DIHYDROGEN

Occurrence

Dihydrogen emerges as the most prevalent element throughout the universe, composing approximately 70% of the total mass of cosmic matter. Despite its cosmic abundance, dihydrogen is relatively scarce in the Earth's atmosphere, constituting a mere 0.15% by mass. This scarcity on Earth can be attributed to the planet's relatively weak gravitational field, which struggles to retain such a lightweight element.

In its free state, hydrogen is found in volcanic gases, while in combined forms, it contributes to 15.4% of the Earth's crust and oceans. Beyond geological formations, hydrogen is integral to various biological structures, including plant and animal tissues, as well as essential organic compounds such as carbohydrates and proteins. Additionally, hydrogen is present in mineral resources like coal and petroleum.

Moreover, hydrogen holds a significant role in the composition of the solar atmosphere, standing as the principal element in the outer layers of the Sun. This prevalence extends beyond our solar system, as hydrogen also features prominently in the outer atmospheres of other celestial bodies such as Jupiter and Saturn, establishing its widespread presence in the broader cosmic landscape.

Preparation of Dihydrogen

Method Of Preparation

(i) **From Acids:**

Metals that are positioned near hydrogen (H_2) in the electrochemical series display a notable behavior when exposed to dilute acids. When these metals react with dilute acids, they release hydrogen gas (H_2). This reaction is a consequence of the relative reactivity of these metals in the electrochemical series and their tendency to displace hydrogen from acids. As a result, they are often referred to as "H_2 liberating" metals when they encounter dilute acidic solutions, and the process can be described as the liberation or evolution of hydrogen gas. This reaction is a key characteristic of these metals and is significant in various chemical and industrial applications.

Ex.

$$Fe + \underset{\text{(dil)}}{H_2SO_4} \longrightarrow FeSO_4 + H_2$$

$$Cu + H_2SO_4 \longrightarrow \times \text{ (No reaction)}$$

Laboratory Preparation and Commercial Production of Dihydrogen

Lab preparation:

When impure Zn reacts with dil H_2SO_4 it forms H_2

$$\underset{\text{(impure)}}{Zn + H_2SO_4} \longrightarrow \underset{\text{(dil)}}{ZnSO_4 + H_2}$$

Ex. Why we use impure Zn.

Ans. Because the rate of reaction with pure Zn is very slow.

Commercial Or Industrial Method to Prepare H_2

(i) **Lane Process**

Steam is passes over hot iron it converts into Fe_3O_4 & H_2.

$$3Fe + 4H_2O \longrightarrow Fe_3O_4 + 4H_2$$

Iron is regenerated by reducing Fe_3O_4 into Fe by water gas ($CO + H_2$)

$$2Fe_3O_4 + 4CO + 4H_2 \longrightarrow 6Fe + 4CO_2 + 4H_2O$$

$$Fe_3O_4 + 2CO + 2H_2 \longrightarrow 3Fe + 2CO_2 + 2H_2O$$

This process is a continuous process.

(ii) Bosch Process

In this process initially, steam is passed over red-hot coke then water gas is formed.

$$C + H_2O \longrightarrow CO + H_2$$

Then water gas is mixed with more stem in presence of Fe_2O_3/Cr_2O_3 then CO will convert into O_2 & we can obtain more H_2.

$$CO + H_2 + H_2O \longrightarrow CO_2 + 2H_2$$

(iii) From Natural Gas

$$C_nH_{2n+2} + nH_2O \longrightarrow nCO + (2n + 1)H_2$$

Various Forms of Hydrogen

Different Forms of Hydrogen

(A) Based On Oxidation Number

There are three types of hydrogen

	H^+ Proton	H^- Hydride	H Atomic hydrogen
Number of electrons	0	2	1
Oxidation number	+1	–1	0
Formation	$H \rightarrow H^+ + e^-$	$H + e^- \rightarrow H^-$	$H_2 \xrightarrow{\triangle} 2H$

Note: In the aqueous state proton (H^+) exist as $H^+ (H_2O)_n$

Where n is a large number.

If $n = 1 \longrightarrow H_3O^+$

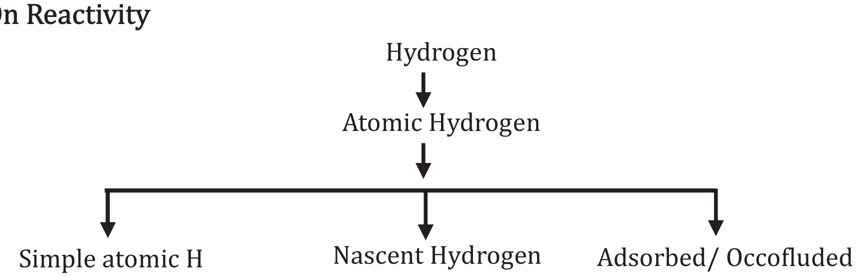
$n = 2 \longrightarrow H^+(H_2O)_2$

Ex. In the aqueous solution hydrogen ion exist as

(1) H_3O^+ (2) $H^+(H_2O)_2$ (3) $H^+(H_2O)_n$ (4) All

Ans. (4)

(B) Based On Reactivity



Atomic Hydrogen

In 1922, Irving Langmuir demonstrated that, under specific conditions, molecular hydrogen undergoes a process of dissociation into atomic hydrogen when subjected to heat generated by an electric current. This phenomenon occurs when molecular hydrogen is in contact with tungsten or platinum wire and is executed at low pressure.

(i) Simple atomic hydrogen

It is formed by simple dissociation of hydrogen.

$$H_2 \xrightarrow{3000-5000} 2H$$

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

(ii) Nascent Hydrogen

Nascent hydrogen, also referred to as "hydrogen at the moment of its birth," is a term used to describe hydrogen in its freshly formed state. This unique form of hydrogen is generated instantaneously during certain specific chemical reactions.

In essence, nascent hydrogen is hydrogen that is created as a reactive intermediate during the course of a chemical reaction. It is highly reactive and displays distinctive properties because of its instantaneous formation. Nascent hydrogen can play a critical role in various chemical processes, including reductions and hydrogenation reactions, due to its high reactivity and ability to readily participate in chemical transformations.

(a) Acid + Metals

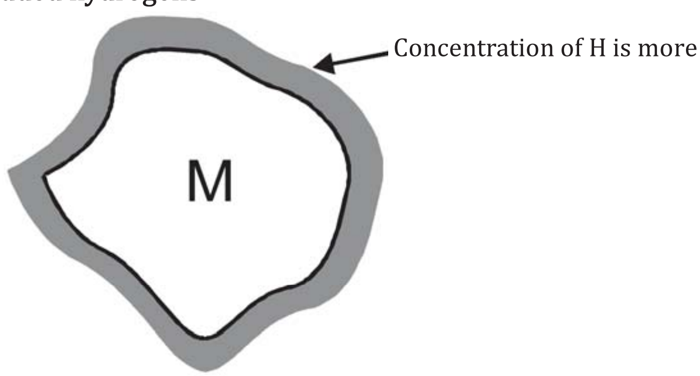
$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + 2H$$

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

(c) C_2H_5OH + Alkali metal

$$C_2H_5OH + Na \longrightarrow C_2H_5ONa + H$$

(iii) Adsorbed/Occluded hydrogens



Adsorbed H is hydrogen present at the outer surface of metal.

Occlusion – The property of metal to adsorb any gas is called occlusion.

Reactivity order

Atomic hydrogen > Nascent hydrogen > Molecular hydrogen

Ortho & Para-Hydrogen

(i) **Ortho hydrogen –** Ortho hydrogen is the molecular variant of hydrogen in which the protons have the same spin.

(ii) **Para hydrogen –** Para hydrogen is the molecular configuration of hydrogen where the proton's spin is in the opposite direction. On the other hand, in ortho hydrogen, both protons have the same spin, leading to mutual repulsion between them. This repulsive interaction results in the internal energy of ortho hydrogen being higher than that of para hydrogen. In other words, ortho hydrogen possesses greater internal energy due to the repulsive forces between the protons, while para hydrogen has a lower internal energy because its protons have opposite spins, reducing intermolecular repulsion.

Difference between Ortho and Para-Hydrogen

Stability of ortho & para hydrogen

The stability of both ortho and para hydrogen is contingent upon the prevailing temperature conditions.

This relationship varies with temperature:

1. At Low Temperatures:
   - Para hydrogen is the more stable configuration compared to ortho hydrogen.
   - The lower the temperature, the more prevalent para hydrogen is due to its lower energy state under these conditions.
2. At High Temperatures:
   - Ortho hydrogen becomes more stable than para hydrogen.
   - As the temperature increases, the kinetic energy of the hydrogen molecules also rises, leading to a higher probability of proton spins aligning in the same direction. This aligning of spins results in the formation of more ortho hydrogen.

In summary, the relative stability of ortho and para hydrogen depends on the temperature at which they are examined. Para hydrogen dominates at lower temperatures, while ortho hydrogen becomes the more stable configuration at higher temperatures due to the alignment of proton spins.

$$^{P}H_2 \underset{T\downarrow}{\overset{T\uparrow}{\rightleftharpoons}} {}^{O}H_2$$

	Ortho	Para
At 25°C	75%	25%
At –253°C/20K	0	100%

Preparation of Pure Para-Hydrogen

At standard room temperature, ordinary dihydrogen is composed of 75% ortho-hydrogen and 25% para-hydrogen. However, as the temperature decreases, the proportion of ortho-hydrogen in the mixture diminishes, while that of para-hydrogen increases. At around 20 Kelvin, the dihydrogen mixture becomes predominantly para-hydrogen, reaching a state of purity.

Conversely, when ordinary hydrogen is heated to temperatures of 400 K or higher, the ratio between ortho- and para-hydrogen remains constant at 3:1. Consequently, while achieving pure para-hydrogen is feasible, obtaining pure ortho-hydrogen proves to be impractical.

The conversion of para-hydrogen to ortho-hydrogen can be achieved through several methods:

i. By subjecting para-hydrogen to temperatures of 800°C or higher.

ii. Through the passage of an electric discharge through para-H_2.

iii. By treating para-H_2 with catalysts such as Pt, Ni, Fe, W, O_2, NO_2, CO_2, Cr_2O_3.

iv. By blending para-H_2 with paramagnetic molecules like O_2 (oxygen).

v. By mixing para-H_2 with atomic hydrogen, as demonstrated by Gelb and Hetrick, where collisions between atomic hydrogen and para-H_2 result in the conversion to the ortho-H_2 form.

Physical And Chemical Properties of Dihydrogen

Physical Properties of Hydrogen

(i) Hydrogen is a gas that is extremely lightweight, colorless, odorless, and tasteless. It exhibits limited solubility in water and is flammable, yet it is relatively unreactive.

(ii) With an exceptionally low freezing point (-259.2°C) and boiling point (-252°C), hydrogen displays minimal intermolecular attraction. This low freezing point makes liquid hydrogen valuable as a cryogenic fluid for achieving extremely low temperatures.

(iii) The bond energy of the H—H bond is 104 kilocalories per mole (436 kilojoules per mole).

(iv) The H—H bond length is 74 picometers (pm), contributing to hydrogen's reduced reactivity, requiring elevated temperatures for reactions to occur.

Chemical Properties of H_2

(i) H_2 is neutral in nature i.e., why it does not react with acids & bases.

(ii) Less Reactive: Hydrogen is very less reactive in nature because of very high bond dissociation energy.

(iii) Combustible Nature: H_2 is highly combustible in nature & it burns with oxygen or air with pale blue flame to give water.

$$H_2 + \frac{1}{2} O_2 \longrightarrow H_2O$$

(iv) Reaction With Highly Electropositive Metals

IA & IIA group elements are called highly electropositive metal. Whenever H reacts with these metals, they form ionic hydrides.

$$2Na + H_2 \longrightarrow 2NaH$$

$$CO + H_2 \longrightarrow CaH_2$$

Uses of Dihydrogen

1. The process of hydrogenating vegetable oil to produce solid fats, known as vanaspati ghee.
2. Utilized in its liquid state as a component of rocket fuel (Liquid H_2 + Liquid O_2).
3. Employed in airships or balloons as a mixture of hydrogen and helium, with a composition of 15% H_2 and 85% He.
4. It plays a pivotal role in the creation of various compounds, including but not limited to NH_3 (through the Haber process), alkanes, alcohols, and diverse hydrocarbons.
5. Hydrogen finds application in the production of hydrogen chloride, a crucial chemical compound with significant industrial importance.
6. Additionally, hydrogen plays a role in the manufacturing process of various metal hydrides, contributing to the synthesis of these important compounds.
7. Dihydrogen proves invaluable in metallurgical processes as a potent reducing agent. Its capacity to reduce heavy metal oxides to metals makes it an essential component in various metallurgical applications.
8. For cutting and welding purposes, hydrogen serves a vital role in both atomic hydrogen torches and oxyhydrogen torches. Through the application of an electric arc, dihydrogen undergoes dissociation into atomic hydrogen. The resulting hydrogen atoms combine on the surface to be welded, generating temperatures as high as 4000 K.
9. In the realm of space exploration, hydrogen plays a pivotal role as a rocket fuel. Specifically, in the form of liquid hydrogen and liquid oxygen, it serves as a propellant in rocket engines, contributing to advancements in space research.

10. Fuel cells utilize dihydrogen for the generation of electrical energy. Distinguished by its environmentally friendly attributes, hydrogen in fuel cells produces minimal pollution. Furthermore, it offers a higher energy yield per unit mass compared to conventional fuels like gasoline, making it a favorable and advantageous choice in the realm of energy production.