= Helium =

Helium is a chemical element with symbol He and atomic number 2 . It is a colorless , odorless , tasteless , non @-@ toxic , inert , monatomic gas , the first in the noble gas group in the periodic table . The He boiling and melting points are the lowest among all the elements .

Helium is the second lightest element and is the second most abundant element in the observable universe , being present at about 24 % of the total elemental mass , which is more than 12 times the mass of all the heavier elements combined . Its abundance is similar to this figure in the Sun and in Jupiter . This is due to the very high nuclear binding energy (per nucleon) of helium @-@ 4 with respect to the next three elements after helium . This helium @-@ 4 binding energy also accounts for why it is a product of both nuclear fusion and radioactive decay . Most helium in the universe is helium @-@ 4 , and is believed to have been formed during the Big Bang . Large amounts of new helium are being created by nuclear fusion of hydrogen in stars .

Helium is named for the Greek god of the Sun , Helios . It was first detected as an unknown yellow spectral line signature in sunlight during a solar eclipse in 1868 by French astronomer Jules Janssen . Janssen is jointly credited with detecting the element along with Norman Lockyer . Jannsen observed during the solar eclipse of 1868 while Lockyer observed from Britain . Lockyer was the first to propose that the line was due to a new element , which he named . The formal discovery of the element was made in 1895 by two Swedish chemists , Per Teodor Cleve and Nils Abraham Langlet , who found helium emanating from the uranium ore cleveite . In 1903 , large reserves of helium were found in natural gas fields in parts of the United States , which is by far the largest supplier of the gas today .

Liquid helium is used in cryogenics (its largest single use , absorbing about a quarter of production) , particularly in the cooling of superconducting magnets , with the main commercial application being in MRI scanners . Helium 's other industrial uses ? as a pressurizing and purge gas , as a protective atmosphere for arc welding and in processes such as growing crystals to make silicon wafers ? account for half of the gas produced . A well @-@ known but minor use is as a lifting gas in balloons and airships . As with any gas whose density differs from that of air , inhaling a small volume of helium temporarily changes the timbre and quality of the human voice . In scientific research , the behavior of the two fluid phases of helium @-@ 4 (helium I and helium II) is important to researchers studying quantum mechanics (in particular the property of superfluidity) and to those looking at the phenomena , such as superconductivity , produced in matter near absolute zero .

On Earth it is relatively rare ? 5 @.@ 2 ppm by volume in the atmosphere . Most terrestrial helium present today is created by the natural radioactive decay of heavy radioactive elements (thorium and uranium , although there are other examples) , as the alpha particles emitted by such decays consist of helium @-@ 4 nuclei . This radiogenic helium is trapped with natural gas in concentrations up to 7 % by volume , from which it is extracted commercially by a low @-@ temperature separation process called fractional distillation . Previously , terrestrial helium was thought to be a non @-@ renewable resource because once released into the atmosphere , it readily escapes into space . However , recent studies suggest that helium is produced deep in the earth by radioactive decay , and that large untapped reserves may exist under the Rocky Mountains in North America and in natural gas reserves . Geologists / Researchers of Durham and Oxford universities found large quantities of helium within the Tanzanian East African Rift Valley .

= = History = =

= = = Scientific discoveries = = =

The first evidence of helium was observed on August 18 , 1868 , as a bright yellow line with a wavelength of 587 @.@ 49 nanometers in the spectrum of the chromosphere of the Sun . The line was detected by French astronomer Jules Janssen during a total solar eclipse in Guntur , India .

This line was initially assumed to be sodium . On October 20 of the same year , English astronomer Norman Lockyer observed a yellow line in the solar spectrum , which he named the D3 Fraunhofer line because it was near the known D1 and D2 lines of sodium . He concluded that it was caused by an element in the Sun unknown on Earth . Lockyer and English chemist Edward Frankland named the element with the Greek word for the Sun , ????? (helios) .

In 1882 , Italian physicist Luigi Palmieri detected helium on Earth for the first time through its D3 spectral line , when he analyzed the lava of Mount Vesuvius .

On March 26 , 1895 , Scottish chemist Sir William Ramsay isolated helium on Earth by treating the mineral cleveite (a variety of uraninite with at least 10 % rare earth elements) with mineral acids . Ramsay was looking for argon but , after separating nitrogen and oxygen from the gas liberated by sulfuric acid , he noticed a bright yellow line that matched the D3 line observed in the spectrum of the Sun . These samples were identified as helium by Lockyer and British physicist William Crookes . It was independently isolated from cleveite in the same year by chemists Per Teodor Cleve and Abraham Langlet in Uppsala , Sweden , who collected enough of the gas to accurately determine its atomic weight . Helium was also isolated by the American geochemist William Francis Hillebrand prior to Ramsay 's discovery when he noticed unusual spectral lines while testing a sample of the mineral uraninite . Hillebrand , however , attributed the lines to nitrogen . His letter of congratulations to Ramsay offers an interesting case of discovery and near @-@ discovery in science .

In 1907 , Ernest Rutherford and Thomas Royds demonstrated that alpha particles are helium nuclei by allowing the particles to penetrate the thin glass wall of an evacuated tube , then creating a discharge in the tube to study the spectra of the new gas inside . In 1908 , helium was first liquefied by Dutch physicist Heike Kamerlingh Onnes by cooling the gas to less than one kelvin . He tried to solidify it by further reducing the temperature but failed because helium does not solidify at atmospheric pressure . Onnes ' student Willem Hendrik Keesom was eventually able to solidify 1 cm3 of helium in 1926 by applying additional external pressure .

In 1938 , Russian physicist Pyotr Leonidovich Kapitsa discovered that helium @-@ 4 has almost no viscosity at temperatures near absolute zero , a phenomenon now called superfluidity . This phenomenon is related to Bose ? Einstein condensation . In 1972 , the same phenomenon was observed in helium @-@ 3 , but at temperatures much closer to absolute zero , by American physicists Douglas D. Osheroff , David M. Lee , and Robert C. Richardson . The phenomenon in helium @-@ 3 is thought to be related to pairing of helium @-@ 3 fermions to make bosons , in analogy to Cooper pairs of electrons producing superconductivity .

= = = Extraction and use = = =

After an oil drilling operation in 1903 in Dexter , Kansas , produced a gas geyser that would not burn , Kansas state geologist Erasmus Haworth collected samples of the escaping gas and took them back to the University of Kansas at Lawrence where , with the help of chemists Hamilton Cady and David McFarland , he discovered that the gas consisted of , by volume , 72 % nitrogen , 15 % methane (a combustible percentage only with sufficient oxygen) , 1 % hydrogen , and 12 % an unidentifiable gas . With further analysis , Cady and McFarland discovered that 1 @.@ 84 % of the gas sample was helium . This showed that despite its overall rarity on Earth , helium was concentrated in large quantities under the American Great Plains , available for extraction as a byproduct of natural gas .

This enabled the United States to become the world 's leading supplier of helium . Following a suggestion by Sir Richard Threlfall , the United States Navy sponsored three small experimental helium plants during World War I. The goal was to supply barrage balloons with the non @-@ flammable , lighter @-@ than @-@ air gas . A total of 5 @,@ 700 m3 (200 @,@ 000 cu ft) of 92 % helium was produced in the program even though less than a cubic meter of the gas had previously been obtained . Some of this gas was used in the world 's first helium @-@ filled airship , the U.S. Navy 's C @-@ 7 , which flew its maiden voyage from Hampton Roads , Virginia , to Bolling Field in Washington , D.C. , on December 1 , 1921 , nearly two years before the Navy 's first rigid helium @-@ filled airship , the Naval Aircraft Factory @-@ built USS Shenandoah , flew in September

1923 .

Although the extraction process , using low @-@ temperature gas liquefaction , was not developed in time to be significant during World War I , production continued . Helium was primarily used as a lifting gas in lighter @-@ than @-@ air craft . During World War II , the demand increased for helium for lifting gas and for shielded arc welding . The helium mass spectrometer was also vital in the atomic bomb Manhattan Project .

The government of the United States set up the National Helium Reserve in 1925 at Amarillo , Texas , with the goal of supplying military airships in time of war and commercial airships in peacetime . Because of the Helium Control Act (1927) , which banned the export of scarce helium on which the US then had a production monopoly , together with the prohibitive cost of the gas , the Hindenburg , like all German Zeppelins , was forced to use hydrogen as the lift gas . The helium market after World War II was depressed but the reserve was expanded in the 1950s to ensure a supply of liquid helium as a coolant to create oxygen / hydrogen rocket fuel (among other uses) during the Space Race and Cold War . Helium use in the United States in 1965 was more than eight times the peak wartime consumption .

After the " Helium Acts Amendments of 1960 " (Public Law 86 ? 777) , the U.S. Bureau of Mines arranged for five private plants to recover helium from natural gas . For this helium conservation program , the Bureau built a 425 @-@ mile (684 km) pipeline from Bushton , Kansas , to connect those plants with the government 's partially depleted Cliffside gas field near Amarillo , Texas . This helium @-@ nitrogen mixture was injected and stored in the Cliffside gas field until needed , at which time it was further purified .

By 1995 , a billion cubic meters of the gas had been collected and the reserve was US $ 1 @.@ 4 billion in debt , prompting the Congress of the United States in 1996 to phase out the reserve . The resulting " Helium Privatization Act of 1996 " (Public Law 104 ? 273) directed the United States Department of the Interior to empty the reserve , with sales starting by 2005 .

Helium produced between 1930 and 1945 was about 98 @.@ 3 % pure (2 % nitrogen) , which was adequate for airships . In 1945 , a small amount of 99 @.@ 9 % helium was produced for welding use . By 1949 , commercial quantities of Grade A 99 @.@ 95 % helium were available .

For many years , the United States produced more than 90 % of commercially usable helium in the world , while extraction plants in Canada , Poland , Russia , and other nations produced the remainder . In the mid @-@ 1990s , a new plant in Arzew , Algeria , producing 17 million cubic meters (600 million cubic feet) began operation , with enough production to cover all of Europe 's demand . Meanwhile , by 2000 , the consumption of helium within the U.S. had risen to more than 15 million kg per year . In 2004 ? 2006 , additional plants in Ras Laffan , Qatar , and Skikda , Algeria were built . Algeria quickly became the second leading producer of helium . Through this time , both helium consumption and the costs of producing helium increased . From 2002 to 2007 helium prices doubled .

As of 2012 , the United States National Helium Reserve accounted for 30 percent of the world 's helium . The reserve was expected to run out of helium in 2018 . Despite that , a proposed bill in the United States Senate would allow the reserve to continue to sell the gas . Other large reserves were in the Hugoton in Kansas , United States , and nearby gas fields of Kansas and the panhandles of Texas and Oklahoma . New helium plants were scheduled to open in 2012 in Qatar , Russia , and the United States state of Wyoming , but they were not expected to ease the shortage .

In 2013 , Qatar started up the world 's largest helium unit . 2014 was widely acknowledged to be a year of over @-@ supply in the helium business , following years of renowned shortages . Nasdaq reported (2015) that for Air Products , an international corporation that sells gases for industrial use , helium volumes remain under pressure due to feedstock supply constraints .

= = Characteristics = =

= = = The helium atom = = =

= = = = Helium in quantum mechanics = = = =

In the perspective of quantum mechanics , helium is the second simplest atom to model , following the hydrogen atom . Helium is composed of two electrons in atomic orbitals surrounding a nucleus containing two protons and (usually) two neutrons . As in Newtonian mechanics , no system that consists of more than two particles can be solved with an exact analytical mathematical approach (see 3 @-@ body problem) and helium is no exception . Thus , numerical mathematical methods are required , even to solve the system of one nucleus and two electrons . Such computational chemistry methods have been used to create a quantum mechanical picture of helium electron binding which is accurate to within < 2 % of the correct value , in a few computational steps . Such models show that each electron in helium partly screens the nucleus from the other , so that the effective nuclear charge Z which each electron sees , is about 1 @.@ 69 units , not the 2 charges of a classic " bare " helium nucleus .

= = = = The related stability of the helium @-@ 4 nucleus and electron shell = = = =

The nucleus of the helium @-@ 4 atom is identical with an alpha particle . High @-@ energy electron @-@ scattering experiments show its charge to decrease exponentially from a maximum at a central point , exactly as does the charge density of helium 's own electron cloud . This symmetry reflects similar underlying physics : the pair of neutrons and the pair of protons in helium 's nucleus obey the same quantum mechanical rules as do helium 's pair of electrons (although the nuclear particles are subject to a different nuclear binding potential) , so that all these fermions fully occupy 1s orbitals in pairs , none of them possessing orbital angular momentum , and each cancelling the other 's intrinsic spin . Adding another of any of these particles would require angular momentum and would release substantially less energy (in fact , no nucleus with five nucleons is stable) . This arrangement is thus energetically extremely stable for all these particles , and this stability accounts for many crucial facts regarding helium in nature .

For example , the stability and low energy of the electron cloud state in helium accounts for the element 's chemical inertness , and also the lack of interaction of helium atoms with each other , producing the lowest melting and boiling points of all the elements .

In a similar way , the particular energetic stability of the helium @-@ 4 nucleus , produced by similar effects , accounts for the ease of helium @-@ 4 production in atomic reactions that involve either heavy @-@ particle emission or fusion . Some stable helium @-@ 3 (2 protons and 1 neutron) is produced in fusion reactions from hydrogen , but it is a very small fraction compared to the highly favorable helium @-@ 4 .

The unusual stability of the helium @-@ 4 nucleus is also important cosmologically : it explains the fact that in the first few minutes after the Big Bang , as the " soup " of free protons and neutrons which had initially been created in about 6 : 1 ratio cooled to the point that nuclear binding was possible , almost all first compound atomic nuclei to form were helium @-@ 4 nuclei . So tight was helium @-@ 4 binding that helium @-@ 4 production consumed nearly all of the free neutrons in a few minutes , before they could beta @-@ decay , and also leaving few to form heavier atoms such as lithium , beryllium , or boron . Helium @-@ 4 nuclear binding per nucleon is stronger than in any of these elements (see nucleogenesis and binding energy) and thus , once helium had been formed , no energetic drive was available to make elements 3 , 4 and 5 . It was barely energetically favorable for helium to fuse into the next element with a lower energy per nucleon , carbon . However , due to lack of intermediate elements , this process requires three helium nuclei striking each other nearly simultaneously (see triple alpha process) . There was thus no time for significant carbon to be formed in the few minutes after the Big Bang , before the early expanding universe cooled to the temperature and pressure point where helium fusion to carbon was no longer possible . This left the early universe with a very similar ratio of hydrogen / helium as is observed today (3 parts hydrogen to 1 part helium @-@ 4 by mass) , with nearly all the neutrons in the universe trapped in helium @-@ 4 .

All heavier elements (including those necessary for rocky planets like the Earth , and for carbon @-@ based or other life) have thus been created since the Big Bang in stars which were hot enough to fuse helium itself . All elements other than hydrogen and helium today account for only 2 % of the mass of atomic matter in the universe . Helium @-@ 4 , by contrast , makes up about 23 % of the universe 's ordinary matter ? nearly all the ordinary matter that is not hydrogen .

= = = Gas and plasma phases = = =

Helium is the second least reactive noble gas after neon , and thus the second least reactive of all elements . It is inert and monatomic in all standard conditions . Because of helium 's relatively low molar (atomic) mass , its thermal conductivity , specific heat , and sound speed in the gas phase are all greater than any other gas except hydrogen . For these reasons and the small size of helium monatomic molecules , helium diffuses through solids at a rate three times that of air and around 65 % that of hydrogen .

Helium is the least water @-@ soluble monatomic gas , and one of the least water @-@ soluble of any gas (CF4 , SF6 , and C4F8 have lower mole fraction solubilities : 0 @.@ 3802 , 0 @.@ 4394 , and 0 @.@ 2372 x2 / 10 ? 5 , respectively , versus helium 's 0 @.@ 70797 x2 / 10 ? 5) , and helium 's index of refraction is closer to unity than that of any other gas . Helium has a negative Joule @-@ Thomson coefficient at normal ambient temperatures , meaning it heats up when allowed to freely expand . Only below its Joule @-@ Thomson inversion temperature (of about 32 to 50 K at 1 atmosphere) does it cool upon free expansion . Once precooled below this temperature , helium can be liquefied through expansion cooling .

Most extraterrestrial helium is found in a plasma state , with properties quite different from those of atomic helium . In a plasma , helium 's electrons are not bound to its nucleus , resulting in very high electrical conductivity , even when the gas is only partially ionized . The charged particles are highly influenced by magnetic and electric fields . For example , in the solar wind together with ionized hydrogen , the particles interact with the Earth 's magnetosphere , giving rise to Birkeland currents and the aurora .

= = = Liquid helium = = =

Unlike any other element , helium will remain liquid down to absolute zero at normal pressures . This is a direct effect of quantum mechanics : specifically , the zero point energy of the system is too high to allow freezing . Solid helium requires a temperature of 1 ? 1 @.@ 5 K (about ? 272 ° C or ? 457 ° F) and about 25 bar (2 @.@ 5 MPa) of pressure . It is often hard to distinguish solid from liquid helium since the refractive index of the two phases are nearly the same . The solid has a sharp melting point and has a crystalline structure , but it is highly compressible ; applying pressure in a laboratory can decrease its volume by more than 30 % . With a bulk modulus of about 27 MPa it is ~ 100 times more compressible than water . Solid helium has a density of 0 @.@ 214 ± 0 @.@ 006 g / cm3 at 1 @.@ 15 K and 66 atm ; the projected density at 0 K and 25 bar (2 @.@ 5 MPa) is 0 @.@ 187 ± 0 @.@ 009 g / cm3 .

= = = = Helium I state = = = =

Below its boiling point of 4 @.@ 22 kelvins and above the lambda point of 2 @.@ 1768 kelvins , the isotope helium @-@ 4 exists in a normal colorless liquid state , called helium I. Like other cryogenic liquids , helium I boils when it is heated and contracts when its temperature is lowered . Below the lambda point , however , helium does not boil , and it expands as the temperature is lowered further .

Helium I has a gas @-@ like index of refraction of 1 @.@ 026 which makes its surface so hard to see that floats of Styrofoam are often used to show where the surface is . This colorless liquid has a very low viscosity and a density of 0 @.@ 145 ? 0 @.@ 125 g / mL (between about 0 and 4 K) , which is only one @-@ fourth the value expected from classical physics . Quantum mechanics is

needed to explain this property and thus both states of liquid helium (helium I and helium II) are called quantum fluids , meaning they display atomic properties on a macroscopic scale . This may be an effect of its boiling point being so close to absolute zero , preventing random molecular motion (thermal energy) from masking the atomic properties .

= = = = Helium II state = = = =

Liquid helium below its lambda point (called helium II) exhibits very unusual characteristics . Due to its high thermal conductivity , when it boils , it does not bubble but rather evaporates directly from its surface . Helium @-@ 3 also has a superfluid phase , but only at much lower temperatures ; as a result , less is known about the properties of the isotope .

Helium II is a superfluid , a quantum mechanical state (see : macroscopic quantum phenomena) of matter with strange properties . For example , when it flows through capillaries as thin as 10 ? 7 to 10 ? 8 m it has no measurable viscosity . However , when measurements were done between two moving discs , a viscosity comparable to that of gaseous helium was observed . Current theory explains this using the two @-@ fluid model for helium II . In this model , liquid helium below the lambda point is viewed as containing a proportion of helium atoms in a ground state , which are superfluid and flow with exactly zero viscosity , and a proportion of helium atoms in an excited state , which behave more like an ordinary fluid .

In the fountain effect , a chamber is constructed which is connected to a reservoir of helium II by a sintered disc through which superfluid helium leaks easily but through which non @-@ superfluid helium cannot pass . If the interior of the container is heated , the superfluid helium changes to non @-@ superfluid helium . In order to maintain the equilibrium fraction of superfluid helium , superfluid helium leaks through and increases the pressure , causing liquid to fountain out of the container .

The thermal conductivity of helium II is greater than that of any other known substance , a million times that of helium I and several hundred times that of copper . This is because heat conduction occurs by an exceptional quantum mechanism . Most materials that conduct heat well have a valence band of free electrons which serve to transfer the heat . Helium II has no such valence band but nevertheless conducts heat well . The flow of heat is governed by equations that are similar to the wave equation used to characterize sound propagation in air . When heat is introduced , it moves at 20 meters per second at 1 @.@ 8 K through helium II as waves in a phenomenon known as second sound .

Helium II also exhibits a creeping effect . When a surface extends past the level of helium II , the helium II moves along the surface , against the force of gravity . Helium II will escape from a vessel that is not sealed by creeping along the sides until it reaches a warmer region where it evaporates . It moves in a 30 nm @-@ thick film regardless of surface material . This film is called a Rollin film and is named after the man who first characterized this trait , Bernard V. Rollin . As a result of this creeping behavior and helium II 's ability to leak rapidly through tiny openings , it is very difficult to confine liquid helium . Unless the container is carefully constructed , the helium II will creep along the surfaces and through valves until it reaches somewhere warmer , where it will evaporate . Waves propagating across a Rollin film are governed by the same equation as gravity waves in shallow water , but rather than gravity , the restoring force is the van der Waals force . These waves are known as third sound .

= = Isotopes = =

There are nine known isotopes of helium , but only helium @-@ 3 and helium @-@ 4 are stable . In the Earth 's atmosphere , one atom is 3He for every million that are 4He . Unlike most elements , helium 's isotopic abundance varies greatly by origin , due to the different formation processes . The most common isotope , helium @-@ 4 , is produced on Earth by alpha decay of heavier radioactive elements ; the alpha particles that emerge are fully ionized helium @-@ 4 nuclei . Helium @-@ 4 is an unusually stable nucleus because its nucleons are arranged into complete shells . It was also formed in enormous quantities during Big Bang nucleosynthesis .

Helium @-@ 3 is present on Earth only in trace amounts ; most of it since Earth 's formation , though some falls to Earth trapped in cosmic dust . Trace amounts are also produced by the beta decay of tritium . Rocks from the Earth 's crust have isotope ratios varying by as much as a factor of ten , and these ratios can be used to investigate the origin of rocks and the composition of the Earth 's mantle . 3He is much more abundant in stars as a product of nuclear fusion . Thus in the interstellar medium , the proportion of 3He to 4He is about 100 times higher than on Earth . Extraplanetary material , such as lunar and asteroid regolith , have trace amounts of helium @-@ 3 from being bombarded by solar winds . The Moon 's surface contains helium @-@ 3 at concentrations on the order of 10 ppb , much higher than the approximately 5 ppt found in the Earth 's atmosphere . A number of people , starting with Gerald Kulcinski in 1986 , have proposed to explore the moon , mine lunar regolith , and use the helium @-@ 3 for fusion .

Liquid helium @-@ 4 can be cooled to about 1 kelvin using evaporative cooling in a 1 @-@ K pot . Similar cooling of helium @-@ 3 , which has a lower boiling point , can achieve about 0 @.@ 2 kelvin in a helium @-@ 3 refrigerator . Equal mixtures of liquid 3He and 4He below 0 @.@ 8 K separate into two immiscible phases due to their dissimilarity (they follow different quantum statistics : helium @-@ 4 atoms are bosons while helium @-@ 3 atoms are fermions) . Dilution refrigerators use this immiscibility to achieve temperatures of a few millikelvins .

It is possible to produce exotic helium isotopes , which rapidly decay into other substances . The shortest @-@ lived heavy helium isotope is helium @-@ 5 with a half @-@ life of 7 @.@ 6 × 10 ? 22 s . Helium @-@ 6 decays by emitting a beta particle and has a half @-@ life of 0 @.@ 8 second . Helium @-@ 7 also emits a beta particle as well as a gamma ray . Helium @-@ 7 and helium @-@ 8 are created in certain nuclear reactions . Helium @-@ 6 and helium @-@ 8 are known to exhibit a nuclear halo .

= = Compounds = =

Helium has a valence of zero and is chemically unreactive under all normal conditions . It is an electrical insulator unless ionized . As with the other noble gases , helium has metastable energy levels that allow it to remain ionized in an electrical discharge with a voltage below its ionization potential . Helium can form unstable compounds , known as excimers , with tungsten , iodine , fluorine , sulfur , and phosphorus when it is subjected to a glow discharge , to electron bombardment , or reduced to plasma by other means . The molecular compounds HeNe , HgHe10 , and WHe2 , and the molecular ions He +
2 , He2 +
2 , HeH + , and HeD + have been created this way . HeH + is also stable in its ground state , but is extremely reactive ? it is the strongest Brønsted acid known , and therefore can exist only in isolation , as it will protonate any molecule or counteranion it contacts . This technique has also produced the neutral molecule He2 , which has a large number of band systems , and HgHe , which is apparently held together only by polarization forces .

Van der Waals compounds of helium can also be formed with cryogenic helium gas and atoms of some other substance , such as LiHe and He2 .

Theoretically , other true compounds may be possible , such as helium fluorohydride (HHeF) which would be analogous to HArF , discovered in 2000 . Calculations show that two new compounds containing a helium @-@ oxygen bond could be stable . Two new molecular species , predicted using theory , CsFHeO and N (CH3) 4FHeO , are derivatives of a metastable [F ? HeO] anion first theorized in 2005 by a group from Taiwan . If confirmed by experiment , the only remaining element with no known stable compounds would be neon .

Helium atoms have been inserted into the hollow carbon cage molecules (the fullerenes) by heating under high pressure . The endohedral fullerene molecules formed are stable at high temperatures . When chemical derivatives of these fullerenes are formed , the helium stays inside . If helium @-@ 3 is used , it can be readily observed by helium nuclear magnetic resonance spectroscopy . Many fullerenes containing helium @-@ 3 have been reported . Although the helium atoms are not attached by covalent or ionic bonds , these substances have distinct properties and a

definite composition , like all stoichiometric chemical compounds .
Under high pressures helium can form compounds with various other elements . Helium @-@ nitrogen clathrate (He (N2) 11) crystals have been grown at room temperature at pressures ca . 10 GPa in a diamond anvil cell . At 130 GPa Na2He is thermodynamically stable with a fluorite structure .

= = Occurrence and production = =

= = = Natural abundance = = =

Although it is rare on Earth , helium is the second most abundant element in the known Universe (after hydrogen) , constituting 23 % of its baryonic mass . The vast majority of helium was formed by Big Bang nucleosynthesis one to three minutes after the Big Bang . As such , measurements of its abundance contribute to cosmological models . In stars , it is formed by the nuclear fusion of hydrogen in proton @-@ proton chain reactions and the CNO cycle , part of stellar nucleosynthesis .

In the Earth 's atmosphere , the concentration of helium by volume is only 5 @.@ 2 parts per million . The concentration is low and fairly constant despite the continuous production of new helium because most helium in the Earth 's atmosphere escapes into space by several processes . In the Earth 's heterosphere , a part of the upper atmosphere , helium and other lighter gases are the most abundant elements .
Most helium on Earth is a result of radioactive decay . Helium is found in large amounts in minerals of uranium and thorium , including cleveite , pitchblende , carnotite and monazite , because they emit alpha particles (helium nuclei , He2 +) to which electrons immediately combine as soon as the particle is stopped by the rock . In this way an estimated 3000 metric tons of helium are generated per year throughout the lithosphere . In the Earth 's crust , the concentration of helium is 8 parts per billion . In seawater , the concentration is only 4 parts per trillion . There are also small amounts in mineral springs , volcanic gas , and meteoric iron . Because helium is trapped in the subsurface under conditions that also trap natural gas , the greatest natural concentrations of helium on the planet are found in natural gas , from which most commercial helium is extracted . The concentration varies in a broad range from a few ppm up to over 7 % in a small gas field in San Juan County , New Mexico .
As of 2011 the world 's helium reserves were estimated at 40 billion cubic meters , with a quarter of that being in the South Pars / North Dome Gas @-@ Condensate field owned jointly by Qatar and Iran .

= = = Modern extraction and distribution = = =

For large @-@ scale use , helium is extracted by fractional distillation from natural gas , which can contain up to 7 % helium . Since helium has a lower boiling point than any other element , low temperature and high pressure are used to liquefy nearly all the other gases (mostly nitrogen and methane) . The resulting crude helium gas is purified by successive exposures to lowering temperatures , in which almost all of the remaining nitrogen and other gases are precipitated out of the gaseous mixture . Activated charcoal is used as a final purification step , usually resulting in 99 @.@ 995 % pure Grade @-@ A helium . The principal impurity in Grade @-@ A helium is neon . In a final production step , most of the helium that is produced is liquefied via a cryogenic process . This is necessary for applications requiring liquid helium and also allows helium suppliers to reduce the cost of long distance transportation , as the largest liquid helium containers have more than five times the capacity of the largest gaseous helium tube trailers .
In 2008 , approximately 169 million standard cubic meters (SCM) of helium were extracted from natural gas or withdrawn from helium reserves with approximately 78 % from the United States , 10 % from Algeria , and most of the remainder from Russia , Poland and Qatar . By 2013 , increases in

helium production in Qatar (under the company RasGas managed by Air Liquide) had increased Qatar 's fraction of world helium production to 25 % , and made it the second largest exporter after the United States .

In the United States , most helium is extracted from natural gas of the Hugoton and nearby gas fields in Kansas , Oklahoma , and the Panhandle Field in Texas . Much of this gas was once sent by pipeline to the National Helium Reserve , but since 2005 this reserve is being depleted and sold off , and is expected under present law to be largely depleted by 2021 .

Diffusion of crude natural gas through special semipermeable membranes and other barriers is another method to recover and purify helium . In 1996 , the U.S. had proven helium reserves , in such gas well complexes , of about 147 billion standard cubic feet (4 @.@ 2 billion SCM) . At rates of use at that time (72 million SCM per year in the U.S. ; see pie chart below) this would have been enough helium for about 58 years of U.S. use , and less than this (perhaps 80 % of the time) at world use rates , although factors in saving and processing impact effective reserve numbers .

Helium must be extracted from natural gas because it is present in air at only a fraction of that of neon , yet the demand for it is far higher . It is estimated that if all neon production were retooled to save helium , that 0 @.@ 1 % of the world 's helium demands would be satisfied . Similarly , only 1 % of the world 's helium demands could be satisfied by re @-@ tooling all air distillation plants . Helium can be synthesized by bombardment of lithium or boron with high @-@ velocity protons , but this process is a completely uneconomic method of production .

Helium is commercially available in either liquid or gaseous form . As a liquid , it can be supplied in small insulated containers called dewars which hold up to 1 @,@ 000 liters of helium , or in large ISO containers which have nominal capacities as large as 42 m3 (around 11 @,@ 000 U.S. gallons) . In gaseous form , small quantities of helium are supplied in high @-@ pressure cylinders holding up to 8 m3 (approx . 282 standard cubic feet) , while large quantities of high @-@ pressure gas are supplied in tube trailers which have capacities of up to 4 @,@ 860 m3 (approx . 172 @,@ 000 standard cubic feet) .

In Tanzania there are large amounts of helium detected .

= = = Conservation advocates = = =

According to helium conservationists like Nobel laureate physicist Robert Coleman Richardson , the free market price of helium has contributed to " wasteful " usage (e.g. for helium balloons) . Prices in the 2000s have been lowered by U.S. Congress ' decision to sell off the country 's large helium stockpile by 2015 . According to Richardson , the current price needs to be multiplied by 20 to eliminate the excessive wasting of helium . In their book , the Future of helium as a natural resource (Routledge , 2012) , Nuttall , Clarke & Glowacki (2012) also proposed to create an International Helium Agency (IHA) to build a sustainable market for this precious commodity .

= = Applications = =

While balloons are perhaps the best known use of helium , they are a minor part of all helium use . Helium is used for many purposes that require some of its unique properties , such as its low boiling point , low density , low solubility , high thermal conductivity , or inertness . Of the 2014 world helium total production of about 32 million kg (180 million standard cubic meters) helium per year , the largest use (about 32 % of the total in 2014) is in cryogenic applications , most of which involves cooling the superconducting magnets in medical MRI scanners and NMR spectrometers . Other major uses were pressurizing and purging systems , welding , maintenance of controlled atmospheres , and leak detection . Other uses by category were relatively minor fractions .

= = = Controlled atmospheres = = =

Helium is used as a protective gas in growing silicon and germanium crystals , in titanium and zirconium production , and in gas chromatography , because it is inert . Because of its inertness ,

thermally and calorically perfect nature , high speed of sound , and high value of the heat capacity ratio , it is also useful in supersonic wind tunnels and impulse facilities .

= = = Gas tungsten arc welding = = =

Helium is used as a shielding gas in arc welding processes on materials that at welding temperatures are contaminated and weakened by air or nitrogen . A number of inert shielding gases are used in gas tungsten arc welding , but helium is used instead of cheaper argon especially for welding materials that have higher heat conductivity , like aluminium or copper .

= = = Minor uses = = =

= = = = Industrial leak detection = = = =

One industrial application for helium is leak detection . Because helium diffuses through solids three times faster than air , it is used as a tracer gas to detect leaks in high @-@ vacuum equipment (such as cryogenic tanks) and high @-@ pressure containers . The tested object is placed in a chamber , which is then evacuated and filled with helium . The helium that escapes through the leaks is detected by a sensitive device (helium mass spectrometer) , even at the leak rates as small as 10 ? 9 mbar · L / s (10 ? 10 Pa · m3 / s) . The measurement procedure is normally automatic and is called helium integral test . A simpler procedure is to fill the tested object with helium and to manually search for leaks with a hand @-@ held device .

Helium leaks through cracks should not be confused with gas permeation through a bulk material . While helium has documented permeation constants (thus a calculable permeation rate) through glasses , ceramics , and synthetic materials , inert gases such as helium will not permeate most bulk metals .

= = = = Flight = = = =

Because it is lighter than air , airships and balloons are inflated with helium for lift . While hydrogen gas is more buoyant , and escapes permeating through a membrane at a lower rate , helium has the advantage of being non @-@ flammable , and indeed fire @-@ retardant . Another minor use is in rocketry , where helium is used as an ullage medium to displace fuel and oxidizers in storage tanks and to condense hydrogen and oxygen to make rocket fuel . It is also used to purge fuel and oxidizer from ground support equipment prior to launch and to pre @-@ cool liquid hydrogen in space vehicles . For example , the Saturn V rocket used in the Apollo program needed about 370 @,@ 000 m3 (13 million cubic feet) of helium to launch .

= = = = Minor commercial and recreational uses = = = =

Helium as a breathing gas has no narcotic properties , so helium mixtures such as trimix , heliox and heliair are used for deep diving to reduce the effects of narcosis , which worsen with increasing depth . As pressure increases with depth , the density of the breathing gas also increases , and the low molecular weight of helium is found to considerably reduce the effort of breathing by lowering the density of the mixture . This reduces the Reynolds number of flow , leading to a reduction of turbulent flow and an increase in laminar flow , which requires less work of breathing . At depths below 150 metres (490 ft) divers breathing helium ? oxygen mixtures begin to experience tremors and a decrease in psychomotor function , symptoms of high @-@ pressure nervous syndrome . This effect may be countered to some extent by adding an amount of narcotic gas such as hydrogen or nitrogen to a helium ? oxygen mixture .

Helium ? neon lasers , a type of low @-@ powered gas laser producing a red beam , had various practical applications which included barcode readers and laser pointers , before they were almost

universally replaced by cheaper diode lasers .

For its inertness and high thermal conductivity , neutron transparency , and because it does not form radioactive isotopes under reactor conditions , helium is used as a heat @-@ transfer medium in some gas @-@ cooled nuclear reactors .

Helium , mixed with a heavier gas such as xenon , is useful for thermoacoustic refrigeration due to the resulting high heat capacity ratio and low Prandtl number . The inertness of helium has environmental advantages over conventional refrigeration systems which contribute to ozone depletion or global warming .

Helium is also used in some hard disk drives .

= = = = Scientific uses = = = =

The use of helium reduces the distorting effects of temperature variations in the space between lenses in some telescopes , due to its extremely low index of refraction . This method is especially used in solar telescopes where a vacuum tight telescope tube would be too heavy .

Helium is a commonly used carrier gas for gas chromatography .

The age of rocks and minerals that contain uranium and thorium can be estimated by measuring the level of helium with a process known as helium dating .

Helium at low temperatures is used in cryogenics , and in certain cryogenics applications . As examples of applications , liquid helium is used to cool certain metals to the extremely low temperatures required for superconductivity , such as in superconducting magnets for magnetic resonance imaging . The Large Hadron Collider at CERN uses 96 metric tons of liquid helium to maintain the temperature at 1 @.@ 9 kelvin .

= = Inhalation and safety = =

= = = Effects = = =

Neutral helium at standard conditions is non @-@ toxic , plays no biological role and is found in trace amounts in human blood .

The speed of sound in helium is nearly three times the speed of sound in air . Because the fundamental frequency of a gas @-@ filled cavity is proportional to the speed of sound in the gas , when helium is inhaled there is a corresponding increase in the resonant frequencies of the vocal tract . The fundamental frequency (sometimes called pitch) does not change , since this is produced by direct vibration of the vocal folds , which is unchanged . However , the higher resonant frequencies cause a change in timbre , resulting in a reedy , duck @-@ like vocal quality . The opposite effect , lowering resonant frequencies , can be obtained by inhaling a dense gas such as sulfur hexafluoride or xenon .

= = = Hazards = = =

Inhaling helium can be dangerous if done to excess , since helium is a simple asphyxiant and so displaces oxygen needed for normal respiration . Fatalities have been recorded , including a youth who suffocated in Vancouver in 2003 and two adults who suffocated in South Florida in 2006 . In 1998 , an Australian girl (her age is not known) from Victoria fell unconscious and temporarily turned blue after inhaling the entire contents of a party balloon . Inhaling helium directly from pressurized cylinders or even (pressure reduzing) balloon filling valves is extremely dangerous , as high flow rate and pressure can result in barotrauma , fatally rupturing lung tissue .

Death caused by helium is rare . The first media @-@ recorded case was that of a 15 @-@ year @-@ old girl from Texas who died in 1998 from helium inhalation at a friend 's party ; the exact type of helium death is unidentified .

In the United States only two fatalities were reported between 2000 and 2004 , including a man who

died in North Carolina of barotrauma in 2002 . A youth asphyxiated in Vancouver during 2003 , and a 27 @-@ year @-@ old man in Australia had an embolism after breathing from a cylinder in 2000 . Since then two adults asphyxiated in South Florida in 2006 , and there were cases in 2009 and 2010 , one a Californian youth who was found with a bag over his head , attached to a helium tank , and another teenager in Northern Ireland died of asphyxiation . At Eagle Point , Oregon a teenage girl died in 2012 from barotrauma at a party . A girl from Michigan died from hypoxia later in the year .

On February 4 , 2015 it was revealed that during the recording of their main TV show on January 28 , a 12 @-@ year @-@ old member (name withheld) of Japanese all @-@ girl singing group 3B Junior suffered from air embolism , losing consciousness and falling in a coma as a result of air bubbles blocking the flow of blood to the brain , after inhaling huge quantities of helium as part of a game . The incident was not made public until a week later . The staff of TV Asahi held an emergency press conference to communicate that the member had been taken to the hospital and is showing signs of rehabilitation such as moving eyes and limbs , but her consciousness has not been sufficiently recovered as of yet . Police have launched an investigation due to a neglect of safety measures .

The safety issues for cryogenic helium are similar to those of liquid nitrogen ; its extremely low temperatures can result in cold burns , and the liquid @-@ to @-@ gas expansion ratio can cause explosions if no pressure @-@ relief devices are installed . Containers of helium gas at 5 to 10 K should be handled as if they contain liquid helium due to the rapid and significant thermal expansion that occurs when helium gas at less than 10 K is warmed to room temperature .

At high pressures (more than about 20 atm or two MPa) , a mixture of helium and oxygen (heliox) can lead to high @-@ pressure nervous syndrome , a sort of reverse @-@ anesthetic effect ; adding a small amount of nitrogen to the mixture can alleviate the problem .

= = Additional images = =