Chemical of the Week

HYDROGEN — H_2

Hydrogen is an important commercial chemical. It is prepared industrially by two processes: the "water gas reaction" using coke and water (equation 1), and the steam reforming process using natural gas and water (equation 2). Both reactions require high temperatures.

$$C(s) + H_2O(g) \longrightarrow CO(g) + H_2(g) \quad (1)$$

$$CH_4(g) + H_2O(g) \longrightarrow CO(g) + 3\,H_2(g) \quad (2)$$

The mixture of products from these two reactions is often called synthesis gas or syngas. The carbon monoxide in this gaseous mixture can be made to react with more water in the "water gas shift reaction" (equation 3) to produce hydrogen and CO_2.

$$CO(g) + H_2O(g) \longrightarrow CO_2(g) + H_2(g) \quad (3)$$

The CO_2 is then easily removed by passing this gas through a solution of sodium hydroxide. The carbon dioxide reacts and dissolves (equation 4), leaving pure hydrogen.

$$CO_2(g) + 2\,OH^-(aq) \longrightarrow CO_3^{2-}(aq) + H_2O(l) \quad (4)$$

A subject of much current interest in chemistry is the conversion of synthesis gas ($CO + H_2$) to other products such as methanol (equation 5) and liquid hydrocarbons (equation 6). These substances could be used as synthetic fuels, such as substitutes for gasoline.

$$CO(g) + 2\,H_2(g) \longrightarrow CH_3OH(l) \quad (5)$$

$$n\,CO(g) + (2n+1)\,H_2(g) \longrightarrow C_nH_{2n+2}(l) + n\,H_2O(l) \quad (6)$$

In the laboratory, hydrogen is easily prepared by the reaction of a reactive metal such as zinc or magnesium with an acid (equation 7). It can also be obtained by electrolysis of water (equation 8). These methods are too expensive for use in commercial production of H_2.

$$Zn(s) + 2\,H^+(aq) \longrightarrow Zn^{2+}(aq) + H_2(g) \quad (7)$$

$$2\,H_2O(l) \longrightarrow 2\,H_2(g) + O_2(g) \quad (8)$$

Hydrogen is a colorless, odorless gas. It is the least dense gas, having a density of 0.089 g/liter at 0°C and 1 atmosphere (standard temperature and pressure, STP). It is not very soluble in water; only 1.9 mg dissolves in a liter of water at 0°C. It reacts vigorously with many elements including oxygen and halogens, as was demonstrated in lecture (equations 9 and 10).

$$H_2(g) + \tfrac{1}{2}\,O_2(g) \xrightarrow{\text{spark}} H_2O(g) \quad (9)$$

$$H_2(g) + Cl_2(g) \xrightarrow{\text{light}} 2\,HCl(g) \quad (10)$$

At high temperatures, H_2 reacts with metal oxides to form water vapor and metal. For example, as shown in lecture, hot copper oxide is reduced to copper metal by hydrogen (equation 11).

$$CuO(s) + H_2(g) \xrightarrow{\text{high temp}} Cu(s) + H_2O(g) \quad (11)$$

The copper oxide used in lecture was formed by heating copper in air.

Hydrogen also reacts with active metals such as sodium to give a group of compounds known as metal hydrides, which contain the hydride anion, H^- (equation 12).

$$2\ Na(s) + H_2(g) \longrightarrow 2\ NaH(s) \qquad (12)$$

About 40% of the hydrogen produced industrially is used in the preparation of ammonia by the Haber process. Ammonia's primary use is as an agricultural fertilizer. A large portion of manufactured ammonia is also used in the production of nitric acid. Oxidation of NH_3 gives H_2O and NO_2, and the latter can be converted to nitric acid, HNO_3.

REFERENCES

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