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The Role of Helium in Today's World

"Helium" comes from the Greek word Helios, or sun, because it was first detected as a new spectral line during a solar eclipse. Helium is the only element that was first discovered outside of Earth; later, it was found in air at very low (0.0005%) concentration.

During an 1868 solar eclipse in India, a spectrometer was used to study the chromosphere around the sun. The chromosphere is a relatively thin layer of the Sun's atmosphere, roughly 2000km deep. Its red coloring can only be seen directly with the naked eye during a total solar eclipse, when the chromosphere is briefly visible as a flash of color, in the short time as the visible edge of the photosphere disappears behind the Moon. The photosphere is the region from which externally received light originates. Scientists can observe the chemical composition of celestial objects by studying the spectrum of visible light emitted. Different elements absorb different wavelengths of light as shown on the spectrum. The sun's spectrum revealed characteristic absorption lines for hydrogen on the spectrum along with a yellow stripe that was thought to correspond to sodium. However, Pierre Janssen, a French astronomer, proved that the yellow stripe indicated a new element. His proof follows from a comparison of the yellow strip of Sodium and Helium when he tried to reproduce the chromosphere's spectrum. For the discovery of Helium, Janssen is jointly credited with Norman Lockyer who observed the same eclipse in India in 1868 and proposed to name the new element Helium.

The largest supply of Helium was found in 1903 in the n some US natural-gas fields. Helium is used for cryogenics for studying the properties of materials at very low temperatures, deep-sea breathing systems, superconducting magnets, helium-dating, balloon inflation, airships, and as a protective gas for arc welding and for growing silicon wafers. Helium-dating is a method of determining the age of a substance using the decay of radioactive isotopes.

Helium is a colorless, odorless, tasteless, non-toxic, monatomic element that leads the noble-gas group in the periodic table. It has the lowest boiling point in the periodic table and, unless the temperature is extremely low, it only exists as a gas. Except for unusual conditions, helium is chemically inert. It was generally believed that helium was not present on Earth until 1895 when Sir William Ramsay examined a gas produced by reacting acid with a Norwegian ore called cleveite. The gas spectrum revealed the same bright yellow stripe seen in the Sun, proving helium's existence on Earth. Since helium has a low molar atomic mass, its thermal conductivity, specific heat, and speed of sound are all greater than those for any other gas except hydrogen. Also, due to the small radius of a helium atom, helium's diffusion rate through solids is three times larger than that of air. In the plasma state, more extraterrestrial helium is found with properties different from those of atomic helium. As plasma, helium's electrons are not nucleus-bound giving a high electrical conductivity, even when only partially ionized. These charged particles are highly influenced by magnetic and electric fields.

Unlike other elements, at normal pressures, helium remains liquid (i.e. it does not freeze into a solid) down to absolute zero due to the zero-point energy that is too high to allow freezing. Solid helium requires a temperature about 1 to 1.5K and about 2.5Mpa pressure. Although highly compressible, solid helium has a sharp melting point and a crystalline structure. When applying pressure, its volume can decrease by more than 30% and compress 50 times more than water.

Helium exists in 2 states. Helium I is the isotope Helium-4 which can be cooled to give a normal, colorless liquid. Like other cryogenic liquids, Helium I boils when heated and condenses when cooled. However, below the lambda point of Helium I (2.18K), helium doesn't boil; instead, helium expands when cooled.

The difference between Helium I and II is that Helium I exists above the lambda point while Helium II is below the lambda point. Unlike other liquids, Helium II will creep along surfaces to reach an equal level, almost as if against gravitational force. When it flows through capillaries as thin as 10^{-7} to 10^{-8}m, it has no measurable viscosity. Helium II's thermal conductivity is larger than that of any other known substance. It is 10^{6} times larger than that of Helium I and several hundred times larger than that of copper.

Helium has eight known isotopes, but only Helium-3 and Helium-4 are stable. The isotopes range from Helium-3 to Helium-10. In the Earth's atmosphere, there is one He-3 atom for every million He-4 atoms. He-4 is produced on Earth through alpha decay of heavier radioactive elements. The alpha particles that emerge are fully ionized He-4 nuclei. He-4 has a very stable nucleus because nucleons are arranged in complete shells. It was formed in enormous quantities during Big Bang nucleosynthesis. He-3 is only present on earth in trace amounts produced by the beta decay of tritium. Tritium is the radioactive isotope of hydrogen with one proton and two neutrons. Rocks from the Earth's crust have isotope ratios that can be used to explore the origin of rocks and the composition of the Earth's mantle. He-3 is a product of nuclear fusion and is more abundant in stars. Therefore, the proportion of He-3 to He-4 is 100 times higher in space than on Earth.

Because of its zero valence, helium is chemically unreactive under all normal conditions and is an electrical insulator unless ionized. Helium can form unstable compounds, called excimers, with tungsten, iodine, fluorine, sulfur, and phosphorus, when subjected to an electric glow discharge.

Helium is the second most abundant element in the Universe making up 23% of the "baryonic"[1] mass of the Universe. Most of it was formed by Big Bang nucleosynthesis from 1-2 minutes after the Big Bang. Thus, measurements of its abundance can contribute to establishing cosmological models. Helium forms in stars through nuclear fusion of hydrogen in proton-proton chain reactions and the CNO cycle[2], which is part of stellar nucleosynthesis. Unlike space, the Earth's atmosphere only holds a concentration of helium equal to 5.2 parts per million because, although there is continuous production of new helium, most helium in the Earth's atmosphere escapes into space. Almost all helium on Earth is due to radioactive decay of uranium and thorium. About 3000 tons of helium are generated every year throughout the Earth's lithosphere. The greatest concentrations of helium on Earth are found in natural gas, which, in some cases, can contain up to 7 mol % Helium.

[1] Baryonic mass consist of atoms of any sort (and thus includes nearly all matter that we may encounter or experience in everyday life, including our bodies). Non-baryonic mass is any sort of matter that is not primarily composed of baryons such as neutrinos or free electrons.

[2] Also called the Bethe-Weizsäcker cycle, the CNO cycle is one of two sets of fusion reactions where stars convert hydrogen to helium. The other set is called the proton-proton chain. It is called the CNO cycle because four protons fuse by using carbon, nitrogen, and oxygen isotopes as a catalyst to produce one alpha particle, two positrons, and two electron neutrinos.

Applications

For large-scale, commercial use, helium is extracted using fractional distillation from natural gas. Because helium's boiling point is lower than that of any other substance, low temperature and high pressure are used to liquefy all components in natural gas (nitrogen and methane). Crude helium is purified by successive condensation of almost all nitrogen and other gases. Activated charcoal is then used as a final purification step. The result is 99.995% pure Grade-A Helium. The main impurity is Neon.

Much of the helium produced is liquefied through a cryogenic process for applications that need liquid Helium. Liquid (rather than gaseous) helium allows helium suppliers to minimize the price for long-distance transportation. The largest liquid helium containers have over 5 times the capacity of the largest gaseous helium tube trailers. In 2005, almost 160 million m^3 of gaseous helium were extracted from natural gas or withdrawn from Helium reserves. Almost 83% came from Kansas, Oklahoma, and Texas, 11% from Algeria, and the rest from Russia and Poland.

There are other methods for producing Helium. The first is by diffusing crude natural gas through semi-permeable membranes to recover and then purify helium. The second is to synthesize Helium by bombarding lithium or boron with high-velocity protons. However, the second method is rarely used because it is too expensive.

Helium possesses a low boiling point, low density, low solubility in liquids, and high thermal conductivity. Since helium is lighter than air, airships and balloons are inflated with helium for lift. Although hydrogen gas is 7% more buoyant, helium is preferred because it is nonflammable. Since helium is less dense than atmospheric air, it can also change the timbre of someone’s voice when inhaled. However, there is risk of asphyxiation from lack of oxygen and from contaminants that may be present. To reduce the effects of narcosis in deep-sea diving, helium is also used in mixtures with oxygen because of its low solubility in nerve tissue. At depths exceeding 150m, helium’s low density considerably reduces the effort of breathing. Helium-Neon lasers are also used as barcode readers. Helium is used as a heat-transfer medium for gas-cooled nuclear reactors because of its inertness, high thermal conductivity, neutron transparency, and its inability to form radioactive isotopes under reactor conditions. Further, helium is used as a shielding gas in arc welding processes for materials that are easily contaminated by air. It is also used as a protective gas for growing silicon and germanium crystals, for titanium and zirconium production, and as a carrier gas in chromatography.

Helium’s unique properties have made a large contribution to society, especially through essential contributions to the space program. Helium is preferred because hydrogen is too flammable. Without helium, we would not be able to send rockets into space. Without rockets, we would have no satellites for world-wide telephone communication. Because helium is present throughout space at high concentrations, the discovery of helium has enabled astrophysicists and astrochemists to learn more about our Universe.