[Template:About](/wiki/Template:About" \o "Template:About) [Template:Pp-semi-indef](/wiki/Template:Pp-semi-indef) [Template:Infobox helium](/wiki/Template:Infobox_helium) **Helium** is a [chemical element](/wiki/Chemical_element) with [symbol](/wiki/Chemical_symbol) **He** and [atomic number](/wiki/Atomic_number) 2. It is a colorless, odorless, tasteless, non-toxic, [inert](/wiki/Inert), [monatomic](/wiki/Monatomic) [gas](/wiki/Gas), the first in the [noble gas](/wiki/Noble_gas) group in the [periodic table](/wiki/Periodic_table). The He [boiling](/wiki/Boiling_point) and [melting](/wiki/Melting_point) points are the lowest among all the [elements](/wiki/Chemical_element).

Helium is the second lightest element and is the second most [abundant element](/wiki/Abundance_of_the_chemical_elements) in the observable [universe](/wiki/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](/wiki/Sun) and in [Jupiter](/wiki/Jupiter). This is due to the very high [nuclear binding energy](/wiki/Nuclear_binding_energy) (per [nucleon](/wiki/Nucleon)) of [helium-4](/wiki/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](/wiki/Nuclear_fusion) and [radioactive decay](/wiki/Radioactive_decay). Most helium in the universe is helium-4, and is believed to have been formed during the [Big Bang](/wiki/Big_Bang). Large amounts of new helium are being created by nuclear fusion of [hydrogen](/wiki/Hydrogen) in [stars](/wiki/Stars).

Helium is named for the [Greek god](/wiki/Greek_god) of the Sun, [Helios](/wiki/Helios). It was first detected as an unknown yellow [spectral line](/wiki/Spectroscopy) signature in sunlight during a [solar eclipse in 1868](/wiki/Solar_eclipse_of_August_18,_1868) by French astronomer [Jules Janssen](/wiki/Pierre_Janssen). Janssen is jointly credited with detecting the element along with [Norman Lockyer](/wiki/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](/wiki/Discovery_of_the_chemical_elements) was made in 1895 by two [Swedish](/wiki/Sweden) chemists, [Per Teodor Cleve](/wiki/Per_Teodor_Cleve) and [Nils Abraham Langlet](/wiki/Nils_Abraham_Langlet), who found helium emanating from the [uranium](/wiki/Uranium) [ore](/wiki/Ore) [cleveite](/wiki/Cleveite). In 1903, large reserves of helium were found in [natural gas fields](/wiki/Natural_gas_field) in parts of the United States, which is by far the largest supplier of the gas today.

Liquid helium is used in [cryogenics](/wiki/Helium_cryogenics) (its largest single use, absorbing about a quarter of production), particularly in the cooling of [superconducting magnets](/wiki/Superconducting_magnet), with the main commercial application being in [MRI](/wiki/MRI) scanners. Helium's other industrial uses—as a pressurizing and purge gas, as a protective atmosphere for [arc welding](/wiki/Arc_welding) and in processes such as growing crystals to make [silicon wafers](/wiki/Silicon_wafer)—account for half of the gas produced. A well-known but minor use is as a lifting gas in [balloons](/wiki/Balloon) and [airships](/wiki/Airship).[[1]](#cite_note-1) 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](/wiki/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](/wiki/Quantum_mechanics) (in particular the property of [superfluidity](/wiki/Superfluidity)) and to those looking at the phenomena, such as [superconductivity](/wiki/Superconductivity), produced in [matter](/wiki/Matter) near [absolute zero](/wiki/Absolute_zero).

On Earth it is relatively rare—5.2 [ppm](/wiki/Parts_per_million) by volume in the [atmosphere](/wiki/Atmosphere). Most terrestrial helium present today is created by the natural [radioactive decay](/wiki/Radioactive_decay) of heavy radioactive elements ([thorium](/wiki/Thorium) and [uranium](/wiki/Uranium), although there are other examples), as the [alpha particles](/wiki/Alpha_particle) emitted by such decays consist of helium-4 [nuclei](/wiki/Atomic_nucleus). This [radiogenic](/wiki/Radiogenic) helium is trapped with [natural gas](/wiki/Natural_gas) in concentrations up to 7% by volume, from which it is extracted commercially by a low-temperature separation process called [fractional distillation](/wiki/Fractional_distillation). Previously, terrestrial helium was thought to be a non-renewable resource because once released into the atmosphere, it readily [escapes into space](/wiki/Atmospheric_escape).[[2]](#cite_note-2)[[3]](#cite_note-3)[[4]](#cite_note-4) 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](/wiki/Rocky_Mountains) in [North America](/wiki/North_America) and in natural gas reserves.[[5]](#cite_note-5)[[6]](#cite_note-6) Geologists/Researchers of Durham and Oxford universities found large quantities of helium within the Tanzanian [East African Rift Valley](/wiki/East_African_Rift_Valley). [[7]](#cite_note-7)

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## History[[edit](/index.php?title=(none)&action=edit&section=1)]

### Scientific discoveries[[edit](/index.php?title=(none)&action=edit&section=2)]

The first evidence of helium was observed on August 18, 1868, as a bright yellow line with a [wavelength](/wiki/Wavelength) of 587.49 nanometers in the [spectrum](/wiki/Emission_spectrum) of the [chromosphere](/wiki/Chromosphere) of the [Sun](/wiki/Sun). The line was detected by French astronomer [Jules Janssen](/wiki/Pierre_Janssen) during a total [solar eclipse](/wiki/Solar_eclipse) in [Guntur](/wiki/Guntur), [India](/wiki/British_Raj).[[8]](#cite_note-8)[[9]](#cite_note-9) This line was initially assumed to be [sodium](/wiki/Sodium). On October 20 of the same year, English astronomer [Norman Lockyer](/wiki/Norman_Lockyer) observed a yellow line in the solar spectrum, which he named the D3 [Fraunhofer line](/wiki/Fraunhofer_line) because it was near the known D1 and D2 lines of sodium.<ref name=enc>[Template:Cite book](/wiki/Template:Cite_book)</ref> He concluded that it was caused by an element in the Sun unknown on Earth. Lockyer and English chemist [Edward Frankland](/wiki/Edward_Frankland) named the element with the Greek word for the Sun, ἥλιος ([*helios*](/wiki/Helios)).[[10]](#cite_note-10)[[11]](#cite_note-11)[left|thumb|Spectral lines of helium|alt=Picture of visible spectrum with superimposed sharp yellow and blue and violet lines.](/wiki/File:Helium_spectrum.jpg) In 1882, Italian physicist [Luigi Palmieri](/wiki/Luigi_Palmieri) detected helium on Earth for the first time through its D3 spectral line, when he analyzed the [lava](/wiki/Lava) of [Mount Vesuvius](/wiki/Mount_Vesuvius).[[12]](#cite_note-12)[thumb|Sir](/wiki/File:William_Ramsay_working.jpg) [William Ramsay](/wiki/William_Ramsay), the discoverer of terrestrial helium On March 26, 1895, Scottish chemist [Sir William Ramsay](/wiki/William_Ramsay) isolated helium on Earth by treating the mineral [cleveite](/wiki/Cleveite) (a variety of [uraninite](/wiki/Uraninite) with at least 10% [rare earth elements](/wiki/Rare_earth_elements)) with mineral [acids](/wiki/Acid). Ramsay was looking for [argon](/wiki/Argon) but, after separating [nitrogen](/wiki/Nitrogen) and [oxygen](/wiki/Oxygen) from the gas liberated by [sulfuric acid](/wiki/Sulfuric_acid), he noticed a bright yellow line that matched the D3 line observed in the spectrum of the Sun.<ref name=enc/>[[13]](#cite_note-13)[[14]](#cite_note-14)[[15]](#cite_note-15) These samples were identified as helium by Lockyer and British physicist [William Crookes](/wiki/William_Crookes). It was independently isolated from cleveite in the same year by chemists [Per Teodor Cleve](/wiki/Per_Teodor_Cleve) and [Abraham Langlet](/wiki/Abraham_Langlet) in [Uppsala, Sweden](/wiki/Uppsala,_Sweden), who collected enough of the gas to accurately determine its [atomic weight](/wiki/Atomic_weight).[[9]](#cite_note-9)[[16]](#cite_note-16)[[17]](#cite_note-17) Helium was also isolated by the American geochemist [William Francis Hillebrand](/wiki/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.[[18]](#cite_note-18) In 1907, [Ernest Rutherford](/wiki/Ernest_Rutherford) and Thomas Royds demonstrated that [alpha particles](/wiki/Alpha_particle) are helium [nuclei](/wiki/Atomic_nucleus) 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](/wiki/Netherlands) physicist [Heike Kamerlingh Onnes](/wiki/Heike_Kamerlingh_Onnes) by cooling the gas to less than one [kelvin](/wiki/Kelvin).[[19]](#cite_note-19) 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](/wiki/Willem_Hendrik_Keesom) was eventually able to solidify 1 cm3 of helium in 1926 by applying additional external pressure.[[20]](#cite_note-20) In 1938, Russian physicist [Pyotr Leonidovich Kapitsa](/wiki/Pyotr_Leonidovich_Kapitsa) discovered that [helium-4](/wiki/Helium-4) has almost no [viscosity](/wiki/Viscosity) at temperatures near [absolute zero](/wiki/Absolute_zero), a phenomenon now called [superfluidity](/wiki/Superfluidity).[[21]](#cite_note-21) This phenomenon is related to [Bose–Einstein condensation](/wiki/Bose–Einstein_condensation). In 1972, the same phenomenon was observed in [helium-3](/wiki/Helium-3), but at temperatures much closer to absolute zero, by American physicists [Douglas D. Osheroff](/wiki/Douglas_D._Osheroff), [David M. Lee](/wiki/David_M._Lee), and [Robert C. Richardson](/wiki/Robert_Coleman_Richardson). The phenomenon in helium-3 is thought to be related to pairing of helium-3 [fermions](/wiki/Fermion) to make [bosons](/wiki/Boson), in analogy to [Cooper pairs](/wiki/Cooper_pairs) of electrons producing [superconductivity](/wiki/Superconductivity).[[22]](#cite_note-22)

### Extraction and use[[edit](/index.php?title=(none)&action=edit&section=3)]

After an oil drilling operation in 1903 in [Dexter, Kansas](/wiki/Dexter,_Kansas), produced a gas geyser that would not burn, Kansas state geologist [Erasmus Haworth](/wiki/Erasmus_Haworth) collected samples of the escaping gas and took them back to the [University of Kansas](/wiki/University_of_Kansas) at Lawrence where, with the help of chemists [Hamilton Cady](/wiki/Hamilton_Cady) and David McFarland, he discovered that the gas consisted of, by volume, 72% nitrogen, 15% [methane](/wiki/Methane) (a [combustible](/wiki/Combustible) percentage only with sufficient oxygen), 1% [hydrogen](/wiki/Hydrogen), and 12% an unidentifiable gas.[[9]](#cite_note-9)[[23]](#cite_note-23) With further analysis, Cady and McFarland discovered that 1.84% of the gas sample was helium.[[24]](#cite_note-24)[[25]](#cite_note-25) This showed that despite its overall rarity on Earth, helium was concentrated in large quantities under the [American Great Plains](/wiki/American_Great_Plains), available for extraction as a byproduct of [natural gas](/wiki/Natural_gas).[[26]](#cite_note-26) This enabled the United States to become the world's leading supplier of helium. Following a suggestion by Sir [Richard Threlfall](/wiki/Richard_Threlfall), the [United States Navy](/wiki/United_States_Navy) sponsored three small experimental helium plants during World War I. The goal was to supply [barrage balloons](/wiki/Barrage_balloon) with the non-flammable, lighter-than-air gas. A total of [Template:Convert](/wiki/Template:Convert) of 92% helium was produced in the program even though less than a cubic meter of the gas had previously been obtained.<ref name=enc/> 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](/wiki/Hampton_Roads,_Virginia), to [Bolling Field](/wiki/Bolling_Field) in Washington, D.C., on December 1, 1921,[[27]](#cite_note-27) nearly two years before the Navy's first *rigid* helium-filled airship, the [Naval Aircraft Factory](/wiki/Naval_Aircraft_Factory)-built [*USS Shenandoah*](/wiki/USS_Shenandoah_(ZR-1)), flew in September 1923.

Although the extraction process, using low-temperature [gas liquefaction](/wiki/Gas_liquefaction), was not developed in time to be significant during World War I, production continued. Helium was primarily used as a [lifting gas](/wiki/Lifting_gas) in lighter-than-air craft. During World War II, the demand increased for helium for lifting gas and for shielded arc [welding](/wiki/Welding). The [helium mass spectrometer](/wiki/Helium_mass_spectrometer) was also vital in the atomic bomb [Manhattan Project](/wiki/Manhattan_Project).[[28]](#cite_note-28) The [government of the United States](/wiki/Government_of_the_United_States) set up the [National Helium Reserve](/wiki/National_Helium_Reserve) in 1925 at [Amarillo, Texas](/wiki/Amarillo,_Texas), with the goal of supplying military [airships](/wiki/Airship) in time of war and commercial airships in peacetime.<ref name=enc/> Because of the [Helium Control Act](/wiki/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](/wiki/LZ_129_Hindenburg), like all German [Zeppelins](/wiki/Zeppelin), 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](/wiki/Liquid_helium) as a coolant to create oxygen/hydrogen [rocket fuel](/wiki/Rocket_fuel) (among other uses) during the [Space Race](/wiki/Space_Race) and [Cold War](/wiki/Cold_War). Helium use in the United States in 1965 was more than eight times the peak wartime consumption.[[29]](#cite_note-29) After the "Helium Acts Amendments of 1960" (Public Law 86–777), the [U.S. Bureau of Mines](/wiki/United_States_Bureau_of_Mines) arranged for five private plants to recover helium from natural gas. For this *helium conservation* program, the Bureau built a [Template:Convert](/wiki/Template:Convert) pipeline from [Bushton, Kansas](/wiki/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.[[30]](#cite_note-30) 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](/wiki/Congress_of_the_United_States) in 1996 to phase out the reserve.[[9]](#cite_note-9)[[31]](#cite_note-31) The resulting "Helium Privatization Act of 1996"[[32]](#cite_note-32) (Public Law 104–273) directed the [United States Department of the Interior](/wiki/United_States_Department_of_the_Interior) to empty the reserve, with sales starting by 2005.[[33]](#cite_note-33) 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.[[34]](#cite_note-34) 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](/wiki/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.[[35]](#cite_note-35) In 2004–2006, additional plants in [Ras Laffan](/wiki/Ras_Laffan_Industrial_City), [Qatar](/wiki/Qatar), and [Skikda](/wiki/Skikda), Algeria were built. Algeria quickly became the second leading producer of helium.[[36]](#cite_note-36) Through this time, both helium consumption and the costs of producing helium increased.[[37]](#cite_note-37) From 2002 to 2007 helium prices doubled.[[38]](#cite_note-38) As of 2012, the [United States National Helium Reserve](/wiki/National_Helium_Reserve) accounted for 30 percent of the world's helium.<ref name=Newcomb>[Template:Cite news](/wiki/Template:Cite_news)</ref> The reserve was expected to run out of helium in 2018.<ref name=Newcomb/> Despite that, a proposed bill in the [United States Senate](/wiki/United_States_Senate) would allow the reserve to continue to sell the gas. Other large reserves were in the [Hugoton](/wiki/Hugoton_Natural_Gas_Area) in [Kansas](/wiki/Kansas), United States, and nearby gas fields of Kansas and the [panhandles](/wiki/Panhandles) of [Texas](/wiki/Texas) and [Oklahoma](/wiki/Oklahoma). New helium plants were scheduled to open in 2012 in [Qatar](/wiki/Qatar), Russia, and the United States state of [Wyoming](/wiki/Wyoming), but they were not expected to ease the shortage.<ref name=Newcomb/>

In 2013, Qatar started up the world's largest helium unit.[[39]](#cite_note-39) 2014 was widely acknowledged to be a year of over-supply in the helium business, following years of renowned shortages.[[40]](#cite_note-40) Nasdaq reported (2015) that for [Air Products](/wiki/Air_Products_&_Chemicals), an international corporation that sells gases for industrial use, helium volumes remain under pressure due to feedstock supply constraints.[[41]](#cite_note-41)

## Characteristics[[edit](/index.php?title=(none)&action=edit&section=4)]

### The helium atom[[edit](/index.php?title=(none)&action=edit&section=5)]

[Template:Main](/wiki/Template:Main) [thumb|right|alt=Picture of a diffuse gray sphere with grayscale density decreasing from the center. Length scale about 1 Angstrom. An inset outlines the structure of the core, with two red and two blue atoms at the length scale of 1 femtometer.|**The helium atom.** Depicted are the](/wiki/File:Helium_atom_QM.svg) [nucleus](/wiki/Atomic_nucleus) (pink) and the [electron cloud](/wiki/Electron_cloud) distribution (black). The nucleus (upper right) in helium-4 is in reality spherically symmetric and closely resembles the electron cloud, although for more complicated nuclei this is not always the case.

#### Helium in quantum mechanics[[edit](/index.php?title=(none)&action=edit&section=6)]

In the perspective of [quantum mechanics](/wiki/Quantum_mechanics), helium is the second simplest [atom](/wiki/Atom) to model, following the [hydrogen atom](/wiki/Hydrogen_atom). Helium is composed of two electrons in [atomic orbitals](/wiki/Atomic_orbital) 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](/wiki/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](/wiki/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.[[42]](#cite_note-42) 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[[edit](/index.php?title=(none)&action=edit&section=7)]

The nucleus of the helium-4 atom is identical with an [alpha particle](/wiki/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](/wiki/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](/wiki/Fermion) fully occupy [1s](/wiki/1s1s) 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.

[thumb|right|Binding energy per nucleon of common isotopes. The binding energy per particle of helium-4 is significantly larger than all nearby nuclides.](/wiki/File:Binding_energy_curve_-_common_isotopes.svg) The unusual stability of the helium-4 nucleus is also important [cosmologically](/wiki/Cosmology): it explains the fact that in the first few minutes after the [Big Bang](/wiki/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](/wiki/Nucleogenesis) and [binding energy](/wiki/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](/wiki/Nucleon), carbon. However, due to lack of intermediate elements, this process requires three helium nuclei striking each other nearly simultaneously (see [triple alpha process](/wiki/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[[edit](/index.php?title=(none)&action=edit&section=8)]

[thumb|left|upright|Helium discharge tube shaped like the element's atomic symbol|alt=Illuminated light red gas discharge tubes shaped as letters H and e](/wiki/File:HeTube.jpg) Helium is the second least reactive [noble gas](/wiki/Noble_gas) after [neon](/wiki/Neon), and thus the second least reactive of all elements.[[43]](#cite_note-43) It is [inert](/wiki/Inert) and [monatomic](/wiki/Monatomic) in all standard conditions. Because of helium's relatively low molar (atomic) mass, its [thermal conductivity](/wiki/Thermal_conductivity), [specific heat](/wiki/Specific_heat), and [sound speed](/wiki/Speed_of_sound) in the gas phase are all greater than any other gas except [hydrogen](/wiki/Hydrogen). For these reasons and the small size of helium monatomic molecules, helium [diffuses](/wiki/Diffusion) through solids at a rate three times that of air and around 65% that of hydrogen.<ref name=enc/>

Helium is the least water-[soluble](/wiki/Solubility) monatomic gas,[[44]](#cite_note-44) 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),[[45]](#cite_note-45) and helium's [index of refraction](/wiki/Index_of_refraction) is closer to unity than that of any other gas.[[46]](#cite_note-46) Helium has a negative [Joule-Thomson coefficient](/wiki/Joule-Thomson_coefficient) at normal ambient temperatures, meaning it heats up when allowed to freely expand. Only below its [Joule-Thomson inversion temperature](/wiki/Joule-Thomson_inversion_temperature) (of about 32 to 50 K at 1 atmosphere) does it cool upon free expansion.<ref name=enc/> Once precooled below this temperature, helium can be liquefied through expansion cooling.

Most extraterrestrial helium is found in a [plasma](/wiki/Plasma_(physics)) 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](/wiki/Solar_wind) together with ionized hydrogen, the particles interact with the Earth's [magnetosphere](/wiki/Magnetosphere), giving rise to [Birkeland currents](/wiki/Birkeland_current) and the [aurora](/wiki/Aurora_(phenomenon)).[[47]](#cite_note-47)

### Liquid helium[[edit](/index.php?title=(none)&action=edit&section=9)]

[thumb|Liquefied helium. This helium is not only liquid, but has been cooled to the point of](/wiki/File:2_Helium.png) [superfluidity](/wiki/Superfluid). The drop of liquid at the bottom of the glass represents helium spontaneously escaping from the container over the side, to empty out of the container. The energy to drive this process is supplied by the potential energy of the falling helium. [Template:Main](/wiki/Template:Main)

Unlike any other element, helium will remain liquid down to [absolute zero](/wiki/Absolute_zero) at normal pressures. This is a direct effect of quantum mechanics: specifically, the [zero point energy](/wiki/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.[[48]](#cite_note-48) It is often hard to distinguish solid from liquid helium since the [refractive index](/wiki/Refractive_index) of the two phases are nearly the same. The solid has a sharp [melting point](/wiki/Melting_point) and has a [crystalline](/wiki/Crystal) structure, but it is highly [compressible](/wiki/Compressibility); applying pressure in a laboratory can decrease its volume by more than 30%.[[49]](#cite_note-49) With a [bulk modulus](/wiki/Bulk_modulus) of about 27 [MPa](/wiki/Megapascal)[[50]](#cite_note-50) 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.[[51]](#cite_note-51)

#### Helium I state[[edit](/index.php?title=(none)&action=edit&section=10)]

Below its [boiling point](/wiki/Boiling_point) of 4.22 kelvins and above the [lambda point](/wiki/Lambda_point) of 2.1768 kelvins, the [isotope](/wiki/Isotope) helium-4 exists in a normal colorless liquid state, called *helium I*.<ref name=enc/> Like other [cryogenic](/wiki/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](/wiki/Index_of_refraction) of 1.026 which makes its surface so hard to see that floats of [Styrofoam](/wiki/Styrofoam) are often used to show where the surface is.<ref name=enc/> This colorless liquid has a very low [viscosity](/wiki/Viscosity) and a density of 0.145–0.125 g/mL (between about 0 and 4 K),<ref name=crc6120>[Template:RubberBible86th](/wiki/Template:RubberBible86th)</ref> which is only one-fourth the value expected from [classical physics](/wiki/Classical_physics).<ref name=enc/> [Quantum mechanics](/wiki/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](/wiki/Thermal_energy)) from masking the atomic properties.<ref name=enc/>

#### Helium II state[[edit](/index.php?title=(none)&action=edit&section=11)]

[Template:Main](/wiki/Template:Main) Liquid helium below its lambda point (called *helium II*) exhibits very unusual characteristics. Due to its high [thermal conductivity](/wiki/Thermal_conductivity), when it boils, it does not bubble but rather evaporates directly from its surface. [Helium-3](/wiki/Helium-3) also has a [superfluid](/wiki/Superfluid) phase, but only at much lower temperatures; as a result, less is known about the properties of the isotope.<ref name=enc/> [thumb|upright|Unlike ordinary liquids, helium II will creep along surfaces in order to reach an equal level; after a short while, the levels in the two containers will equalize. The](/wiki/File:helium-II-creep.svg) [Rollin film](/wiki/Rollin_film) also covers the interior of the larger container; if it were not sealed, the helium II would creep out and escape.<ref name=enc/>|alt=A cross-sectional drawing showing one vessel inside another. There is a liquid in the outer vessel, and it tends to flow into the inner vessel over its walls.

Helium II is a superfluid, a quantum mechanical state (see: [macroscopic quantum phenomena](/wiki/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](/wiki/Viscosity).[[9]](#cite_note-9) 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](/wiki/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.[[52]](#cite_note-52) In the *fountain effect*, a chamber is constructed which is connected to a reservoir of helium II by a [sintered](/wiki/Sintering) 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.[[53]](#cite_note-53) 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](/wiki/Copper).<ref name=enc/> This is because heat conduction occurs by an exceptional quantum mechanism. Most materials that conduct heat well have a [valence band](/wiki/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](/wiki/Heat_transfer) is governed by equations that are similar to the [wave equation](/wiki/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*](/wiki/Second_sound).<ref name=enc/>

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](/wiki/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](/wiki/Nanometre)-thick film regardless of surface material. This film is called a [Rollin film](/wiki/Rollin_film) and is named after the man who first characterized this trait, [Bernard V. Rollin](/wiki/Bernard_V._Rollin).<ref name=enc/>[[54]](#cite_note-54)[[55]](#cite_note-55) 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](/wiki/Gravity_wave) in shallow water, but rather than gravity, the restoring force is the [van der Waals force](/wiki/Van_der_Waals_force).[[56]](#cite_note-56) These waves are known as [*third sound*](/wiki/Third_sound).[[57]](#cite_note-57)

## Isotopes[[edit](/index.php?title=(none)&action=edit&section=12)]

[Template:Main](/wiki/Template:Main) There are nine known [isotopes](/wiki/Isotope) of helium, but only [helium-3](/wiki/Helium-3) and [helium-4](/wiki/Helium-4) are [stable](/wiki/Stable_isotope). In the Earth's atmosphere, one atom is [Template:Chem](/wiki/Template:Chem) for every million that are [Template:Chem](/wiki/Template:Chem).[[9]](#cite_note-9) 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](/wiki/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](/wiki/Nucleon) are arranged into [complete shells](/wiki/Nuclear_shell_model). It was also formed in enormous quantities during [Big Bang nucleosynthesis](/wiki/Big_Bang_nucleosynthesis).[[58]](#cite_note-58) 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](/wiki/Cosmic_dust).[[59]](#cite_note-59) Trace amounts are also produced by the [beta decay](/wiki/Beta_decay) of [tritium](/wiki/Tritium).[[60]](#cite_note-60) 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](/wiki/Mantle_(geology)).[[59]](#cite_note-59) [Template:Chem](/wiki/Template:Chem) is much more abundant in stars as a product of nuclear fusion. Thus in the [interstellar medium](/wiki/Interstellar_medium), the proportion of [Template:Chem](/wiki/Template:Chem) to [Template:Chem](/wiki/Template:Chem) is about 100 times higher than on Earth.[[61]](#cite_note-61) Extraplanetary material, such as [lunar](/wiki/Moon) and [asteroid](/wiki/Asteroid) [regolith](/wiki/Regolith), have trace amounts of helium-3 from being bombarded by [solar winds](/wiki/Solar_wind). The [Moon's](/wiki/Moon) surface contains helium-3 at concentrations on the order of 10 [ppb](/wiki/Parts_per_billion), much higher than the approximately 5 [ppt](/wiki/Parts_per_trillion) found in the Earth's atmosphere.[[62]](#cite_note-62)[[63]](#cite_note-63) A number of people, starting with Gerald Kulcinski in 1986,[[64]](#cite_note-64) have proposed to explore the moon, mine lunar regolith, and use the helium-3 for [fusion](/wiki/Nuclear_fusion).

Liquid helium-4 can be cooled to about 1 kelvin using [evaporative cooling](/wiki/Evaporative_cooling) in a [1-K pot](/wiki/1-K_pot). Similar cooling of helium-3, which has a lower boiling point, can achieve about [Template:Val](/wiki/Template:Val) in a [helium-3 refrigerator](/wiki/Helium-3_refrigerator). Equal mixtures of liquid [Template:Chem](/wiki/Template:Chem) and [Template:Chem](/wiki/Template:Chem) below [Template:Val](/wiki/Template:Val) separate into two immiscible phases due to their dissimilarity (they follow different [quantum statistics](/wiki/Quantum_statistics): helium-4 atoms are [bosons](/wiki/Boson) while helium-3 atoms are [fermions](/wiki/Fermion)).<ref name = enc/> [Dilution refrigerators](/wiki/Dilution_refrigerator) use this immiscibility to achieve temperatures of a few millikelvins.

It is possible to produce [exotic helium isotopes](/wiki/Exotic_helium_isotopes), which rapidly decay into other substances. The shortest-lived heavy helium isotope is helium-5 with a [half-life](/wiki/Half-life) of [Template:Val](/wiki/Template:Val). Helium-6 decays by emitting a [beta particle](/wiki/Beta_particle) and has a half-life of 0.8 second. Helium-7 also emits a beta particle as well as a [gamma ray](/wiki/Gamma_ray). Helium-7 and helium-8 are created in certain [nuclear reactions](/wiki/Nuclear_reaction).<ref name=enc/> Helium-6 and helium-8 are known to exhibit a [nuclear halo](/wiki/Nuclear_halo).<ref name = enc/>

## Compounds[[edit](/index.php?title=(none)&action=edit&section=13)]

[Template:Main](/wiki/Template:Main) [thumb|Structure of the](/wiki/File:Helium-hydride-cation-3D-SF.png) [helium hydride ion](/wiki/Helium_hydride_ion), HHe+ [thumb|Structure of the suspected fluoroheliate anion, OHeF−](/wiki/File:Fluoroheliate-ion-3D-vdW.png) Helium has a [valence](/wiki/Valence_(chemistry)) of zero and is chemically unreactive under all normal conditions.[[49]](#cite_note-49) It is an electrical insulator unless [ionized](/wiki/Ion). As with the other noble gases, helium has metastable [energy levels](/wiki/Energy_level) that allow it to remain ionized in an electrical discharge with a [voltage](/wiki/Voltage) below its [ionization potential](/wiki/Ionization_potential).<ref name=enc/> Helium can form unstable [compounds](/wiki/Compound_(chemistry)), known as [excimers](/wiki/Excimer), with tungsten, iodine, fluorine, sulfur, and phosphorus when it is subjected to a [glow discharge](/wiki/Glow_discharge), to electron bombardment, or reduced to [plasma](/wiki/Plasma_physics) by other means. The molecular compounds HeNe, HgHe10, and WHe2, and the molecular ions [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), and [Template:Chem](/wiki/Template:Chem) have been created this way.[[65]](#cite_note-65) HeH+ is also stable in its ground state, but is extremely reactive—it is the strongest [Brønsted acid](/wiki/Brønsted–Lowry_acid–base_theory) 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](/wiki/Spectral_band), and HgHe, which is apparently held together only by polarization forces.<ref name=enc/>

[Van der Waals compounds](/wiki/Van_der_Waals_compound) of helium can also be formed with cryogenic helium gas and atoms of some other substance, such as [LiHe](/wiki/LiHe) and [He2](/wiki/Dihelium).<ref name=fr13>[Template:Cite journal](/wiki/Template:Cite_journal)</ref>

Theoretically, other true compounds may be possible, such as helium fluorohydride (HHeF) which would be analogous to [HArF](/wiki/Argon_fluorohydride), discovered in 2000.[[66]](#cite_note-66) Calculations show that two new compounds containing a helium-oxygen bond could be stable.[[67]](#cite_note-67) 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](/wiki/Neon).[[68]](#cite_note-68) Helium atoms have been inserted into the hollow carbon cage molecules (the [fullerenes](/wiki/Fullerene)) by heating under high pressure. The [endohedral fullerene molecules](/wiki/Endohedral_fullerene) formed are stable at high temperatures. When chemical derivatives of these fullerenes are formed, the helium stays inside.[[69]](#cite_note-69) If [helium-3](/wiki/Helium-3) is used, it can be readily observed by helium [nuclear magnetic resonance spectroscopy](/wiki/Nuclear_magnetic_resonance_spectroscopy).[[70]](#cite_note-70) 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](/wiki/Clathrate) (He(N2)11) crystals have been grown at room temperature at pressures ca. 10 GPa in a [diamond anvil cell](/wiki/Diamond_anvil_cell).[[71]](#cite_note-71) At 130 GPa Na2He is thermodynamically stable with a [fluorite](/wiki/Fluorite) structure.[[72]](#cite_note-72)

## Occurrence and production[[edit](/index.php?title=(none)&action=edit&section=14)]

### Natural abundance[[edit](/index.php?title=(none)&action=edit&section=15)]

Although it is rare on Earth, helium is the second most abundant element in the known Universe (after [hydrogen](/wiki/Hydrogen)), constituting 23% of its [baryonic](/wiki/Baryon) mass.[[9]](#cite_note-9) The vast majority of helium was formed by [Big Bang nucleosynthesis](/wiki/Big_Bang_nucleosynthesis) one to three minutes after the Big Bang. As such, measurements of its abundance contribute to cosmological models. In [stars](/wiki/Star), it is formed by the [nuclear fusion](/wiki/Nuclear_fusion) of hydrogen in [proton-proton chain reactions](/wiki/Proton-proton_chain_reaction) and the [CNO cycle](/wiki/CNO_cycle), part of [stellar nucleosynthesis](/wiki/Stellar_nucleosynthesis).[[58]](#cite_note-58) In the [Earth's atmosphere](/wiki/Earth's_atmosphere), the concentration of helium by volume is only 5.2 parts per million.[[73]](#cite_note-73)[[74]](#cite_note-74) 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](/wiki/Atmospheric_escape) by several processes.[[75]](#cite_note-75)[[76]](#cite_note-76)<ref name=TalkOriginsCreationism>[Template:Cite web](/wiki/Template:Cite_web)</ref> In the Earth's [heterosphere](/wiki/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](/wiki/Radioactive_decay). Helium is found in large amounts in minerals of [uranium](/wiki/Uranium) and [thorium](/wiki/Thorium), including [cleveite](/wiki/Cleveite), [pitchblende](/wiki/Pitchblende), [carnotite](/wiki/Carnotite) and [monazite](/wiki/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](/wiki/Lithosphere).[[77]](#cite_note-77)[[78]](#cite_note-78)[[79]](#cite_note-79) 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](/wiki/Spring_(hydrosphere)), volcanic gas, and [meteoric iron](/wiki/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](/wiki/San_Juan_County,_New_Mexico).[[80]](#cite_note-80)[[81]](#cite_note-81) 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](/wiki/South_Pars_/_North_Dome_Gas-Condensate_field) owned jointly by [Qatar](/wiki/Qatar) and Iran.[[82]](#cite_note-82)[[127]](#cite_note-127)[[128]](#cite_note-128)