Hydrogen (chemical symbol, H) is the simplest atom and the most abundant chemical element. The basic hydrogen atom consists of a single proton with one electron bound to it. About 90 percent of all atoms in the universe are hydrogen atoms. Under normal conditions on Earth, pure hydrogen exists in the form of bound pairs of atoms. This type of hydrogen, called molecular hydrogen or H_2, is a tasteless, odorless, colorless gas.

Hydrogen's simplicity and abundance make the element vital to the study of chemistry, physics, and astronomy. Studies of the *spectrum* (range of colors of light) given off by hydrogen atoms helped physicists determine the structure of the atom. This work led to the development of *quantum mechanics,* a branch of physics that describes the structure and behavior of matter.

The English scientist Henry Cavendish first described hydrogen as an individual substance in 1766. Cavendish later burned hydrogen in air and showed that the result was pure water. The French chemist Antoine Lavoisier concluded from this experiment that water is a compound of hydrogen and oxygen. The name *hydrogen* comes from the Greek words meaning *water-forming.*

Properties. Hydrogen's *atomic number* (the number of protons in its nucleus) is 1. Its *relative atomic mass* is 1.00794. An element's relative atomic mass equals its *mass* (amount of matter) divided by 1/12 the mass of carbon 12, the most abundant form of carbon.

H_2 gas has the lowest density of any known substance. At 0 °C and atmospheric pressure, its density measures only 0.09 milligrams per cubic centimeter, making it about 14 times lighter than air. The Scottish scientist James Dewar created liquid hydrogen in 1898 and solid hydrogen one year later. Liquid hydrogen boils at −252.87 °C (20.28 K) and freezes at −259.14 °C (14.01 K).

Isotopes. Hydrogen has three *isotopes,* forms of the same element that have different numbers of neutrons in their nucleus. In the most common hydrogen isotope, called *protium,* the nucleus consists of only a proton.

In 1931, the American chemist Harold C. Urey discovered the second isotope, called *deuterium* or *heavy hydrogen* (chemical symbol, D). The nucleus of a deuterium atom has one proton and one neutron. Deuterium formed soon after the *big bang,* the cosmic explosion that scientists think started the expansion of the universe. Deuterium makes up about 1 part in 6,700 parts of normal hydrogen. See **Deuterium.**

In 1934, scientists discovered the third isotope, *tritium* (chemical symbol, T). Its nucleus has one proton and two neutrons. Tritium is radioactive, with a *half-life* of about 12.3 years—that is, because of radioactive decay, only half the atoms in a sample of tritium will still be atoms of that isotope after 12.3 years. Tritium has been used in the hydrogen bomb. See **Tritium.**

Compounds. A wide variety of natural and artificial chemical compounds contain hydrogen. It serves as an important component of *organic* (carbon-based) compounds, including ethers, esters, and such alcohols as methanol and ethanol. It appears in most biologically important compounds, including proteins, fats, and *DNA* (deoxyribonucleic acid, the genetic material of life). Organic compounds called *hydrocarbons* consist entirely of hydrogen and carbon. They include methane, ethylene, acetylene, and propane. Complex hydrocarbons appear in gasoline, diesel fuel, and oils and greases. Plastics and other *polymers,* long molecules made up of chains of smaller molecules, also contain hydrogen.

Acids, such as hydrochloric acid (HCl) and sulfuric acid (H_2SO_4), have weakly bound hydrogen atoms. These bonds break when the acid is dissolved, releasing positive *ions* of hydrogen (H^+) into the solution. Ions are electrically charged atoms or molecules. The H^+ ions give a solution its acidity. The pH scale, used to measure acidity, describes the concentration of dissolved H^+ in a solution. Most bases, including sodium hydroxide (NaOH), contain a hydrogen atom bound to an oxygen atom. Some saltlike compounds, such as *sodium bicarbonate* (baking soda, $NaHCO_3$), also contain hydrogen.

Occurrence. Stars consist mainly of hydrogen. In the cores of stars, hydrogen nuclei *fuse* (combine) to form helium nuclei. This process, a type of *nuclear fusion,* produces the tremendous energy that stars give off. Inside stars and in the energetic regions around them, hydrogen atoms lose an electron, becoming H^+ ions. In the atmospheres of some stars, including the sun, hydrogen can gain an electron to form the negative ion H^-.

Large amounts of hydrogen also occur in *interstellar clouds,* clouds of gas and dust in the space between stars. This hydrogen consists mostly of neutral H atoms or H_2 molecules. Hydrogen in interstellar clouds can also react to form a three-atom ion, H_3^+. Astronomers study the concentrations of H, H_2, and H_3^+ in interstellar clouds to learn more about the structure and conditions in other parts of our galaxy.

Hydrogen also serves as an important component of planets in our solar system. The *gas giant* planets—Jupiter, Saturn, Uranus, and Neptune—consist mainly of hydrogen. Hydrogen is less abundant on Earth because the planet's gravity is not strong enough to prevent H_2 from escaping into space. Nevertheless, hydrogen ranks in number of atoms as the third most abundant element on Earth, following oxygen and silicon. Because it is so light, however, hydrogen accounts for only 0.14 percent of the weight of Earth's crust, ranking 10th among the elements. Most of the hydrogen that remains on Earth occurs in compounds. Much hydrogen is found in water (H_2O), in organic compounds in the cells of living things, and in the hydrocarbons that make up crude oil and natural gas.

Preparation. In the laboratory, scientists sometimes produce hydrogen by the *electrolysis* of water. In this process, an electric current passes through the water, breaking it down into hydrogen and oxygen gases. Manufacturers make most commercial hydrogen by passing steam over hot coke or iron, or by reacting steam with natural gas in the presence of a *catalyst* (substance that speeds up a chemical reaction). Large amounts of hydrogen also result from the manufacture of sodium hydroxide by the electrolysis of *brine* (extremely salty water).

Sodium and many other chemically active metals react directly with water to release hydrogen even at room temperature. Less active metals, such as magnesium, will free hydrogen from steam. Zinc and many other metals will release hydrogen from solutions of acids in water.

Deuterium comes primarily from the separation and electrolysis of *heavy water* (D_2O), which occurs naturally in small concentrations in ordinary water. Tritium occurs naturally in Earth's upper atmosphere, but in extremely small amounts. Most tritium is produced in devices called *nuclear reactors.*

Uses. The major industrial use of hydrogen is in the production of ammonia by a method called the *Haber process* (see **Haber process**). Hydrogen also serves as a raw material in the production of other chemicals, including methanol, hydrogen peroxide, and various polymers and *solvents* (chemicals used to dissolve other substances). Manufacturers use hydrogen in the production of certain pharmaceuticals, in the refining of petroleum, and in the making of devices called *integrated circuits* used in computers and other electronic equipment. Food companies combine hydrogen with liquid vegetable oils to produce *hydrogenated oils* that are used in shortening, margarine, and other foods. Hydrogen is widely used to recover metals from their ores because it is a good *reducing agent*—that is, hydrogen can withdraw oxygen and other nonmetallic elements from metallic compounds, leaving a pure metal.

Hydrogen can also serve as a fuel. The United States space shuttle and many other rockets burn hydrogen fuel with oxygen. Engine manufacturers can modify the internal combustion engines used in automobiles and other vehicles to burn hydrogen rather than gasoline. Devices called *fuel cells* produce electrical energy by reacting hydrogen with oxygen to make water.

Some experts have suggested working to replace the use of *fossil fuels,* such as coal, oil, and natural gas, with more widespread use of hydrogen. They argue that hydrogen is a renewable fuel that produces little pollution. However, the production of H_2 requires energy, usually obtained by burning fossil fuels. To reduce fossil fuel consumption, engineers must develop affordable ways to make H_2 using renewable energy sources, such as solar power, wind power, or hydroelectric power. They must also create safe and affordable methods for storing and transporting hydrogen.

Researchers are also attempting to develop *fusion reactors* that combine hydrogen nuclei, producing energy in the same way that stars do. Hydrogen undergoes fusion in the form of a *plasma,* a state of matter consisting of electrically charged particles. Scientists and engineers are trying to build a reactor that can contain hydrogen plasma at the high temperature and density needed to sustain fusion. To be practical, the reactor must not use more energy to create and sustain the plasma than the fusion reaction produces.

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