent hydride (PH_3).

(b) Element with Z = 19 is an alkali metal (K) and hence form ionic or saline hydride (K^+H^-).

(c) Element with Z = 23 is a transition element (*i.e.*, V) of group 5 and hence forms metallic or interstitial hydride (*i.e.*, $VH_{1.6}$).

(d) Element with Z = 44 is a transition metal (R) of group 8 and therefore, it does not form any hydride.

Behaciour towards water: Only ionic hydrides (*e.g.*, K^+H^-) react with water evolving H_2 gas as

$$2KH(s) + \underset{\text{Water}}{2H_2O(l)} \longrightarrow 2KOH(aq) + 2H_2(l)$$

S45. H_2O_2 can act as an oxidising as well as a reducing agent both in acidic and basic media as illustrated below:

(a) **Oxidising agent in acidic medium:**

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

(b) **Oxidising agent in basic medium:**

$$Mn^{2+}(aq) + H_2O_2(aq) + 2OH^-(aq) \longrightarrow MnO_2(s) + 2H_2O(l)$$

(a) **Reducing agent in acidic medium:**

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

(a) **Reducing agent in basic medium:**

$$2[Fe(CN)_6]^{3-}(s) + H_2O_2(aq) + 2OH^-(aq) \longrightarrow 2[Fe(CN)_6]^{4-}(aq) + 2H_2O(l) + O_2(g)$$

S46. Saline hydrides (such as NaH, CaH_2, etc.), react with water violently to form the corresponding metal hydroxides with the evolution of dihydrogen. The dihydrogen gas so liberated undergoes spontaneous combustion causing fire. This is because of exothermic nature of combustion reactions.

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

The fire so porduced cannot be extinguished by CO_2 because it gets reduced by the hot metal hydride to formate ions

$$NaH + CO_2 \longrightarrow HCOONa$$

However, sand (because of its stable nature) is more effective fire extinguisher in such a case.

S47. These are hydrides which have low hydrogen content. In these hydrides the ratio of the metal to hydrogen atoms is fractional and they are called *non-stoichiometric hydrides*. Furthermore, even this fractional ratio of atoms is not fixed but varies with the temperature and the pressure conditions. This type of hydrides are formed by *d*- and *f*-block elements. In these hydrides, the hydrogen aotoms occupy holes in the metal lattice. Usally some holes always remain unoccupied and hence these metals form non-stoichiometric hydrides.

Alkali metals are highly reducing, they transfer their lone electron to the H atom, therby forming H^- ions. In other words, alkali metal hydrides are ionic in nature, Since such hydrides are formed by complete transfer of an electron, therefore, the ratio of metal to hydrogen is always fixed. Therefore, alkali metals form only stoichiometric hydrides. They do not form non-stoichiometric hydrides at all.

S48. (a) Hydrides of elements of group-13 such as BH_3, AlH_3, etc., do not have sufficient number of electrons to form normal covalent bonds and hence are called *electron-deficiend hydrides*. To make up this deficiency, they generally exist in polymeric forms such as B_2H_6, B_4H_{10}, $(AlH_3)_n$, etc.

(b) Hydrides of elements of group-14 like CH_4, SiH_4, GeH_4, etc., have exact number of electrons to form covalent bonds and hence are called *electron-precise hydrides*. All these hydrides have tetrahedral shapes.

(c) Hydrides of elements of group-15, 16 and 17, like NH_3, PH_3, H_2O, H_2S, HF, HCl, etc., have more electrons than required to form normal covalent bonds and hence are called *electron-rich hydrides*. The excess electron in these hydrides are present as lone pairs of electrons.

S49. Atomic hydrogen is produced when molecular hydrogen is passed through an electric arc struck between tungsten electrodes (3773 – 4273 K).

$$H_2(g) \xrightarrow{\text{Electric arc}} H(g) + H(g); \quad \Delta H = 436.0 \text{ kJ mol}^{-1}.$$

The life span of atomic hydrogen is about 0.3 sec and therefore, it immediately gets converted into the molecular hydrogen (H_2) liberating a large amount of energy which is used for cutting and welding purposes in form of atomic hydrogen torch.

S50. Water has a high dielectric constant and high dipole moment. Because of these properties, water dissolves most of the inorganic (ionic) compounds and many covalent compounds. That is why water is called a *universal solvent*. Ionic compounds dissolve in water due to ion-dipole interactions but, covalent compounds such as alcohol, amines, urea, glucose, sugar, etc., dissolve in water dut to H-*bonding*.

Water can hydrolyse many metallic or non-metallic oxides, hydrides, carbides, nitrides phosphides and other salts. Some of the important hydrolytic reactions are given below.

$$CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(aq)$$

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

$$Ca_3N_2(s) + 6H_2O(s) \longrightarrow 3Ca(OH)_2(aq) + \underset{\text{Ammonia}}{2HN_3(g)}$$

S51. Saline hydrides (*i.e.*, NaH, CaH_2 etc.), react with liberation of H_2 gas. Thus, traces of water present in organic solvents can be easily removed by distilling them over saline hydrides when H_2 escapes into the atmosphere, metal hydroxide is left in the flask while dry organic solvent distils over.

Alternatively, organic compounds containing traces of water can be dried by placing them in a desiccator containing saline hydrides at the bottom for a few hours or preferably overnight.

S52. Advantages of hydrogen use as a fuel:

(a) It releases greater energy per unit weight of fuel.

(b) It is free form pollutants such as CO, CO_2, NO_2, SO_2 hydrocarbons, aldehydes and lead compounds.

(c) Its combustion product is water with just some traces of nitrogen oxides.

(d) Internal combustion engines can be easily modified for use of hydrogen as a fuel.

(e) Fuel cells for generation of electric power with conversion efficiency of 70 – 85% have been successfully operated commercially. Fuel cell has been for power generation.

S53. Some unusual properties of water are:

- The peculiar properties of water in condensed form are due to the presence of extensive hydrogen bonding between water molecule.
- The abnormally high freezing point, boiling point and heat of vaporisation and heat of fusion as compared to (the hydrides of other element of the same group of the periodic table *e.g.*, H_2S, H_2Se) are due to hydrogen bonding.
- It has higher specific heat, thermal conductivity and surface tension than most other liquids.
- These properties allow water to play a vital role in the biosphere. It is an excellent solvent.
- Under higher pressure and temperature, it behaves like a non-polar solvent and dissolves organic compounds.
- It freeze to form ice – the crystalline form of water. It has lesser density than water and prevent aquatic life.

S54. Water gas shift reaction: When steam is passed over red hot coke in presence of high temperature.

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

Thus formed CO is converted to CO_2 by passing the gases and steam over an iron oxide or cobalt oxide catalyst at 673 K in the generation of more H_2.

$$CO + H_2O \xrightarrow[\text{Catalyst}]{673\,K} CO_2 + H_2$$

This reaction is called the water gas shift reaction. By this process the more hydrogen gas is prepared. This method is used for the production of 77% of industrial hydrogen.

S55. Hydrogen is the first elements in the periodic table. It has the electronic configuration $1s^1$. It is similar to alkali metal (ns^1) of group I. It shows resemblance with alkali metals of group I of the periodic tagble. Do it can be placed above the alkali metals in group I of the periodic table.

On the other hand the electronic configuration of hydrogen shows that it is short of one electron to the nearest noble gas configuration (He) having the electronic configuration $1s^2$. Like halogens it forms covalent bonds (H_2, Cl_2, Br_2, etc.) as well as ionic bonds (*e.g.*, Na^+H^-). It forms H+ ion by giving one electron and hydride ion (H^-) by gaining one electron. On the basis of its electronic configuration ($1s^1$) hydrogen is placed with other ns_1 elements namely alkali metals in the group I as well as in group 17 of the periodic table. Thus the position of hydrogen in the periodic table is anomalous.

S56. KCl is the salt of a strong acid and a strong base. It does not undergo hydrolysis in normal water. It just dissociates to give $K^+(aq)$ and $Cl^-(aq)$ ion giving neutral solution.

$$KCl(s) \xrightarrow{\text{Water}} K^+(aq) + Cl^-(aq)$$

$AlCl_3$, on the other hand, is a salt of a weak base $Al(OH)_3$ and a strong acid HCl. Therefore, in normal water, it undergoes hydrolysis, as follows giving acidic solution.

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

In *acidic* water, both KCl and $AlCl_3$ undergo ionisation.

$$KCl \xrightarrow{\text{Acidified water}} K^+(aq) + Cl^-(aq)$$

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

In alkaline water, $AlCl_3$ reacts to form soluble tetrahydroxoaluminate complex or metaaluminate ion, *i.e.*,

$$AlCl_3(s) + 4OH^-(aq) \longrightarrow \underset{\text{Tetrahydroxoaluminate}}{[Al(OH)_4]^-(aq)} + 3Cl^-(aq)$$

$$\longrightarrow \underset{\text{Meltaaluminate ion}}{AlO_2^-(aq)} + 2H_2O(l)$$

KCl does not react and only undergoes ionsiation as K^+ and Cl^- ions.

S57. (a) In the atomic hydrogen torch, it is used to melt some of the most refractory materials such as tungsten, tantalum and thorium oxide.

(b) In the hydrogenation of unsaturated vegetable oil to give solid fats *e.g.*, vanspati and for the production of organic chemicals *e.g.*, methanol by reaction.

$$\text{Oils} + H_2(g) \xrightarrow[175^\circ, 5\text{ atm}]{Ni, H_2} \text{Solid fats} \qquad CO + 2H_2 \xrightarrow[\text{Catalyst}]{\text{Cobalt}} \underset{\text{(Methanol)}}{CH_3OH}$$

(c) Its ability to combine with nitrogen in the presence of Fe as catalyst and Mo as promoter at 675 K under 200 atm results in the production of ammonia by Haber's process

$$N_2(g) + 3H_2(g) \xrightarrow[Fe/Mo]{675\,K,\,200\text{ atm}} 2NH_3(g).$$

S58. (a) Dehydrogen in prepared by reaction a highly reacting metal like sodium with water.

$$2Na(s) + \underset{\text{(Cold)}}{2H_2O(l)} \longrightarrow 2NaOH(aq) + H_2(g).$$

(b) In the laboratory dihydrogen ins prepared by electrolysis of acidified water using platinum electrode:

$$2H_2O(l) \xrightarrow[\text{Traces of acid/base}]{\text{Electorlysis}} 2H_2(g) + O_2(g)$$

At cathode : $2H^+ + 2e^- \longrightarrow H_2$

At anode : $4\,^{\ominus}OH \longrightarrow 2\,H_2O\,(l) + O_2(g) + 4e^-$

(c) From hydrocarbon : Reaction of steam on hydrocarbons at higher temperature;

$$C_nH_{2n} + 2nH_2O \xrightarrow[\text{Catalyst}]{1270\,K} nCO + (2n+1)H_2$$

$$CH_4 + H_2O \xrightarrow[1270\,K]{1270\,K} CO + 3H_2$$

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

S59. Hydrogen peroxide acts as an oxidising agent and a reducing agent:

(a) **As an oxidizing agent (*in neutral medium*):**

(i)
$$H_2O_2 \longrightarrow H_2O + O$$
$$H_2S + O \longrightarrow S + H_2O$$
$$H_2S + H_2O \longrightarrow S + 2H_2O$$

(ii) ***in acidic medium:***

$$2\,FeSO_4(aq) + H_2SO_4(aq) + H_2O_2(aq) \longrightarrow Fe_2(SO_4)_3(aq) + 2\,H_2O\,(l)$$
$$PbS\,(s) + 4\,H_2O_2(aq) \longrightarrow PbSO_4(s) + 4H_2O\,(l)$$

(iii) ***in alkaline medium:***

$$H_2O_2 + {}^{\ominus}OH + 2e^- \longrightarrow 3\,OH^-$$
$$MnSO_4 + H_2O_2 + 2\,NaOH \longrightarrow MnO_2 + Na_2SO_4 + 2\,H_2O$$

(b) **Reducing nature: (*in acidic medium*):**

$$2\,KMnO_4 + 3\,H_2SO_4 + 5\,H_2O_2 \longrightarrow K_2SO_4 + 2\,MnSO_4 + 8\,H_2O + 5O_2$$
$$HOCl + H_2O_2 \longrightarrow H_3O^+ + Cl^- + O_2$$

In alkaline medium:

$$2\,Fe^{3+} + H_2O_2 + 2\,OH^- \longrightarrow 2Fe^{2+} + 2\,H_2O + O_2$$
$$2\,KMnO_4 + 3\,H_2O_2 \longrightarrow 2\,MnO_2 + 3\,O_2 + 2\,H_2O + 2\,KOH$$

S60. (a) $PbS\,(s) + H_2O_2(aq) \longrightarrow PbSO_4(s) + 4H_2O\,(l)$

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

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

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

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

S61. (a) $H_2(g) + M_mO_n(s) \xrightarrow{\Delta} m\,M(s) + n\,H_2O(l)$

(b) $CO(g) + 2H_2(g) \xrightarrow[\text{Catalyst}]{\Delta} \underset{\text{Methanol}}{CH_3OH(l)}$

(c) $Zn(s) + 2NaOH(aq) \xrightarrow{\text{Heat}} Na_2ZnO_2(aq) + H_2(g)$

S62. (a) $BeH_2 < CaH_2 < TiH_2$

(b) $LiH < NaH < CsH$

(c) $F — F < H — H < D — D$

(d) $H_2O < MgH_2 < NaH$

S63. (a) **Hydrogen economy:** Hydrogen economy refers to the proposal to use hydrogen as a fuel in *industry*, *power plants*, *automobiles* and also for *domestic needs*. The basic principle of hydrogen economy is the transportation and storage of energy in the form of liquid or gaseous dihydrogen.

(b) **Hydrogenation:** Hydrogenation means addition of hydrogen (H_2) across double and triple bonds to form saturated compounds. The vegetables oils such as soyabean oil, cotton seed oil, groundnut oil, etc, are called polyunsaturated oils since they contain many C ═ C bonds in their molecules. When these oils are hydrogenated in presence of finely divided nickel at 473 K they get converted with solid fats due to hydrogenation of C ═ C bonds.

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

This process is called *hydrogenation* or *hardening* of oils and is used in the manufacture of vegetable ghee.

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

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

These days 'syngas' is produced from sewage, saw dust, scrap wood, newspapers, etc. The process of producting syngas form coal is called 'coal gasification'.

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

(d) **Water gas shift reaction:** This reaction involves the commercial preparation of H_2 by selective oxidation of CO of syngas to CO_2 with the help of steam in the presence of iron chromate as catalyst.

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

(e) **Fuel cell:** Fuel cell is a device which converts the energy produced during the combustion of a fuel directly into electrical energy. Dihydrogen is used in *hydrogen-oxygen fuel cells* for generating electrical energy. It has many advantages over the conventional fossil fuels. It does not cause any pollution and releases more amount of energy per unit mass of fuel as compared to gasoline and other fuels.

S64. Properties of H_2O_2 :

(a) **Dissciation:** Pure H_2O_2 is unstable liquid and decomposes into water and oxygen upon heating.

$$2H_2O_2 \xrightarrow{\Delta} 2H_2O + O_2$$

(b) **Acidic nature:** Pure hydrogen peroxide is a acid and dissociates as:

$$H_2O_2 + H_2O \longrightarrow H_3O + HO_2^- \quad \text{(Hydro peroxide ion)}$$

$$HO_2^- + H_2O \longrightarrow H_3O+ + O_2^{2-} \quad \text{(Neutral medium)}$$

(c) **Oxidising and reducing character:** It behaves as an oxidisng agent:

(a) $H_2S + H_2O_2 \longrightarrow S + 2H_2O$ (Neutral medium)

(b) $2FeSO_4 + H_2SO_4 + H_2O_2 \longrightarrow Fe_2(SO_4)_3 + 2H_2O$ (Acidic medium)

(c) $MnSO_4 + H_2O_2 + 2NaOH \longrightarrow MnO_2 + Na_2SO_4 + 2H_2O$ (Basic medium)

Reducing character: It reduces acdified potassium dichromate solution:

(a) $K_2Cr_2O_7 + 4H_2SO_4 + 3H_2O_2 \longrightarrow K_2SO_4 + Cr(SO_4)_3 + 7H_2O + 3O_2$

(b) $Cl_2 + H_2O_2 \longrightarrow 2HCl + O_2$

(d) **Bleaching action:** It acts as a bleaching agent due to the release of nascent oxygen: $H_2O_2 \longrightarrow H_2O + O$. Colouring matter + O $\longrightarrow$ colourless matter.

(e) **Addition reaction:** It adds to alkene to form glycerols:

$$CH_2 = CH_2 + H_2O_2 \longrightarrow \underset{\displaystyle CH_2OH}{\overset{\displaystyle CH_2OH}{|}}$$

(Ethylene glycol)

S65. Chemical properties of water:

(a) **Dissociation of water:** Water is quite stable and does not dissociate at high temperature. Pure water has a small but a measurable electrical conductivity and it dissociates as

$$H_2O + H_2O \rightleftharpoons \underset{\text{(Hydronium ion)}}{H_3O^+} + OH^-$$

(b) **Amphoteric nature:** Water can act as an acid and a base and is said to be amphoteric.

$$HCl + H_2O \rightleftharpoons Cl^- + H_3O^+ \qquad NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

(c) **Oxidising and reducing nature:** It acts both as oxidising and a reducing agent.

$$\underset{\text{(Oxidising agent)}}{2Na} + 2H_2O \longrightarrow 2NaOH + 2H_2 \qquad 2F_2 + \underset{\text{(Reducing agent)}}{2H_2O} \longrightarrow 4HF + O_2$$

(d) **Hydrolysis reaction:** Water can easily hydrolyse oxides, and halides of non-metals.

(i) $SO_2 + H_2O \longrightarrow H_2SO_3$ (Sulphurous acid)

$SO_3 + H_2O \longrightarrow H_2SO_4$ (Sulphuric acid)

(ii) $CaC_2 + 2H_2O \longrightarrow Ca(OH)_3 + C_2H_2$ (Acetylene)

$AlN + 3H_2O \longrightarrow Al(OH)_3 + NH_3$ (Ammonia)

(e) **Hydration reaction:** Water molecules are coordinated to metal ion in a complex.

$$Ni^{2+} + 6H_2O \longrightarrow [Ni(H_2O)]^{2+}$$

It is also hydrogen bonded with oxygen containing anions as $CuSO_4 . 5H_2O$. Four H_2O molecule are co ordinated to Cu^{2+} ion while the fifth one is hydrogen bonded to SO_4^{2-} ion.