# PHYSICAL AND CHEMICAL PROPERTIES OF HYDROGEN

**Isao Abe**
*Office Tera, Chiba, Japan*

**Keywords:** Hydrogen, physical properties, chemical properties

**Contents**



**Summary**

The physical and chemical properties of hydrogen are described with data. Only those properties relating to the use of hydrogen as an energy medium are noted.

## 1. Introduction

Hydrogen, the simplest element in the universe being composed of only one proton and one electron, makes up the major part of the composition of the universe. On the earth's surface, hydrogen exists as a compound with other elements such as oxygen, carbon, and nitrogen; most hydrogen is found as a compound with oxygen, in the form of water. Normally, pure hydrogen exists in the form of a hydrogen molecule with two atoms, $H_2$.

There are many reports and data on the properties of hydrogen, but the properties most related to the applications of hydrogen as an energy medium are described in this article.

## 2. Physical and Chemical Properties

Hydrogen has two isotopes: deuterium (D; atomic weight 2.01410222) and tritium (T; atomic weight 3.0160497). Tritium is radioactive and emits very low energy β rays with a half-life of 12.26 years. The isotopes have different physical properties but quite similar chemical properties. In this article, only H is described, since $H_2$ gas is important as an energy medium in hydrogen energy systems.

### 2.1 Basic and Chemical Properties of Hydrogen

A hydrogen molecule consists of two hydrogen atoms. Hydrogen is a colorless and odorless gas at room temperature and is the lightest gas, being about 1/14 as dense as air. Liquefied hydrogen, which has very low boiling point (–252.88 °C), takes up much

less space, about 1/700 times as much space as gaseous hydrogen. But even in liquefied state, it is still very light. Its density is about 0.07 g $cm^{-3}$. Hydrogen itself is a rather stable molecule with high bond energy (435.99 kJ $mol^{-1}$), but it reacts with many different kinds of elements to form compounds with them. As is well known, hydrogen easily reacts (burns) with oxygen at a wide range of mixing ratios and forms water. This makes it possible to use hydrogen as an energy medium. The mixture of hydrogen and air can be ignited with very low energy sparks and safety precautions are required. The reactivity of hydrogen with other elements is used for various chemical industries, but this article focuses on its application as an energy medium. The reactions of hydrogen with some organic compounds can be used to store and carry hydrogen. For instance, by reacting hydrogen with benzene to make cyclohexane, hydrogen can be stored as cyclohexane, which can later be separated to benzene and hydrogen. Ammonia and metal hydrides are also applications of the reactivity of hydrogen for storage. For details of these processes, refer to each topic of this encyclopedia. The most important chemical properties of hydrogen as an energy medium are the ones related to combustion. Table 1 shows the basic and chemical properties of hydrogen.

| |
|---|
| **Hydrogen atom** |
| Atomic number: 1 |
| Atomic weight: 1.00782519 (on $^{12}C$ scale) |
| CAS Registry Number: 12385–13–6 |
| **Hydrogen molecule** |
| Formula: $H_2$ |
| Chemical structure: H–H |
| Molecular weight: 2.0159 |
| CAS Registry Number: 1333–74–0 |
| UN Number: UN1049 (gas); UN1966 (liquid) |
| RTECS Number: MW 8900 000 |
| Appearance: Colorless and odorless gas at room temperature |
| Density (gas): 0.08988 g $L^{-1}$ (0 °C, 1 atm) |
| Relative vapor density (air = 1): 0.07 |
| Density (liquid): 70.8 g $L^{-1}$ (at –253 °C ) |
| Melting point: –259.35 °C |
| Boiling point: –252.88 °C (at 1 atm) |
| Solubility in water: 0.0214 $cm^3$ $g^{-1}$ (0 °C, 1 atm) |
| Energy content for 1 kg hydrogen (when reacting with oxygen to form water) |
| Higher heating value: 141 900 kJ; 33 900 kcal; 39.4 kWh |
| Lower heating value: 120 000 kJ; 28 680 kcal; 32.9 kWh |
| Auto-ignition temperature: 500–571 °C |
| Explosive limits: 4–76% (vol. % in air) |

Table 1. The basic and chemical properties of hydrogen.

-
-
-



**Bibliography**

Dean J. (1999). *Lange's Handbook of Chemistry*, 15th ed. 3.30 pp New York: McGraw-Hill. [A reference book of chemical and physical properties of chemical substances.]

Grayson M. (1980). *Kirk-Othmer Encyclopedia of Chemical Technology* 3rd ed., Vol. 12, 938 pp. New York, Chichester: John Wiley and Sons. [General information on hydrogen energy including chemical and physical properties of hydrogen.]

Lide D. (1998). *CRC Handbook of Chemistry and Physics*, 79th ed. **4**-14 – **4**-15 pp. Boca Raton, FL: CRC Press. [A Ready-Reference Book of Chemical and Physical Data.]

http://www.webelements.com/webelements/elements/text/H/index.html. [A website for general properties of hydrogen.]
http://www.eren.doe.gov/hydrogen/. [A website of US DOE for hydrogen energy with general information of hydrogen.]

http://siri.uvm.edu/nioshdb/ipcsneng/neng0001.htm. [A website for International Chemical Safety Cards including properties related to safety.]

**Biographical Sketch**

**Isao Abe**, born 16 September 1939, in Osaka, Japan, received his Bachelor of Engineering Degree from the Department of Fuel Engineering, Faculty of Engineering, University of Tokyo (1963), and Master of Engineering from the Department of Reaction Chemistry of the same faculty, the same university (1966). He worked for Showa Denko K.K. as a chemical engineer (1966–1999), and was involved in development of the advanced alkaline water electrolyzer under the Sunshine Project of the Japanese government as the director of technical development (1974–1984); during that period, he worked as formal alternate representative of Japan to the IEA Task IV (water electrolysis) workshop. He has been editor-in-chief of *Journal of the Hydrogen Energy System Society of Japan* since 1998.