

Noble Gases

An Overview

Contents

1	Properties	1
1.1	Noble gas	1
1.1.1	History	1
1.1.2	Physical and atomic properties	2
1.1.3	Chemical properties	3
1.1.4	Occurrence and production	5
1.1.5	Applications	6
1.1.6	Discharge color	7
1.1.7	See also	7
1.1.8	Notes	7
1.1.9	References	9
2	Elements	11
2.1	Helium	11
2.1.1	History	11
2.1.2	Characteristics	13
2.1.3	Isotopes	16
2.1.4	Compounds	17
2.1.5	Occurrence and production	18
2.1.6	Applications	19
2.1.7	Inhalation and safety	20
2.1.8	Additional images	21
2.1.9	See also	21
2.1.10	References	21
2.1.11	Bibliography	26
2.1.12	External links	26
2.2	Neon	27
2.2.1	History	27
2.2.2	Isotopes	28
2.2.3	Characteristics	29
2.2.4	Occurrence	29
2.2.5	Applications	29
2.2.6	Compounds	30

2.2.7	See also	30
2.2.8	References	30
2.2.9	External links	31
2.3	Argon	31
2.3.1	Characteristics	31
2.3.2	History	32
2.3.3	Occurrence	32
2.3.4	Isotopes	32
2.3.5	Compounds	33
2.3.6	Production	33
2.3.7	Applications	33
2.3.8	Safety	36
2.3.9	See also	36
2.3.10	References	36
2.3.11	Further reading	37
2.3.12	External links	37
2.4	Krypton	37
2.4.1	History	38
2.4.2	Characteristics	38
2.4.3	Applications	39
2.4.4	Precautions	40
2.4.5	See also	40
2.4.6	References	40
2.4.7	Further reading	41
2.4.8	External links	41
2.5	Xenon	41
2.5.1	History	41
2.5.2	Characteristics	42
2.5.3	Occurrence and production	43
2.5.4	Isotopes and isotopic studies	43
2.5.5	Compounds	44
2.5.6	Applications	46
2.5.7	Precautions	49
2.5.8	See also	49
2.5.9	References	49
2.5.10	External links	56
2.6	Radon	56
2.6.1	Characteristics	57
2.6.2	History and etymology	59
2.6.3	Occurrence	60
2.6.4	Applications	62

2.6.5	Health risks	63
2.6.6	See also	66
2.6.7	References	66
2.6.8	External links	70
2.7	Ununoctium	71
2.7.1	History	71
2.7.2	Naming	72
2.7.3	Characteristics	73
2.7.4	See also	74
2.7.5	Notes	74
2.7.6	References	75
2.7.7	Further reading	77
2.7.8	External links	77
3	Text and image sources, contributors, and licenses	78
3.1	Text	78
3.2	Images	84
3.3	Content license	88

Chapter 1

Properties

1.1 Noble gas

The **noble gases** make a group of chemical elements with similar properties: under standard conditions, they are all odorless, colorless, monatomic gases with very low chemical reactivity. The six noble gases that occur naturally are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and the radioactive radon (Rn).

For the first six periods of the periodic table, the noble gases are exactly the members of **group 18** of the periodic table. It is possible that due to relativistic effects, the group 14 element flerovium exhibits some noble-gas-like properties,^[1] instead of the group 18 element ununoctium.^[2] Noble gases are typically highly unreactive except when under particular extreme conditions. The inertness of noble gases makes them very suitable in applications where reactions are not wanted. For example: argon is used in lightbulbs to prevent the hot tungsten filament from oxidizing; also, helium is breathed by deep-sea divers to prevent oxygen and nitrogen toxicity.

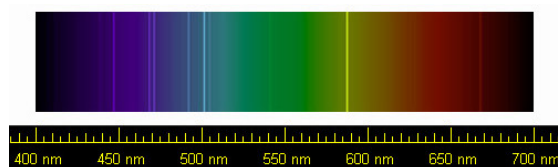
The properties of the noble gases can be well explained by modern theories of atomic structure: their outer shell of valence electrons is considered to be “full”, giving them little tendency to participate in chemical reactions, and it has been possible to prepare only a few hundred noble gas compounds. The melting and boiling points for a given noble gas are close together, differing by less than 10 °C (18 °F); that is, they are liquids over only a small temperature range.

Neon, argon, krypton, and xenon are obtained from air in an air separation unit using the methods of liquefaction of gases and fractional distillation. Helium is sourced from natural gas fields which have high concentrations of helium in the natural gas, using cryogenic gas separation techniques, and radon is usually isolated from the radioactive decay of dissolved radium, thorium, or uranium compounds (since those compounds give off alpha particles), which are equivalent in mass to the nuclei of a helium-4 atom. Noble gases have several important applications in industries such as lighting, welding, and space exploration. A helium-oxygen breathing gas is often used by deep-sea divers at depths of seawater over 55 m (180 ft) to keep the diver from experiencing oxygen

toxemia, the lethal effect of high-pressure oxygen, and nitrogen narcosis, the distracting narcotic effect of the nitrogen in air beyond this partial-pressure threshold. After the risks caused by the flammability of hydrogen became apparent, it was replaced with helium in blimps and balloons.

1.1.1 History

Noble gas is translated from the German noun *Edelgas*, first used in 1898 by Hugo Erdmann^[3] to indicate their extremely low level of reactivity. The name makes an analogy to the term "noble metals", which also have low reactivity. The noble gases have also been referred to as *inert gases*, but this label is deprecated as many noble gas compounds are now known.^[4] *Rare gases* is another term that was used,^[5] but this is also inaccurate because argon forms a fairly considerable part (0.94% by volume, 1.3% by mass) of the Earth's atmosphere due to decay of radioactive potassium-40.^[6]



Helium was first detected in the Sun due to its characteristic spectral lines.

Pierre Janssen and Joseph Norman Lockyer discovered a new element on August 18, 1868 while looking at the chromosphere of the Sun, and named it helium after the Greek word for the Sun, ἥλιος (*lios* or *helios*).^[7] No chemical analysis was possible at the time, but helium was later found to be a noble gas. Before them, in 1784, the English chemist and physicist Henry Cavendish had discovered that air contains a small proportion of a substance less reactive than nitrogen.^[8] A century later, in 1895, Lord Rayleigh discovered that samples of nitrogen from the air were of a different density than nitrogen resulting from chemical reactions. Along with Scottish scientist William Ramsay at University College, London, Lord Rayleigh theorized that the nitrogen extracted

from air was mixed with another gas, leading to an experiment that successfully isolated a new element, argon, from the Greek word *αργός* (*argós*, “inactive”).^[8] With this discovery, they realized an entire class of gases was missing from the periodic table. During his search for argon, Ramsay also managed to isolate helium for the first time while heating *cleveite*, a mineral. In 1902, having accepted the evidence for the elements helium and argon, Dmitri Mendeleev included these noble gases as group 0 in his arrangement of the elements, which would later become the periodic table.^[9]

Ramsay continued to search for these gases using the method of fractional distillation to separate liquid air into several components. In 1898, he discovered the elements krypton, neon, and xenon, and named them after the Greek words *κρυπτός* (*kryptós*, “hidden”), *νέος* (*néos*, “new”), and *ξένος* (*xénos*, “stranger”), respectively. Radon was first identified in 1898 by Friedrich Ernst Dorn,^[10] and was named *radium emanation*, but was not considered a noble gas until 1904 when its characteristics were found to be similar to those of other noble gases.^[11] Rayleigh and Ramsay received the 1904 Nobel Prizes in Physics and in Chemistry, respectively, for their discovery of the noble gases;^{[12][13]} in the words of J. E. Cederblom, then president of the Royal Swedish Academy of Sciences, “the discovery of an entirely new group of elements, of which no single representative had been known with any certainty, is something utterly unique in the history of chemistry, being intrinsically an advance in science of peculiar significance”.^[13]

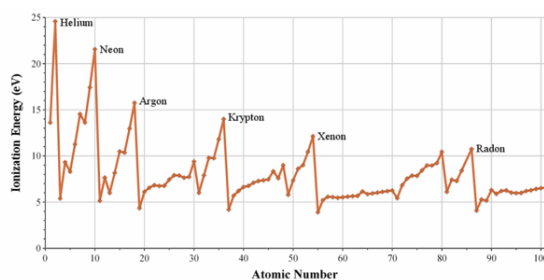
The discovery of the noble gases aided in the development of a general understanding of atomic structure. In 1895, French chemist Henri Moissan attempted to form a reaction between fluorine, the most electronegative element, and argon, one of the noble gases, but failed. Scientists were unable to prepare compounds of argon until the end of the 20th century, but these attempts helped to develop new theories of atomic structure. Learning from these experiments, Danish physicist Niels Bohr proposed in 1913 that the electrons in atoms are arranged in shells surrounding the nucleus, and that for all noble gases except helium the outermost shell always contains eight electrons.^[11] In 1916, Gilbert N. Lewis formulated the *octet rule*, which concluded an octet of electrons in the outer shell was the most stable arrangement for any atom; this arrangement caused them to be unreactive with other elements since they did not require any more electrons to complete their outer shell.^[14]

In 1962, Neil Bartlett discovered the first chemical compound of a noble gas, xenon hexafluoroplatinate.^[15] Compounds of other noble gases were discovered soon after: in 1962 for radon, radon difluoride,^[16] and in 1963 for krypton, krypton difluoride (KrF_2).^[17] The first stable compound of argon was reported in 2000 when argon fluorohydride (HArF) was formed at a temperature of 40 K ($-233.2\text{ }^\circ\text{C}$; $-387.7\text{ }^\circ\text{F}$).^[18]

In December 1998, scientists at the Joint Institute for Nuclear Research working in Dubna, Russia bombarded plutonium (Pu) with calcium (Ca) to produce a single atom of element 114,^[19] flerovium (Fl).^[20] Preliminary chemistry experiments have indicated this element may be the first superheavy element to show abnormal noble-gas-like properties, even though it is a member of group 14 on the periodic table.^[21] In October 2006, scientists from the Joint Institute for Nuclear Research and Lawrence Livermore National Laboratory successfully created synthetically ununoctium (Uuo), the seventh element in group 18,^[22] by bombarding californium (Cf) with calcium (Ca).^[23]

1.1.2 Physical and atomic properties

The noble gases have weak interatomic force, and consequently have very low melting and boiling points. They are all monatomic gases under standard conditions, including the elements with larger atomic masses than many normally solid elements.^[11] Helium has several unique qualities when compared with other elements: its boiling and melting points are lower than those of any other known substance; it is the only element known to exhibit superfluidity; it is the only element that cannot be solidified by cooling under standard conditions—a pressure of 25 standard atmospheres (2,500 kPa; 370 psi) must be applied at a temperature of 0.95 K ($-272.200\text{ }^\circ\text{C}$; $-457.960\text{ }^\circ\text{F}$) to convert it to a solid.^[26] The noble gases up to xenon have multiple stable isotopes. Radon has no stable isotopes; its longest-lived isotope, ^{222}Rn , has a half-life of 3.8 days and decays to form helium and polonium, which ultimately decays to lead.^[11] Melting and boiling points generally increase going down the group.



This is a plot of ionization potential versus atomic number. The noble gases, which are labeled, have the largest ionization potential for each period.

The noble gas atoms, like atoms in most groups, increase steadily in atomic radius from one period to the next due to the increasing number of electrons. The size of the atom is related to several properties. For example, the ionization potential decreases with an increasing radius because the valence electrons in the larger noble gases are farther away from the nucleus and are therefore not held as tightly together by the atom. Noble gases have the largest ionization potential among the elements of each

period, which reflects the stability of their electron configuration and is related to their relative lack of chemical reactivity.^[24] Some of the heavier noble gases, however, have ionization potentials small enough to be comparable to those of other elements and molecules. It was the insight that xenon has an ionization potential similar to that of the oxygen molecule that led Bartlett to attempt oxidizing xenon using platinum hexafluoride, an oxidizing agent known to be strong enough to react with oxygen.^[15] Noble gases cannot accept an electron to form stable anions; that is, they have a negative electron affinity.^[27]

The macroscopic physical properties of the noble gases are dominated by the weak van der Waals forces between the atoms. The attractive force increases with the size of the atom as a result of the increase in polarizability and the decrease in ionization potential. This results in systematic group trends: as one goes down group 18, the atomic radius, and with it the interatomic forces, increases, resulting in an increasing melting point, boiling point, enthalpy of vaporization, and solubility. The increase in density is due to the increase in atomic mass.^[24]

The noble gases are nearly ideal gases under standard conditions, but their deviations from the ideal gas law provided important clues for the study of intermolecular interactions. The Lennard-Jones potential, often used to model intermolecular interactions, was deduced in 1924 by John Lennard-Jones from experimental data on argon before the development of quantum mechanics provided the tools for understanding intermolecular forces from first principles.^[28] The theoretical analysis of these interactions became tractable because the noble gases are monatomic and the atoms spherical, which means that the interaction between the atoms is independent of direction, or isotropic.

1.1.3 Chemical properties

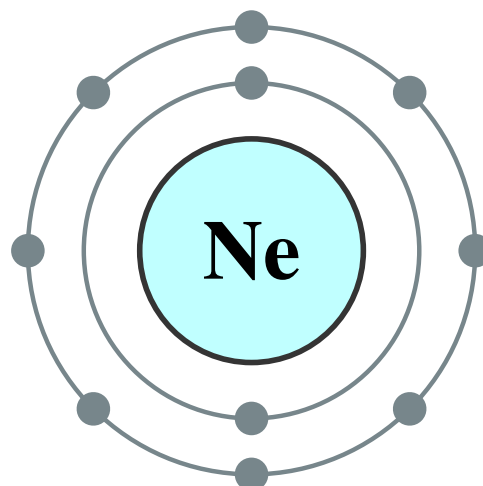
The noble gases are colorless, odorless, tasteless, and non-flammable under standard conditions. They were once labeled *group 0* in the periodic table because it was believed they had a valence of zero, meaning their atoms cannot combine with those of other elements to form compounds. However, it was later discovered some do indeed form compounds, causing this label to fall into disuse.^[11]

Configuration

Main article: Noble gas configuration

Like other groups, the members of this family show patterns in its electron configuration, especially the outermost shells resulting in trends in chemical behavior:

The noble gases have full valence electron shells. Valence electrons are the outermost electrons of an atom and are



Neon, like all noble gases, has a full valence shell. Noble gases have eight electrons in their outermost shell, except in the case of helium, which has two.

normally the only electrons that participate in chemical bonding. Atoms with full valence electron shells are extremely stable and therefore do not tend to form chemical bonds and have little tendency to gain or lose electrons.^[29] However, heavier noble gases such as radon are held less firmly together by electromagnetic force than lighter noble gases such as helium, making it easier to remove outer electrons from heavy noble gases.

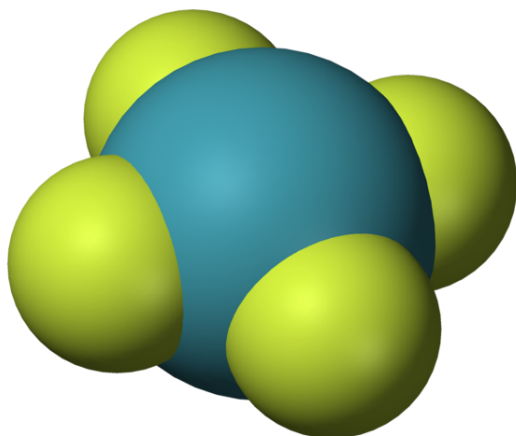
As a result of a full shell, the noble gases can be used in conjunction with the electron configuration notation to form the *noble gas notation*. To do this, the nearest noble gas that precedes the element in question is written first, and then the electron configuration is continued from that point forward. For example, the electron notation of Phosphorus is $1s^2 2s^2 2p^6 3s^2 3p^3$, while the noble gas notation is $[\text{Ne}] 3s^2 3p^3$. This more compact notation makes it easier to identify elements, and is shorter than writing out the full notation of atomic orbitals.^[30]

Compounds

Main article: Noble gas compound

The noble gases show extremely low chemical reactivity; consequently, only a few hundred noble gas compounds have been formed. Neutral compounds in which helium and neon are involved in chemical bonds have not been formed (although there is some theoretical evidence for a few helium compounds), while xenon, krypton, and argon have shown only minor reactivity.^[31] The reactivity follows the order $\text{Ne} < \text{He} < \text{Ar} < \text{Kr} < \text{Xe} < \text{Rn}$.

In 1933, Linus Pauling predicted that the heavier noble gases could form compounds with fluorine and oxygen. He predicted the existence of krypton hexafluoride (KrF_6) and xenon hexafluoride (XeF_6)



Structure of XeF

4, one of the first noble gas compounds to be discovered

6), speculated that XeF

8 might exist as an unstable compound, and suggested xenic acid could form perxenate salts.^{[32][33]} These predictions were shown to be generally accurate, except that XeF

8 is now thought to be both thermodynamically and kinetically unstable.^[34]

Xenon compounds are the most numerous of the noble gas compounds that have been formed.^[35] Most of them have the xenon atom in the oxidation state of +2, +4, +6, or +8 bonded to highly electronegative atoms such as fluorine or oxygen, as in xenon difluoride (XeF

2), xenon tetrafluoride (XeF

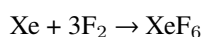
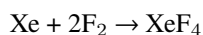
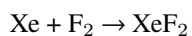
4), xenon hexafluoride (XeF

6), xenon tetroxide (XeO

4), and sodium perxenate (Na

4XeO

6). Xenon reacts with fluorine to form numerous xenon fluorides according to the following equations:

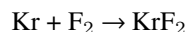


Some of these compounds have found use in chemical synthesis as oxidizing agents; XeF

2, in particular, is commercially available and can be used as a fluorinating agent.^[36] As of 2007, about five hundred compounds of xenon bonded to other elements have been identified, including organoxenon compounds (containing xenon bonded to carbon), and xenon bonded to nitrogen, chlorine, gold, mercury, and xenon itself.^{[31][37]} Compounds of xenon bound to boron, hydrogen, bromine, iodine, beryllium, sulphur, titanium, copper, and silver have also been observed but only at low temperatures in noble gas matrices, or in supersonic noble gas jets.^[31]

In theory, radon is more reactive than xenon, and therefore should form chemical bonds more easily than xenon does. However, due to the high radioactivity and short half-life of radon isotopes, only a few fluorides and oxides of radon have been formed in practice.^[38]

Krypton is less reactive than xenon, but several compounds have been reported with krypton in the oxidation state of +2.^[31] Krypton difluoride is the most notable and easily characterized. Under extreme conditions, krypton reacts with fluorine to form KrF₂ according to the following equation:



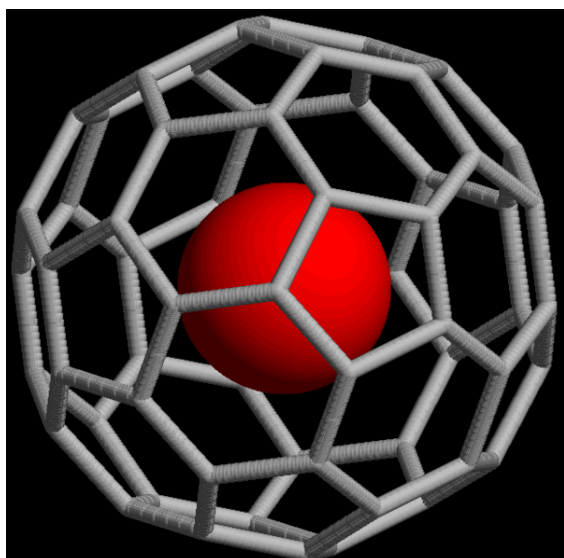
Compounds in which krypton forms a single bond to nitrogen and oxygen have also been characterized,^[39] but are only stable below -60 °C (-76 °F) and -90 °C (-130 °F) respectively.^[31]

Krypton atoms chemically bound to other nonmetals (hydrogen, chlorine, carbon) as well as some late transition metals (copper, silver, gold) have also been observed, but only either at low temperatures in noble gas matrices, or in supersonic noble gas jets.^[31] Similar conditions were used to obtain the first few compounds of argon in 2000, such as argon fluorohydride (HArF), and some bound to the late transition metals copper, silver, and gold.^[31] As of 2007, no stable neutral molecules involving covalently bound helium or neon are known.^[31]

The noble gases—including helium—can form stable molecular ions in the gas phase. The simplest is the helium hydride molecular ion, HeH⁺, discovered in 1925.^[40] Because it is composed of the two most abundant elements in the universe, hydrogen and helium, it is believed to occur naturally in the interstellar medium, although it has not been detected yet.^[41] In addition to these ions, there are many known neutral excimers of the noble gases. These are compounds such as ArF and KrF that are stable only when in an excited electronic state; some of them find application in excimer lasers.

In addition to the compounds where a noble gas atom is involved in a covalent bond, noble gases also form non-covalent compounds. The clathrates, first described in 1949,^[42] consist of a noble gas atom trapped within cavities of crystal lattices of certain organic and inorganic substances. The essential condition for their formation is that the guest (noble gas) atoms must be of appropriate size to fit in the cavities of the host crystal lattice. For instance, argon, krypton, and xenon form clathrates with hydroquinone, but helium and neon do not because they are too small or insufficiently polarizable to be retained.^[43] Neon, argon, krypton, and xenon also form clathrate hydrates, where the noble gas is trapped in ice.^[44]

Noble gases can form endohedral fullerene compounds, in which the noble gas atom is trapped inside a fullerene molecule. In 1993, it was discovered that when C

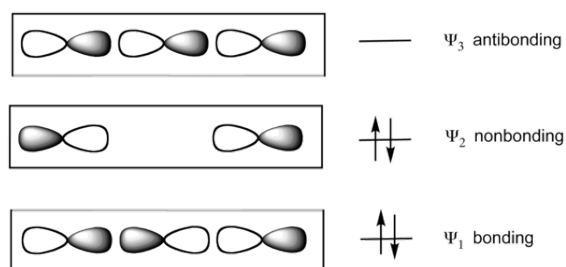


An endohedral fullerene compound containing a noble gas atom

60, a spherical molecule consisting of 60 carbon atoms, is exposed to noble gases at high pressure, complexes such as He@C

60 can be formed (the @ notation indicates He is contained inside C

60 but not covalently bound to it).^[45] As of 2008, endohedral complexes with helium, neon, argon, krypton, and xenon have been obtained.^[46] These compounds have found use in the study of the structure and reactivity of fullerenes by means of the nuclear magnetic resonance of the noble gas atom.^[47]



Bonding in XeF

2 according to the 3-center-4-electron bond model

Noble gas compounds such as xenon difluoride (XeF₂) are considered to be hypervalent because they violate the octet rule. Bonding in such compounds can be explained using a three-center four-electron bond model.^{[48][49]} This model, first proposed in 1951, considers bonding of three collinear atoms. For example, bonding in XeF

2 is described by a set of three molecular orbitals (MOs) derived from p-orbitals on each atom. Bonding results from the combination of a filled p-orbital from Xe with one half-filled p-orbital from each F atom, resulting in a filled bonding orbital, a filled non-bonding orbital, and an empty antibonding orbital. The highest occupied molec-

ular orbital is localized on the two terminal atoms. This represents a localization of charge which is facilitated by the high electronegativity of fluorine.^[50]

The chemistry of heavier noble gases, krypton and xenon, are well established. The chemistry of the lighter ones, argon and helium, is still at an early stage, while a neon compound is yet to be identified.

1.1.4 Occurrence and production

The abundances of the noble gases in the universe decrease as their atomic numbers increase. Helium is the most common element in the universe after hydrogen, with a mass fraction of about 24%. Most of the helium in the universe was formed during Big Bang nucleosynthesis, but the amount of helium is steadily increasing due to the fusion of hydrogen in stellar nucleosynthesis (and, to a very slight degree, the alpha decay of heavy elements).^{[51][52]} Abundances on Earth follow different trends; for example, helium is only the third most abundant noble gas in the atmosphere. The reason is that there is no primordial helium in the atmosphere; due to the small mass of the atom, helium cannot be retained by the Earth's gravitational field.^[53] Helium on Earth comes from the alpha decay of heavy elements such as uranium and thorium found in the Earth's crust, and tends to accumulate in natural gas deposits.^[53] The abundance of argon, on the other hand, is increased as a result of the beta decay of potassium-40, also found in the Earth's crust, to form argon-40, which is the most abundant isotope of argon on Earth despite being relatively rare in the Solar System. This process is the base for the potassium-argon dating method.^[54] Xenon has an unexpectedly low abundance in the atmosphere, in what has been called the *missing xenon problem*; one theory is that the missing xenon may be trapped in minerals inside the Earth's crust.^[55] After the discovery of xenon dioxide, a research showed that Xe can substitute for Si in the quartz.^[56] Radon is formed in the lithosphere as from the alpha decay of radium. It can seep into buildings through cracks in their foundation and accumulate in areas that are not well ventilated. Due to its high radioactivity, radon presents a significant health hazard; it is implicated in an estimated 21,000 lung cancer deaths per year in the United States alone.^[57]

For large-scale use, helium is extracted by fractional distillation from natural gas, which can contain up to 7% helium.^[62]

Neon, argon, krypton, and xenon are obtained from air using the methods of liquefaction of gases, to convert elements to a liquid state, and fractional distillation, to separate mixtures into component parts. Helium is typically produced by separating it from natural gas, and

radon is isolated from the radioactive decay of radium compounds.^[11] The prices of the noble gases are influenced by their natural abundance, with argon being the cheapest and xenon the most expensive. As an example, the table to the right lists the 2004 prices in the United States for laboratory quantities of each gas.

1.1.5 Applications



Liquid helium is used to cool the superconducting magnets in modern MRI scanners

Noble gases have very low boiling and melting points, which makes them useful as cryogenic refrigerants.^[63] In particular, liquid helium, which boils at 4.2 K (−268.95 °C; −452.11 °F), is used for superconducting magnets, such as those needed in nuclear magnetic resonance imaging and nuclear magnetic resonance.^[64] Liquid neon, although it does not reach temperatures as low as liquid helium, also finds use in cryogenics because it has over 40 times more refrigerating capacity than liquid helium and over three times more than liquid hydrogen.^[60]

Helium is used as a component of breathing gases to replace nitrogen, due its low solubility in fluids, especially in lipids. Gases are absorbed by the blood and body tissues when under pressure like in scuba diving, which causes an anesthetic effect known as nitrogen narcosis.^[65] Due to its reduced solubility, little helium is taken into cell membranes, and when helium is used to replace part of the breathing mixtures, such as in trimix or heliox, a decrease in the narcotic effect of the gas at depth is obtained.^[66] Helium's reduced solubility offers further advantages for the condition known as decompression sickness, or *the bends*.^{[11][67]} The reduced amount of dissolved gas in the body means that fewer gas bubbles form during the decrease in pressure of the ascent. Another noble gas, argon, is considered the best option for use as a drysuit inflation gas for scuba diving.^[68] Helium is also used as filling gas in nuclear fuel rods for nuclear reactors.^[69]

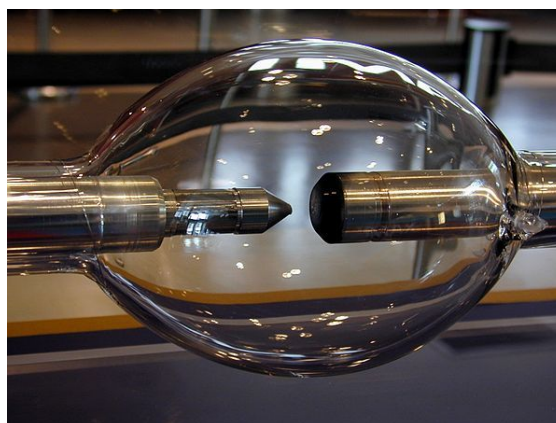
Since the *Hindenburg* disaster in 1937,^[70] helium has replaced hydrogen as a lifting gas in blimps and balloons due to its lightness and incombustibility, despite an



Goodyear Blimp

8.6%^[71] decrease in buoyancy.^[11]

In many applications, the noble gases are used to provide an inert atmosphere. Argon is used in the synthesis of air-sensitive compounds that are sensitive to nitrogen. Solid argon is also used for the study of very unstable compounds, such as reactive intermediates, by trapping them in an inert matrix at very low temperatures.^[72] Helium is used as the carrier medium in gas chromatography, as a filler gas for thermometers, and in devices for measuring radiation, such as the Geiger counter and the bubble chamber.^[61] Helium and argon are both commonly used to shield welding arcs and the surrounding base metal from the atmosphere during welding and cutting, as well as in other metallurgical processes and in the production of silicon for the semiconductor industry.^[60]



15,000-watt xenon short-arc lamp used in IMAX projectors

Noble gases are commonly used in lighting because of their lack of chemical reactivity. Argon, mixed with nitrogen, is used as a filler gas for incandescent light bulbs.^[60] Krypton is used in high-performance light bulbs, which have higher color temperatures and greater efficiency, because it reduces the rate of evaporation of the filament more than argon; halogen lamps, in particular, use krypton mixed with small amounts of compounds of iodine or bromine.^[60] The noble gases glow in distinctive colors when used inside gas-discharge lamps, such as "neon lights". These lights are called after neon but often contain other gases and phosphors, which add various hues to the orange-red color of neon. Xenon is commonly used in xenon arc lamps which, due to their nearly continuous spectrum that resembles daylight, find appli-

cation in film projectors and as automobile headlamps.^[60]

The noble gases are used in excimer lasers, which are based on short-lived electronically excited molecules known as excimers. The excimers used for lasers may be noble gas dimers such as Ar₂, Kr₂ or Xe₂, or more commonly, the noble gas is combined with a halogen in excimers such as ArF, KrF, XeF, or XeCl. These lasers produce ultraviolet light which, due to its short wavelength (193 nm for ArF and 248 nm for KrF), allows for high-precision imaging. Excimer lasers have many industrial, medical, and scientific applications. They are used for microlithography and microfabrication, which are essential for integrated circuit manufacture, and for laser surgery, including laser angioplasty and eye surgery.^[73]

Some noble gases have direct application in medicine. Helium is sometimes used to improve the ease of breathing of asthma sufferers.^[60] Xenon is used as an anesthetic because of its high solubility in lipids, which makes it more potent than the usual nitrous oxide, and because it is readily eliminated from the body, resulting in faster recovery.^[74] Xenon finds application in medical imaging of the lungs through hyperpolarized MRI.^[75] Radon, which is highly radioactive and is only available in minute amounts, is used in radiotherapy.^[11]

1.1.6 Discharge color

The color of gas discharge emission depends on several factors, including the following:^[76]

- discharge parameters (local value of current density and electric field, temperature, etc. – note the color variation along the discharge in the top row);
- gas purity (even small fraction of certain gases can affect color);
- material of the discharge tube envelope – note suppression of the UV and blue components in the bottom-row tubes made of thick household glass.

1.1.7 See also

- Noble gas (data page), for extended tables of physical properties.
- Noble metal, for metals that are resistant to corrosion or oxidation.
- Inert gas, for any gas that is not reactive under normal circumstances.
- Industrial gas
- Neutronium
- Noble gas configuration

1.1.8 Notes

- [1] “Flerov laboratory of nuclear reactions” (PDF). JINR. Retrieved 2009-08-08.
- [2] Nash, Clinton S. (2005). “Atomic and Molecular Properties of Elements 112, 114, and 118”. *J. Phys. Chem. A* **109** (15): 3493–3500. doi:10.1021/jp050736o. PMID 16833687.
- [3] Renouf, Edward (1901). “Noble gases”. *Science* **13** (320): 268–270. Bibcode:1901Sci....13..268R. doi:10.1126/science.13.320.268.
- [4] Ojima 2002, p. 30
- [5] Ojima 2002, p. 4
- [6] “argon”. *Encyclopædia Britannica*. 2008.
- [7] *Oxford English Dictionary* (1989), s.v. “helium”. Retrieved December 16, 2006, from Oxford English Dictionary Online. Also, from quotation there: Thomson, W. (1872). *Rep. Brit. Assoc.* xcix: “Frankland and Lockyer find the yellow prominences to give a very decided bright line not far from D, but hitherto not identified with any terrestrial flame. It seems to indicate a new substance, which they propose to call Helium.”
- [8] Ojima 2002, p. 1
- [9] Mendeleev 1903, p. 497
- [10] Partington, J. R. (1957). “Discovery of Radon”. *Nature* **179** (4566): 912. Bibcode:1957Natur.179..912P. doi:10.1038/179912a0.
- [11] “Noble Gas”. *Encyclopædia Britannica*. 2008.
- [12] Cederblom, J. E. (1904). “The Nobel Prize in Physics 1904 Presentation Speech”.
- [13] Cederblom, J. E. (1904). “The Nobel Prize in Chemistry 1904 Presentation Speech”.
- [14] Gillespie, R. J.; Robinson, E. A. (2007). “Gilbert N. Lewis and the chemical bond: the electron pair and the octet rule from 1916 to the present day”. *J Comput Chem* **28** (1): 87–97. doi:10.1002/jcc.20545. PMID 17109437.
- [15] Bartlett, N. (1962). “Xenon hexafluoroplatinate Xe⁺[PtF₆]⁻”. *Proceedings of the Chemical Society* (6): 218. doi:10.1039/PS9620000197.
- [16] Fields, Paul R.; Stein, Lawrence; Zirin, Moshe H. (1962). “Radon Fluoride”. *Journal of the American Chemical Society* **84** (21): 4164–4165. doi:10.1021/ja00880a048.
- [17] Grosse, A. V.; Kirschenbaum, A. D.; Streng, A. G.; Streng, L. V. (1963). “Krypton Tetrafluoride: Preparation and Some Properties”. *Science* **139** (3559): 1047–1048. Bibcode:1963Sci...139.1047G. doi:10.1126/science.139.3559.1047. PMID 17812982.
- [18] Khriachtchev, Leonid; Pettersson, Mika; Runeberg, Nino; Lundell, Jan; Räsänen, Markku (2000). “A stable argon compound”. *Nature* **406** (6798): 874–876. doi:10.1038/35022551. PMID 10972285.

- [19] Oganessian, Yu. Ts.; Utyonkov, V.; Lobanov, Yu.; Abdullin, F.; Polyakov, A. et al. (1999). "Synthesis of Superheavy Nuclei in the $^{48}\text{Ca} + ^{244}\text{Pu}$ Reaction". *Physical Review Letters* (American Physical Society) **83** (16): 3154. Bibcode:1999PhRvL...83.3154O. doi:10.1103/PhysRevLett.83.3154.
- [20] Woods, Michael (2003-05-06). "Chemical element No. 110 finally gets a name—darmstadtium". *Pittsburgh Post-Gazette*. Retrieved 2008-06-26.
- [21] "Gas Phase Chemistry of Superheavy Elements" (PDF). Texas A&M University. Retrieved 2008-05-31.
- [22] Robert C. Barber, Paul J. Karol, Hiromichi Nakahara, Emanuele Vardaci, and Erich W. Vogt (2011). "Discovery of the elements with atomic numbers greater than or equal to 113 (IUPAC Technical Report)*" (PDF). *Pure Appl. Chem.* (IUPAC) **83** (7). doi:10.1515/ci.2011.33.5.25b. Retrieved 2014-05-30.
- [23] Oganessian, Yu. Ts.; Utyonkov, V.; Lobanov, Yu.; Abdullin, F.; Polyakov, A. et al. (2006). "Synthesis of the isotopes of elements 118 and 116 in the ^{249}Cf and $^{245}\text{Cm} + ^{48}\text{Ca}$ fusion reactions". *Physical Review C* **74** (4): 44602. Bibcode:2006PhRvC..74d4602O. doi:10.1103/PhysRevC.74.044602.
- [24] Greenwood 1997, p. 891
- [25] Allen, Leland C. (1989). "Electronegativity is the average one-electron energy of the valence-shell electrons in ground-state free atoms". *Journal of the American Chemical Society* **111** (25): 9003. doi:10.1021/ja00207a003.
- [26] "Solid Helium". University of Alberta. Retrieved 2008-06-22.
- [27] Wheeler, John C. (1997). "Electron Affinities of the Alkaline Earth Metals and the Sign Convention for Electron Affinity". *Journal of Chemical Education* **74**: 123–127. Bibcode:1997JChEd..74..123W. doi:10.1021/ed074p123.; Kalcher, Josef; Sax, Alexander F. (1994). "Gas Phase Stabilities of Small Anions: Theory and Experiment in Cooperation". *Chemical Reviews* **94** (8): 2291–2318. doi:10.1021/cr00032a004.
- [28] Mott, N. F. (1955). "John Edward Lennard-Jones. 1894–1954". *Biographical Memoirs of Fellows of the Royal Society* **1**: 175–184. doi:10.1098/rsbm.1955.0013.
- [29] Ojima 2002, p. 35
- [30] CliffsNotes 2007, p. 15
- [31] Grochala, Wojciech (2007). "Atypical compounds of gases, which have been called noble". *Chemical Society Reviews* **36** (10): 1632–1655. doi:10.1039/b702109g. PMID 17721587.
- [32] Pauling, Linus (1933). "The Formulas of Antimonic Acid and the Antimonates". *Journal of the American Chemical Society* **55** (5): 1895–1900. doi:10.1021/ja01332a016.
- [33] Holloway 1968
- [34] Seppelt, Konrad (1979). "Recent developments in the Chemistry of Some Electronegative Elements". *Accounts of Chemical Research* **12** (6): 211–216. doi:10.1021/ar50138a004.
- [35] Moody, G. J. (1974). "A Decade of Xenon Chemistry". *Journal of Chemical Education* **51** (10): 628–630. Bibcode:1974JChEd..51..628M. doi:10.1021/ed051p628. Retrieved 2007-10-16.
- [36] Zupan, Marko; Iskra, Jernej; Stavber, Stojan (1998). "Fluorination with XeF_2 . 44. Effect of Geometry and Heteroatom on the Regioselectivity of Fluorine Introduction into an Aromatic Ring". *J. Org. Chem* **63** (3): 878–880. doi:10.1021/jo971496e. PMID 11672087.
- [37] Harding 2002, pp. 90–99
- [38] Avrorin, V. V.; Krasikova, R. N.; Nefedov, V. D.; Toropova, M. A. (1982). "The Chemistry of Radon". *Russian Chemical Review* **51** (1): 12–20. Bibcode:1982RuCRv..51...12A. doi:10.1070/RC1982v051n01ABEH002787.
- [39] Lehmann, J (2002). "The chemistry of krypton". *Coordination Chemistry Reviews*. 233–234: 1–39. doi:10.1016/S0010-8545(02)00202-3.
- [40] Hogness, T. R.; Lunn, E. G. (1925). "The Ionization of Hydrogen by Electron Impact as Interpreted by Positive Ray Analysis". *Physical Review* **26**: 44–55. Bibcode:1925PhRv...26...44H. doi:10.1103/PhysRev.26.44.
- [41] Fernandez, J.; Martin, F. (2007). "Photoionization of the HeH_2^+ molecular ion". *J. Phys. B: At. Mol. Opt. Phys* **40** (12): 2471–2480. Bibcode:2007JPhB...40.2471F. doi:10.1088/0953-4075/40/12/020.
- [42] H. M. Powell and M. Guter (1949). "An Inert Gas Compound". *Nature* **164** (4162): 240–241. Bibcode:1949Natur.164..240P. doi:10.1038/164240b0.
- [43] Greenwood 1997, p. 893
- [44] Dyadin, Yuri A. et al. (1999). "Clathrate hydrates of hydrogen and neon". *Mendeleev Communications* **9** (5): 209–210. doi:10.1070/MC1999v009n05ABEH001104.
- [45] Saunders, M.; Jiménez-Vázquez, H. A.; Cross, R. J.; Poreda, R. J. (1993). "Stable compounds of helium and neon. $\text{He}@C_{60}$ and $\text{Ne}@C_{60}$ ". *Science* **259** (5100): 1428–1430. Bibcode:1993Sci...259.1428S. doi:10.1126/science.259.5100.1428. PMID 17801275.
- [46] Saunders, Martin; Jimenez-Vazquez, Hugo A.; Cross, R. James; Mroczkowski, Stanley; Gross, Michael L.; Giblin, Daryl E.; Poreda, Robert J. (1994). "Incorporation of helium, neon, argon, krypton, and xenon into fullerenes using high pressure". *J. Am. Chem. Soc.* **116** (5): 2193–2194. doi:10.1021/ja00084a089.
- [47] Frunzi, Michael; Cross, R. Jame; Saunders, Martin (2007). "Effect of Xenon on Fullerene Reactions". *Journal of the American Chemical Society* **129** (43): 13343–6. doi:10.1021/ja075568n. PMID 17924634.
- [48] Greenwood 1997, p. 897

- [49] Weinhold 2005, pp. 275–306
- [50] Pimentel, G. C. (1951). “The Bonding of Trihalide and Bifluoride Ions by the Molecular Orbital Method”. *The Journal of Chemical Physics* **19** (4): 446–448. Bibcode:1951JChPh..19..446P. doi:10.1063/1.1748245.
- [51] Weiss, Achim. “Elements of the past: Big Bang Nucleosynthesis and observation”. Max Planck Institute for Gravitational Physics. Retrieved 2008-06-23.
- [52] Coc, A.; et al. (2004). “Updated Big Bang Nucleosynthesis confronted to WMAP observations and to the Abundance of Light Elements”. *Astrophysical Journal* **600** (2): 544. arXiv:astro-ph/0309480. Bibcode:2004ApJ...600..544C. doi:10.1086/380121.
- [53] Morrison, P.; Pine, J. (1955). “Radiogenic Origin of the Helium Isotopes in Rock”. *Annals of the New York Academy of Sciences* **62** (3): 71–92. Bibcode:1955NYASA..62...71M. doi:10.1111/j.1749-6632.1955.tb35366.x.
- [54] Scherer, Alexandra (2007-01-16). “⁴⁰Ar/³⁹Ar dating and errors”. Technische Universität Bergakademie Freiberg. Archived from the original on 2007-10-14. Retrieved 2008-06-26.
- [55] Sanloup, Chrystèle; Schmidt, Burkhard C. et al. (2005). “Retention of Xenon in Quartz and Earth’s Missing Xenon”. *Science* **310** (5751): 1174–1177. Bibcode:2005Sci...310.1174S. doi:10.1126/science.1119070. PMID 16293758.
- [56] Tyler Irving (May 2011). “Xenon Dioxide May Solve One of Earth’s Mysteries”. *L’Actualité chimique canadienne* (Canadian Chemical News). Retrieved 2012-05-18.
- [57] “A Citizen’s Guide to Radon”. U.S. Environmental Protection Agency. 2007-11-26. Retrieved 2008-06-26.
- [58] Lodders, Katharina (July 10, 2003). “Solar System Abundances and Condensation Temperatures of the Elements” (PDF). *The Astrophysical Journal* (The American Astronomical Society) **591** (2): 1220–1247. Bibcode:2003ApJ...591.1220L. doi:10.1086/375492.
- [59] “The Atmosphere”. National Weather Service. Retrieved 2008-06-01.
- [60] Häussinger, Peter; Glatthaar, Reinhard; Rhode, Wilhelm; Kick, Helmut; Benkmann, Christian; Weber, Josef; Wunschel, Hans-Jörg; Stenke, Viktor; Leicht, Edith; Stenger, Hermann (2002). “Noble gases”. *Ullmann’s Encyclopedia of Industrial Chemistry*. Wiley. doi:10.1002/14356007.a17_485.
- [61] Hwang, Shuen-Chen; Lein, Robert D.; Morgan, Daniel A. (2005). “Noble Gases”. *Kirk Othmer Encyclopedia of Chemical Technology*. Wiley. pp. 343–383. doi:10.1002/0471238961.0701190508230114.a01.
- [62] Winter, Mark (2008). “Helium: the essentials”. University of Sheffield. Retrieved 2008-07-14.
- [63] “Neon”. *Encarta*. 2008.
- [64] Zhang, C. J.; Zhou, X. T.; Yang, L. (1992). “Demountable coaxial gas-cooled current leads for MRI superconducting magnets”. *Magnetics, IEEE Transactions on (IEEE)* **28** (1): 957–959. Bibcode:1992ITM....28..957Z. doi:10.1109/20.120038.
- [65] Fowler, B; Ackles, K. N.; Porlier, G. (1985). “Effects of inert gas narcosis on behavior—a critical review”. *Undersea Biomed. Res.* **12** (4): 369–402. ISSN 0093-5387. OCLC 2068005. PMID 4082343. Retrieved 2008-04-08.
- [66] Bennett 1998, p. 176
- [67] Vann, R. D. (ed) (1989). “The Physiological Basis of Decompression”. *38th Undersea and Hyperbaric Medical Society Workshop*. 75(Phys)6-1-89: 437. Retrieved 2008-05-31.
- [68] Maiken, Eric (2004-08-01). “Why Argon?”. Decompression. Retrieved 2008-06-26.
- [69] Horhoianu, G; Ionescu, D.V; Olteanu, G (1999). “Thermal behaviour of CANDU type fuel rods during steady state and transient operating conditions”. *Annals of Nuclear Energy* **26** (16): 1437. doi:10.1016/S0306-4549(99)00022-5.
- [70] “Disaster Ascribed to Gas by Experts”. *The New York Times*. 1937-05-07. p. 1.
- [71] Freudenrich, Craig (2008). “How Blimps Work”. HowStuffWorks. Retrieved 2008-07-03.
- [72] Dunkin, I. R. (1980). “The matrix isolation technique and its application to organic chemistry”. *Chem. Soc. Rev.* **9**: 1–23. doi:10.1039/CS9800900001.
- [73] Basting, Dirk; Marowsky, Gerd (2005). *Excimer Laser Technology*. Springer. ISBN 3-540-20056-8.
- [74] Sanders, Robert D.; Ma, Daqing; Maze, Mervyn (2005). “Xenon: elemental anaesthesia in clinical practice”. *British Medical Bulletin* **71** (1): 115–135. doi:10.1093/bmb/ldh034. PMID 15728132.
- [75] Albert, M. S.; Balamore, D. (1998). “Development of hyperpolarized noble gas MRI”. *Nuclear Instruments and Methods in Physics Research A* **402** (2–3): 441–453. Bibcode:1998NIMPA.402..441A. doi:10.1016/S0168-9002(97)00888-7. PMID 11543065.
- [76] Ray, Sidney F. (1999). *Scientific photography and applied imaging*. Focal Press. pp. 383–384. ISBN 0-240-51323-1.

1.1.9 References

- Bennett, Peter B.; Elliott, David H. (1998). *The Physiology and Medicine of Diving*. SPCK Publishing. ISBN 0-7020-2410-4.
- Bobrow Test Preparation Services (2007-12-05). *CliffsAP Chemistry*. CliffsNotes. ISBN 0-470-13500-X.

- Greenwood, N. N.; Earnshaw, A. (1997). *Chemistry of the Elements* (2nd ed.). Oxford:Butterworth-Heinemann. ISBN 0-7506-3365-4.
- Harding, Charlie J.; Janes, Rob (2002). *Elements of the P Block*. Royal Society of Chemistry. ISBN 0-85404-690-9.
- Holloway, John H. (1968). *Noble-Gas Chemistry*. London: Methuen Publishing. ISBN 0-412-21100-9.
- Mendeleev, D. (1902–1903). *Osnovy Khimii (The Principles of Chemistry)* (in Russian) (7th ed.).
- Ojima, Minoru; Podosek, Frank A. (2002). *Noble Gas Geochemistry*. Cambridge University Press. ISBN 0-521-80366-7.
- Weinhold, F.; Landis, C. (2005). *Valency and bonding*. Cambridge University Press. ISBN 0-521-83128-8.
- Scerri, Eric R. (2007). *The Periodic Table, Its Story and Its Significance*. Oxford University Press. ISBN 0-19-530573-6.

Chapter 2

Elements

2.1 Helium

This article is about the chemical element. For other uses, see Helium (disambiguation).

Helium is a chemical element with symbol **He** and atomic number 2. It is a colorless, odorless, tasteless, non-toxic, inert, monatomic gas that heads the noble gas group in the periodic table. Its boiling and melting points are the lowest among all the elements and it exists only as a gas except in extremely cold conditions.

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. Janssen 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

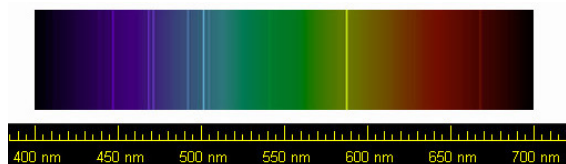
other industrial uses—as a pressurizing and purge gas, as a protective atmosphere for arc welding and in processes such as growing crystals to make silicon wafers—account for half of the gas produced. A well-known but minor use is as a lifting gas in balloons and airships.^[4] As with any gas whose density 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. Helium is a finite resource, and once released into the atmosphere, it readily escapes into space.^{[5][6][7]}

2.1.1 History

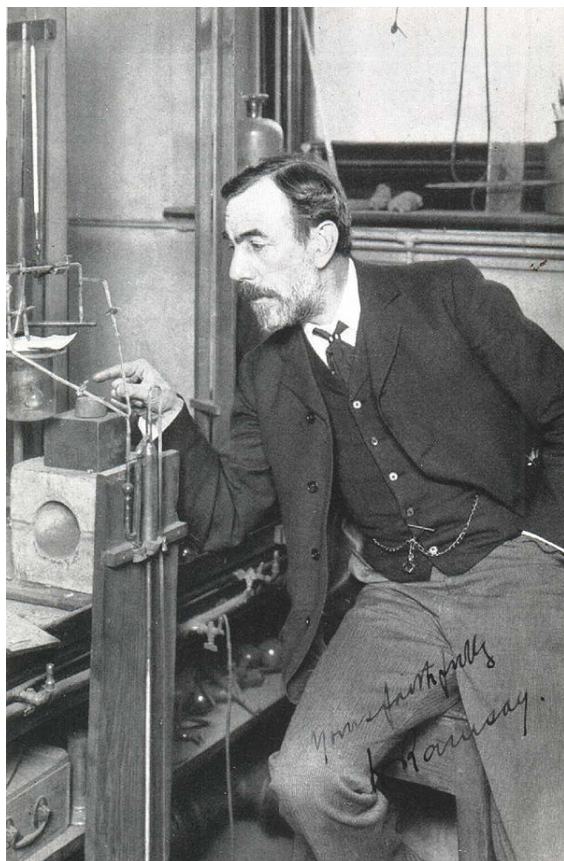
Scientific discoveries

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.^{[8][9]} 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.^[10] 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, ἥλιος (*helios*).^{[11][12]}



Spectral lines of helium

In 1882, Italian physicist Luigi Palmieri detected helium on Earth, for the first time, through its D_3 spectral line, when he analyzed the lava of Mount Vesuvius.^[13]



Sir William Ramsay, the discoverer of terrestrial helium

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 D_3 line observed in the spectrum of the Sun.^{[10][14][15][16]} 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.^{[9][17][18]} 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.^[19]

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.^[20] He tried to solidify it by further reducing the temperature but failed because helium does not have a triple point temperature at which the solid, liquid, and gas phases are at equilibrium. Onnes' student Willem Hendrik Keesom was eventually able to solidify 1 cm³ of helium in 1926 by applying additional external pressure.^[21]

In 1938, Russian physicist Pyotr Leonidovich Kapitza discovered that helium-4 has almost no viscosity at temperatures near absolute zero, a phenomenon now called superfluidity.^[22] 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.^[23]

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.^{[9][24]} With further analysis, Cady and McFarland discovered that 1.84% of the gas sample was helium.^{[25][26]} 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.^[27]

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.^[10] 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.^[28]

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. This use increased demand during World War II, as well as demands for shielded arc welding. The helium mass spectrometer was also vital in the atomic bomb Manhattan Project.^[29]

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.^[10] 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. Helium use following 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.^[30]

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, when it then was further purified.^[31]

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.^{[9][32]} The resulting "Helium Privatization Act of 1996"^[33] (Public Law 104-273) directed the United States Department of the Interior to empty the reserve, with sales starting by 2005.^[34]

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.^[35]

For many years the United States produced over 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,

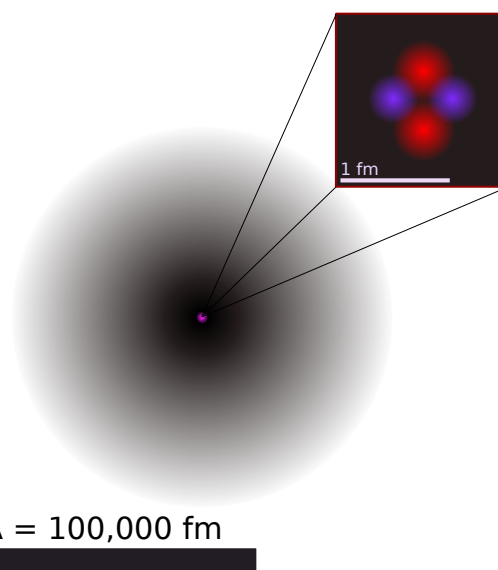
by 2000, the consumption of helium within the U.S. had risen to above 15 million kg per year.^[36] In 2004–2006, two additional plants, one in Ras Laffan, Qatar, and the other in Skikda, Algeria, were built. Algeria quickly became the second leading producer of helium.^[37] Through this time, both helium consumption and the costs of producing helium increased.^[38] From 2002 to 2007 helium prices doubled.^[39]

As of 2012 the United States National Helium Reserve accounted for 30 percent of the world's helium.^[40] The reserve was expected to run out of helium in 2018.^[40] 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.^[40]

2.1.2 Characteristics

The helium atom

Main article: Helium atom



The helium atom. Depicted are the nucleus (pink) and the 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 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

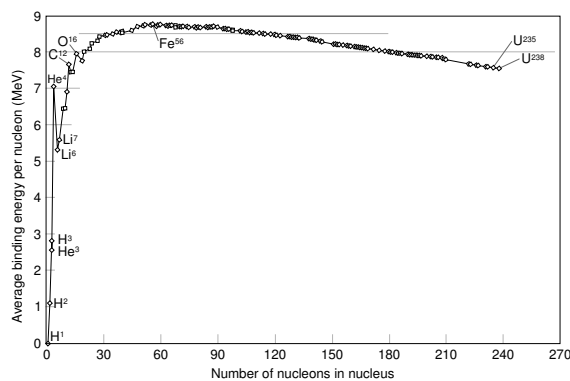
a nucleus containing two protons along with some neutrons. As in Newtonian mechanics, no system consisting of more than two particles can be solved with an exact analytical mathematical approach (see **3-body problem**) and helium is no exception. Thus, numerical mathematical methods are required, even 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.^[41] In such models it is found 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 involving both heavy-particle emission, and fusion. Some stable helium-3 is produced in fusion reactions from hydrogen, but it is a very small fraction, compared with 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



Binding energy per nucleon of common isotopes. The binding energy per particle of helium-4 is significantly larger than all nearby nuclides.

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 no energetic drive was available, once helium had been formed, 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.^[42] 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 similar reasons, and also due to the small size of helium atoms, helium’s diffusion rate through



Helium discharge tube shaped like the element's atomic symbol

solids is three times that of air and around 65% that of hydrogen.^[10]

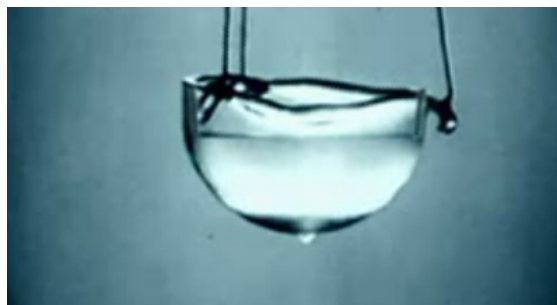
Helium is the least water soluble monatomic gas,^[43] and one of the least water soluble of any gas (CF₄, SF₆, and C₄F₈ have lower mole fraction solubilities: 0.3802, 0.4394, and 0.2372 x₂/10⁻⁵, respectively, versus helium's 0.70797 x₂/10⁻⁵),^[44] and helium's index of refraction is closer to unity than that of any other gas.^[45] 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.^[10] 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.^[46]

Liquid Helium

Main article: 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



Liquefied helium. This helium is not only liquid, but has been cooled to the point of superfluidity. 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.

or –457 °F) and about 25 bar (2.5 MPa) of pressure.^[47] 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%.^[48] With a bulk modulus of about 27 MPa^[49] 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.^[50]

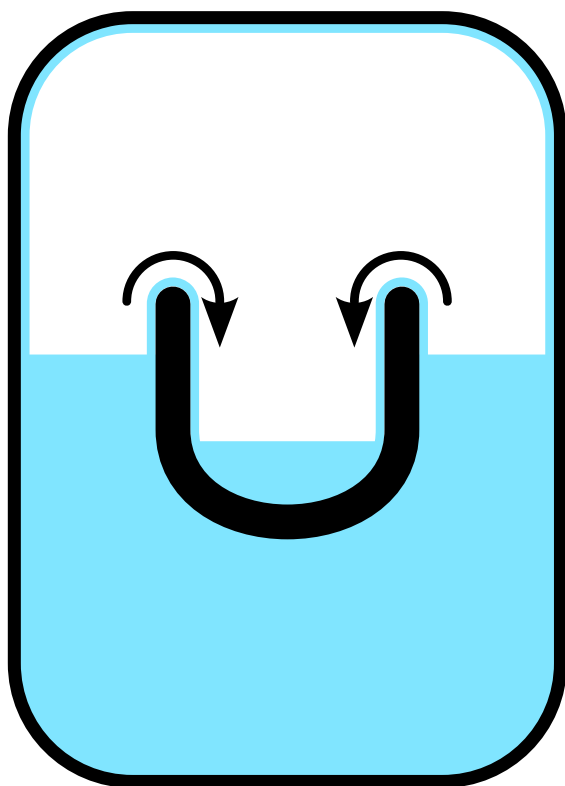
Helium I state Below its boiling point of 4.22 kelvins and above the lambda point of 2.1768 kelvins, the isotope helium-4 exists in a normal colorless liquid state, called *helium I*.^[10] Like other cryogenic liquids, helium I boils when it is heated and contracts when its temperature is lowered. Below 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.^[10] This colorless liquid has a very low viscosity and a density of 0.145–0.125 g/mL (between about 0 and 4 K),^[51] which is only one-fourth the value expected from classical physics.^[10] Quantum mechanics is needed to explain this property and thus both types of liquid helium 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.^[10]

Helium II state Main article: Superfluid helium-4

Liquid helium below its lambda point begins to exhibit very unusual characteristics, in a state called *helium II*. When helium II boils, due to its high thermal conductivity

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 such properties in the isotope.^[10]



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 Rollin film also covers the interior of the larger container; if it were not sealed, the helium II would creep out and escape.^[10]

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.^[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, 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]

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.^[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.^[10] 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*.^[10]

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.^{[10][54][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 in shallow water, but rather than gravity, the restoring force is the van der Waals force.^[56] These waves are known as *third sound*.^[57]

2.1.3 Isotopes

Main article: [Isotopes of helium](#)

There are nine known isotopes of helium, but only helium-3 and helium-4 are stable. In the Earth's atmosphere, there is one 3

He atom for every million 4

He atoms.^[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 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.^[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.^[59] Trace amounts are also produced by the beta decay of tritium.^[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.^[59] 3

He is much more abundant in stars, as a product of nuclear fusion. Thus in the **interstellar medium**, the proportion of 3

He to 4

He is around 100 times higher than on Earth.^[61] Extraterrestrial 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.^{[62][63]} A number of people, starting with Gerald Kulcinski in 1986,^[64] 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 3

He and 4

He 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).^[10] Dilution refrigerators use this immiscibility to achieve temperatures of a few millikelvins.

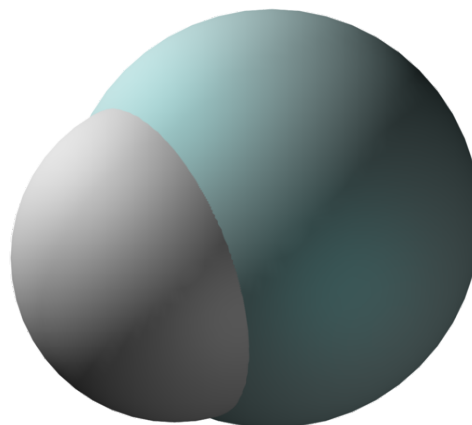
It is possible to produce exotic helium isotopes, which rapidly decay into other substances. The shortest-lived heavy helium isotope is helium-5 with a half-life of 7.6×10^{-22} s. Helium-6 decays by emitting a beta particle and has a half-life of 0.8 second. Helium-7 also emits a beta particle as well as a **gamma ray**. Helium-7 and helium-8 are created in certain nuclear reactions.^[10] Helium-6 and helium-8 are known to exhibit a **nuclear halo**.^[10]

2.1.4 Compounds

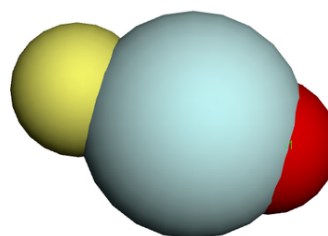
See also: Noble gas compound

Helium has a valence of zero and is chemically unreactive under all normal conditions.^[48] 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.^[10] 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 else is a **plasma** for another reason. The molecular compounds HeNe, HgHe₁₀, and WHe₂, and the molecular ions He⁺₂, He²⁺₂, HeH⁺, and HeD⁺

have been created this way.^[65] 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



Structure of the helium hydride ion, HHe^+



Structure of the suspected fluoroheliate anion, $OHeF^-$

it comes into contact with. This technique has also allowed the production of the neutral molecule He₂, which has a large number of **band systems**, and HgHe, which is apparently held together only by polarization forces.^[10]

Van der Waals compounds of helium can also be formed with cryogenic helium gas and atoms of a substance, such as LiHe and He₂.^[66]

Theoretically, other true compounds may also be possible, such as helium fluorohydride (HHeF) which would be analogous to HArF, discovered in 2000.^[67] Calculations show that two new compounds containing a helium-oxygen bond could be stable.^[68] 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**.^[69]

Helium has been put inside the hollow carbon cage molecules (the **fullerenes**) by heating under high pressure. The endohedral fullerene molecules formed are stable up to high temperatures. When chemical derivatives of these fullerenes are formed, the helium stays inside.^[70] If helium-3 is used, it can be readily observed by helium nuclear magnetic resonance spectroscopy.^[71] Many fullerenes containing helium-3 have been reported. Al-

though 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 extremely high pressures helium can react with many elements. At 130 GPa Na_2He has a fluorite structure.^[72]

2.1.5 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.^[9] 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.^[58]

In the Earth's atmosphere, the concentration of helium by volume is only 5.2 parts per million.^{[73][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 by several processes.^{[75][76][77]} 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, He^{2+}) 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.^{[78][79][80]} 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.^{[81][82]}

As at 2011 the world's helium reserves were estimated at 40 billion cubic meters, with 1/4 of that being in the South Pars / North Dome Gas-Condensate field owned jointly by Qatar and Iran.^[83]

Modern extraction and distribution

For large-scale use, helium is extracted by fractional distillation from natural gas, which can contain up to 7% helium.^[84] 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.^[10] 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.^{[37][85]}

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.^[86] 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.^{[37][87]} 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.

Diffusion of crude natural gas through special semipermeable membranes and other barriers is another method to recover and purify helium.^[88] 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).^[89] At rates of use at that time (72 million SCM per year in the U.S.; see pie chart below) this is 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.^[90] Helium can be synthesized by bombardment of lithium or boron with high-velocity protons, but this process is a completely uneconomic method of production.^[91]

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).

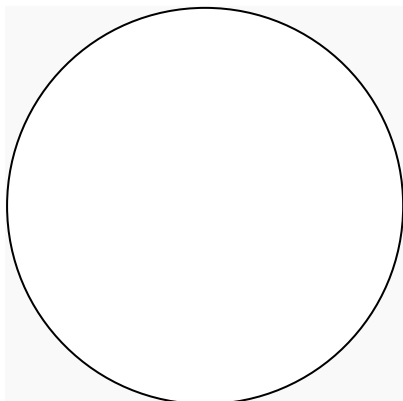
Conservation advocates

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.^[92] 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.^[93]

2.1.6 Applications



The largest single use of liquid helium is to cool the superconducting magnets in modern MRI scanners.



Estimated 2013 U.S. fractional helium use by category. Total use is 47 million cubic meters.^[94]

- Cryogenics (32%)
- Pressurizing and purging (18%)
- Welding (13%)
- Controlled atmospheres (18%)
- Leak detection (4%)
- Breathing mixtures (2%)
- Other (13%)

While balloons are perhaps the best known use of helium, they are a minor part of all helium use.^[32] 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 2008 world helium total production of about 32 million kg (193 million standard cubic meters) helium per year, the largest use (about 22% of the total in 2008) is in cryogenic applications, most of which involves cooling the superconducting magnets in medical MRI scanners.^[95] Other major uses (totalling to about 60% of use in 1996) were pressurizing and purging systems, maintenance of controlled atmospheres, welding, and leak detection. Other uses by category were relatively minor fractions.^[96]

Controlled atmospheres

Helium is used as a protective gas in growing silicon and germanium crystals, in titanium and zirconium production, and in gas chromatography,^[48] 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^[97] and impulse facilities.^[98]

Gas tungsten arc welding

Main article: 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.^[9] 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.^[99] The



A dual chamber helium leak detection machine

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.^[100]

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.^[101]



Because of its low density and incombustibility, helium is the gas of choice to fill airships such as the Goodyear blimp.

Flight Because it is lighter than air, airships and balloons are inflated with helium for lift. While hydrogen gas is also buoyant, helium has the advantage of being non-flammable (in addition to being 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.^[48]

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.^{[102][103]} 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.^[104] 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.^[105] At these depths the low density of helium is found to considerably reduce the effort of breathing.^[106]

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.^[9]

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.^[99]

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.^[107] The inertness of helium has environmental advantages over conventional refrigeration systems which contribute to ozone depletion or global warming.^[108]

Helium is also used in some hard disk drives.^[109]

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.^[110] This method is especially used in solar telescopes where a vacuum tight telescope tube would be too heavy.^{[110][111]}

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.^{[9][10]}

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.^[112]

2.1.7 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.^{[9][113]} The fundamental frequency (sometimes called pitch) does not change, since this is produced by direct vibration of the vocal folds, which is unchanged.^[114] 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.^{[9][115]} Fatalities have been recorded, including a youth who suffocated in Vancouver in 2003 and two adults who suffocated in South Florida in 2006.^{[116][117]} 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.^{[118][119][120]} Breathing pure helium continuously causes death by asphyxiation within minutes. This fact is utilized in the design of suicide bags.

Inhaling helium directly from pressurized cylinders is extremely dangerous, as the high flow rate can result in barotrauma, fatally rupturing lung tissue.^{[115][121]}

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.^{[118][119][120]}

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.^{[116][121]} 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.^[116] Since then two adults asphyxiated in South Florida in 2006,^{[116][117][122]} 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,^[123] and another teenager in Northern Ireland died of asphyxiation.^[124] At Eagle Point, Oregon a teenage girl died in 2012 from barotrauma at a party.^{[125][126][127][128]} A girl from Michigan died from hypoxia later in the year.^[129]

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 in-

haling huge quantities of helium as part of a game. The incident wasn't made public until a week later.^{[130][131]} 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 hasn't been sufficiently recovered as of yet. Police have launched an investigation due to a neglect of safety measures.^{[132][133]}

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.^[48]

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.^{[134][135]}

2.1.8 Additional images

- 3D schematic of a Helium atom

2.1.9 See also

- Abiogenic petroleum origin
- Helium-3 propulsion
- Leidenfrost effect
- Quantum solid
- Superfluid
- Tracer-gas leak testing method

2.1.10 References

- [1] Standard Atomic Weights 2013. Commission on Isotopic Abundances and Atomic Weights
- [2] Shuen-Chen Hwang, Robert D. Lein, Daniel A. Morgan (2005). "Noble Gases". Kirk Othmer Encyclopedia of Chemical Technology. Wiley. pp. 343–383. doi:10.1002/0471238961.0701190508230114.a01.
- [3] Magnetic susceptibility of the elements and inorganic compounds, in Handbook of Chemistry and Physics 81st edition, CRC press.
- [4] Helium: Up, Up and Away? Melinda Rose, Photonics Spectra, October 2008. Accessed February 27, 2010. For a more authoritative but older 1996 pie chart showing U.S. helium use by sector, showing much the same result, see

- the chart reproduced in “Applications” section of this article.
- [5] Connor, Steve (2010-08-23). “Why the world is running out of helium – Science – News”. London: The Independent. Retrieved 2013-09-16.
- [6] Ethan on December 12, 2012 (2012-12-12). “Why the World Will Run Out of Helium – Starts With A Bang”. Scienceblogs.com. Retrieved 2013-09-16.
- [7] Witchalls, Clint (18 August 2010) Nobel prizewinner: We are running out of helium. *New Scientist*.(subscription required)
- [8] Kochhar, R. K. (1991). “French astronomers in India during the 17th – 19th centuries”. *Journal of the British Astronomical Association* **101** (2): 95–100. Bibcode:1991JBAA..101...95K.
- [9] Emsley, John (2001). *Nature’s Building Blocks*. Oxford: Oxford University Press. pp. 175–179. ISBN 0-19-850341-5.
- [10] Clifford A. Hampel (1968). *The Encyclopedia of the Chemical Elements*. New York: Van Nostrand Reinhold. pp. 256–268. ISBN 0-442-15598-0.
- [11] Harper, Douglas. “helium”. *Online Etymology Dictionary*.
- [12] Thomson, William (August 3, 1871). “Inaugural Address of Sir William Thomson”. *Nature* **4** (92): 261–278 [268]. Bibcode:1871Natur...4..261.. doi:10.1038/004261a0. Frankland and Lockyer find the yellow prominences to give a very decided bright line not far from D, but hitherto not identified with any terrestrial flame. It seems to indicate a new substance, which they propose to call Helium
- [13] Stewart, Alfred Walter (2008). *Recent Advances in Physical and Inorganic Chemistry*. BiblioBazaar, LLC. p. 201. ISBN 0-554-80513-8.
- [14] Ramsay, William (1895). “On a Gas Showing the Spectrum of Helium, the Reputed Cause of D₃, One of the Lines in the Coronal Spectrum. Preliminary Note”. *Proceedings of the Royal Society of London* **58** (347–352): 65–67. doi:10.1098/rspl.1895.0006.
- [15] Ramsay, William (1895). “Helium, a Gaseous Constituent of Certain Minerals. Part I”. *Proceedings of the Royal Society of London* **58** (347–352): 80–89. doi:10.1098/rspl.1895.0010.
- [16] Ramsay, William (1895). “Helium, a Gaseous Constituent of Certain Minerals. Part II--”. *Proceedings of the Royal Society of London* **59** (1): 325–330. doi:10.1098/rspl.1895.0097.
- [17] Langlet, N. A. (1895). “Das Atomgewicht des Heliums”. *Zeitschrift für anorganische Chemie* (in German) **10** (1): 289–292. doi:10.1002/zaac.18950100130.
- [18] Weaver, E.R. (1919). “Bibliography of Helium Literature”. *Industrial & Engineering Chemistry*.
- [19] Munday, Pat (1999). John A. Garraty; Mark C. Carnes, eds. *Biographical entry for W.F. Hillebrand (1853–1925), geochemist and U.S. Bureau of Standards administrator in American National Biography*. 10–11. Oxford University Press. pp. 808–9; 227–8.
- [20] van Delft, Dirk (2008). “Little cup of Helium, big Science” (PDF). *Physics Today* **61** (3): 36–42. Bibcode:2008PhT...61c..36V. doi:10.1063/1.2897948. Archived from the original (PDF) on June 25, 2008. Retrieved 2008-07-20.
- [21] “Coldest Cold”. Time Inc. 1929-06-10. Retrieved 2008-07-27.
- [22] Kapitza, P. (1938). “Viscosity of Liquid Helium below the λ -Point”. *Nature* **141** (3558): 74. Bibcode:1938Natur.141...74K. doi:10.1038/141074a0.
- [23] Osheroff, D. D.; Richardson, R. C.; Lee, D. M. (1972). “Evidence for a New Phase of Solid He³”. *Phys. Rev. Lett.* **28** (14): 885–888. Bibcode:1972PhRvL..28..885O. doi:10.1103/PhysRevLett.28.885.
- [24] McFarland, D. F. (1903). “Composition of Gas from a Well at Dexter, Kan”. *Transactions of the Kansas Academy of Science* **19**: 60–62. doi:10.2307/3624173. JSTOR 3624173.
- [25] “Discovery of Helium in Natural Gas at the University of Kansas”. *National Historic Chemical Landmarks*. American Chemical Society. Retrieved 2014-02-21.
- [26] Cady, H.P.; McFarland, D. F. (1906). “Helium in Natural Gas”. *Science* **24** (611): 344. Bibcode:1906Sci...24..344D. doi:10.1126/science.24.611.344. PMID 17772798.
- [27] Cady, H.P.; McFarland, D. F. (1906). “Helium in Kansas Natural Gas”. *Transactions of the Kansas Academy of Science* **20**: 80–81. doi:10.2307/3624645. JSTOR 3624645.
- [28] Emme, Eugene M. comp., ed. (1961). “Aeronautics and Astronautics Chronology, 1920–1924”. *Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915–1960*. Washington, D.C.: NASA. pp. 11–19.
- [29] Hilleret, N. (1999). “Leak Detection”. In S. Turner. *CERN Accelerator School, vacuum technology: proceedings: Scanticon Conference Centre, Snekersten, Denmark, 28 May – 3 June 1999* (PDF). Geneva, Switzerland: CERN. pp. 203–212. At the origin of the helium leak detection method was the Manhattan Project and the unprecedented leak-tightness requirements needed by the uranium enrichment plants. The required sensitivity needed for the leak checking led to the choice of a mass spectrometer designed by Dr. A.O.C. Nier tuned on the helium mass.
- [30] Williamson, John G. (1968). “Energy for Kansas”. *Transactions of the Kansas Academy of Science* (Kansas Academy of Science) **71** (4): 432–438. doi:10.2307/3627447. JSTOR 3627447.
- [31] “Conservation Helium Sale” (PDF). *Federal Register* **70** (193): 58464. 2005-10-06. Retrieved 2008-07-20.

- [32] Stwertka, Albert (1998). *Guide to the Elements: Revised Edition*. New York; Oxford University Press, p. 24. ISBN 0-19-512708-0
- [33] Helium Privatization Act of 1996 Pub.L. 104–273
- [34] “Executive Summary”. nap.edu. Retrieved 2008-07-20.
- [35] Mullins, P.V.; Goodling, R. M. (1951). *Helium*. Bureau of Mines / Minerals yearbook 1949. pp. 599–602. Retrieved 2008-07-20.
- [36] “Helium End User Statistic” (PDF). U.S. Geological Survey. Retrieved 2008-07-20.
- [37] Smith, E. M.; Goodwin, T. W.; Schillinger, J. (2003). “Challenges to the Worldwide Supply of Helium in the Next Decade”. *Advances in Cryogenic Engineering*. 49 A (710): 119–138. doi:10.1063/1.1774674.
- [38] Kaplan, Karen H. (June 2007). “Helium shortage hampers research and industry”. *Physics Today* (American Institute of Physics) **60** (6): 31–32. Bibcode:2007PhT....60f..31K. doi:10.1063/1.2754594.
- [39] Basu, Sourish (October 2007). Yam, Philip, ed. “Updates: Into Thin Air”. *Scientific American* **297** (4) (Scientific American, Inc.). p. 18. Retrieved 2008-08-04.
- [40] @tdnewcomb (2012-08-21). “There’s a Helium Shortage On — and It’s Affecting More than Just Balloons Time August 21, 2012”. Newsfeed.time.com. Retrieved 2013-09-16.
- [41] Watkins, Thayer. “The Old Quantum Physics of Niels Bohr and the Spectrum of Helium: A Modified Version of the Bohr Model”. San Jose State University.
- [42] Lewars, Errol G. (2008). *Modelling Marvels*. Springer. pp. 70–71. ISBN 1-4020-6972-3.
- [43] Weiss, Ray F. (1971). “Solubility of helium and neon in water and seawater”. *J. Chem. Eng. Data* **16** (2): 235–241. doi:10.1021/jc60049a019.
- [44] Scharlin, P.; Battino, R. Silla, E.; Tuñón, I.; Pascual-Ahuir, J. L. (1998). “Solubility of gases in water: Correlation between solubility and the number of water molecules in the first solvation shell”. *Pure & Appl. Chem.* **70** (10): 1895–1904. doi:10.1351/pac199870101895.
- [45] Stone, Jack A.; Stejskal, Alois (2004). “Using helium as a standard of refractive index: correcting errors in a gas refractometer”. *Metrologia* **41** (3): 189–197. Bibcode:2004Metro..41..189S. doi:10.1088/0026-1394/41/3/012.
- [46] Buhler, F.; Axford, W. I.; Chivers, H. J. A.; Martin, K. (1976). “Helium isotopes in an aurora”. *J. Geophys. Res.* **81** (1): 111–115. Bibcode:1976JGR....81..111B. doi:10.1029/JA081i001p00111.
- [47] “Solid Helium”. Department of Physics University of Alberta. 2005-10-05. Archived from the original on May 31, 2008. Retrieved 2008-07-20.
- [48] Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
- [49] Grilly, E. R. (1973). “Pressure-volume-temperature relations in liquid and solid 4He”. *Journal of Low Temperature Physics* **11** (1–2): 33–52. Bibcode:1973JLTP...11...33G. doi:10.1007/BF00655035.
- [50] Henshaw, D. B. (1958). “Structure of Solid Helium by Neutron Diffraction”. *Physical Review Letters* **109** (2): 328–330. Bibcode:1958PhRv..109..328H. doi:10.1103/PhysRev.109.328.
- [51] Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. p. 6-120. ISBN 0-8493-0486-5.
- [52] Hohenberg, P. C.; Martin, P. C. (2000). “Microscopic Theory of Superfluid Helium”. *Annals of Physics* **281** (1–2): 636–705 12091211. Bibcode:2000AnPhy.281..636H. doi:10.1006/aphy.2000.6019.
- [53] Warner, Brent. “Introduction to Liquid Helium”. NASA. Archived from the original on 2005-09-01. Retrieved 2007-01-05.
- [54] Fairbank, H. A.; Lane, C. T. (1949). “Rollin Film Rates in Liquid Helium”. *Physical Review* **76** (8): 1209–1211. Bibcode:1949PhRv...76.1209F. doi:10.1103/PhysRev.76.1209.
- [55] Rollin, B. V.; Simon, F. (1939). “On the “film” phenomenon of liquid helium II”. *Physica* **6** (2): 219–230. Bibcode:1939Phy.....6..219R. doi:10.1016/S0031-8914(39)80013-1.
- [56] Ellis, Fred M. (2005). “Third sound”. Wesleyan Quantum Fluids Laboratory. Retrieved 2008-07-23.
- [57] Bergman, D. (1949). “Hydrodynamics and Third Sound in Thin He II Films”. *Physical Review* **188** (1): 370–384. Bibcode:1969PhRv..188..370B. doi:10.1103/PhysRev.188.370.
- [58] Weiss, Achim. “Elements of the past: Big Bang Nucleosynthesis and observation”. Max Planck Institute for Gravitational Physics. Retrieved 2008-06-23.; Coc, Alain; Vangioni-Flam, Elisabeth; Descouvement, Pierre; Adahchour, Abderrahim; Angulo, Carmen (2004). “Updated Big Bang Nucleosynthesis confronted to WMAP observations and to the Abundance of Light Elements”. *Astrophysical Journal* **600** (2): 544. arXiv:astro-ph/0309480. Bibcode:2004ApJ...600..544C. doi:10.1086/380121.
- [59] Anderson, Don L.; Foulger, G. R.; Meibom, A. (2006-09-02). “Helium Fundamentals”. MantlePlumes.org. Retrieved 2008-07-20.
- [60] Novick, Aaron (1947). “Half-Life of Tritium”. *Physical Review* **72** (10): 972–972. Bibcode:1947PhRv...72..972N. doi:10.1103/PhysRev.72.972.2.

- [61] Zastenker, G. N.; Salerno, E.; Buehler, F.; Bochsler, P.; Bassi, M.; Agafonov, Yu.N.; Eisomont, N. A.; Khrapchenkov, V. V. et al. (2002). "Isotopic Composition and Abundance of Interstellar Neutral Helium Based on Direct Measurements". *Astrophysics* **45** (2): 131–142. Bibcode:2002Ap....45..131Z. doi:10.1023/A:1016057812964.
- [62] "Lunar Mining of Helium-3". Fusion Technology Institute of the University of Wisconsin-Madison. 2007-10-19. Retrieved 2008-07-09.
- [63] Slyuta, E. N.; Abdrakhimov, A. M.; Galimov, E. M. (2007). "The estimation of helium-3 probable reserves in lunar regolith" (PDF). *Lunar and Planetary Science XXXVIII*. Retrieved 2008-07-20.
- [64] Hedman, Eric R. (2006-01-16). "A fascinating hour with Gerald Kulcinski". *The Space Review*. Retrieved 2008-07-20.
- [65] Hiby, Julius W. (1939). "Massenspektrographische Untersuchungen an Wasserstoff- und Heliumkanalstrahlen (H⁺, H⁻, HeH⁺, HeD⁺, He⁻)". *Annalen der Physik* **426** (5): 473–487. Bibcode:1939AnP...426..473H. doi:10.1002/andp.19394260506.
- [66] Friedrich, Bretislav (8 April 2013). "A Fragile Union Between Li and He Atoms". *Physics* **6**: 42. doi:10.1103/Physics.6.42.
- [67] Wong, Ming Wah (2000). "Prediction of a Metastable Helium Compound: HHeF". *Journal of the American Chemical Society* **122** (26): 6289–6290. doi:10.1021/ja9938175.
- [68] Grochala, W. (2009). "On Chemical Bonding Between Helium and Oxygen". *Polish Journal of Chemistry* **83**: 87–122.
- [69] "Collapse of helium's chemical nobility predicted by Polish chemist" (PDF). Archived from the original (PDF) on 2009-03-19. Retrieved 2009-05-15.
- [70] Saunders, Martin; Jiménez-Vázquez, Hugo A.; Cross, R. James; Poreda, Robert J. (1993). "Stable Compounds of Helium and Neon: He@C₆₀ and Ne@C₆₀". *Science* **259** (5100): 1428–1430. Bibcode:1993Sci...259.1428S. doi:10.1126/science.259.5100.1428. PMID 17801275.
- [71] Saunders, Martin; Jiménez-Vázquez, Hugo A.; Cross, R. James; Mroczkowski, Stanley; Freedberg, Darón I.; Anet, Frank A. L. (1994). "Probing the interior of fullerenes by ³He NMR spectroscopy of endohedral ³He@C₆₀ and ³He@C₇₀". *Nature* **367** (6460): 256–258. Bibcode:1994Natur.367..256S. doi:10.1038/367256a0.
- [72] Dong, Xiao; Oganov, Artem R. (25 April 2014). "Stable Compound of Helium and Sodium at High Pressure". arXiv:1309.3827.
- [73] Oliver, B. M.; Bradley, James G. (1984). "Helium concentration in the Earth's lower atmosphere". *Geochimica et Cosmochimica Acta* **48** (9): 1759–1767. Bibcode:1984GeCoA..48.1759O. doi:10.1016/0016-7037(84)90030-9.
- [74] "The Atmosphere: Introduction". *JetStream – Online School for Weather*. National Weather Service. 2007-08-29. Archived from the original on January 13, 2008. Retrieved 2008-07-12.
- [75] Lie-Svendsen, Ø.; Rees, M. H. (1996). "Helium escape from the terrestrial atmosphere: The ion outflow mechanism". *Journal of Geophysical Research* **101** (A2): 2435–2444. Bibcode:1996JGR...101.2435L. doi:10.1029/95JA02208.
- [76] Strobel, Nick (2007). "Atmospheres". *Nick Strobel's Astronomy Notes*. Retrieved 2007-09-25.
- [77] G. Brent Dalrymple. "How Good Are Those Young-Earth Arguments?".
- [78] Cook, Melvine A. (1957). "Where is the Earth's Radiogenic Helium?". *Nature* **179** (4552): 213. Bibcode:1957Natur.179..213C. doi:10.1038/179213a0.
- [79] Aldrich, L. T.; Nier, Alfred O. (1948). "The Occurrence of He³ in Natural Sources of Helium". *Phys. Rev.* **74** (11): 1590–1594. Bibcode:1948PhRv...74.1590A. doi:10.1103/PhysRev.74.1590.
- [80] Morrison, P.; Pine, J. (1955). "Radiogenic Origin of the Helium Isotopes in Rock". *Annals of the New York Academy of Sciences* **62** (3): 71–92. Bibcode:1955NYASA..62...71M. doi:10.1111/j.1749-6632.1955.tb35366.x.
- [81] Zartman, R. E.; Wasserburg, G. J.; Reynolds, J. H. (1961). "Helium Argon and Carbon in Natural Gases". *Journal of Geophysical Research* **66** (1): 277–306. Bibcode:1961JGR....66..277Z. doi:10.1029/JZ066i001p00277.
- [82] Broadhead, Ronald F. (2005). "Helium in New Mexico – geology distribution resource demand and exploration possibilities" (PDF). *New Mexico Geology* **27** (4): 93–101. Retrieved 2008-07-21.
- [83] <http://presstv.com/detail/201960.html>
- [84] Winter, Mark (2008). "Helium: the essentials". University of Sheffield. Retrieved 2008-07-14.
- [85] Cai, Z. et al. (2007). *Modelling Helium Markets* (PDF). University of Cambridge. Archived from the original (PDF) on 2009-03-26. Retrieved 2008-07-14.
- [86] *Helium* (PDF). *Mineral Commodity Summaries* (U.S. Geological Survey). 2009: 74–75. Retrieved 2009-12-19.
- [87] Pierce, A.P., Gott, G.B., and Mytton, J.W., Uranium and Helium in the Panhandle Gas Field Texas, and Adjacent Areas, Geological Survey Professional Paper 454-G, Washington:US Government Printing Office, 1964

- [88] Belyakov, V.P.; Durgar'yan, S. G.; Mirzoyan, B. A. (1981). "Membrane technology—A new trend in industrial gas separation". *Chemical and Petroleum Engineering* **17** (1): 19–21. doi:10.1007/BF01245721.
- [89] Committee on the Impact of Selling, Table 4.2
- [90] Committee on the Impact of Selling, see page 40 for the estimate of total theoretical helium production by neon and liquid air plants
- [91] Dee, P. I.; Walton E. T. S. (1933). "A Photographic Investigation of the Transmutation of Lithium and Boron by Protons and of Lithium by Ions of the Heavy Isotope of Hydrogen". *Proceedings of the Royal Society of London* **141** (845): 733–742. Bibcode:1933RSPSA.141..733D. doi:10.1098/rspa.1933.0151.
- [92] Connor, Steve (2010-08-23). "Richard Coleman campaigning against US Congress' decision to sell all helium supplies by 2015". London: Independent.co.uk. Retrieved 2010-11-27.
- [93] Nuttall, William J.; Clarke, Richard H.; Glowacki, Bartek A. (2012). "Resources: Stop squandering helium". *Nature* **485** (7400): 573–575. Bibcode:2012Natur.485..573N. doi:10.1038/485573a. PMID 22660302.
- [94] U.S. Department of the Interior, U.S. Geological Survey (2014). "Helium" (PDF). *Mineral Commodity Summaries 2014*. pp. 72–73.
- [95] Helium sell-off risks future supply, Michael Banks, *Physics World*, 27 January 2010. accessed February 27, 2010.
- [96] Information source is given in pie chart graph at right
- [97] Beckwith, I.E.; Miller, C. G. (1990). "Aerothermodynamics and Transition in High-Speed Wind Tunnels at Nasa Langley". *Annual Review of Fluid Mechanics* **22** (1): 419–439. Bibcode:1990AnRFM..22..419B. doi:10.1146/annurev.fl.22.010190.002223.
- [98] Morris, C.I. (2001). *Shock Induced Combustion in High Speed Wedge Flows* (PDF). Stanford University Thesis. Archived from the original (PDF) on 2009-03-04.
- [99] Considine, Glenn D., ed. (2005). "Helium". *Van Nostrand's Encyclopedia of Chemistry*. Wiley-Interscience. pp. 764–765. ISBN 0-471-61525-0.
- [100] Hablanian, M. H. (1997). *High-vacuum technology: a practical guide*. CRC Press. p. 493. ISBN 0-8247-9834-1.
- [101] Ekin, Jack W. (2006). *Experimental Techniques for Low-Temperature measurements*. Oxford University Press. ISBN 0-19-857054-6.
- [102] Fowler, B; Ackles, KN; G, Porlier (1985). "Effects of inert gas narcosis on behavior—a critical review". *Undersea Biomedical Research Journal* **12** (4): 369–402. PMID 4082343. Retrieved 2008-06-27.
- [103] Thomas, J. R. (1976). "Reversal of nitrogen narcosis in rats by helium pressure". *Undersea Biomed. Res.* **3** (3): 249–59. PMID 969027. Retrieved 2008-08-06.
- [104] Hunger, Jr., W. L.; Bennett, P. B. (1974). "The causes, mechanisms and prevention of the high pressure nervous syndrome". *Undersea Biomed. Res.* **1** (1): 1–28. ISSN 0093-5387. OCLC 2068005. PMID 4619860. Retrieved 2008-04-07.
- [105] Rostain, J. C.; Gardette-Chauffour, M. C.; Lemaire, C.; Naquet, R. (1988). "Effects of a H₂-He-O₂ mixture on the HPNS up to 450 msw". *Undersea Biomed. Res.* **15** (4): 257–70. OCLC 2068005. PMID 3212843. Retrieved 2008-06-24.
- [106] Butcher, Scott J.; Jones, Richard L.; Mayne, Jonathan R.; Hartley, Timothy C.; Petersen, Stewart R. (2007). "Impaired exercise ventilatory mechanics with the self-contained breathing apparatus are improved with heliox". *European Journal of Applied Physiology* (Netherlands: Springer) **101** (6): 659–69. doi:10.1007/s00421-007-0541-5. PMID 17701048.
- [107] Belcher, James R.; Slaton, William V.; Rasket, Richard; Bass, Henry E.; Lightfoot, Jay (1999). "Working gases in thermoacoustic engines". *The Journal of the Acoustical Society of America* **105** (5): 2677–2684. Bibcode:1999ASAJ..105.2677B. doi:10.1121/1.426884. PMID 10335618.
- [108] Makhijani, Arjun; Gurney, Kevin (1995). *Mending the Ozone Hole: Science, Technology, and Policy*. MIT Press. ISBN 0-262-13308-3.
- [109] HGST balloons disk capacity with helium-filled 6TB drive | Ars Technica
- [110] Jakobsson, H. (1997). "Simulations of the dynamics of the Large Earth-based Solar Telescope". *Astronomical & Astrophysical Transactions* **13** (1): 35–46. Bibcode:1997A&AT...13...35J. doi:10.1080/10556799708208113.
- [111] Engvold, O.; Dunn, R.B.; Smartt, R. N.; Livingston, W. C. (1983). "Tests of vacuum VS. helium in a solar telescope". *Applied Optics* **22** (1): 10–12. Bibcode:1983ApOpt..22...10E. doi:10.1364/AO.22.000010. PMID 20401118.
- [112] "LHC: Facts and Figures" (PDF). CERN. Archived from the original (PDF) on 2011-07-06. Retrieved 2008-04-30.
- [113] Ackerman MJ; Maitland G (1975). "Calculation of the relative speed of sound in a gas mixture". *Undersea Biomed Res* **2** (4): 305–10. PMID 1226588. Retrieved 2008-08-09.
- [114] "Why does helium make your voice squeaky?". 2000-07-14. Retrieved 2013-06-08.
- [115] Grassberger, Martin; Krauskopf, Astrid (2007). "Suicidal asphyxiation with helium: Report of three cases Suizid mit Helium Gas: Bericht über drei Fälle". *Wiener Klinische Wochenschrift* (in German & English) **119** (9–10): 323–325. doi:10.1007/s00508-007-0785-4. PMID 17571238.
- [116] Montgomery B.; Hayes S. (2006-06-03). "2 found dead under deflated balloon". Tampa Bay Times.

- Helium at the Helsinki University of Technology; includes pressure-temperature phase diagrams for helium-3 and helium-4
- Lancaster University, Ultra Low Temperature Physics – includes a summary of some low temperature techniques

Miscellaneous

- Physics in Speech with audio samples that demonstrate the unchanged voice pitch
- Article about helium and other noble gases

Helium shortage

- America's Helium Supply: Options for Producing More Helium from Federal Land: Oversight Hearing before the Subcommittee on Energy and Mineral Resources of the Committee on Natural Resources, U.S. House Of Representatives, One Hundred Thirteenth Congress, First Session, Thursday, July 11, 2013
- Helium Program: Urgent Issues Facing BLM's Storage and Sale of Helium Reserves: Testimony before the Committee on Natural Resources, House of Representatives Government Accountability Office
- Kramer, David (May 22, 2012). "Senate bill would preserve US helium reserve: Measure would give scientists first dibs on helium should a shortage develop. Physics Today web site".

2.2 Neon

This article is about the noble gas. For other uses, see Neon (disambiguation).

Neon is a chemical element with symbol **Ne** and atomic number 10. It is in group 18 (noble gases) of the periodic table.^[9] Neon is a colorless, odorless, inert monatomic gas under standard conditions, with about two-thirds the density of air. It was discovered (along with krypton and xenon) in 1898 as one of the three residual rare inert elements remaining in dry air, after nitrogen, oxygen, argon and carbon dioxide were removed. Neon was the second of these three rare gases to be discovered, and was immediately recognized as a new element from its bright red emission spectrum. The name neon is derived from the Greek word, *νέον*, neuter singular form of *νέος* [*neos*], meaning new. Neon is chemically inert and forms no uncharged chemical compounds.

During cosmic nucleogenesis of the elements, large amounts of neon are built up from the alpha-capture fusion process in stars. Although neon is a very common element in the universe and solar system (it is fifth in cosmic abundance after hydrogen, helium, oxygen and carbon), it is very rare on Earth. It composes about 18.2 ppm of air by volume (this is about the same as the molecular or mole fraction), and a smaller fraction in Earth's crust. The reason for neon's relative scarcity on Earth and the inner (terrestrial) planets is that neon forms no compounds to fix it to solids, and is highly volatile. This led to its escaping from the planetesimals under the warmth of the newly ignited Sun in the early Solar System. Even the atmosphere of Jupiter is somewhat depleted of neon, presumably for this reason.

Neon gives a distinct reddish-orange glow when used in either low-voltage neon glow lamps or in high-voltage discharge tubes or neon advertising signs.^{[10][11]} The red emission line from neon is also responsible for the well known red light of helium–neon lasers. Neon is used in some plasma tube and refrigerant applications but has few other commercial uses. It is commercially extracted by the fractional distillation of liquid air. It is considerably more expensive than helium, since air is its only source.

2.2.1 History



Neon gas-discharge lamps forming the symbol for neon "Ne"

Neon (Greek *νέον* (*néon*), neuter singular form of *νέος* meaning "new"), was discovered in 1898 by the British chemists Sir William Ramsay (1852–1916) and Morris W. Travers (1872–1961) in London, England.^[12] Neon was discovered when Ramsay chilled a sample of air until it became a liquid, then warmed the liquid and captured the gases as they boiled off. The gases nitrogen, oxygen, and argon had been identified, but the remaining gases were isolated in roughly their order of abun-

dance, in a six-week period beginning at the end of May 1898. First to be identified was **krypton**. The next, after krypton had been removed, was a gas which gave a brilliant red light under spectroscopic discharge. This gas, identified in June, was named **neon**, the Greek analogue of “novum”, (new), the name Ramsay’s son suggested.^[13] The characteristic brilliant red-orange color that is emitted by gaseous neon when excited electrically was noted immediately; Travers later wrote, “the blaze of crimson light from the tube told its own story and was a sight to dwell upon and never forget.”^[14] Finally, the same team discovered xenon by the same process, in June.

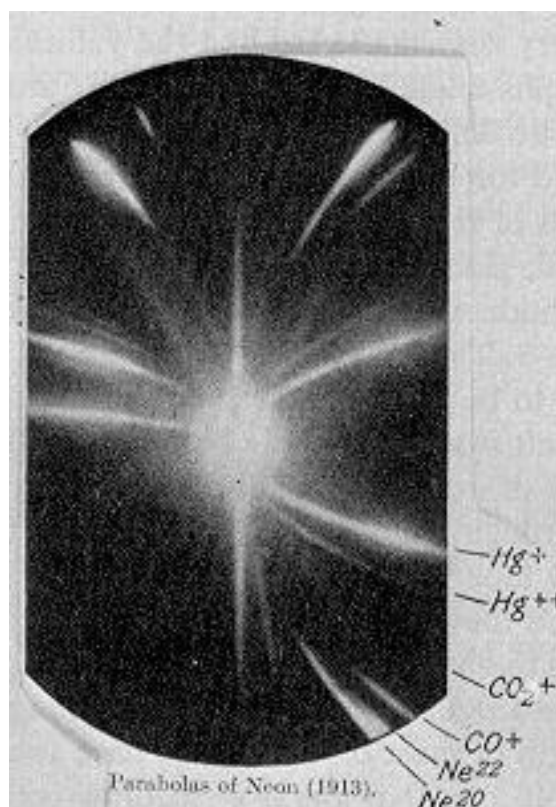
Neon’s scarcity precluded its prompt application for lighting along the lines of **Moore tubes**, which used nitrogen and which were commercialized in the early 1900s. After 1902, **Georges Claude’s** company, **Air Liquide**, was producing industrial quantities of neon as a byproduct of his air liquefaction business. In December 1910 Claude demonstrated modern **neon lighting** based on a sealed tube of neon. Claude tried briefly to get neon tubes to be used for indoor lighting, due to their intensity, but failed, as homeowners rejected neon light sources due to their color. Finally in 1912, Claude’s associate began selling neon discharge tubes as **advertising signs**, where they were instantly more successful as eye catchers. They were introduced to the U.S. in 1923, when two large neon signs were bought by a Los Angeles Packard car dealership. The glow and arresting red color made neon advertising completely different from the competition.^[15]

Neon played a role in the basic understanding of the nature of atoms in 1913, when J. J. Thomson, as part of his exploration into the composition of canal rays, channeled streams of neon ions through a magnetic and an electric field and measured their deflection by placing a photographic plate in their path. Thomson observed two separate patches of light on the photographic plate (see image), which suggested two different parabolas of deflection. Thomson eventually concluded that some of the atoms in the neon gas were of higher mass than the rest. Though not understood at the time by Thomson, this was the first discovery of isotopes of stable atoms. It was made by using a crude version of an instrument we now term as a **mass spectrometer**.

2.2.2 Isotopes

Main article: **Isotopes of neon**

Neon is the second lightest inert gas. Neon has three stable isotopes: ^{20}Ne (90.48%), ^{21}Ne (0.27%) and ^{22}Ne (9.25%). ^{21}Ne and ^{22}Ne are partly primordial and partly nucleogenic (i.e., made by nuclear reactions of other nuclides with neutrons or other particles in the environment) and their variations in natural abundance are well understood. In contrast, ^{20}Ne (the chief primordial isotope made in stellar nucleosynthesis) is not known to be nucleogenic or radiogenic (save for cluster decay production, which is thought to produce only a small amount).



The first evidence for isotopes of a stable element was provided in 1913 by experiments on neon plasma. In the bottom right corner of J. J. Thomson’s photographic plate are the separate impact marks for the two isotopes neon-20 and neon-22.

The causes of the variation of ^{20}Ne in the Earth have thus been hotly debated.^[16]

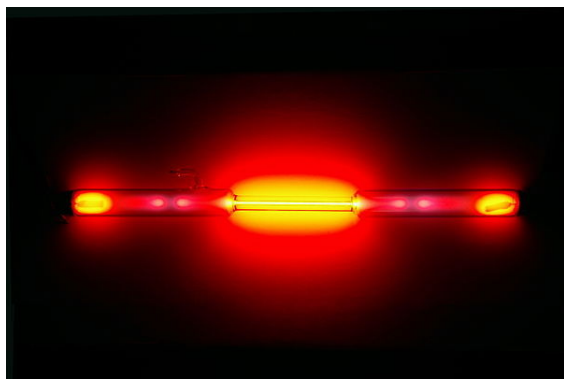
The principal nuclear reactions which generate nucleogenic neon isotopes start from ^{24}Mg and ^{25}Mg , which produce ^{21}Ne and ^{22}Ne , respectively, after neutron capture and immediate emission of an alpha particle. The neutrons that produce the reactions are mostly produced by secondary spallation reactions from alpha particles, in turn derived from uranium-series decay chains. The net result yields a trend towards lower $^{20}\text{Ne}/^{22}\text{Ne}$ and higher $^{21}\text{Ne}/^{22}\text{Ne}$ ratios observed in uranium-rich rocks such as granites.^[17] Neon-21 may also be produced in a nucleogenic reaction, when ^{20}Ne absorbs a neutron from various natural terrestrial neutron sources.

In addition, isotopic analysis of exposed terrestrial rocks has demonstrated the cosmogenic (cosmic ray) production of ^{21}Ne . This isotope is generated by spallation reactions on magnesium, sodium, silicon, and aluminium. By analyzing all three isotopes, the cosmogenic component can be resolved from magmatic neon and nucleogenic neon. This suggests that neon will be a useful tool in determining cosmic exposure ages of surface rocks and meteorites.^[18]

Similar to xenon, neon content observed in samples of volcanic gases is enriched in ^{20}Ne , as well as nucleogenic

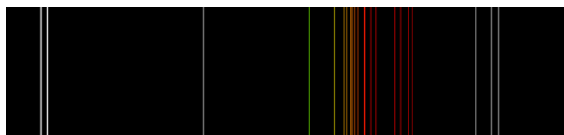
^{21}Ne , relative to ^{22}Ne content. The neon isotopic content of these mantle-derived samples represents a non-atmospheric source of neon. The ^{20}Ne -enriched components are attributed to exotic primordial rare gas components in the Earth, possibly representing solar neon. Elevated ^{20}Ne abundances are found in diamonds, further suggesting a solar neon reservoir in the Earth.^[19]

2.2.3 Characteristics



Neon discharge tube

Neon is the second-lightest noble gas, after helium. It glows reddish-orange in a vacuum discharge tube. Also, neon has the narrowest liquid range of any element: from 24.55 K to 27.05 K (−248.45 °C to −245.95 °C, or −415.21 °F to −410.71 °F). It has over 40 times the refrigerating capacity of liquid helium and three times that of liquid hydrogen (on a per unit volume basis).^[2] In most applications it is a less expensive refrigerant than helium.^{[20][21]}



Spectrum of neon with ultraviolet (at left) and infrared (at right) lines shown in white

Neon plasma has the most intense light discharge at normal voltages and currents of all the noble gases. The average color of this light to the human eye is red-orange due to many lines in this range; it also contains a strong green line which is hidden, unless the visual components are dispersed by a spectroscope.^[22]

Two quite different kinds of neon lighting are in common use. Neon glow lamps are generally tiny, with most operating at about 100–250 volts.^[23] They have been widely used as power-on indicators and in circuit-testing equipment, but light-emitting diodes (LEDs) now dominate in such applications. These simple neon devices were the forerunners of plasma displays and plasma television screens.^{[24][25]} Neon signs typically operate at much

higher voltages (2–15 kilovolts), and the luminous tubes are commonly meters long.^[26] The glass tubing is often formed into shapes and letters for signage as well as architectural and artistic applications.

2.2.4 Occurrence

Stable isotopes of neon are produced in stars. ^{20}Ne is created in fusing helium and oxygen in the alpha process, which requires temperatures above 100 megakelvins and masses greater than 3 solar masses.

Neon is abundant on a universal scale; it is the fifth most abundant chemical element in the universe by mass, after hydrogen, helium, oxygen, and carbon (see chemical element). Its relative rarity on Earth, like that of helium, is due to its relative lightness, high vapor pressure at very low temperatures, and chemical inertness, all properties which tend to keep it from being trapped in the condensing gas and dust clouds which resulted in the formation of smaller and warmer solid planets like Earth.

Neon is monatomic, making it lighter than the molecules of diatomic nitrogen and oxygen which form the bulk of Earth's atmosphere; a balloon filled with neon will rise in air, albeit more slowly than a helium balloon.^[27]

Neon's abundance in the universe is about 1 part in 750 and in the Sun and presumably in the proto-solar system nebula, about 1 part in 600. The Galileo spacecraft atmospheric entry probe found that even in the upper atmosphere of Jupiter, the abundance of neon is reduced (depleted) by about a factor of 10, to a level of 1 part in 6,000 by mass. This may indicate that even the ice-planetesimals which brought neon into Jupiter from the outer solar system, formed in a region which was too warm for them to have kept their neon (abundances of heavier inert gases on Jupiter are several times that found in the Sun).^[28]

Neon is rare on Earth, found in the Earth's atmosphere at 1 part in 55,000, or 18.2 ppm by volume (this is about the same as the molecule or mole fraction), or 1 part in 79,000 of air by mass. It comprises a smaller fraction in the crust. It is industrially produced by cryogenic fractional distillation of liquefied air.^[2]

2.2.5 Applications

Neon is often used in signs and produces an unmistakable bright reddish-orange light. Although still referred to as "neon", other colors are generated with different noble gases or by varied colors of fluorescent lighting.

Neon is used in vacuum tubes, high-voltage indicators, lightning arrestors, wave meter tubes, television tubes, and helium–neon lasers. Liquefied neon is commercially used as a cryogenic refrigerant in applications not requiring the lower temperature range attainable with more extreme liquid helium refrigeration.



Neon signs may use neon along with other noble gases

Both neon gas and liquid neon are relatively expensive – for small quantities, the price of liquid neon can be more than 55 times that of liquid helium. The driver for neon’s expense is the rarity of neon, which unlike helium, can only be obtained from air.

The triple point temperature of neon (24.5561 K) is a defining fixed point in the International Temperature Scale of 1990.^[3]

2.2.6 Compounds

Neon is the first p-block noble gas. Neon is generally considered to be inert. No true neutral compounds of neon are known. However, the ions Ne^+ , $(\text{NeAr})^+$, $(\text{NeH})^+$, and (HeNe^+) have been observed from optical and mass spectrometric studies, and there are some unverified reports of an unstable hydrate.^[2]

2.2.7 See also

- Expansion ratio
- Neon sign
- Neon lamp

2.2.8 References

- [1] Standard Atomic Weights 2013. Commission on Isotopic Abundances and Atomic Weights
- [2] Hammond, C.R. (2000). *The Elements, in Handbook of Chemistry and Physics 81st edition* (PDF). CRC press. p. 19. ISBN 0849304814.
- [3] Preston-Thomas, H. (1990). “The International Temperature Scale of 1990 (ITS-90)”. *Metrologia* **27**: 3–10. Bibcode:1990Metro..27....3P. doi:10.1088/0026-1394/27/1/002.

- [4] Haynes, William M., ed. (2011). *CRC Handbook of Chemistry and Physics* (92nd ed.). Boca Raton, FL: CRC Press. p. 4.122. ISBN 1439855110.
- [5] Shuen-Chen Hwang, Robert D. Lein, Daniel A. Morgan (2005). “Noble Gases”. Kirk Othmer Encyclopedia of Chemical Technology. Wiley. pp. 343–383. doi:10.1002/0471238961.0701190508230114.a01.
- [6] Magnetic susceptibility of the elements and inorganic compounds, in Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
- [7] Ramsay, William, Travers, Morris W. (1898). “On the Companions of Argon”. *Proceedings of the Royal Society of London* **63** (1): 437–440. doi:10.1098/rspl.1898.0057.
- [8] “Neon: History”. Softciências. Retrieved 2007-02-27.
- [9] Group 18 refers to the modern numbering of the periodic table. Older numberings described the rare gases as Group 0 or Group VIIIA (sometimes shortened to 8). See also Group (periodic table).
- [10] Coyle, Harold P. (2001). *Project STAR: The Universe in Your Hands*. Kendall Hunt. p. 464. ISBN 978-0-7872-6763-6.
- [11] Kohmoto, Kohtaro (1999). “Phosphors for lamps”. In Shionoya, Shigeo; Yen, William M. *Phosphor Handbook*. CRC Press. p. 940. ISBN 978-0-8493-7560-6.
- [12] Ramsay, William, Travers, Morris W. (1898). “On the Companions of Argon”. *Proceedings of the Royal Society of London* **63** (1): 437–440. doi:10.1098/rspl.1898.0057.
- [13] “Neon: History”. Softciências. Retrieved 2007-02-27.
- [14] Weeks, Mary Elvira (2003). *Discovery of the Elements: Third Edition (reprint)*. Kessinger Publishing. p. 287. ISBN 978-0-7661-3872-8.
- [15] Mangum, Aja (December 8, 2007). “Neon: A Brief History”. *New York Magazine*. Retrieved 2008-05-20.
- [16] Dickin, Alan P (2005). “Neon”. *Radiogenic isotope geology*. p. 303. ISBN 978-0-521-82316-6.
- [17] Resources on Isotopes. Periodic Table—Neon. explanation of the nucleogenic sources of Ne-21 and Ne-22. USGS.gov
- [18] “Neon: Isotopes”. Softciências. Retrieved 2007-02-27.
- [19] Anderson, Don L. “Helium, Neon & Argon”. Mantleplumes.org. Retrieved 2006-07-02.
- [20] “NASSMC: News Bulletin”. December 30, 2005. Retrieved 2007-03-05.
- [21] Mukhopadhyay, Mamata (2012). *Fundamentals of Cryogenic Engineering*. p. 195. ISBN 9788120330573.
- [22] “Plasma”. Retrieved 2007-03-05.
- [23] Baumann, Edward (1966). *Applications of Neon Lamps and Gas Discharge Tubes*. Carlton Press.

- [24] Myers, Robert L. (2002). *Display interfaces: fundamentals and standards*. John Wiley and Sons. pp. 69–71. ISBN 978-0-471-49946-6. Plasma displays are closely related to the simple neon lamp.
- [25] Weber, Larry F. (April 2006). "History of the plasma display panel". *IEEE Transactions on Plasma Science* **34** (2): 268–278. Bibcode:2006ITPS...34..268W. doi:10.1109/TPS.2006.872440. Paid access.
- [26] "ANSI Luminous Tube Footage Chart" (PDF). American National Standards Institute (ANSI). Retrieved 2010-12-10. Reproduction of a chart in the catalog of a lighting company in Toronto; the original ANSI specification is not given.
- [27] Gallagher, R.; Ingram, P. (2001-07-19). *Chemistry for Higher Tier*. University Press. p. 282. ISBN 978-0-19-914817-2.
- [28] Morse, David (January 26, 1996). "Galileo Probe Science Result". Galileo Project. Retrieved 2007-02-27.

2.2.9 External links

- Neon at *The Periodic Table of Videos* (University of Nottingham)
- WebElements.com – Neon.
- It's Elemental – Neon
- USGS Periodic Table – Neon
- Atomic Spectrum of Neon
- Neon Museum, Las Vegas

2.3 Argon

This article is about the chemical element. For other uses, see Argon (disambiguation).
Not to be confused with Argonne (disambiguation).

Argon is a chemical element with symbol **Ar** and atomic number 18. It is in group 18 of the periodic table and is a noble gas.^[5] Argon is the third most common gas in the Earth's atmosphere, at 0.93% (9,300 ppm), making it approximately 23.7 times as abundant as the next most common atmospheric gas, carbon dioxide (390 ppm), and more than 500 times as abundant as the next most common noble gas, neon (18 ppm). Nearly all of this argon is radiogenic argon-40 derived from the decay of potassium-40 in the Earth's crust. In the universe, argon-36 is by far the most common argon isotope, being the preferred argon isotope produced by stellar nucleosynthesis in supernovas. In addition, argon is the most prevalent of the noble gases in Earth's crust, with the element composing 0.00015% of this crust.^[6]

The name "argon" is derived from the Greek word *αργον*, neuter singular form of *αργος* meaning "lazy" or "inactive", as a reference to the fact that the element undergoes almost no chemical reactions. The complete octet (eight electrons) in the outer atomic shell makes argon stable and resistant to bonding with other elements. Its triple point temperature of 83.8058 K is a defining fixed point in the International Temperature Scale of 1990.

Argon is produced industrially by the fractional distillation of liquid air. Argon is mostly used as an inert shielding gas in welding and other high-temperature industrial processes where ordinarily non-reactive substances become reactive; for example, an argon atmosphere is used in graphite electric furnaces to prevent the graphite from burning. Argon gas also has uses in incandescent and fluorescent lighting, and other types of gas discharge tubes. Argon makes a distinctive blue-green gas laser. Argon is also used in fluorescent glow starters.

2.3.1 Characteristics



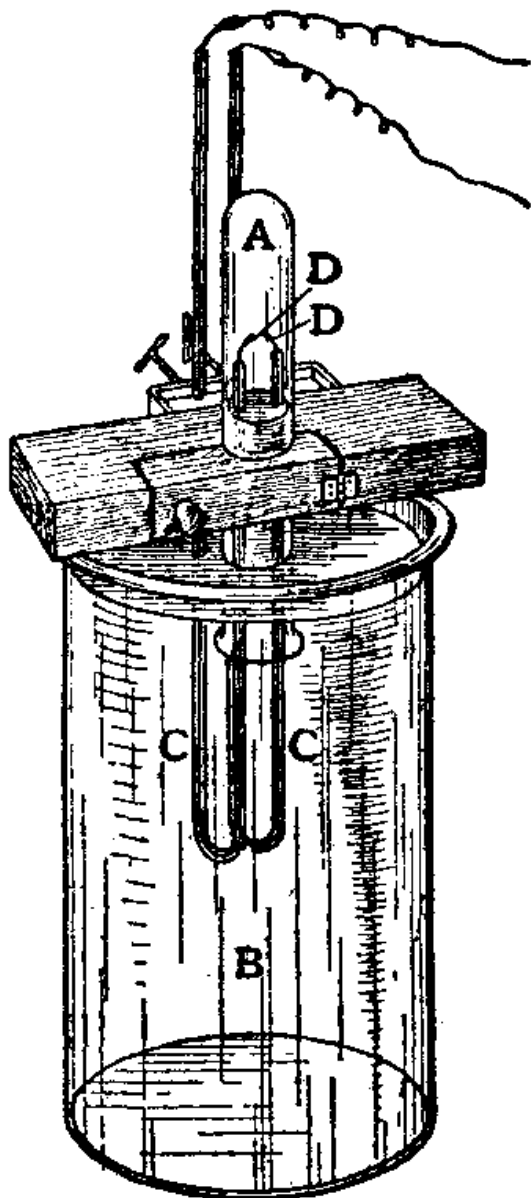
A small piece of rapidly melting solid argon.

Argon has approximately the same solubility in water as oxygen, and is 2.5 times more soluble in water than nitrogen. Argon is colorless, odorless, nonflammable and nontoxic as a solid, liquid, and gas.^[7] Argon is chemically inert under most conditions and forms no confirmed stable compounds at room temperature.

Although argon is a noble gas, it has been found to have the capability of forming some compounds. For example, the creation of argon fluorohydride (HArF), a compound of argon with fluorine and hydrogen which is stable below 17 K, was reported by researchers at the University of Helsinki in 2000.^{[8][9]} Although the neutral ground-state chemical compounds of argon are presently limited to HArF, argon can form clathrates with water when atoms of it are trapped in a lattice of the water molecules.^[10] Argon-containing ions and excited state complexes, such

as ArH^+ and ArF , respectively, are known to exist. Theoretical calculations have predicted several argon compounds that should be stable,^[11] but for which no synthesis routes are currently known.

2.3.2 History



Lord Rayleigh's method for the isolation of argon, based on an experiment of Henry Cavendish's. The gases are contained in a test-tube (A) standing over a large quantity of weak alkali (B), and the current is conveyed in wires insulated by U-shaped glass tubes (CC) passing through the liquid and round the mouth of the test-tube. The inner platinum ends (DD) of the wire receive a current from a battery of five Grove cells and a Ruhmkorff coil of medium size.

Argon (ἄργόν, neuter singular form of ἄργός, Greek meaning “inactive”, in reference to its chemical inactivity)^{[12][13]} was suspected to be present in air by Henry Cavendish in 1785 but was not isolated until 1894 by Lord Rayleigh and Sir William Ramsay at University College London in an experiment in which they removed all of the oxygen, carbon dioxide, water and nitrogen from a sample of clean air.^{[14][15][16]} They had determined that nitrogen produced from chemical compounds was one-half percent lighter than nitrogen from the atmosphere. The difference seemed insignificant, but it was important enough to attract their attention for many months. They concluded that there was another gas in the air mixed in with the nitrogen.^[17] Argon was also encountered in 1882 through independent research of H. F. Newall and W. N. Hartley. Each observed new lines in the color spectrum of air but were unable to identify the element responsible for the lines. Argon became the first member of the noble gases to be discovered. The symbol for argon is now “Ar”, but up until 1957 it was “A”.^[18]

2.3.3 Occurrence

Argon constitutes 0.934% by volume and 1.288% by mass of the Earth's atmosphere,^[19] and air is the primary raw material used by industry to produce purified argon products. Argon is isolated from air by fractionation, most commonly by cryogenic fractional distillation, a process that also produces purified nitrogen, oxygen, neon, krypton and xenon.^[20] The Earth's crust and seawater contain 1.2 ppm and 0.45 ppm of argon, respectively.^[21]

2.3.4 Isotopes

Main article: [Isotopes of argon](#)

The main isotopes of argon found on Earth are ^{40}Ar (99.6%), ^{36}Ar (0.34%), and ^{38}Ar (0.06%). Naturally occurring ^{40}K , with a half-life of 1.25×10^9 years, decays to stable ^{40}Ar (11.2%) by electron capture or positron emission, and also to stable ^{40}Ca (88.8%) via beta decay. These properties and ratios are used to determine the age of rocks by the method of K-Ar dating.^{[21][22]}

In the Earth's atmosphere, ^{39}Ar is made by cosmic ray activity, primarily with ^{40}Ar . In the subsurface environment, it is also produced through neutron capture by ^{39}K or alpha emission by calcium. ^{37}Ar is created from the neutron spallation of ^{40}Ca as a result of subsurface nuclear explosions. It has a half-life of 35 days.^[22]

Argon is notable in that its isotopic composition varies greatly between different locations in the Solar System. Where the major source of argon is the decay of ^{40}K in rocks, ^{40}Ar

will be the dominant isotope, as it is on Earth. Argon produced directly by stellar nucleosynthesis, in contrast, is dominated by the alpha process nuclide, ^{36}Ar

Correspondingly, solar argon contains 84.6% ^{36}Ar based on solar wind measurements,^[23] and the ratio of the three isotopes $^{36}\text{Ar} : ^{38}\text{Ar} : ^{40}\text{Ar}$ in the atmospheres of the outer planets is measured to be 8400 : 1600 : 1.^[24] This contrasts with the abundance of primordial ^{36}Ar

in Earth's atmosphere: only 31.5 ppmv (= 9340 ppmv \times 0.337%), comparable to that of neon (18.18 ppmv); and with measurements by interplanetary probes.

The Martian atmosphere contains 1.6% of ^{40}Ar and 5 ppm of ^{36}Ar

The Mariner probe fly-by of the planet Mercury in 1973 found that Mercury has a very thin atmosphere with 70% argon, believed to result from releases of the gas as a decay product from radioactive materials on the planet. In 2005, the Huygens probe discovered the presence of exclusively ^{40}Ar

on Titan, the largest moon of Saturn.^{[21][25]}

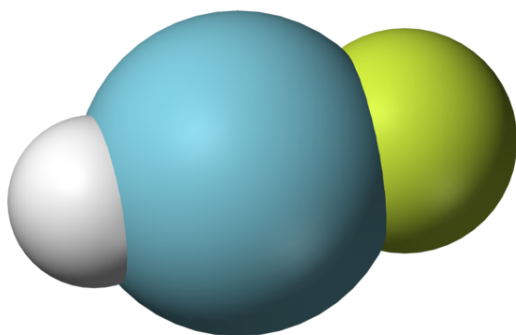
The predominance of radiogenic ^{40}Ar

is responsible for the standard atomic weight of terrestrial argon being greater than that of the next element, potassium, which was puzzling at the time when argon was discovered. Mendeleev had placed the elements in his periodic table in order of atomic weight, but the inertness of argon suggested a placement *before* the reactive alkali metal. Henry Moseley later solved this problem by showing that the periodic table is actually arranged in order of atomic number. (See History of the periodic table).

2.3.5 Compounds

See also: Van der Waals molecule

Argon's complete octet of electrons indicates full s and p



Space-filling model of argon fluorohydride.

This full outer energy level makes argon very

stable and extremely resistant to bonding with other elements. Before 1962, argon and the other noble gases were considered to be chemically inert and unable to form compounds; however, compounds of the heavier noble gases have since been synthesized. In August 2000, the first argon compound was formed by researchers at the University of Helsinki. By shining ultraviolet light onto frozen argon containing a small amount of hydrogen fluoride with caesium iodide,^[26] argon fluorohydride (HArF) was formed.^{[9][27]} It is stable up to 40 kelvin ($-233\text{ }^\circ\text{C}$). The metastable ArCF_2^+ 2 dication, which is valence isoelectronic with carbonyl fluoride, was observed in 2010.^[28] Argon-36, in the form of argon hydride ions, has been detected in cosmic dust associated with the Crab Nebula supernova; this was the first noble-gas molecule detected in outer space.^{[29][30]}

2.3.6 Production

Industrial

Argon is produced industrially by the fractional distillation of liquid air in a cryogenic air separation unit; a process that separates liquid nitrogen, which boils at 77.3 K, from argon, which boils at 87.3 K, and liquid oxygen, which boils at 90.2 K. About 700,000 tonnes of argon are produced worldwide every year.^{[21][31]}

In radioactive decays

^{40}Ar , the most abundant isotope of argon, is produced by the decay of ^{40}K with a half-life of 1.25×10^9 years by electron capture or positron emission. Because of this, it is used in potassium-argon dating to determine the age of rocks.

2.3.7 Applications

There are several different reasons argon is used in particular applications:

- An inert gas is needed. In particular, argon is the cheapest alternative when nitrogen is not sufficiently inert.
- Low thermal conductivity is required.
- The electronic properties (ionization and/or the emission spectrum) are necessary.

Other noble gases would probably work as well in most of these applications, but argon is by far the cheapest. Argon is inexpensive since it occurs naturally in air, and is readily obtained as a byproduct of cryogenic air separation in the production of liquid oxygen and liquid nitrogen: the primary constituents of air are used on a large



Cylinders containing argon gas for use in extinguishing fire without damaging server equipment

industrial scale. The other noble gases (except helium) are produced this way as well, but argon is the most plentiful by far. The bulk of argon applications arise simply because it is inert and relatively cheap.

Industrial processes

Argon is used in some high-temperature industrial processes, where ordinarily non-reactive substances become reactive. For example, an argon atmosphere is used in graphite electric furnaces to prevent the graphite from burning.

For some of these processes, the presence of nitrogen or oxygen gases might cause defects within the material. Argon is used in various types of arc welding such as gas metal arc welding and gas tungsten arc welding, as well as in the processing of titanium and other reactive elements. An argon atmosphere is also used for growing crystals of silicon and germanium.

See also: shielding gas

Argon is used in the poultry industry to asphyxiate birds, either for mass culling following disease outbreaks, or as a means of slaughter more humane than the electric bath. Argon's relatively high density causes it to remain close to

the ground during gassing. Its non-reactive nature makes it suitable in a food product, and since it replaces oxygen within the dead bird, argon also enhances shelf life.^[32]

Argon is sometimes used for extinguishing fires where damage to equipment is to be avoided.

Scientific research

Liquid argon is used as the target for neutrino experiments and direct dark matter searches. The interaction of a hypothetical WIMP particle with the argon nucleus produces scintillation light that is detected by photomultiplier tubes. Two-phase detectors also use argon gas to detect the ionized electrons produced during the WIMP-nucleus scattering. As with most other liquefied noble gases, argon has a high scintillation light yield (~ 51 photons/keV^[33]), is transparent to its own scintillation light, and is relatively easy to purify. Compared to xenon, argon is cheaper and has a distinct scintillation time profile which allows the separation of electronic recoils from nuclear recoils. On the other hand, its intrinsic beta-ray background is larger due to ³⁹

Ar contamination, unless one uses underground argon sources which has much less ³⁹

Ar contamination. Most of the argon in the Earth's atmosphere was produced by electron capture of long-lived ⁴⁰K (⁴⁰

$K + e^- \rightarrow ^{40}$

$Ar + \nu$) present in natural potassium within the earth. The ³⁹

Ar activity in the atmosphere is maintained by cosmogenic production through ⁴⁰

$Ar(n,2n)^{39}$

Ar and similar reactions. The half-life of ³⁹

Ar is only 269 yr. As a result, the underground Ar, shielded by rock and water, has much less ³⁹

Ar contamination.^[34] Dark matter detectors currently operating with liquid argon include DarkSide, WArP, ArDM, microCLEAN and DEAP-I. Neutrino experiments include Icarus and MicroBooNE both of which use high purity liquid argon in a time projection chamber for fine grained three-dimensional imaging of neutrino interactions.

Preservative

Argon is used to displace oxygen- and moisture-containing air in packaging material to extend the shelf-lives of the contents (argon has the European food additive code of E938). Aerial oxidation, hydrolysis, and other chemical reactions which degrade the products are retarded or prevented entirely. Bottles of high-purity chemicals and certain pharmaceutical products are available in sealed bottles or ampoules packed in argon. In wine making, argon is used to top-off barrels to avoid the aerial oxidation of ethanol to acetic acid during the aging process.



A sample of caesium is packed under argon to avoid reactions with air

Argon is also available in aerosol-type cans, which may be used to preserve compounds such as varnish, polyurethane, paint, etc. for storage after opening.^[35]

Since 2002, the American National Archives stores important national documents such as the Declaration of Independence and the Constitution within argon-filled cases to retard their degradation. Using argon reduces gas leakage, compared with the helium used in the preceding five decades.^[36]

Laboratory equipment



Gloveboxes are often filled with argon, which recirculates over scrubbers to maintain an oxygen-, nitrogen-, and moisture-free atmosphere

See also: Air-free technique

Argon may be used as the inert gas within Schlenk lines and gloveboxes. The use of argon over comparatively less expensive nitrogen is preferred where nitrogen may react with the experimental reagents or apparatus.

Argon may be used as the carrier gas in gas chromatography and in electrospray ionization mass spectrometry; it is the gas of choice for the plasma used in ICP spectroscopy.

Argon is preferred for the sputter coating of specimens for scanning electron microscopy. Argon gas is also commonly used for sputter deposition of thin films as in microelectronics and for wafer cleaning in microfabrication.

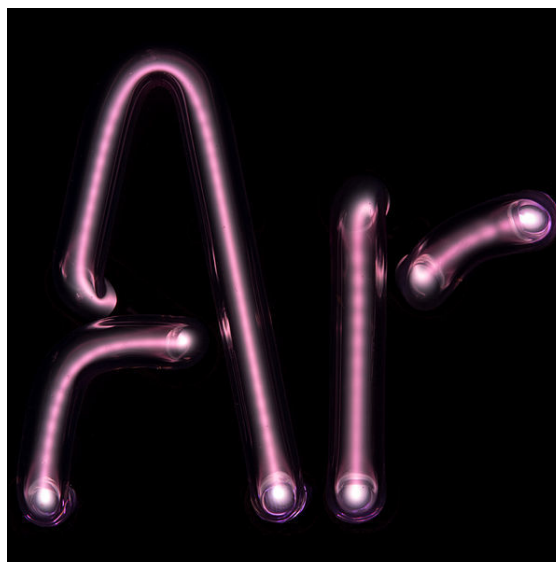
Medical use

Cryosurgery procedures such as cryoablation use liquefied argon to destroy tissue such as cancer cells. In surgery it is used in a procedure called “argon enhanced coagulation” which is a form of argon plasma beam electrosurgery. The procedure carries a risk of producing gas embolism in the patient and has resulted in the death of one person via this type of accident.^[37]

Blue argon lasers are used in surgery to weld arteries, destroy tumors, and to correct eye defects.^[21]

Argon has also been used experimentally to replace nitrogen in the breathing or decompression mix known as Argox, to speed the elimination of dissolved nitrogen from the blood.^[38]

Lighting



Argon gas-discharge lamp forming the symbol for argon “Ar”.

Incandescent lights are filled with argon, to preserve the filaments at high temperature from oxidation. It is used for the specific way it ionizes and emits light, such as in plasma globes and calorimetry in experimental particle physics. Gas-discharge lamps filled with pure argon provide lilac/violet light, filled with argon and some mercury blue light. Argon is also used for the creation of blue and green laser light.

Miscellaneous uses

Argon is used for thermal insulation in energy efficient windows.^[39] Argon is also used in technical scuba diving to inflate a dry suit, because it is inert and has low thermal conductivity.^[40] Argon is being used as a propellant in the development of the Variable Specific Impulse Magnetoplasma Rocket (VASIMR). Compressed argon gas is allowed to expand, to cool the seeker heads of the AIM-9 Sidewinder missile, and other missiles that use cooled thermal seeker heads. The gas is stored at high pressure.^[41]

Argon-39, with a half-life of 269 years, has been used for a number of applications, primarily ice core and ground water dating. Also, potassium-argon dating is used in dating igneous rocks.^[21]

Argon has been used by athletes as a doping agent to simulate hypoxic conditions. On August 31, 2014 the World Anti Doping Agency (WADA) added argon and xenon to the list of prohibited substances and methods, although at this time there is no reliable test for abuse.^[42]

2.3.8 Safety

Although argon is non-toxic, it is 38% denser than air and is therefore considered a dangerous asphyxiant in closed areas. It is also difficult to detect because it is colorless, odorless, and tasteless. A 1994 incident in which a man was asphyxiated after entering an argon filled section of oil pipe under construction in Alaska highlights the dangers of argon tank leakage in confined spaces, and emphasizes the need for proper use, storage and handling.^[43]

2.3.9 See also

- Industrial gas

2.3.10 References

- [1] Standard Atomic Weights 2013. Commission on Isotopic Abundances and Atomic Weights
- [2] Haynes, William M., ed. (2011). *CRC Handbook of Chemistry and Physics* (92nd ed.). Boca Raton, FL: CRC Press. p. 4.121. ISBN 1439855110.
- [3] Shuen-Chen Hwang, Robert D. Lein, Daniel A. Morgan (2005). "Noble Gases". *Kirk Othmer Encyclopedia of Chemical Technology*. Wiley. pp. 343–383. doi:10.1002/0471238961.0701190508230114.a01.
- [4] Magnetic susceptibility of the elements and inorganic compounds, in Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
- [5] In older versions of the periodic table, the noble gases were identified as Group VIIIA or as Group 0. See Group (periodic table).
- [6] <http://www.ptable.com/#Property/Abundance/Crust>
- [7] Material Safety Data Sheet Gaseous Argon, Universal Industrial Gases, Inc. Retrieved 14 October 2013.
- [8] Leonid Khriachtchev; Mika Pettersson; Nino Runeberg; Jan Lundell et al. (2000). "A stable argon compound". *Nature* **406**: 874–876. doi:10.1038/35022551. PMID 10972285.
- [9] Perkins, S. (26 August 2000). "HArF! Argon's not so noble after all – researchers make argon fluorohydride". *Science News*.
- [10] Belosludov, V. R.; Subbotin, O. S.; Krupskii, D. S.; Prokuda, O. V. et al. (2006). "Microscopic model of clathrate compounds". *Journal of Physics: Conference Series* **29**: 1. Bibcode:2006JPhCS..29....1B. doi:10.1088/1742-6596/29/1/001.
- [11] Cohen, A.; Lundell, J.; Gerber, R. B. (2003). "First compounds with argon–carbon and argon–silicon chemical bonds". *Journal of Chemical Physics* **119** (13): 6415. Bibcode:2003JChPh.119.6415C. doi:10.1063/1.1613631.
- [12] Hiebert, E. N. (1963). "In Noble-Gas Compounds". In Hyman, H. H. *Historical Remarks on the Discovery of Argon: The First Noble Gas*. University of Chicago Press. pp. 3–20.
- [13] Travers, M. W. (1928). *The Discovery of the Rare Gases*. Edward Arnold & Co. pp. 1–7.
- [14] Lord Rayleigh; Ramsay, William (1894–1895). "Argon, a New Constituent of the Atmosphere". *Proceedings of the Royal Society* **57** (1): 265–287. doi:10.1098/rspl.1894.0149. JSTOR 115394.
- [15] Lord Rayleigh; Ramsay, William (1895). "VI. Argon: A New Constituent of the Atmosphere". *Philosophical Transactions of the Royal Society A* **186**: 187. Bibcode:1895RSPTA.186..187R. doi:10.1098/rsta.1895.0006. JSTOR 90645.
- [16] Ramsay, W. (1904). "Nobel Lecture". The Nobel Foundation.
- [17] "About Argon, the Inert; The New Element Supposedly Found in the Atmosphere". *The New York Times*. 3 March 1895. Retrieved 1 February 2009.
- [18] Holden, N. E. (12 March 2004). "History of the Origin of the Chemical Elements and Their Discoverers". National Nuclear Data Center.
- [19] "Encyclopædia Britannica Online, s.v. "argon (Ar)". Retrieved 14 January 2014.
- [20] "Argon, Ar". Etacude.com. Retrieved 8 March 2007.
- [21] Emsley, J. (2001). *Nature's Building Blocks*. Oxford University Press. pp. 44–45. ISBN 978-0-19-960563-7.
- [22] "⁴⁰Ar/³⁹Ar dating and errors". Archived from the original on 9 May 2007. Retrieved 7 March 2007.

- [23] Lodders, K. (2008). “The solar argon abundance”. *Astrophysical Journal* **674**: 607. arXiv:0710.4523. Bibcode:2008ApJ...674..607L. doi:10.1086/524725.
- [24] Cameron, A. G. W. (1973). “Elemental and isotopic abundances of the volatile elements in the outer planets”. *Space Science Reviews* **14** (3–4): 392–400. doi:10.1007/BF00214750.
- [25] “Seeing, touching and smelling the extraordinarily Earth-like world of Titan”. European Space Agency. 21 January 2005.
- [26] Kean, Sam (2011). “Chemistry Way, Way Below Zero”. *The Disappearing Spoon*. Black Bay Books.
- [27] Bartlett, Neil (8 September 2003). “The Noble Gases”. *Chemical & Engineering News* **81** (36).
- [28] Lockyear, JF; Douglas, K; Price, SD; Karwowska, M et al. (2010). “Generation of the ArCF_2^{2+} Dication”. *Journal of Physical Chemistry Letters* **1**: 358. doi:10.1021/jz900274p.
- [29] Barlow, M. J. et al. (2013). “Detection of a Noble Gas Molecular Ion, $^{36}\text{ArH}^+$, in the Crab Nebula”. *Science* **342** (6164): 1343–1345. arXiv:1312.4843. Bibcode:2013Sci...342.1343B. doi:10.1126/science.1243582.
- [30] Quenqua, Douglas (13 December 2013). “Noble Molecules Found in Space”. *New York Times*. Retrieved 13 December 2013.
- [31] “Periodic Table of Elements: Argon – Ar”. Environmentalchemistry.com. Retrieved 12 September 2008.
- [32] Fletcher, D. L. “Slaughter Technology” (PDF). *Symposium: Recent Advances in Poultry Slaughter Technology*. Retrieved 1 January 2010.
- [33] Gastler, Dan; Kearns, Ed; Hime, Andrew; Stonehill, Laura C. et al. (2012). “Measurement of scintillation efficiency for nuclear recoils in liquid argon”. *Physical Review C* **85** (6). arXiv:1004.0373. Bibcode:2012PhRvC..85f5811G. doi:10.1103/PhysRevC.85.065811.
- [34] Xu, J.; Calaprice, F.; Galbiati, C.; Goretti, A.; Guray, G. et al. (2012). “A Study of the Residual ^{39}Ar Content in Argon from Underground Sources”. arXiv:1204.6011v1.
- [35] Zawalick, Steven Scott “Method for preserving an oxygen sensitive liquid product” U.S. Patent 6,629,402 Issue date: 7 October 2003
- [36] “Schedule for Renovation of the National Archives Building”. Retrieved 7 July 2009.
- [37] “Fatal Gas Embolism Caused by Overpressurization during Laparoscopic Use of Argon Enhanced Coagulation”. MDSR. 24 June 1994.
- [38] Pilmanis Andrew A; Balldin UI; Webb James T; Krause KM (2003). “Staged decompression to 3.5 psi using argon-oxygen and 100% oxygen breathing mixtures”. *Aviation, Space, Environmental Medicine* **74** (12): 1243–50. PMID 14692466.
- [39] “Energy-Efficient Windows”. FineHomebuilding.com. Retrieved 1 August 2009.
- [40] Nuckols ML; Giblo J; Wood-Putnam JL (15–18 September 2008). “Thermal Characteristics of Diving Garments When Using Argon as a Suit Inflation Gas”. *Proceedings of the Oceans 08 MTS/IEEE Quebec, Canada Meeting (MTS/IEEE)*. Retrieved 2 March 2009.
- [41] “Description of Aim-9 Operation”. planken.org. Archived from the original on 22 December 2008. Retrieved 1 February 2009.
- [42] “WADA amends Section S.2.1 of 2014 Prohibited List”. 31 August 2014.
- [43] Alaska FACE Investigation 94AK012 (23 June 1994). “Welder’s Helper Asphyxiated in Argon-Inerted Pipe – Alaska (FACE AK-94-012)”. State of Alaska Department of Public Health. Retrieved 29 January 2011.

2.3.11 Further reading

- Brown, T. L.; Bursten, B. E.; LeMay, H. E. (2006). J. Challice; N. Folchetti, eds. *Chemistry: The Central Science* (10th ed.). Pearson Education. pp. 276 & 289. ISBN 978-0-13-109686-8.
- Triple point temperature: 83.8058 K – Preston-Thomas, H. (1990). “The International Temperature Scale of 1990 (ITS-90)”. *Metrologia* **27**: 3–10. Bibcode:1990Metro..27....3P. doi:10.1088/0026-1394/27/1/002.
- Triple point pressure: 69 kPa – Lide, D. R. (2005). “Properties of the Elements and Inorganic Compounds; Melting, boiling, triple, and critical temperatures of the elements”. *CRC Handbook of Chemistry and Physics* (86th ed.). CRC Press. §4. ISBN 0-8493-0486-5.

2.3.12 External links

- Silicon at *The Periodic Table of Videos* (University of Nottingham)
- USGS Periodic Table – Argon
- Diving applications: Why Argon?

2.4 Krypton

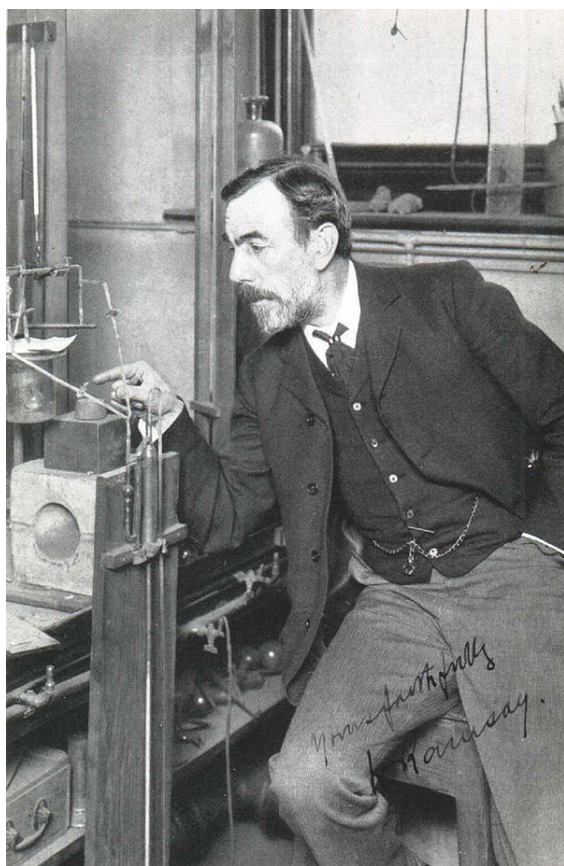
This article is about the chemical element. For other uses, see Krypton (disambiguation).

Krypton (from Greek: *κρυπτός* *kryptos* “the hidden one”) is a chemical element with symbol **Kr** and atomic number 36. It is a member of group 18 (noble gases) elements. A colorless, odorless, tasteless noble gas, krypton

occurs in trace amounts in the atmosphere, is isolated by fractionally distilling liquefied air, and is often used with other rare gases in fluorescent lamps. Krypton is inert for most practical purposes.

Krypton, like the other noble gases, can be used in lighting and photography. Krypton light has a large number of spectral lines, and krypton's high light output in plasmas allows it to play an important role in many high-powered gas lasers (krypton ion and excimer lasers), which pick out one of the many spectral lines to amplify. There is also a specific krypton fluoride laser. The high power and relative ease of operation of krypton discharge tubes caused (from 1960 to 1983) the official length of a meter to be defined in terms of the wavelength of the 605 nm (orange) spectral line of krypton-86.

2.4.1 History



Sir William Ramsay, the discoverer of krypton

Krypton was discovered in Britain in 1898 by Sir William Ramsay, a Scottish chemist, and Morris Travers, an English chemist, in residue left from evaporating nearly all components of liquid air. Neon was discovered by a similar procedure by the same workers just a few weeks later.^[7] William Ramsay was awarded the 1904 Nobel Prize in Chemistry for discovery of a series of noble gases, including krypton.

In 1960, the International Conference on Weights and Measures defined the meter as 1,650,763.73 wavelengths of light emitted by the krypton-86 isotope.^{[8][9]} This agreement replaced the 1889 international prototype meter located in Paris, which was a metal bar made of a platinum-iridium alloy (one of a series of standard meter bars, originally constructed to be one ten-millionth of a quadrant of the Earth's polar circumference). This also obsoleted the 1927 definition of the ångström based on the red cadmium spectral line,^[10] replacing it with $1 \text{ \AA} = 10^{-10} \text{ m}$. The krypton-86 definition lasted until the October 1983 conference, which redefined the meter as the distance that light travels in a vacuum during $1/299,792,458 \text{ s}$.^{[11][12][13]}

2.4.2 Characteristics

Krypton is characterized by several sharp emission lines (spectral signatures) the strongest being green and yellow.^[14] It is one of the products of uranium fission.^[15] Solidified krypton is white and crystalline with a face-centered cubic crystal structure, which is a common property of all noble gases (except helium, with a hexagonal close-packed crystal structure).

Isotopes

Main article: Isotopes of krypton

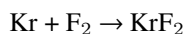
Naturally occurring krypton is made of six stable isotopes. In addition, about thirty unstable isotopes and isomers are known.^[16] ^{81}Kr , the product of atmospheric reactions, is produced with the other naturally occurring isotopes of krypton. Being radioactive, it has a half-life of 230,000 years. Krypton is highly volatile when it is near surface waters but ^{81}Kr has been used for dating old (50,000–800,000 years) groundwater.^[17]

^{85}Kr is an inert radioactive noble gas with a half-life of 10.76 years. It is produced by the fission of uranium and plutonium, such as in nuclear bomb testing and nuclear reactors. ^{85}Kr is released during the reprocessing of fuel rods from nuclear reactors. Concentrations at the North Pole are 30% higher than at the South Pole due to convective mixing.^[18]

Chemistry

Like the other noble gases, krypton is highly chemically unreactive. However, following the first successful synthesis of xenon compounds in 1962, synthesis of krypton difluoride (KrF_2) was reported in 1963.

In fact, before the 1960s, no noble gas compounds had been discovered.^[19] Under extreme conditions, krypton reacts with fluorine to form KrF_2 according to the following equation:



In the same year, KrF

4 was reported by Grosse, *et al.*,^[20] but was subsequently shown to be a mistaken identification.^[21] There are also unverified reports of a barium salt of a krypton oxoacid.^[22] ArKr^+ and KrH^+ polyatomic ions have been investigated and there is evidence for KrXe or KrXe^+ .^[23]

Compounds with krypton bonded to atoms other than fluorine have also been discovered. The reaction of KrF_2 with $\text{B}(\text{OTeF}_5)_2$

5)

3 produces an unstable compound, $\text{Kr}(\text{OTeF}_5)_2$

5)

2, that contains a krypton-oxygen bond. A krypton-nitrogen bond is found in the cation $[\text{HC}\equiv\text{N}-\text{Kr}-\text{F}]^+$

, produced by the reaction of KrF_2

2 with $[\text{HC}\equiv\text{NH}]^+$

$[\text{AsF}_6]^-$

6] below -50°C .^{[24][25]} HKrCN and $\text{HKrC}\equiv\text{CH}$ (krypton hydride-cyanide and hydrokryptoacetylene) were reported to be stable up to 40 K.^[19]

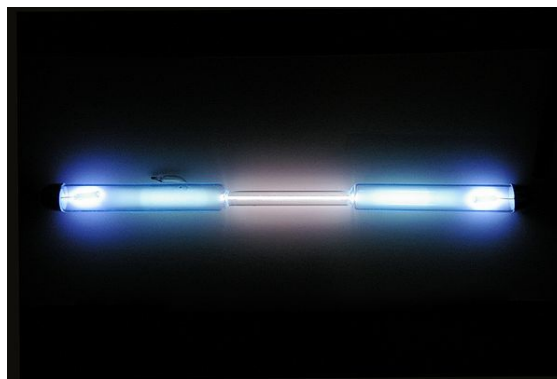
Natural occurrence

The Earth has retained all of the noble gases that were present at its formation except for helium. Krypton's concentration in the atmosphere is about 1 ppm. It can be extracted from liquid air by fractional distillation.^[26] The amount of krypton in space is uncertain, as the amount is derived from the meteoric activity and that from solar winds. The first measurements suggest an overabundance of krypton in space.^[27]

2.4.3 Applications



Krypton gas discharge tube



Krypton discharge (spectrum) tube

Krypton's multiple emission lines make ionized krypton gas discharges appear whitish, which in turn makes krypton-based bulbs useful in photography as a brilliant white light source. Krypton is thus used in some types of photographic flashes used in high speed photography. Krypton gas is also combined with other gases to make luminous signs that glow with a bright greenish-yellow light.^[28]

Krypton mixes with argon as the fill gas of energy saving fluorescent lamps. This reduces their power consumption. Unfortunately this also reduces their light output and raises their cost.^[29] Krypton costs about 100 times as much as argon. Krypton (along with xenon) is also used to fill incandescent lamps to reduce filament evaporation and allow higher operating temperatures to be used for the filament.^[30] A brighter light results which contains more blue than conventional lamps.

Krypton's white discharge is often used to good effect in colored gas discharge tubes, which are then simply painted or stained in other ways to allow the desired color (for example, "neon" type advertising signs where the letters appear in differing colors are often entirely krypton-based). Krypton is also capable of much higher light power density than neon in the red spectral line region, and for this reason, red lasers for high-power laser light-shows are often krypton lasers with mirrors which select out the red spectral line for laser amplification and emission, rather than the more familiar helium-neon variety, which could never practically achieve the multi-watt red laser light outputs needed for this application.^[31]

Krypton has an important role in production and usage of the krypton fluoride laser. The laser has been important in the nuclear fusion energy research community in confinement experiments. The laser has high beam uniformity, short wavelength, and the ability to modify the spot size to track an imploding pellet.^[32]

In experimental particle physics, liquid krypton is used to construct quasi-homogeneous electromagnetic calorimeters. A notable example is the calorimeter of the NA48 experiment at CERN containing about 27 tonnes of liquid krypton. This usage is rare, since the cheaper

liquid argon is typically used. The advantage of krypton over argon is a small Molière radius of 4.7 cm, which allows for excellent spatial resolution and low degree of overlapping. The other parameters relevant for calorimetry application are: radiation length of $X_0=4.7$ cm, density of 2.4 g/cm^3 .

The sealed spark gap assemblies contained in ignition exciters used in some older jet engines contain a very small amount of Krypton-85 to obtain consistent ionization levels and uniform operation.

Krypton-83 has application in magnetic resonance imaging (MRI) for imaging airways. In particular, it may be used to distinguish between hydrophobic and hydrophilic surfaces containing an airway.^[33]

Although xenon has potential for use in computed tomography (CT) to assess regional ventilation, its anesthetic properties limit its fraction in the breathing gas to 35%. The use of a breathing mixture containing 30% xenon and 30% krypton is comparable in effectiveness for CT to a 40% xenon fraction, while avoiding the unwanted effects of a high fraction xenon gas.^[34]

Methods for the detection of concentrations of Krypton-85 in the atmosphere have been used to detect suspected clandestine nuclear fuel reprocessing facilities in North Korea^[35] and Pakistan.^[36] These facilities were detected in the early 2000s and were believed to be producing weapons-grade plutonium.

2.4.4 Precautions

Krypton is considered to be a non-toxic asphyxiant.^[37] Krypton has a narcotic potency seven times greater than air, so breathing a gas containing 50% krypton and 50% air would cause narcosis similar to breathing air at four times atmospheric pressure. This would be comparable to scuba diving at a depth of 30 m (100 ft) (see nitrogen narcosis) and potentially could affect anyone breathing it. Nevertheless, that mixture would contain only 10% oxygen and hypoxia would be a greater concern.

2.4.5 See also

2.4.6 References

- [1] Standard Atomic Weights 2013. Commission on Isotopic Abundances and Atomic Weights
- [2] Krypton. encyclopedia.airliquide.com
- [3] "Section 4, Properties of the Elements and Inorganic Compounds; Melting, boiling, triple, and critical temperatures of the elements". *CRC Handbook of Chemistry and Physics* (85th edition ed.). Boca Raton, Florida: CRC Press. 2005.
- [4] Haynes, William M., ed. (2011). *CRC Handbook of Chemistry and Physics* (92nd ed.). Boca Raton, FL: CRC Press. p. 4.121. ISBN 1439855110.
- [5] Shuen-Chen Hwang, Robert D. Lein, Daniel A. Morgan (2005). "Noble Gases". *Kirk Othmer Encyclopedia of Chemical Technology*. Wiley. pp. 343–383. doi:10.1002/0471238961.0701190508230114.a01.
- [6] Magnetic susceptibility of the elements and inorganic compounds, in Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
- [7] William Ramsay; Morris W. Travers (1898). "On a New Constituent of Atmospheric Air". *Proceedings of the Royal Society of London* **63** (1): 405–408. doi:10.1098/rspl.1898.0051.
- [8] "The BIPM and the evolution of the definition of the metre". Bureau International des Poids et Mesures. 2014-07-26. Retrieved 2014-09-24.
- [9] Penzes, William B. (2009-01-08). "Time Line for the Definition of the Meter". National Institute of Standards and Technology. Retrieved 2014-09-24.
- [10] Burdun, G. D. (1958). "On the new determination of the meter" (PDF). *Measurement Techniques* **1** (3): 259–264. doi:10.1007/BF00974680. (subscription required (help)).
- [11] Shri Krishna Kimothi (2002). *The uncertainty of measurements: physical and chemical metrology: impact and analysis*. American Society for Quality. p. 122. ISBN 0-87389-535-5.
- [12] Gibbs, Philip (1997). "How is the speed of light measured?". Department of Mathematics, University of California. Retrieved 2007-03-19.
- [13] Unit of length (meter), NIST
- [14] "Spectra of Gas Discharges".
- [15] "Krypton". Argonne National Laboratory, EVS. 2005. Archived from the original (PDF) on 2009-12-20. Retrieved 2007-03-17.
- [16] Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
- [17] Thonnard, Norbert; Larry D. McKay; Theodore C. Labotka (2001-02-05). "Development of Laser-Based Resonance Ionization Techniques for 81-Kr and 85-Kr Measurements in the Geosciences" (PDF). University of Tennessee, Institute for Rare Isotope Measurements. pp. 4–7. Retrieved 2007-03-20.
- [18] "Resources on Isotopes". U.S. Geological Survey. Retrieved 2007-03-20.
- [19] Bartlett, Neil (2003). "The Noble Gases". *Chemical & Engineering News*. Retrieved 2006-07-02.
- [20] Grosse, A. V.; Kirshenbaum, A. D.; Streng, A. G.; Streng, L. V. (1963). "Krypton Tetrafluoride: Preparation and Some Properties". *Science* **139** (3559): 1047–1048. Bibcode:1963Sci...139.1047G. doi:10.1126/science.139.3559.1047. PMID 17812982.

- [21] Prusakov, V. N.; Sokolov, V. B. (1971). “Krypton difluoride”. *Soviet Atomic Energy* **31** (3): 990–999. doi:10.1007/BF01375764.
- [22] Streng, A.; Grosse, A. (1964). “Acid of Krypton and Its Barium Salt”. *Science* **143** (3603): 242–243. Bibcode:1964Sci...143..242S. doi:10.1126/science.143.3603.242. PMID 17753149.
- [23] “Periodic Table of the Elements” (PDF). Los Alamos National Laboratory’s Chemistry Division. pp. 100–101. Archived from the original (PDF) on November 25, 2006. Retrieved 2007-04-05.
- [24] John H. Holloway; Eric G. Hope (1998). A. G. Sykes, ed. *Advances in Inorganic Chemistry*. Academic Press. p. 57. ISBN 0-12-023646-X.
- [25] Errol G. Lewars (2008). *Modeling Marvels: Computational Anticipation of Novel Molecules*. Springer. p. 68. ISBN 1-4020-6972-3.
- [26] “How Products are Made: Krypton”. Retrieved 2006-07-02.
- [27] Cardelli, Jason A.; Meyer, David M. (1996). “The Abundance of Interstellar Krypton”. *The Astrophysical Journal Letters*. The American Astronomical Society. pp. L57–L60. Retrieved 2007-04-05.
- [28] “Mercury in Lighting” (PDF). Cape Cod Cooperative Extension. Archived from the original (PDF) on September 29, 2007. Retrieved 2007-03-20.
- [29] “Energy-saving” lamps
- [30] Properties, Applications and Uses of the “Rare Gases” Neon, Krypton and Xenon
- [31] “Laser Devices, Laser Shows and Effect” (PDF). Retrieved 2007-04-05.
- [32] Sethian, J.; M. Friedman; M. Myers. “Krypton Fluoride Laser Development for Inertial Fusion Energy” (PDF). Plasma Physics Division, Naval Research Laboratory. pp. 1–8. Retrieved 2007-03-20.
- [33] Pavlovskaya, GE; Cleveland, ZI; Stupic, KF; Basaraba, RJ et al. (2005). “Hyperpolarized krypton-83 as a contrast agent for magnetic resonance imaging”. *Proceedings of the National Academy of Sciences U.S.A.* **102** (51): 18275–9. Bibcode:2005PNAS..10218275P. doi:10.1073/pnas.0509419102. PMC 1317982. PMID 16344474.
- [34] Chon, D; Beck, KC; Simon, BA; Shikata, H et al. (2007). “Effect of low-xenon and krypton supplementation on signal/noise of regional CT-based ventilation measurements”. *Journal of Applied Physiology* **102** (4): 1535–44. doi:10.1152/jappphysiol.01235.2005. PMID 17122371.
- [35] Sanger, David E.; Shanker, Thom (2003-07-20). “N. Korea may be hiding new nuclear site”. *Oakland Tribune*. Retrieved 2015-05-01 – via Highbeam Research.
- [36] Bradley, Ed; Martin, David (2000-03-16). “U.S. Intelligence Find Evidence of Pakistan Producing Nuclear Weapons, CBS”. *CBS Evening News with Dan Rather*. Retrieved 2015-05-01 – via Highbeam Research.
- [37] Properties of Krypton

2.4.7 Further reading

- William P. Kirk “Krypton 85: a Review of the Literature and an Analysis of Radiation Hazards”, Environmental Protection Agency, Office of Research and Monitoring, Washington (1972)

2.4.8 External links

- Krypton at *The Periodic Table of Videos* (University of Nottingham)
- Krypton Fluoride Lasers, Plasma Physics Division Naval Research Laboratory

2.5 Xenon

This article is about the chemical element. For other uses, see Xenon (disambiguation).

Xenon is a chemical element with symbol **Xe** and atomic number 54. It is a colorless, dense, odorless noble gas, that occurs in the Earth’s atmosphere in trace amounts.^[10] Although generally unreactive, xenon can undergo a few chemical reactions such as the formation of xenon hexafluoroplatinate, the first noble gas compound to be synthesized.^{[11][12][13]}

Naturally occurring xenon consists of eight stable isotopes. There are also over 40 unstable isotopes that undergo radioactive decay. The isotope ratios of xenon are an important tool for studying the early history of the Solar System.^[14] Radioactive xenon-135 is produced from iodine-135 as a result of nuclear fission, and it acts as the most significant neutron absorber in nuclear reactors.^[15]

Xenon is used in flash lamps^[16] and arc lamps,^[17] and as a general anesthetic.^[18] The first excimer laser design used a xenon dimer molecule (Xe₂) as its lasing medium,^[19] and the earliest laser designs used xenon flash lamps as pumps.^[20] Xenon is also being used to search for hypothetical weakly interacting massive particles^[21] and as the propellant for ion thrusters in spacecraft.^[22]

2.5.1 History

Xenon was discovered in England by the Scottish chemist William Ramsay and English chemist Morris Travers on July 12, 1898, shortly after their discovery of the elements krypton and neon. They found xenon in the residue left over from evaporating components of liquid air.^{[23][24]} Ramsay suggested the name *xenon* for this gas from the Greek word ξένον [xenon], neuter singular form of ξένος [xenos], meaning 'foreign(er)', 'strange(r)', or 'guest'.^{[25][26]} In 1902, Ramsay estimated the proportion

of xenon in the Earth's atmosphere as one part in 20 million.^[27]

During the 1930s, American engineer Harold Edgerton began exploring strobe light technology for high speed photography. This led him to the invention of the xenon flash lamp, in which light is generated by sending a brief electrical current through a tube filled with xenon gas. In 1934, Edgerton was able to generate flashes as brief as one microsecond with this method.^{[16][28][29]}

In 1939, American physician Albert R. Behnke Jr. began exploring the causes of "drunkenness" in deep-sea divers. He tested the effects of varying the breathing mixtures on his subjects, and discovered that this caused the divers to perceive a change in depth. From his results, he deduced that xenon gas could serve as an anesthetic. Although Russian toxicologist Nikolay V. Lazarev apparently studied xenon anesthesia in 1941, the first published report confirming xenon anesthesia was in 1946 by American medical researcher John H. Lawrence, who experimented on mice. Xenon was first used as a surgical anesthetic in 1951 by American anesthesiologist Stuart C. Cullen, who successfully operated on two patients.^[30]

Xenon and the other noble gases were for a long time considered to be completely chemically inert and not able to form compounds. However, while teaching at the University of British Columbia, Neil Bartlett discovered that the gas platinum hexafluoride (PtF_6) was a powerful oxidizing agent that could oxidize oxygen gas (O_2) to form dioxygenyl hexafluoroplatinate ($\text{O}_2^+[\text{PtF}_6]^-$).^[31] Since O_2 and xenon have almost the same first ionization potential, Bartlett realized that platinum hexafluoride might also be able to oxidize xenon. On March 23, 1962, he mixed the two gases and produced the first known compound of a noble gas, xenon hexafluoroplatinate.^{[32][13]} Bartlett thought its composition to be $\text{Xe}^+[\text{PtF}_6]^-$, although later work has revealed that it was probably a mixture of various xenon-containing salts.^{[33][34][35]} Since then, many other xenon compounds have been discovered,^[36] along with some compounds of the noble gases argon, krypton, and radon, including argon fluorohydride (HArF),^[37] krypton difluoride (KrF_2),^{[38][39]} and radon fluoride.^[40] By 1971, more than 80 xenon compounds were known.^{[41][42]}

In November 1999 a team of IBM scientists demonstrated a technology capable of manipulating individual atoms. The program, called **IBM in atoms**, used a scanning tunneling microscope to arrange 35 individual xenon atoms on a substrate of chilled crystal of nickel to spell out the three letter company acronym. It was the first time atoms had been precisely positioned on a flat surface.^[43]

2.5.2 Characteristics

Xenon has atomic number 54; that is, its nucleus contains 54 protons. At standard temperature and pressure,



*Xenon flash
(animated version)*

pure xenon gas has a density of 5.761 kg/m^3 , about 4.5 times the surface density of the Earth's atmosphere, 1.217 kg/m^3 .^[44] As a liquid, xenon has a density of up to 3.100 g/mL , with the density maximum occurring at the triple point.^[45] Under the same conditions, the density of solid xenon, 3.640 g/cm^3 , is higher than the average density of granite, 2.75 g/cm^3 .^[45] Using gigapascals of pressure, xenon has been forced into a metallic phase.^[46]

Solid xenon changes from face-centered cubic (fcc) to hexagonal close packed (hcp) crystal phase under pressure and begins to turn metallic at about 140 GPa, with no noticeable volume change in the hcp phase. It is completely metallic at 155 GPa. When metalized, xenon looks sky blue because it absorbs red light and transmits other visible frequencies. Such behavior is unusual for a metal and is explained by the relatively small widths of the electron bands in metallic xenon.^{[47][48]}

Xenon is a member of the zero-valence elements that are called noble or inert gases. It is inert to most common chemical reactions (such as combustion, for example) because the outer valence shell contains eight electrons. This produces a stable, minimum energy configuration in which the outer electrons are tightly bound.^[49]

In a gas-filled tube, xenon emits a blue or lavenderish glow when the gas is excited by electrical discharge. Xenon emits a band of emission lines that span the visual spectrum,^[50] but the most intense lines occur in the region of blue light, which produces the coloration.^[51]

2.5.3 Occurrence and production

Xenon is a trace gas in Earth's atmosphere, occurring at 87 ± 1 parts per billion (nL/L), or approximately 1 part per 11.5 million,^[52] and is also found in gases emitted from some mineral springs.

Xenon is obtained commercially as a byproduct of the separation of air into oxygen and nitrogen. After this separation, generally performed by fractional distillation in a double-column plant, the liquid oxygen produced will contain small quantities of krypton and xenon. By additional fractional distillation steps, the liquid oxygen may be enriched to contain 0.1–0.2% of a krypton/xenon mixture, which is extracted either via absorption onto silica gel or by distillation. Finally, the krypton/xenon mixture may be separated into krypton and xenon via distillation.^{[53][54]} Worldwide production of xenon in 1998 was estimated at 5,000–7,000 m³.^[55] Because of its low abundance, xenon is much more expensive than the lighter noble gases—approximate prices for the purchase of small quantities in Europe in 1999 were 10 €/L for xenon, 1 €/L for krypton, and 0.20 €/L for neon;^[55] the much more plentiful argon costs less than a cent per liter.

Within the Solar System, the nucleon fraction of xenon is 1.56×10^{-8} , for an abundance of approximately one part in 630 thousand of the total mass.^[56] Xenon is relatively rare in the Sun's atmosphere, on Earth, and in asteroids and comets. The planet Jupiter has an unusually high abundance of xenon in its atmosphere; about 2.6 times as much as the Sun.^{[57][58]} This high abundance remains unexplained and may have been caused by an early and rapid buildup of planetesimals—small, subplanetary bodies—before the presolar disk began to heat up.^[59] (Otherwise, xenon would not have been trapped in the planetesimal ices.) The problem of the low terrestrial xenon may potentially be explained by covalent bonding of xenon to oxygen within quartz, hence reducing the outgassing of xenon into the atmosphere.^[60]

Unlike the lower mass noble gases, the normal stellar nucleosynthesis process inside a star does not form xenon. Elements more massive than iron-56 have a net energy cost to produce through fusion, so there is no energy gain for a star when creating xenon.^[61] Instead, xenon is formed during supernova explosions,^[62] by the slow neutron capture process (s-process) of red giant stars that have exhausted the hydrogen at their cores and entered the asymptotic giant branch,^[63] in classical nova explosions^[64] and from the radioactive decay of elements such as iodine, uranium and plutonium.^[65]

2.5.4 Isotopes and isotopic studies

Main article: Isotopes of xenon

Naturally occurring xenon is made of eight stable

isotopes, the most of any element with the exception of tin, which has ten. Xenon and tin are the only elements to have more than seven stable isotopes.^[66] The isotopes ¹²⁴Xe and ¹³⁴Xe are predicted to undergo double beta decay, but this has never been observed so they are considered to be stable.^[67] Besides these stable forms, there are over 40 unstable isotopes that have been studied. The longest lived of these isotopes is ¹³⁶Xe, which has been observed to undergo double beta decay with a half-life of 2.11×10^{21} yr.^[68] ¹²⁹Xe is produced by beta decay of ¹²⁹I, which has a half-life of 16 million years, while ^{131m}Xe, ¹³³Xe, ^{133m}Xe, and ¹³⁵Xe are some of the fission products of both ²³⁵U and ²³⁹Pu,^[65] and therefore used as indicators of nuclear explosions.

Nuclei of two of the stable isotopes of xenon, ¹²⁹Xe and ¹³¹Xe, have non-zero intrinsic angular momenta (nuclear spins, suitable for nuclear magnetic resonance). The nuclear spins can be aligned beyond ordinary polarization levels by means of circularly polarized light and rubidium vapor.^[69] The resulting spin polarization of xenon nuclei can surpass 50% of its maximum possible value, greatly exceeding the thermal equilibrium value dictated by paramagnetic statistics (typically 0.001% of the maximum value at room temperature, even in the strongest magnets). Such non-equilibrium alignment of spins is a temporary condition, and is called *hyperpolarization*. The process of hyperpolarizing the xenon is called *optical pumping* (although the process is different from pumping a laser).^[70]

Because a ¹²⁹Xe nucleus has a spin of 1/2, and therefore a zero electric quadrupole moment, the ¹²⁹Xe nucleus does not experience any quadrupolar interactions during collisions with other atoms, and thus its hyperpolarization can be maintained for long periods of time even after the laser beam has been turned off and the alkali vapor removed by condensation on a room-temperature surface. Spin polarization of ¹²⁹Xe can persist from several seconds for xenon atoms dissolved in blood^[71] to several hours in the gas phase^[72] and several days in deeply frozen solid xenon.^[73] In contrast, ¹³¹Xe has a nuclear spin value of $3/2$ and a nonzero quadrupole moment, and has t_1 relaxation times in the millisecond and second ranges.^[74]

Some radioactive isotopes of xenon, for example, ¹³³Xe and ¹³⁵Xe, are produced by neutron irradiation of fissionable material within nuclear reactors.^[11] ¹³⁵Xe is of considerable significance in the operation of nuclear fission reactors. ¹³⁵Xe has a huge cross section for thermal neutrons, 2.6×10^6 barns,^[15] so it acts as a neutron absorber or "poison" that can slow or stop the chain reaction after a period of operation. This was discovered in the earliest nuclear reactors built by the American Manhattan Project for plutonium production. Fortunately the designers had made provisions in the design to increase the reactor's reactivity (the number of neutrons per fission that go on to fission other atoms of nuclear fuel).^[75] ¹³⁵Xe reactor poisoning played a major role in the Chernobyl disaster.^[76] A shutdown or decrease of power of a reactor can result

in buildup of ^{135}Xe and getting the reactor into the iodine pit.

Under adverse conditions, relatively high concentrations of radioactive xenon isotopes may be found emanating from nuclear reactors due to the release of fission products from cracked fuel rods,^[77] or fissioning of uranium in cooling water.^[78]

Because xenon is a tracer for two parent isotopes, xenon isotope ratios in meteorites are a powerful tool for studying the formation of the solar system. The iodine-xenon method of dating gives the time elapsed between nucleosynthesis and the condensation of a solid object from the solar nebula. In 1960, physicist John H. Reynolds discovered that certain meteorites contained an isotopic anomaly in the form of an overabundance of xenon-129. He inferred that this was a decay product of radioactive iodine-129. This isotope is produced slowly by cosmic ray spallation and nuclear fission, but is produced in quantity only in supernova explosions. As the half-life of ^{129}I is comparatively short on a cosmological time scale, only 16 million years, this demonstrated that only a short time had passed between the supernova and the time the meteorites had solidified and trapped the ^{129}I . These two events (supernova and solidification of gas cloud) were inferred to have happened during the early history of the Solar System, as the ^{129}I isotope was likely generated before the Solar System was formed, but not long before, and seeded the solar gas cloud with isotopes from a second source. This supernova source may also have caused collapse of the solar gas cloud.^{[79][80]}

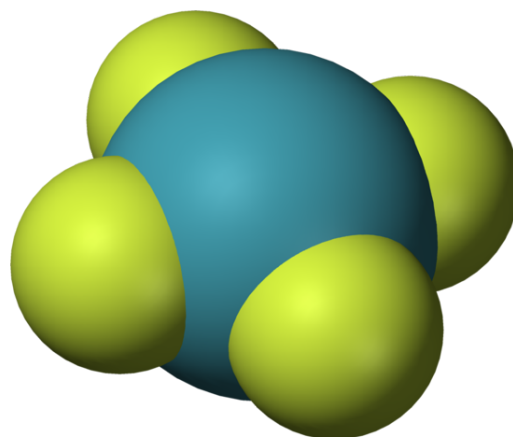
In a similar way, xenon isotopic ratios such as $^{129}\text{Xe}/^{130}\text{Xe}$ and $^{136}\text{Xe}/^{130}\text{Xe}$ are also a powerful tool for understanding planetary differentiation and early outgassing.^[14] For example, The atmosphere of Mars shows a xenon abundance similar to that of Earth: 0.08 parts per million,^[81] however Mars shows a higher proportion of ^{129}Xe than the Earth or the Sun. As this isotope is generated by radioactive decay, the result may indicate that Mars lost most of its primordial atmosphere, possibly within the first 100 million years after the planet was formed.^{[82][83]} In another example, excess ^{129}Xe found in carbon dioxide well gases from New Mexico was believed to be from the decay of mantle-derived gases soon after Earth's formation.^{[65][84]}

2.5.5 Compounds

See also: Category:Xenon compounds.

After Neil Bartlett's discovery in 1962 that xenon can form chemical compounds, a large number of xenon compounds have been discovered and described. Almost all known xenon compounds contain the electronegative atoms fluorine or oxygen.^[85]

Halides



Xenon tetrafluoride



XeF₄ crystals, 1962

Three fluorides are known: XeF

2, XeF

4, and XeF

6. XeF is theorized to be unstable.^[86] The fluorides are the starting point for the synthesis of almost all xenon compounds.

The solid, crystalline difluoride XeF

2 is formed when a mixture of fluorine and xenon gases is exposed to ultraviolet light.^[87] Ordinary daylight is sufficient.^[88] Long-term heating of XeF 2 at high temperatures under an NiF

2 catalyst yields XeF
 6.^[89] Pyrolysis of XeF
 6 in the presence of NaF yields high-purity XeF
 4.^[90]

The xenon fluorides behave as both fluoride acceptors and fluoride donors, forming salts that contain such cations as XeF⁺ and Xe²⁺ and anions such as XeF⁻, XeF⁻, and XeF₂⁻.
 8. The green, paramagnetic Xe⁺ 2 is formed by the reduction of XeF₂ by xenon gas.^[85]

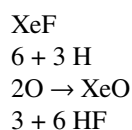
XeF
 2 is also able to form coordination complexes with transition metal ions. Over 30 such complexes have been synthesized and characterized.^[89]

Whereas the xenon fluorides are well-characterized, the other halides are not known, the only exception being the dichloride, XeCl₂. Xenon dichloride is reported to be an endothermic, colorless, crystalline compound that decomposes into the elements at 80 °C, formed by the high-frequency irradiation of a mixture of xenon, fluorine, and silicon or carbon tetrachloride.^[91] However, doubt has been raised as to whether XeCl₂ is a real compound and not merely a van der Waals molecule consisting of weakly bound Xe atoms and Cl₂ molecules.^[92] Theoretical calculations indicate that the linear molecule XeCl₂ is less stable than the van der Waals complex.^[93]

Oxides and oxohalides

Three oxides of xenon are known: xenon trioxide (XeO₃) and xenon tetroxide (XeO₄), both of which are dangerously explosive and powerful oxidizing agents, and xenon dioxide (XeO₂), which was reported in 2011 with a coordination number of four.^[94] XeO₂ forms when xenon tetrafluoride is poured over ice. Its crystal structure may allow it to replace silicon in silicate minerals.^[95] The XeOO⁺ cation has been identified by infrared spectroscopy in solid argon.^[96]

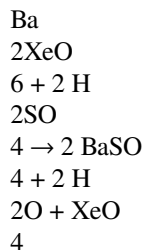
Xenon does not react with oxygen directly; the trioxide is formed by the hydrolysis of XeF₆.^[97]



XeO₃ is weakly acidic, dissolving in alkali to form unstable *xenate* salts containing the HXeO₃⁻

4 anion. These unstable salts easily disproportionate into xenon gas and *perxenate* salts, containing the XeO₄⁻ 6 anion.^[98]

Barium perxenate, when treated with concentrated sulfuric acid, yields gaseous xenon tetroxide:^[91]



To prevent decomposition, the xenon tetroxide thus formed is quickly cooled to form a pale-yellow solid. It explodes above -35.9 °C into xenon and oxygen gas.

A number of xenon oxyfluorides are known, including XeOF₂, XeOF₄, XeO₂F₂, and XeO₃F₂.
 2. XeOF₂ is formed by the reaction of OF₂ with xenon gas at low temperatures. It may also be obtained by the partial hydrolysis of XeF₆. It disproportionates at -20 °C into XeF₄ and XeO₂.
 2.^[99] XeOF₄ is formed by the partial hydrolysis of XeF₆,^[100] or the reaction of XeF₆ with sodium perxenate, Na₂XeO₆. The latter reaction also produces a small amount of XeO₃.
 2. XeOF₃ reacts with CsF to form the XeOF₃⁻ 5 anion,^{[99][101]} while XeOF₃ reacts with the alkali metal fluorides KF, RbF and CsF to form the XeOF₃⁻ 4 anion.^[102]

Other compounds

Recently, there has been an interest in xenon compounds where xenon is directly bonded to a less electronegative element than fluorine or oxygen, particularly carbon.^[103] Electron-withdrawing groups, such as groups with fluorine substitution, are necessary to stabilize these compounds.^[98] Numerous such compounds have been characterized, including:^{[99][104]}

- C

6F
 5–Xe+
 –N≡C–CH
 3, where C₆F₅ is the pentafluorophenyl group.

- [C
 6F
 5]
 2Xe
- C
 6F
 5–Xe–X, where X is CN, F, or Cl.
- R–C≡C–Xe+
 , where R is C
 2F–
 5 or *tert*-butyl.
- C
 6F
 5–XeF+
 2
- (C
 6F
 5Xe)
 2Cl+

Other compounds containing xenon bonded to a less electronegative element include F–Xe–N(SO

2F)
 2 and F–Xe–BF
 2. The latter is synthesized from dioxygenyl tetrafluoroborate, O
 2BF
 4, at –100 °C.^{[99][105]}

An unusual ion containing xenon is the tetraxenonogold(II) cation, AuXe₂⁺
 4, which contains Xe–Au bonds.^[106] This ion occurs in the compound AuXe

4(Sb
 2F
 11)
 2, and is remarkable in having direct chemical bonds between two notoriously unreactive atoms, xenon and gold, with xenon acting as a transition metal ligand.

The compound Xe
 2Sb
 2F
 11 contains a Xe–Xe bond, the longest element-element bond known (308.71 pm = 3.0871 Å).^[107]

In 1995, M. Räsänen and co-workers, scientists at the University of Helsinki in Finland, announced the preparation of xenon dihydride (HXeH), and later xenon hydride-hydroxide (HXeOH), hydroxenoacetylene (HXeCCH), and other Xe-containing molecules.^[108] In 2008, Khriachtchev *et al.* reported the preparation of HXeOXeH

by the photolysis of water within a cryogenic xenon matrix.^[109] Deuterated molecules, HXeOD and DXeOH, have also been produced.^[110]

Clathrates and excimers

In addition to compounds where xenon forms a chemical bond, xenon can form clathrates—substances where xenon atoms are trapped by the crystalline lattice of another compound. An example is xenon hydrate (Xe•5.75 H₂O), where xenon atoms occupy vacancies in a lattice of water molecules.^[111] This clathrate has a melting point of 24 °C.^[112] The deuterated version of this hydrate has also been produced.^[113] Such clathrate hydrates can occur naturally under conditions of high pressure, such as in Lake Vostok underneath the Antarctic ice sheet.^[114] Clathrate formation can be used to fractionally distill xenon, argon and krypton.^[115]

Xenon can also form endohedral fullerene compounds, where a xenon atom is trapped inside a fullerene molecule. The xenon atom trapped in the fullerene can be monitored via ¹²⁹Xe nuclear magnetic resonance (NMR) spectroscopy. Using this technique, chemical reactions on the fullerene molecule can be analyzed, due to the sensitivity of the chemical shift of the xenon atom to its environment. However, the xenon atom also has an electronic influence on the reactivity of the fullerene.^[116]

While xenon atoms are at their ground energy state, they repel each other and will not form a bond. When xenon atoms become energized, however, they can form an excimer (excited dimer) until the electrons return to the ground state. This entity is formed because the xenon atom tends to fill its outermost electronic shell, and can briefly do this by adding an electron from a neighboring xenon atom. The typical lifetime of a xenon excimer is 1–5 ns, and the decay releases photons with wavelengths of about 150 and 173 nm.^{[117][118]} Xenon can also form excimers with other elements, such as the halogens bromine, chlorine and fluorine.^[119]

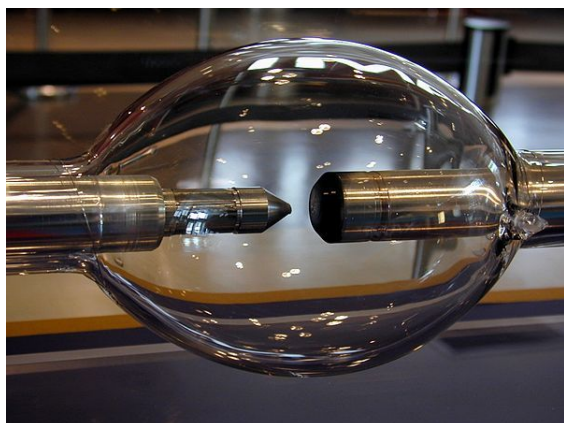
2.5.6 Applications

Although xenon is rare and relatively expensive to extract from the Earth's atmosphere, it has a number of applications.

Illumination and optics

Gas-discharge lamps Xenon is used in light-emitting devices called xenon flash lamps, which are used in photographic flashes and stroboscopic lamps;^[16] to excite the active medium in lasers which then generate coherent light;^[120] and, occasionally, in bactericidal lamps.^[121] The first solid-state laser, invented in 1960, was pumped by a xenon flash lamp,^[20] and lasers used to power

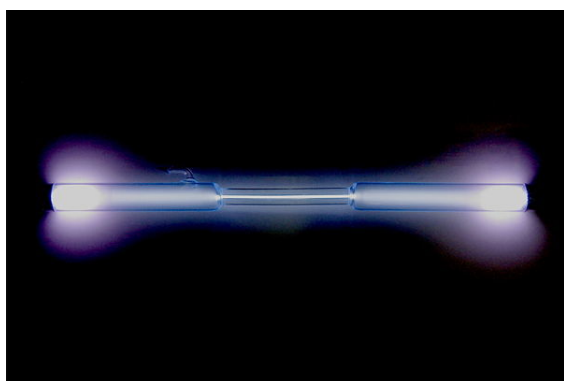
inertial confinement fusion are also pumped by xenon flash lamps.^[122]



Xenon short-arc lamp



Space Shuttle Atlantis bathed in xenon lights



Xenon gas discharge tube

Continuous, short-arc, high pressure xenon arc lamps have a color temperature closely approximating noon sunlight and are used in solar simulators. That is, the chromaticity of these lamps closely approximates a heated black body radiator that has a temperature close to that observed from the Sun. After they were first introduced during the 1940s, these lamps began replacing the shorter-lived carbon arc lamps in movie projectors.^[17] They are employed in typical 35mm, IMAX and the

new digital projectors film projection systems, automotive HID headlights, high-end “tactical” flashlights and other specialized uses. These arc lamps are an excellent source of short wavelength ultraviolet radiation and they have intense emissions in the near infrared, which is used in some night vision systems.

The individual cells in a plasma display use a mixture of xenon and neon that is converted into a plasma using electrodes. The interaction of this plasma with the electrodes generates ultraviolet photons, which then excite the phosphor coating on the front of the display.^{[123][124]}

Xenon is used as a “starter gas” in high pressure sodium lamps. It has the lowest thermal conductivity and lowest ionization potential of all the non-radioactive noble gases. As a noble gas, it does not interfere with the chemical reactions occurring in the operating lamp. The low thermal conductivity minimizes thermal losses in the lamp while in the operating state, and the low ionization potential causes the breakdown voltage of the gas to be relatively low in the cold state, which allows the lamp to be more easily started.^[125]

Lasers In 1962, a group of researchers at Bell Laboratories discovered laser action in xenon,^[126] and later found that the laser gain was improved by adding helium to the lasing medium.^{[127][128]} The first excimer laser used a xenon dimer (Xe_2) energized by a beam of electrons to produce stimulated emission at an ultraviolet wavelength of 176 nm.^[19] Xenon chloride and xenon fluoride have also been used in excimer (or, more accurately, exciplex) lasers.^[129] The xenon chloride excimer laser has been employed, for example, in certain dermatological uses.^[130]

Medical

Anesthesia Xenon has been used as a general anesthetic. Although it is expensive, anesthesia machines that can deliver xenon are about to appear on the European market, because advances in recovery and recycling of xenon have made it economically viable.^{[131][132]}

Xenon interacts with many different receptors and ion channels and like many theoretically multi-modal inhalation anesthetics these interactions are likely complementary. Xenon is a high-affinity glycine-site NMDA receptor antagonist.^[133] However, xenon distinguishes itself from other clinically used NMDA receptor antagonists in its lack of neurotoxicity and its ability to inhibit the neurotoxicity of ketamine and nitrous oxide.^{[134][135]} Unlike ketamine and nitrous oxide, xenon does not stimulate a dopamine efflux from the nucleus accumbens.^[136] Like nitrous oxide and cyclopropane, xenon activates the two-pore domain potassium channel TREK-1. A related channel TASK-3 also implicated in inhalational anesthetic actions is insensitive to xenon.^[137] Xenon inhibits nicotinic acetylcholine $\alpha_4\beta_2$ receptors which contribute to spinally mediated analgesia.^{[138][139]} Xenon is an effec-

tive inhibitor of plasma membrane Ca^{2+} ATPase. Xenon inhibits Ca^{2+} ATPase by binding to a hydrophobic pore within the enzyme and preventing the enzyme from assuming active conformations.^[140]

Xenon is a competitive inhibitor of the serotonin 5-HT₃ receptor. While neither anesthetic nor antinociceptive this activity reduces anesthesia-emergent nausea and vomiting.^[141]

Xenon has a minimum alveolar concentration (MAC) of 72% at age 40, making it 44% more potent than N_2O as an anesthetic.^[142] Thus it can be used in concentrations with oxygen that have a lower risk of hypoxia. Unlike nitrous oxide (N_2O), xenon is not a greenhouse gas and so it is also viewed as environmentally friendly.^[143] Xenon vented into the atmosphere is being returned to its original source, so no environmental impact is likely.

Neuroprotectant Xenon induces robust cardioprotection and neuroprotection through a variety of mechanisms of action. Through its influence on Ca^{2+} , K^+ , KATP/HIF and NMDA antagonism xenon is neuroprotective when administered before, during and after ischemic insults.^{[144][145]} Xenon is a high affinity antagonist at the NMDA receptor glycine site.^[133] Xenon is cardioprotective in ischemia-reperfusion conditions by inducing pharmacologic non-ischemic preconditioning. Xenon is cardioprotective by activating PKC-epsilon & downstream p38-MAPK.^[146] Xenon mimics neuronal ischemic preconditioning by activating ATP sensitive potassium channels.^[147] Xenon allosterically reduces ATP mediated channel activation inhibition independently of the sulfonylurea receptor1 subunit, increasing KATP open-channel time and frequency.^[148] Xenon upregulates hypoxia inducible factor 1 alpha (HIF1a).

Xenon gas was added as an ingredient of the ventilation mix for a newborn baby at St. Michael's Hospital, Bristol, England, whose life chances were otherwise very compromised, and was successful, leading to the authorisation of clinical trials for similar cases.^[149] The treatment is done simultaneously with cooling the body temperature to 33.5 °C.^[150]

Doping Inhaling a xenon/oxygen mixture activates production of the transcription factor HIF-1-alpha, which leads to increased production of erythropoietin. The latter hormone is known to increase red blood cell production and athletes' performance. Xenon inhalation has been used for this purpose in Russia since at least 2004.^[151] On August 31 2014 the World Anti Doping Agency (WADA) added Xenon (and Argon) to the list of prohibited substances and methods, although at this time there is no reliable test for abuse.^[152]

Imaging Gamma emission from the radioisotope ¹³³Xe of xenon can be used to image the heart, lungs,

and brain, for example, by means of single photon emission computed tomography. ¹³³Xe has also been used to measure blood flow.^{[153][154][155]}

Xenon, particularly hyperpolarized ¹²⁹Xe, is a useful contrast agent for magnetic resonance imaging (MRI). In the gas phase, it can be used to image empty space such as cavities in a porous sample or alveoli in lungs. Hyperpolarization renders ¹²⁹Xe much more detectable via magnetic resonance imaging and has been used for studies of the lungs and other tissues. It can be used, for example, to trace the flow of gases within the lungs.^{[156][157]} Because xenon is soluble in water and also in hydrophobic solvents, it can be used to image various soft living tissues.^{[158][159][160]}

Xenon with its high nuclear mass is a useful contrast medium for x-ray photography. For this purpose it is supplemented by Krypton and used at concentrations below 35% as otherwise it would act as a narcotic.

NMR spectroscopy

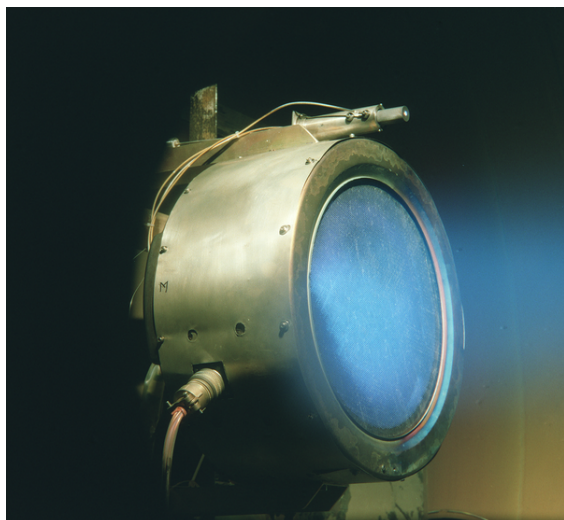
Because of the xenon atom's large, flexible outer electron shell, the NMR spectrum changes in response to surrounding conditions, and can therefore be used as a probe to measure the chemical circumstances around it. For instance xenon dissolved in water, in hydrophobic solvent, and xenon associated with certain proteins can be distinguished by NMR.^{[161][162]}

Hyperpolarized xenon can be used by surface chemists. Normally, it is difficult to characterize surfaces using NMR, because signals from the surface of a sample will be overwhelmed by signals from the far-more-numerous atomic nuclei in the bulk. However, nuclear spins on solid surfaces can be selectively polarized, by transferring spin polarization to them from hyperpolarized xenon gas. This makes the surface signals strong enough to measure, and distinguishes them from bulk signals.^{[163][164]}

Other

In nuclear energy applications, xenon is used in bubble chambers,^[165] probes, and in other areas where a high molecular weight and inert nature is desirable. A by-product of nuclear weapon testing is the release of radioactive xenon-133 and xenon-135. The detection of these isotopes is used to monitor compliance with nuclear test ban treaties,^[166] as well as to confirm nuclear test explosions by states such as North Korea.^[167]

Liquid xenon is being used in calorimeters^[168] for measurements of gamma rays as well as a medium for detecting hypothetical weakly interacting massive particles, or WIMPs. When a WIMP collides with a xenon nucleus, it is predicted to impart enough energy to cause ionization and scintillation. Liquid xenon is useful for this type of experiment due to its high density which makes dark



A prototype of a xenon ion engine being tested at NASA's Jet Propulsion Laboratory.

matter interaction more likely and permits a quiet detector due to self-shielding.

Xenon is the preferred propellant for ion propulsion of spacecraft because of its low ionization potential per atomic weight, and its ability to be stored as a liquid at near room temperature (under high pressure) yet be easily converted back into a gas to feed the engine. The inert nature of xenon makes it environmentally friendly and less corrosive to an ion engine than other fuels such as mercury or caesium. Xenon was first used for satellite ion engines during the 1970s.^[169] It was later employed as a propellant for JPL's Deep Space 1 probe, Europe's SMART-1 spacecraft^[22] and for the three ion propulsion engines on NASA's Dawn Spacecraft.^[170]

Chemically, the perxenate compounds are used as oxidizing agents in analytical chemistry. Xenon difluoride is used as an etchant for silicon, particularly in the production of microelectromechanical systems (MEMS).^[171] The anticancer drug 5-fluorouracil can be produced by reacting xenon difluoride with uracil.^[172] Xenon is also used in protein crystallography. Applied at pressures from 0.5 to 5 MPa (5 to 50 atm) to a protein crystal, xenon atoms bind in predominantly hydrophobic cavities, often creating a high-quality, isomorphous, heavy-atom derivative, which can be used for solving the phase problem.^{[173][174]}

2.5.7 Precautions

Many oxygen-containing xenon compounds are toxic due to their strong oxidative properties, and explosive due to their tendency to break down into elemental xenon plus diatomic oxygen (O₂), which contains much stronger chemical bonds than the xenon compounds.^[175]

Xenon gas can be safely kept in normal sealed glass or

metal containers at standard temperature and pressure. However, it readily dissolves in most plastics and rubber, and will gradually escape from a container sealed with such materials.^[176] Xenon is non-toxic, although it does dissolve in blood and belongs to a select group of substances that penetrate the blood–brain barrier, causing mild to full surgical anesthesia when inhaled in high concentrations with oxygen.^[175]

At 169 m/s, the speed of sound in xenon gas is slower than that in air^[177] due to the slower average speed of the heavy xenon atoms compared to nitrogen and oxygen molecules. Hence, xenon lowers the rate of vibration in the vocal tract when exhaled. This produces a characteristic lowered voice timbre, an effect opposite to the high-timbred voice caused by inhalation of helium. Like helium, xenon does not satisfy the body's need for oxygen. Xenon is both a simple asphyxiant and an anesthetic more powerful than nitrous oxide; consequently, many universities no longer allow the voice stunt as a general chemistry demonstration. As xenon is expensive, the gas sulfur hexafluoride, which is similar to xenon in molecular weight (146 versus 131), is generally used in this stunt, and is an asphyxiant without being anesthetic.^[178]

It is possible to safely breathe dense gases such as xenon or sulfur hexafluoride when they are in a mixture of at least 20% oxygen. Xenon at 80% concentration along with 20% oxygen rapidly produces the unconsciousness of general anesthesia (and has been used for this, as discussed above). Breathing mixes gases of different densities very effectively and rapidly so that heavier gases are purged along with the oxygen, and do not accumulate at the bottom of the lungs.^[179] There is, however, a danger associated with any heavy gas in large quantities: it may sit invisibly in a container, and if a person enters a container filled with an odorless, colorless gas, they may find themselves breathing it unknowingly. Xenon is rarely used in large enough quantities for this to be a concern, though the potential for danger exists any time a tank or container of xenon is kept in an unventilated space.^[180]

2.5.8 See also

- Buoyant levitation
- Penning mixture

2.5.9 References

- [1] Simpson, J. A.; Weiner, E. S. C., eds. (1989). "Xenon". *Oxford English Dictionary* **20** (2nd ed.). Clarendon Press. ISBN 0-19-861232-X.
- [2] "Xenon". *Dictionary.com Unabridged*. 2010. Retrieved 2010-05-06.
- [3] Standard Atomic Weights 2013. Commission on Isotopic Abundances and Atomic Weights

- [4] “Xenon”. *Gas Encyclopedia*. Air Liquide. 2009.
- [5] Haynes, William M., ed. (2011). *CRC Handbook of Chemistry and Physics* (92nd ed.). Boca Raton, FL: CRC Press. p. 4.123. ISBN 1439855110.
- [6] Shuen-Chen Hwang, Robert D. Lein, Daniel A. Morgan (2005). “Noble Gases”. *Kirk Othmer Encyclopedia of Chemical Technology*. Wiley. pp. 343–383. doi:10.1002/0471238961.0701190508230114.a01.
- [7] Magnetic susceptibility of the elements and inorganic compounds, in Lide, D. R., ed. (2005). *CRC Handbook of Chemistry and Physics* (86th ed.). Boca Raton (FL): CRC Press. ISBN 0-8493-0486-5.
- [8] Albert, J. B.; Auger, M.; Auty, D. J.; Barbeau, P. S.; Beauchamp, E.; Beck, D.; Belov, V.; Benitez-Medina, C.; Bonatt, J.; Breidenbach, M.; Brunner, T.; Burenkov, A.; Cao, G. F.; Chambers, C.; Chaves, J.; Cleveland, B.; Cook, S.; Craycraft, A.; Daniels, T.; Danilov, M.; Daugherty, S. J.; Davis, C. G.; Davis, J.; Devoe, R.; Delaquais, S.; Dobi, A.; Dolgolenko, A.; Dolinski, M. J.; Dunford, M. et al. (2014). “Improved measurement of the $2\nu\beta\beta$ half-life of ^{136}Xe with the EXO-200 detector”. *Physical Review C* **89**. doi:10.1103/PhysRevC.89.015502.
- [9] Redshaw, M.; Wingfield, E.; McDaniel, J.; Myers, E. (2007). “Mass and Double-Beta-Decay Q Value of ^{136}Xe ”. *Physical Review Letters* **98** (5): 53003. Bibcode:2007PhRvL..98e3003R. doi:10.1103/PhysRevLett.98.053003.
- [10] Staff (2007). “Xenon”. *Columbia Electronic Encyclopedia* (6th ed.). Columbia University Press. Retrieved 2007-10-23.
- [11] Husted, Robert; Boorman, Mollie (December 15, 2003). “Xenon”. Los Alamos National Laboratory, Chemical Division. Retrieved 2007-09-26.
- [12] Rabinovich, Viktor Abramovich; Vasserman, A. A.; Nedostup, V. I.; Veksler, L. S. (1988). *Thermophysical properties of neon, argon, krypton, and xenon* (English-language ed.). Washington, DC: Hemisphere Publishing Corp. Bibcode:1988wdch...10.....R. ISBN 0-89116-675-0. Retrieved 2009-04-02.—National Standard Reference Data Service of the USSR. Volume 10.
- [13] Freemantel, Michael (August 25, 2003). “Chemistry at its Most Beautiful” (PDF). Chemical & Engineering News. Retrieved 2007-09-13.
- [14] Kaneoka, Ichiro (1998). “Xenon’s Inside Story”. *Science* **280** (5365): 851–852. doi:10.1126/science.280.5365.851b.
- [15] Stacey, Weston M. (2007). *Nuclear Reactor Physics*. Wiley-VCH. p. 213. ISBN 3-527-40679-4.
- [16] Burke, James (2003). *Twin Tracks: The Unexpected Origins of the Modern World*. Oxford University Press. p. 33. ISBN 0-7432-2619-4.
- [17] Mellor, David (2000). *Sound Person’s Guide to Video*. Focal Press. p. 186. ISBN 0-240-51595-1.
- [18] Sanders, Robert D.; Ma, Daqing; Maze, Mervyn (2005). “Xenon: elemental anaesthesia in clinical practice”. *British Medical Bulletin* **71** (1): 115–35. doi:10.1093/bmb/ldh034. PMID 15728132.
- [19] Basov, N. G.; Danilychev, V. A.; Popov, Yu. M. (1971). “Stimulated Emission in the Vacuum Ultraviolet Region”. *Soviet Journal of Quantum Electronics* **1** (1): 18–22. Bibcode:1971QuEle...1...18B. doi:10.1070/QE1971v001n01ABEH003011.
- [20] Toyserkani, E.; Khajepour, A.; Corbin, S. (2004). *Laser Cladding*. CRC Press. p. 48. ISBN 0-8493-2172-7.
- [21] Ball, Philip (May 1, 2002). “Xenon outs WIMPs”. *Nature*. Retrieved 2007-10-08.
- [22] Saccoccia, G.; del Amo, J. G.; Estublier, D. (August 31, 2006). “Ion engine gets SMART-1 to the Moon”. ESA. Retrieved 2007-10-01.
- [23] Ramsay, W.; Travers, M. W. (1898). “On the extraction from air of the companions of argon, and neon”. *Report of the Meeting of the British Association for the Advancement of Science*: 828.
- [24] Gagnon, Steve. “It’s Elemental – Xenon”. Thomas Jefferson National Accelerator Facility. Retrieved 2007-06-16.
- [25] Anonymous (1904). Daniel Coit Gilman; Harry Thurston Peck; Frank Moore Colby, eds. *The New International Encyclopedia*. Dodd, Mead and Company. p. 906.
- [26] Staff (1991). *The Merriam-Webster New Book of Word Histories*. Merriam-Webster, Inc. p. 513. ISBN 0-87779-603-3.
- [27] Ramsay, William (1902). “An Attempt to Estimate the Relative Amounts of Krypton and of Xenon in Atmospheric Air”. *Proceedings of the Royal Society of London* **71** (467–476): 421–426. doi:10.1098/rspl.1902.0121.
- [28] Anonymous. “History”. Millisecond Cinematography. Archived from the original on 2006-08-22. Retrieved 2007-11-07.
- [29] Paschotta, Rüdiger (November 1, 2007). “Lamp-pumped lasers”. *Encyclopedia of Laser Physics and Technology*. RP Photonics. Retrieved 2007-11-07.
- [30] Marx, Thomas; Schmidt, Michael; Schirmer, Uwe; Reinelt, Helmut (2000). “Xenon anesthesia” (PDF). *Journal of the Royal Society of Medicine* **93** (10): 513–7. PMC 1298124. PMID 11064688. Retrieved 2007-10-02.
- [31] Bartlett, Neil; Lohmann, D. H. (1962). “Dioxygenyl hexafluoroplatinate (V), $\text{O}_2^+[\text{PtF}_6]^-$ ”. *Proceedings of the Chemical Society* (London: Chemical Society) (3): 115. doi:10.1039/PS9620000097.
- [32] Bartlett, N. (1962). “Xenon hexafluoroplatinate (V) $\text{Xe}^+[\text{PtF}_6]^-$ ”. *Proceedings of the Chemical Society* (London: Chemical Society) (6): 218. doi:10.1039/PS9620000197.
- [33] Graham, L.; Graudejus, O.; Jha N.K.; Bartlett, N. (2000). “Concerning the nature of XePtF_6 ”. *Coordination Chemistry Reviews* **197** (1): 321–334. doi:10.1016/S0010-8545(99)00190-3.

- [34] Holleman, A. F.; Wiberg, Egon (2001). Bernhard J. Aylett, ed. *Inorganic Chemistry*. translated by Mary Eagleson and William Brewer. San Diego: Academic Press. ISBN 0-12-352651-5.; translation of *Lehrbuch der Anorganischen Chemie*, originally founded by A. F. Holleman, continued by Egon Wiberg, edited by Nils Wiberg, Berlin: de Gruyter, 1995, 34th edition, ISBN 3-11-012641-9.
- [35] Steel, Joanna (2007). "Biography of Neil Bartlett". College of Chemistry, University of California, Berkeley. Retrieved 2007-10-25.
- [36] Bartlett, Neil (2003-09-09). "The Noble Gases". *Chemical & Engineering News* (American Chemical Society) **81** (36). Retrieved 2007-10-01.
- [37] Khriachtchev, Leonid; Pettersson, Mika; Runeberg, Nino; Lundell, Jan; Räsänen, Markku (2000-08-24). "A stable argon compound". *Nature* **406** (6798): 874–6. doi:10.1038/35022551. PMID 10972285. Retrieved 2008-06-04.
- [38] Lynch, C. T.; Summitt, R.; Sliker, A. (1980). *CRC Handbook of Materials Science*. CRC Press. ISBN 0-87819-231-X.
- [39] MacKenzie, D. R. (1963). "Krypton Difluoride: Preparation and Handling". *Science* **141** (3586): 1171. Bibcode:1963Sci...141.1171M. doi:10.1126/science.141.3586.1171. PMID 17751791.
- [40] Paul R. Fields; Lawrence Stein & Moshe H. Zirin (1962). "Radon Fluoride". *Journal of the American Chemical Society* **84** (21): 4164–4165. doi:10.1021/ja00880a048.
- [41] "Xenon". *Periodic Table Online*. CRC Press. Archived from the original on April 10, 2007. Retrieved 2007-10-08.
- [42] Moody, G. J. (1974). "A Decade of Xenon Chemistry". *Journal of Chemical Education* **51** (10): 628–630. Bibcode:1974JChEd..51..628M. doi:10.1021/ed051p628. Retrieved 2007-10-16.
- [43] 2 Researchers Spell 'I.B.M.,' Atom by Atom - New York Times
- [44] Williams, David R. (April 19, 2007). "Earth Fact Sheet". NASA. Retrieved 2007-10-04.
- [45] Aprile, Elena; Bolotnikov, Aleksey E.; Doke, Tadayoshi (2006). *Noble Gas Detectors*. Wiley-VCH. pp. 8–9. ISBN 3-527-60963-6.
- [46] Caldwell, W. A.; Nguyen, J.; Pfrommer, B.; Louie, S.; Jeanloz, R. (1997). "Structure, bonding and geochemistry of xenon at high pressures". *Science* **277** (5328): 930–933. doi:10.1126/science.277.5328.930.
- [47] Fontes, E. "Golden Anniversary for Founder of High-pressure Program at CHESS". Cornell University. Retrieved 2009-05-30.
- [48] Eremets, Mikhail I.; Gregoryanz, Eugene A.; Struzhkin, Victor V.; Mao, Ho-Kwang; Hemley, Russell J.; Mulders, Norbert; Zimmerman, Neil M. (2000). "Electrical Conductivity of Xenon at Megabar Pressures". *Physical Review Letters* **85** (13): 2797–800. Bibcode:2000PhRvL..85.2797E. doi:10.1103/PhysRevLett.85.2797. PMID 10991236.
- [49] Bader, Richard F. W. "An Introduction to the Electronic Structure of Atoms and Molecules". McMaster University. Retrieved 2007-09-27.
- [50] Talbot, John. "Spectra of Gas Discharges". Rheinisch-Westfälische Technische Hochschule Aachen. Retrieved 2006-08-10.
- [51] Watts, William Marshall (1904). *An Introduction to the Study of Spectrum Analysis*. London: Longmans, Green, and Co.
- [52] Hwang, Shuen-Cheng; Robert D. Lein; Daniel A. Morgan (2005). "Noble Gases". *Kirk-Othmer Encyclopedia of Chemical Technology* (5th ed.). Wiley. doi:10.1002/0471238961.0701190508230114.a01. ISBN 0-471-48511-X.
- [53] Kerry, Frank G. (2007). *Industrial Gas Handbook: Gas Separation and Purification*. CRC Press. pp. 101–103. ISBN 0-8493-9005-2.
- [54] "Xenon – Xe". CFC StarTec LLC. August 10, 1998. Retrieved 2007-09-07.
- [55] Häussinger, Peter; Glatthaar, Reinhard; Rhode, Wilhelm; Kick, Helmut; Benkmann, Christian; Weber, Josef; Wunschel, Hans-Jörg; Stenke, Viktor; Leicht, Edith; Stenger, Hermann (2001). "Noble Gases". *Ullmann's Encyclopedia of Industrial Chemistry* (6th ed.). Wiley. doi:10.1002/14356007.a17_485. ISBN 3-527-20165-3.
- [56] Arnett, David (1996). *Supernovae and Nucleosynthesis*. Princeton, New Jersey: Princeton University Press. ISBN 0-691-01147-8.
- [57] Mahaffy, P. R.; Niemann, H. B.; Alpert, A.; Atreya, S. K.; Demick, J.; Donahue, T. M.; Harpold, D. N.; Owen, T. C. (2000). "Noble gas abundance and isotope ratios in the atmosphere of Jupiter from the Galileo Probe Mass Spectrometer". *Journal of Geophysical Research* **105** (E6): 15061–15072. Bibcode:2000JGR...10515061M. doi:10.1029/1999JE001224.
- [58] Mass fraction calculated from the average mass of an atom in the solar system of about 1.29 atomic mass units
- [59] Owen, Tobias; Mahaffy, Paul; Niemann, H. B.; Atreya, Sushil; Donahue, Thomas; Bar-Nun, Akiva; de Pater, Imke (1999). "A low-temperature origin for the planetesimals that formed Jupiter". *Nature* **402** (6759): 269–70. Bibcode:1999Natur.402..269O. doi:10.1038/46232. PMID 10580497.
- [60] Sanloup, Chrystèle et al. (2005). "Retention of Xenon in Quartz and Earth's Missing Xenon". *Science* **310** (5751): 1174–7. Bibcode:2005Sci...310.1174S. doi:10.1126/science.1119070. PMID 16293758.
- [61] Clayton, Donald D. (1983). *Principles of Stellar Evolution and Nucleosynthesis*. University of Chicago Press. ISBN 0-226-10953-4.

- [62] Heymann, D.; Dziczkaniec, M. (March 19–23, 1979). *Xenon from intermediate zones of supernovae. Proceedings 10th Lunar and Planetary Science Conference* (Houston, Texas: Pergamon Press, Inc.): 1943–1959. Bibcode:1979LPSC...10.1943H.
- [63] Beer, H.; Kaeppler, F.; Reffo, G.; Venturini, G. (November 1983). “Neutron capture cross-sections of stable xenon isotopes and their application in stellar nucleosynthesis”. *Astrophysics and Space Science* **97** (1): 95–119. Bibcode:1983Ap&SS..97...95B. doi:10.1007/BF00684613.
- [64] Pignatari, M.; Gallino, R.; Straniero, O.; Davis, A. (2004). “The origin of xenon trapped in presolar mainstream SiC grains”. *Memorie della Societa Astronomica Italiana* **75**: 729–734. Bibcode:2004MmSAI..75..729P.
- [65] Caldwell, Eric (January 2004). “Periodic Table – Xenon”. *Resources on Isotopes*. USGS. Retrieved 2007-10-08.
- [66] Rajam, J. B. (1960). *Atomic Physics* (7th ed.). Delhi: S. Chand and Co. ISBN 81-219-1809-X.
- [67] Barabash, A. S. (2002). “Average (Recommended) Half-Life Values for Two-Neutrino Double-Beta Decay”. *Czechoslovak Journal of Physics* **52** (4): 567–573. arXiv:nucl-ex/0203001. Bibcode:2002CzJPh..52..567B. doi:10.1023/A:1015369612904.
- [68] Ackerman, N. (2011). “Observation of Two-Neutrino Double-Beta Decay in ^{136}Xe with the EXO-200 Detector”. *Physical Review Letters* **107** (21). doi:10.1103/PhysRevLett.107.212501.
- [69] Otten, Ernst W. (2004). “Take a breath of polarized noble gas”. *Europhysics News* **35** (1): 16. Bibcode:2004ENews..35...16O. doi:10.1051/epn:2004109.
- [70] Ruset, I. C.; Ketel, S.; Hersman, F. W. (2006). “Optical Pumping System Design for Large Production of Hyperpolarized ^{129}Xe ”. *Physical Review Letters* **96** (5): 053002. Bibcode:2006PhRvL..96e3002R. doi:10.1103/PhysRevLett.96.053002.
- [71] Wolber, J.; Cherubini, A.; Leach, M. O.; Bifone, A. (2000). “On the oxygenation-dependent ^{129}Xe t_1 in blood”. *NMR in Biomedicine* **13** (4): 234–7. doi:10.1002/1099-1492(200006)13:4<234::AID-NBM632>3.0.CO;2-K. PMID 10867702.
- [72] Chann, B.; Nelson, I. A.; Anderson, L. W.; Driehuys, B.; Walker, T. G. (2002). “ ^{129}Xe -Xe molecular spin relaxation”. *Physical Review Letters* **88** (11): 113–201. Bibcode:2002PhRvL..88k3201C. doi:10.1103/PhysRevLett.88.113201.
- [73] von Schulthess, Gustav Konrad; Smith, Hans-Jørgen; Pettersson, Holger; Allison, David John (1998). *The Encyclopaedia of Medical Imaging*. Taylor & Francis. p. 194. ISBN 1-901865-13-4.
- [74] Warren, W. W.; Norberg, R. E. (1966). “Nuclear Quadrupole Relaxation and Chemical Shift of Xe^{131} in Liquid and Solid Xenon”. *Physical Review* **148** (1): 402–412. Bibcode:1966PhRv..148..402W. doi:10.1103/PhysRev.148.402.
- [75] Staff. “Hanford Becomes Operational”. *The Manhattan Project: An Interactive History*. U.S. Department of Energy. Archived from the original on 2009-12-10. Retrieved 2007-10-10.
- [76] Pfeffer, Jeremy I.; Nir, Shlomo (2000). *Modern Physics: An Introductory Text*. Imperial College Press. pp. 421 ff. ISBN 1-86094-250-4.
- [77] Laws, Edwards A. (2000). *Aquatic Pollution: An Introductory Text*. John Wiley and Sons. p. 505. ISBN 0-471-34875-9.
- [78] Staff (April 9, 1979). “A Nuclear Nightmare”. *Time*. Retrieved 2007-10-09.
- [79] Clayton, Donald D. (1983). *Principles of Stellar Evolution and Nucleosynthesis* (2nd ed.). University of Chicago Press. p. 75. ISBN 0-226-10953-4.
- [80] Bolt, B. A.; Packard, R. E.; Price, P. B. (2007). “John H. Reynolds, Physics: Berkeley”. The University of California, Berkeley. Retrieved 2007-10-01.
- [81] Williams, David R. (September 1, 2004). “Mars Fact Sheet”. NASA. Retrieved 2007-10-10.
- [82] Schilling, James. “Why is the Martian atmosphere so thin and mainly carbon dioxide?”. Mars Global Circulation Model Group. Retrieved 2007-10-10.
- [83] Zahnle, Kevin J. (1993). “Xenological constraints on the impact erosion of the early Martian atmosphere”. *Journal of Geophysical Research* **98** (E6): 10,899–10,913. Bibcode:1993JGR....9810899Z. doi:10.1029/92JE02941.
- [84] Boulos, M. S.; Manuel, O.K. (1971). “The xenon record of extinct radioactivities in the Earth”. *Science* **174** (4016): 1334–6. Bibcode:1971Sci...174.1334B. doi:10.1126/science.174.4016.1334. PMID 17801897.
- [85] Harding, Charlie; Johnson, David Arthur; Janes, Rob (2002). *Elements of the p block*. Great Britain: Royal Society of Chemistry. pp. 93–94. ISBN 0-85404-690-9.
- [86] Dean H Liskow; Henry F I I I Schaefer; Paul S Bagus; Bowen Liu (1973). “Probable nonexistence of xenon monofluoride as a chemically bound species in the gas phase”. *J Amer Chem Soc* **95** (12): 4056–4057. doi:10.1021/ja00793a042.
- [87] Weeks, James L.; Chernick, Cedric; Matheson, Max S. (1962). “Photochemical Preparation of Xenon Difluoride”. *Journal of the American Chemical Society* **84** (23): 4612. doi:10.1021/ja00882a063.
- [88] Streng, L. V.; Streng, A. G. (1965). “Formation of Xenon Difluoride from Xenon and Oxygen Difluoride or Fluorine in Pyrex Glass at Room Temperature”. *Inorganic Chemistry* **4** (9): 1370–1371. doi:10.1021/ic50031a035.
- [89] Tramšek, Melita; Žemva, Boris (December 5, 2006). “Synthesis, Properties and Chemistry of Xenon(II) Fluoride” (PDF). *Acta Chimica Slovenica* **53** (2): 105–116. doi:10.1002/chin.200721209. Retrieved 2009-07-18.

- [90] Ogrin, Tomaz; Bohinc, Matej; Silvnik, Joze (1973). "Melting-point determinations of xenon difluoride-xenon tetrafluoride mixtures". *Journal of Chemical and Engineering Data* **18** (4): 402. doi:10.1021/jc60059a014.
- [91] Scott, Thomas; Eagleson, Mary (1994). "Xenon Compounds". *Concise encyclopedia chemistry*. Walter de Gruyter. p. 1183. ISBN 3-11-011451-8.
- [92] Proserpio, Davide M.; Hoffmann, Roald; Janda, Kenneth C. (1991). "The xenon-chlorine conundrum: van der Waals complex or linear molecule?". *Journal of the American Chemical Society* **113** (19): 7184. doi:10.1021/ja00019a014.
- [93] Richardson, Nancy A.; Hall, Michael B. (1993). "The potential energy surface of xenon dichloride". *The Journal of Physical Chemistry* **97** (42): 10952. doi:10.1021/j100144a009.
- [94] Brock, D.S.; Schrobilgen, G.J. (2011). "Synthesis of the missing oxide of xenon, XeO₂, and its implications for earth's missing xenon". *Journal of the American Chemical Society* **133** (16): 6265–9. doi:10.1021/ja110618g. PMID 21341650.
- [95] "Chemistry: Where did the xenon go?". *Nature* **471** (7337): 138–138. 2011. doi:10.1038/471138d.
- [96] Zhou, M.; Zhao, Y.; Gong, Y.; Li, J. (2006). "Formation and Characterization of the XeOO⁺ Cation in Solid Argon". *Journal of the American Chemical Society* **128** (8): 2504–5. doi:10.1021/ja055650n. PMID 16492012.
- [97] Holloway, John H.; Hope, Eric G. (1998). A. G. Sykes, ed. *Advances in Inorganic Chemistry Press*. Academic. p. 65. ISBN 0-12-023646-X.
- [98] Henderson, W. (2000). *Main group chemistry*. Great Britain: Royal Society of Chemistry. pp. 152–153. ISBN 0-85404-617-8.
- [99] Mackay, Kenneth Malcolm; Mackay, Rosemary Ann; Henderson, W. (2002). *Introduction to modern inorganic chemistry* (6th ed.). CRC Press. pp. 497–501. ISBN 0-7487-6420-8.
- [100] Smith, D. F. (1963). "Xenon Oxyfluoride". *Science* **140** (3569): 899–900. Bibcode:1963Sci...140..899S. doi:10.1126/science.140.3569.899. PMID 17810680.
- [101] K. O. Christie; D. A. Dixon; J. C. P. Sanders; G. J. Schrobilgen; S. S. Tsai; W. W. Wilson (1995). "On the Structure of the [XeOF₅]⁻ Anion and of Heptacoordinated Complex Fluorides Containing One or Two Highly Repulsive Ligands or Sterically Active Free Valence Electron Pairs". *Inorg. Chem.* **34** (7): 1868–1874. doi:10.1021/ic00111a039.
- [102] K. O. Christie; C. J. Schack; D. Pilipovich (1972). "Chlorine trifluoride oxide. V. Complex formation with Lewis acids and bases". *Inorg. Chem.* **11** (9): 2205–2208. doi:10.1021/ic50115a044.
- [103] Holloway, John H.; Hope, Eric G. (1998). *Advances in Inorganic Chemistry*. Contributor A. G. Sykes. Academic Press. pp. 61–90. ISBN 0-12-023646-X.
- [104] Frohn, H; Theißen, Michael (2004). "C₆F₅XeF, a versatile starting material in xenon-carbon chemistry". *Journal of Fluorine Chemistry* **125** (6): 981. doi:10.1016/j.jfluchem.2004.01.019.
- [105] Goetschel, Charles T.; Loos, Karl R. (1972). "Reaction of xenon with dioxygenyl tetrafluoroborate. Preparation of FXe-BF₂". *Journal of the American Chemical Society* **94** (9): 3018. doi:10.1021/ja00764a022.
- [106] Li, Wai-Kee; Zhou, Gong-Du; Mak, Thomas C. W. (2008). Gong-Du Zhou; Thomas C. W. Mak, eds. *Advanced Structural Inorganic Chemistry*. Oxford University Press. p. 678. ISBN 0-19-921694-0.
- [107] Li, Wai-Kee; Zhou, Gong-Du; Mak, Thomas C. W. (2008). *Advanced Structural Inorganic Chemistry*. Oxford University Press. p. 674. ISBN 0-19-921694-0.
- [108] Gerber, R. B. (2004). "Formation of novel rare-gas molecules in low-temperature matrices". *Annual Review of Physical Chemistry* **55** (1): 55–78. Bibcode:2004ARPC...55...55G. doi:10.1146/annurev.physchem.55.091602.094420. PMID 15117247.
- [109] Khriachtchev, Leonid; Isokoski, Karoliina; Cohen, Arik; Räsänen, Markku; Gerber, R. Benny (2008). "A Small Neutral Molecule with Two Noble-Gas Atoms: HXeOXeH". *Journal of the American Chemical Society* **130** (19): 6114–8. doi:10.1021/ja077835v. PMID 18407641.
- [110] Pettersson, Mika; Khriachtchev, Leonid; Lundell, Jan; Räsänen, Markku (1999). "A Chemical Compound Formed from Water and Xenon: HXeOH". *Journal of the American Chemical Society* **121** (50): 11904–11905. doi:10.1021/ja9932784.
- [111] Pauling, L. (1961). "A molecular theory of general anesthesia". *Science* **134** (3471): 15–21. Bibcode:1961Sci...134...15P. doi:10.1126/science.134.3471.15. PMID 13733483. Reprinted as Pauling, Linus; Kamb, Barclay, eds. (2001). *Linus Pauling: Selected Scientific Papers 2*. River Edge, New Jersey: World Scientific. pp. 1328–1334. ISBN 981-02-2940-2.
- [112] Henderson, W. (2000). *Main group chemistry*. Great Britain: Royal Society of Chemistry. p. 148. ISBN 0-85404-617-8.
- [113] Ikeda, Tomoko; Mae, Shinji; Yamamuro, Osamu; Matsuo, Takasuke; Ikeda, Susumu; Ibberson, Richard M. (November 23, 2000). "Distortion of Host Lattice in Clathrate Hydrate as a Function of Guest Molecule and Temperature". *Journal of Physical Chemistry A* **104** (46): 10623–10630. doi:10.1021/jp001313j.
- [114] McKay, C. P.; Hand, K. P.; Doran, P. T.; Andersen, D. T.; Priscu, J. C. (2003). "Clathrate formation and the fate of noble and biologically useful gases in Lake Vostok, Antarctica". *Geophysical Letters* **30** (13): 35. Bibcode:2003GeoRL...30m..35M. doi:10.1029/2003GL017490.

- [115] Barrer, R. M.; Stuart, W. I. (1957). “Non-Stoichiometric Clathrate of Water”. *Proceedings of the Royal Society of London* **243** (1233): 172–189. Bibcode:1957RSPSA.243..172B. doi:10.1098/rspa.1957.0213.
- [116] Frunzi, Michael; Cross, R. James; Saunders, Martin (2007). “Effect of Xenon on Fullerene Reactions”. *Journal of the American Chemical Society* **129** (43): 13343–6. doi:10.1021/ja075568n. PMID 17924634.
- [117] Silfvast, William Thomas (2004). *Laser Fundamentals*. Cambridge University Press. ISBN 0-521-83345-0.
- [118] Webster, John G. (1998). *The Measurement, Instrumentation, and Sensors Handbook*. Springer. ISBN 3-540-64830-5.
- [119] McGhee, Charles; Taylor, Hugh R.; Gartry, David S.; Trokel, Stephen L. (1997). *Excimer Lasers in Ophthalmology*. Informa Health Care. ISBN 1-85317-253-7.
- [120] Staff (2007). “Xenon Applications”. Praxair Technology. Retrieved 2007-10-04.
- [121] Baltás, E.; Csoma, Z.; Bodai, L.; Ignác, F.; Dobozy, A.; Kemény, L. (2003). “A xenon-iodine electric discharge bactericidal lamp”. *Technical Physics Letters* **29** (10): 871–872. Bibcode:2003TePhL..29..871S. doi:10.1134/1.1623874.
- [122] Skeldon, M.D.; Saager, R.; Okishev, A.; Seka, W. (1997). “Thermal distortions in laser-diode- and flash-lamp-pumped Nd:YLF laser rods” (PDF). *LLE Review* **71**: 137–144. Archived from the original (PDF) on October 16, 2003. Retrieved 2007-02-04.
- [123] Anonymous. “The plasma behind the plasma TV screen”. Plasma TV Science. Retrieved 2007-10-14.
- [124] Marin, Rick (March 21, 2001). “Plasma TV: That New Object Of Desire”. The New York Times. Retrieved 2009-04-03.
- [125] Waymouth, John (1971). *Electric Discharge Lamps*. Cambridge, MA: The M.I.T. Press. ISBN 0-262-23048-8.
- [126] Patel, C. K. N.; Bennett Jr., W. R.; Faust, W. L.; McFarlane, R. A. (August 1, 1962). “Infrared spectroscopy using stimulated emission techniques”. *Physical Review Letters* **9** (3): 102–104. Bibcode:1962PhRvL...9..102P. doi:10.1103/PhysRevLett.9.102.
- [127] Patel, C. K. N.; Faust, W. L.; McFarlane, R. A. (December 1, 1962). “High gain gaseous (Xe-He) optical masers”. *Applied Physics Letters* **1** (4): 84–85. Bibcode:1962ApPhL...1...84P. doi:10.1063/1.1753707.
- [128] Bennett, Jr., W. R. (1962). “Gaseous optical masers”. *Applied Optics Supplement* **1**: 24–61. Bibcode:1962ApOpt...1S..24B. doi:10.1364/AO.1.000024.
- [129] “Laser Output”. University of Waterloo. Retrieved 2007-10-07.
- [130] Baltás, E.; Csoma, Z.; Bodai, L.; Ignác, F.; Dobozy, A.; Kemény, L. (2006). “Treatment of atopic dermatitis with the xenon chloride excimer laser”. *Journal of the European Academy of Dermatology and Venereology* **20** (6): 657–60. doi:10.1111/j.1468-3083.2006.01495.x. PMID 16836491.
- [131] Singh, Sanjay (May 15, 2005). “Xenon: A modern anaesthetic”. Indian Express Newspapers Limited. Archived from the original on 2007-08-13. Retrieved 2007-10-10.
- [132] Tonner, P. H. (2006). “Xenon: one small step for anaesthesia ... ? (editorial review)”. *Current Opinion in Anaesthesiology* **19** (4): 382–4. doi:10.1097/01.aco.0000236136.85356.13. PMID 16829718.
- [133] Banks, P; Franks, NP; Dickinson, R (2010). “Competitive inhibition at the glycine site of the N-methyl-D-aspartate receptor mediates xenon neuroprotection against hypoxia-ischemia”. *Anesthesiology* **112** (3): 614–22. doi:10.1097/ALN.0b013e3181cea398. PMID 20124979.
- [134] Ma, D; Wilhelm, S; Maze, M; Franks, NP (2002). “Neuroprotective and neurotoxic properties of the ‘inert’ gas, xenon”. *Br J Anaesth* **89** (5): 739–46. doi:10.1093/bja/89.5.739. PMID 12393773.
- [135] Nagata, A; Nakao Si, S; Nishizawa, N; Masuzawa, M; Inada, T; Murao, K; Miyamoto, E; Shingu, K (2001). “Xenon inhibits but N(2)O enhances ketamine-induced c-Fos expression in the rat posterior cingulate and retrosplenial cortices”. *Anesth Analg* **92** (2): 362–8. doi:10.1213/0000539-200102000-00016. PMID 11159233.
- [136] Sakamoto, S; Nakao, S; Masuzawa, M; Inada, T; Maze, M; Franks, NP; Shingu, K (2006). “The differential effects of nitrous oxide and xenon on extracellular dopamine levels in the rat nucleus accumbens: a microdialysis study”. *Anesth Analg* **103** (6): 1459–63. doi:10.1213/01.ane.0000247792.03959.f1. PMID 17122223.
- [137] Gruss, M; Bushell, TJ; Bright, DP; Lieb, WR; Mathie, A; Franks, NP (2004). “Two-pore-domain K⁺ channels are a novel target for the anesthetic gases xenon, nitrous oxide, and cyclopropane”. *Mol Pharmacol* **65** (2): 443–52. doi:10.1124/mol.65.2.443. PMID 14742687.
- [138] Yamakura, T; Harris, RA (2000). “Effects of gaseous anesthetics nitrous oxide and xenon on ligand-gated ion channels. Comparison with isoflurane and ethanol”. *Anesthesiology* **93** (4): 1095–101. doi:10.1097/0000542-200010000-00034. PMID 11020766.
- [139] Rashid, MH; Furue, H; Yoshimura, M; Ueda, H (2006). “Tonic inhibitory role of alpha4beta2 subtype of nicotinic acetylcholine receptors on nociceptive transmission in the spinal cord in mice”. *Pain* **125** (1–2): 125–35. doi:10.1016/j.pain.2006.05.011. PMID 16781069.
- [140] Lopez, Maria M.; Kosk-Kosicka, Danuta (1995). “How Do Volatile Anesthetics Inhibit Ca²⁺-ATPases?”. *The Journal of Biological Chemistry* **270** (47): 28239–28245. doi:10.1074/jbc.270.47.28239.

- [141] Suzuki, T; Koyama, H; Sugimoto, M; Uchida, I; Mashimo, T (2002). "The diverse actions of volatile and gaseous anesthetics on human-cloned 5-hydroxytryptamine₃ receptors expressed in *Xenopus* oocytes". *Anesthesiology* **96** (3): 699–704. doi:10.1097/00000542-200203000-00028. PMID 11873047.
- [142] Nickalls, R. W. D; Mapleson, W.W. "Age-related iso-MAC charts for isoflurane, sevoflurane and desflurane in man". *British Journal of Anesthesiology*.
- [143] Goto, T; Nakata Y; Morita S (2003). "Will xenon be a stranger or a friend?: the cost, benefit, and future of xenon anesthesia". *Anesthesiology* **98** (1): 1–2. doi:10.1097/00000542-200301000-00002. PMID 12502969. Retrieved 2010-09-15.
- [144] "Xenon Attenuates Cerebral Damage after Ischemia in Pigs" **102** (5). May 2005. pp. 929–936.
- [145] Dingley, J; Tooley, J; Porter, H; Thoresen, M (2006). "Xenon Provides Short-Term Neuroprotection in Neonatal Rats When Administered After Hypoxia-Ischemia". *Stroke*. 2006; 37: 501-506 **37** (2): 501–6. doi:10.1161/01.STR.0000198867.31134.ac. PMID 16373643.
- [146] Weber, NC; Toma, O; Wolter, JI; Obal, D; Müllenheim, J; Preckel, B; Schlack, W (2005). "The noble gas xenon induces pharmacological preconditioning in the rat heart in vivo via induction of PKC-epsilon and p38 MAPK". *Br J Pharmacol* **144** (1): 123–32. doi:10.1038/sj.bjp.0706063. PMC 1575984. PMID 15644876.
- [147] Bantel, C; Maze, M; Trapp, S (2009). "Neuronal preconditioning by inhalational anesthetics: evidence for the role of plasmalemmal adenosine triphosphate-sensitive potassium channels". *Anesthesiology* **110** (5): 986–95. doi:10.1097/ALN.0b013e31819dad7. PMC 2930813. PMID 19352153.
- [148] Bantel, C; Maze, M; Trapp, S (2010). "Noble gas xenon is a novel adenosine triphosphate-sensitive potassium channel opener". *Anesthesiology* **112** (3): 623–30. doi:10.1097/ALN.0b013e3181cf894a. PMC 2935677. PMID 20179498.
- [149] Staff (April 9, 2010). "First baby given xenon gas to prevent brain injury". *BBC News*. Retrieved 2010-04-09.
- [150] Newman, Sian. "Xenon gas used in a bid to reduce brain injury in newborns". Swansea University. Retrieved 2011-10-19.
- [151] "Breathe it in". *The Economist*. 8 February 2014.
- [152] "WADA amends Section S.2.1 of 2014 Prohibited List". 31 August 2014.
- [153] Van Der Wall, Ernst (1992). *What's New in Cardiac Imaging?: SPECT, PET, and MRI*. Springer. ISBN 0-7923-1615-0.
- [154] Frank, John (1999). "Introduction to imaging: The chest". *Student BMJ* **12**: 1–44. Retrieved 2008-06-04.
- [155] Chandak, Puneet K. (July 20, 1995). "Brain SPECT: Xenon-133". Brigham RAD. Retrieved 2008-06-04.
- [156] Albert, M. S.; Balamore, D. (1998). "Development of hyperpolarized noble gas MRI". *Nuclear Instruments and Methods in Physics Research A* **402** (2–3): 441–53. Bibcode:1998NIMPA.402..441A. doi:10.1016/S0168-9002(97)00888-7. PMID 11543065.
- [157] Irion, Robert (March 23, 1999). "Head Full of Xenon?". *Science News*. Archived from the original on January 17, 2004. Retrieved 2007-10-08.
- [158] Wolber, J.; Rowland, I. J.; Leach, M. O.; Bifone, A. (1998). "Intravascular delivery of hyperpolarized ¹²⁹Xenon for in vivo MRI". *Applied Magnetic Resonance* **15** (3–4): 343–352. doi:10.1007/BF03162020.
- [159] Driehuys, B.; Möller, H.E.; Cleveland, Z.I.; Pollaro, J.; Hedlund, L.W. (2009). "Pulmonary perfusion and xenon gas exchange in rats: MR imaging with intravenous injection of hyperpolarized ¹²⁹Xe". *Radiology* **252** (2): 386–93. doi:10.1148/radiol.2522081550. PMC 2753782. PMID 19703880. SSRN 2.
- [160] Cleveland, Z.I.; Möller, H.E.; Hedlund, L.W.; Driehuys, B. (2009). "Continuously infusing hyperpolarized ¹²⁹Xe into flowing aqueous solutions using hydrophobic gas exchange membranes". *The journal of physical chemistry* **113** (37): 12489–99. doi:10.1021/jp9049582. PMC 2747043. PMID 19702286.
- [161] Luhmer, M.; Dejaegere, A.; Reisse, J. (1989). "Interpretation of the solvent effect on the screening constant of Xe-129". *Magnetic Resonance in Chemistry* **27** (10): 950. doi:10.1002/mrc.1260271009.
- [162] Rubin, Seth M.; Spence, Megan M.; Goodson, Boyd M.; Wemmer, David E.; Pines, Alexander (August 15, 2000). "Evidence of nonspecific surface interactions between laser-polarized xenon and myoglobin in solution". *Proceedings of the National Academy of Science USA* **97** (17): 9472–5. Bibcode:2000PNAS...97.9472R. doi:10.1073/pnas.170278897. PMC 16888. PMID 10931956.
- [163] Raftery, Daniel; MacNamara, Ernesto; Fisher, Gregory; Rice, Charles V.; Smith, Jay (1997). "Optical Pumping and Magic Angle Spinning: Sensitivity and Resolution Enhancement for Surface NMR Obtained with Laser-Polarized Xenon". *Journal of the American Chemical Society* **119** (37): 8746. doi:10.1021/ja972035d.
- [164] Gaede, H. C.; Song, Y. -Q.; Taylor, R. E.; Munson, E. J.; Reimer, J. A.; Pines, A. (1995). "High-field cross polarization NMR from laser-polarized xenon to surface nuclei". *Applied Magnetic Resonance* **8** (3–4): 373. doi:10.1007/BF03162652.
- [165] Galison, Peter Louis (1997). *Image and Logic: A Material Culture of Microphysics*. University of Chicago Press. p. 339. ISBN 0-226-27917-0.
- [166] Fontaine, J.-P.; Pointurier, F.; Blanchard, X.; Taffary, T. (2004). "Atmospheric xenon radioactive isotope monitoring". *Journal of Environmental Radioactivity* **72** (1–2): 129–35. doi:10.1016/S0265-931X(03)00194-2. PMID 15162864.

- [167] Garwin, Richard L.; von Hippel Frank N. (November 2006). "A Technical Analysis: Deconstructing North Korea's October 9 Nuclear Test". *Arms Control Today* (Arms Control Association) **38** (9). Retrieved 2009-03-26.
- [168] Gallucci, G. (2009). "The MEG liquid xenon calorimeter". *Journal of Physics: Conference Series* **160** (1): 012011. Bibcode:2009JPhCS.160a2011G. doi:10.1088/1742-6596/160/1/012011.
- [169] Zona, Kathleen (March 17, 2006). "Innovative Engines: Glenn Ion Propulsion Research Tames the Challenges of 21st century Space Travel". NASA. Retrieved 2007-10-04.
- [170] "Dawn Launch: Mission to Vesta and Ceres" (PDF). NASA. Retrieved 2007-10-01.
- [171] Brazzle, J. D.; Dokmeci, M. R.; Mastrangelo, C. H. (July 28 – August 1, 1975). *Modeling and Characterization of Sacrificial Polysilicon Etching Using Vapor-Phase Xenon Difluoride. Proceedings 17th IEEE International Conference on Micro Electro Mechanical Systems (MEMS)* (Maastricht, Netherlands: IEEE): 737–740. ISBN 978-0-7803-8265-7.
- [172] Staff (2007). "Neil Bartlett and the Reactive Noble Gases". American Chemical Society. Retrieved June 5, 2012.
- [173] Staff (December 21, 2004). "Protein Crystallography: Xenon and Krypton Derivatives for Phasing". Daresbury Laboratory, P.X. Archived from the original on 2005-03-16. Retrieved 2007-10-01.
- [174] Drenth, Jan; Mesters, Jeroen (2007). "The Solution of the Phase Problem by the Isomorphous Replacement Method". *Principles of Protein X-Ray Crystallography* (3rd ed.). New York: Springer. pp. 123–171. doi:10.1007/0-387-33746-6_7. ISBN 978-0-387-33334-2.
- [175] Finkel, A. J.; Katz, J. J.; Miller, C. E. (April 1, 1968). "Metabolic and toxicological effects of water-soluble xenon compounds are studied". NASA. Retrieved 2007-10-04.
- [176] LeBlanc, Adrian D.; Johnson, Philip C. (1971). "The handling of xenon-133 in clinical studies". *Physics in Medicine and Biology* **16** (1): 105–9. Bibcode:1971PMB....16..105L. doi:10.1088/0031-9155/16/1/310. PMID 5579743.
- [177] 169.44 m/s in xenon (at 0°C and 107 KPa), compared to 344 m/s in air. See: Vacek, V.; Hallewell, G.; Lindsay, S. (2001). "Velocity of sound measurements in gaseous per-fluorocarbons and their mixtures". *Fluid Phase Equilibria* **185** (1–2): 305–314. doi:10.1016/S0378-3812(01)00479-4.
- [178] Spangler, Steve (2007). "Anti-Helium – Sulfur Hexafluoride". Steve Spangler Science. Retrieved 2007-10-04.
- [179] Yamaguchi, K.; Soejima, K.; Koda, E.; Sugiyama, N (2001). "Inhaling Gas With Different CT Densities Allows Detection of Abnormalities in the Lung Periphery of Patients With Smoking-Induced COPD". *Chest Journal* **51** (6): 1907–16. doi:10.1378/chest.120.6.1907. PMID 11742921.
- [180] Staff (August 1, 2007). "Cryogenic and Oxygen Deficiency Hazard Safety". Stanford Linear Accelerator Center. Archived from the original on June 9, 2007. Retrieved 2007-10-10.

2.5.10 External links

- Xenon at *The Periodic Table of Videos* (University of Nottingham)
- WebElements.com – Xenon
- USGS Periodic Table – Xenon
- EnvironmentalChemistry.com – Xenon
- Xenon as an anesthetic
- Sir William Ramsay's Nobel-Prize lecture (1904)

2.6 Radon

This article is about the chemical element. For other uses, see Radon (disambiguation).

Radon is a chemical element with symbol **Rn** and atomic number 86. It is a radioactive, colorless, odorless, tasteless^[2] noble gas, occurring naturally as an indirect decay product of uranium or thorium. Its most stable isotope, ²²²Rn, has a half-life of 3.8 days. Radon is one of the densest substances that remains a gas under normal conditions. It is also the only gas under normal conditions that only has radioactive isotopes, and is considered a health hazard due to its radioactivity. Intense radioactivity has also hindered chemical studies of radon and only a few compounds are known.

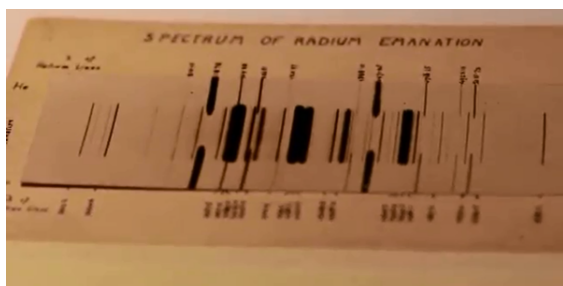
Radon is formed as one intermediate step in the normal radioactive decay chains through which thorium and uranium slowly decay into lead. Thorium and uranium are the two most common radioactive elements on earth; they have been around since the earth was formed. Their naturally occurring isotopes have very long half-lives, on the order of billions of years. Thorium and uranium, their decay product radium, and its decay product radon, will therefore continue to occur for tens of millions of years at almost the same concentrations as they do now.^[3] As radon itself decays, it produces new radioactive elements called radon daughters or decay products. Unlike the gaseous radon itself, radon daughters are solids and stick to surfaces, such as dust particles in the air. If such contaminated dust is inhaled, these particles can stick to the airways of the lung and increase the risk of developing lung cancer.^[4]

Unlike all the other intermediate elements in the aforementioned decay chains, radon is gaseous and easily

inhaled. Thus, even in this age of nuclear reactors, naturally-occurring radon is responsible for the majority of the public exposure to ionizing radiation. It is often the single largest contributor to an individual's background radiation dose, and is the most variable from location to location. Despite its short lifetime, some radon gas from natural sources can accumulate to far higher than normal concentrations in buildings, especially in low areas such as basements and crawl spaces due to its heavy nature. It can also be found in some spring waters and hot springs.^[5]

Epidemiological studies have shown a clear link between breathing high concentrations of radon and incidence of lung cancer. Thus, radon is considered a significant contaminant that affects indoor air quality worldwide. According to the United States Environmental Protection Agency, radon is the second most frequent cause of lung cancer, after cigarette smoking, causing 21,000 lung cancer deaths per year in the United States. About 2,900 of these deaths occur among people who have never smoked. While radon is the second most frequent cause of lung cancer, it is the number one cause among non-smokers, according to EPA estimates.^[6]

2.6.1 Characteristics



Emission spectrum of radon, photographed by Ernest Rutherford in 1908. Numbers at the side of the spectrum are wavenumbers. The middle spectrum is of radon, while the outer two are of helium (added to calibrate the wavenumbers).

Physical properties

Radon is a colorless, odorless, and tasteless gas and therefore not detectable by human senses alone. At standard temperature and pressure, radon forms a monatomic gas with a density of 9.73 kg/m^3 ,^[7] about 8 times the density of the Earth's atmosphere at sea level, 1.217 kg/m^3 .^[8] Radon is one of the densest gases at room temperature and is the densest of the noble gases. Although colorless at standard temperature and pressure, when cooled below its freezing point of 202 K ($-71 \text{ }^\circ\text{C}$; $-96 \text{ }^\circ\text{F}$), radon emits a brilliant radioluminescence that turns from yellow to orange-red as the temperature lowers.^[9] Upon condensation, radon glows because of the intense radiation it produces.^[10] Radon is sparingly soluble in water,

but more soluble than lighter noble gases. Radon is appreciably more soluble in organic liquids than in water.

Chemical properties

Being a noble gas, radon is chemically not very reactive. However, the 3.8-day half-life of radon-222 makes it useful in physical sciences as a natural tracer.

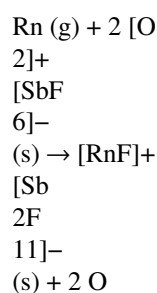
Radon is a member of the zero-valence elements that are called noble gases. It is inert to most common chemical reactions, such as combustion, because the outer valence shell contains eight electrons. This produces a stable, minimum energy configuration in which the outer electrons are tightly bound.^[11] 1037 kJ/mol is required to extract one electron from its shells (also known as the first ionization energy).^[12] However, in accordance with periodic trends, radon has a lower electronegativity than the element one period before it, xenon, and is therefore more reactive. Early studies concluded that the stability of radon hydrate should be of the same order as that of the hydrates of chlorine (Cl_2) or sulfur dioxide (SO_2), and significantly higher than the stability of the hydrate of hydrogen sulfide (H_2S).^[13]

Because of its cost and radioactivity, experimental chemical research is seldom performed with radon, and as a result there are very few reported compounds of radon, all either fluorides or oxides. Radon can be oxidized by a few powerful oxidizing agents such as fluorine, thus forming radon difluoride.^{[14][15]} It decomposes back to elements at a temperature of above $250 \text{ }^\circ\text{C}$. It has a low volatility and was thought to be RnF_2 .

2. But because of the short half-life of radon and the radioactivity of its compounds, it has not been possible to study the compound in any detail. Theoretical studies on this molecule predict that it should have a Rn-F bond distance of 2.08 \AA , and that the compound is thermodynamically more stable and less volatile than its lighter counterpart XeF_2 .

2.^[16] The octahedral molecule RnF_6

6 was predicted to have an even lower enthalpy of formation than the difluoride.^[17] The higher fluorides RnF_4 and RnF_6 have been claimed to exist,^[18] and are calculated to be stable,^[19] but it is doubtful whether they have actually been synthesized.^[18] The $[\text{RnF}]^+$ ion is believed to form by the following reaction:^[20]



2 (g)

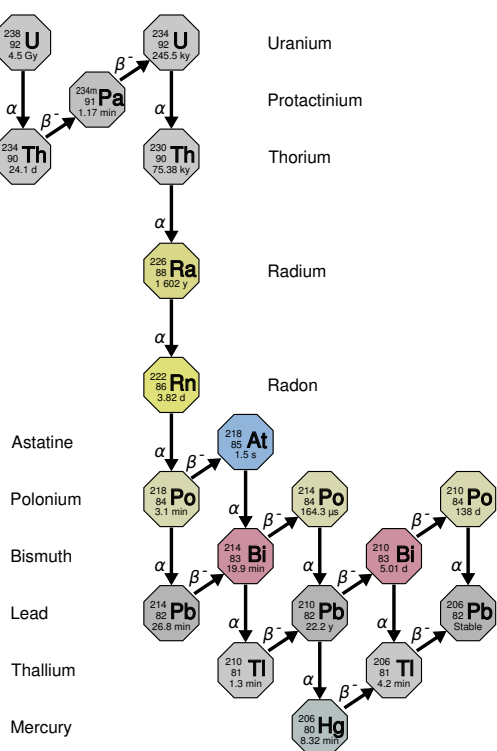
Radon oxides are among the few other reported compounds of radon;^[21] only the trioxide has been confirmed.^[18] Radon carbonyl RnCO has been predicted to be stable and to have a linear molecular geometry.^[22] The molecules Rn

2 and RnXe were found to be significantly stabilized by spin-orbit coupling.^[23] Radon caged inside a fullerene has been proposed as a drug for tumors.^[24] Despite the existence of Xe(VIII), no Rn(VIII) compounds have been claimed to exist; RnF₈ should be highly unstable chemically (XeF₈ is thermodynamically unstable). It is predicted that the most stable Rn(VIII) compound would be barium perradate (Ba₂RnO₆), analogous to barium perxenate.^[19] The instability of Rn(VIII) is due to the relativistic stabilization of the 6s shell, also known as the inert pair effect.^[19]

Isotopes

Main article: Isotopes of radon

Radon has no stable isotopes. However, 36 radioac-



The radium or uranium series.

tive isotopes have been characterized, with their atomic masses ranging from 193 to 228.^[25] The most stable isotope is ²²²Rn, which is a decay product of ²²⁶Ra, a decay product of ²³⁸U.^[26] A very trace amount of the (highly unstable) isotope ²¹⁸Rn is also among the daughters of ²²²Rn.

There are three other radon isotopes that have a half-life of over an hour: ²¹¹Rn, ²¹⁰Rn and ²²⁴Rn. The ²²⁰Rn isotope is a natural decay product of the most stable thorium isotope (²³²Th), and is commonly referred to as thoron. It has a half-life of 55.6 seconds and also emits alpha radiation. Similarly, ²¹⁹Rn is derived from the most stable isotope of actinium (²²⁷Ac)—named “actinon”—and is an alpha emitter with a half-life of 3.96 seconds.^[25] No radon isotopes occur significantly in the neptunium (²³⁷Np) decay series, though a trace amount of the (extremely unstable) isotope ²¹⁷Rn is produced.

Progenies Main article: Decay chain § Radium series (also known as uranium series)

²²²Rn belongs to the radium and uranium-238 decay chain, and has a half-life of 3.8235 days. Its four first products (excluding marginal decay schemes) are very short-lived, meaning that the corresponding disintegrations are indicative of the initial radon distribution. Its decay goes through the following sequence:^[25]

- ²²²Rn, 3.8 days, alpha decaying to...
- ²¹⁸Po, 3.10 minutes, alpha decaying to...
- ²¹⁴Pb, 26.8 minutes, beta decaying to...
- ²¹⁴Bi, 19.9 minutes, beta decaying to...
- ²¹⁴Po, 0.1643 ms, alpha decaying to...
- ²¹⁰Pb, which has a much longer half-life of 22.3 years, beta decaying to...
- ²¹⁰Bi, 5.013 days, beta decaying to...
- ²¹⁰Po, 138.376 days, alpha decaying to...
- ²⁰⁶Pb, stable.

The radon equilibrium factor^[27] is the ratio between the activity of all short-period radon progenies (which are responsible for most of radon’s biological effects), and the activity that would be at equilibrium with the radon parent.

If a closed volume is constantly supplied with radon, the concentration of short-lived isotopes will increase until an equilibrium is reached where the rate of decay of each decay product will equal that of the radon itself. The equilibrium factor is 1 when both activities are equal, meaning that the decay products have stayed close to the radon parent long enough for the equilibrium to be reached, within a couple of hours. Under these conditions each additional pCi/L of radon will increase exposure, by 0.01 WL (see explanation of WL below). These conditions are not always met; in many homes, the equilibrium fraction is typically 40%; that is, there will be 0.004 WL of progeny for each pCi/L of radon in air.^[28] ²¹⁰Pb takes much longer

(decades) to come in equilibrium with radon, but, if the environment permits accumulation of dust over extended periods of time, ^{210}Pb and its decay products may contribute to overall radiation levels as well.

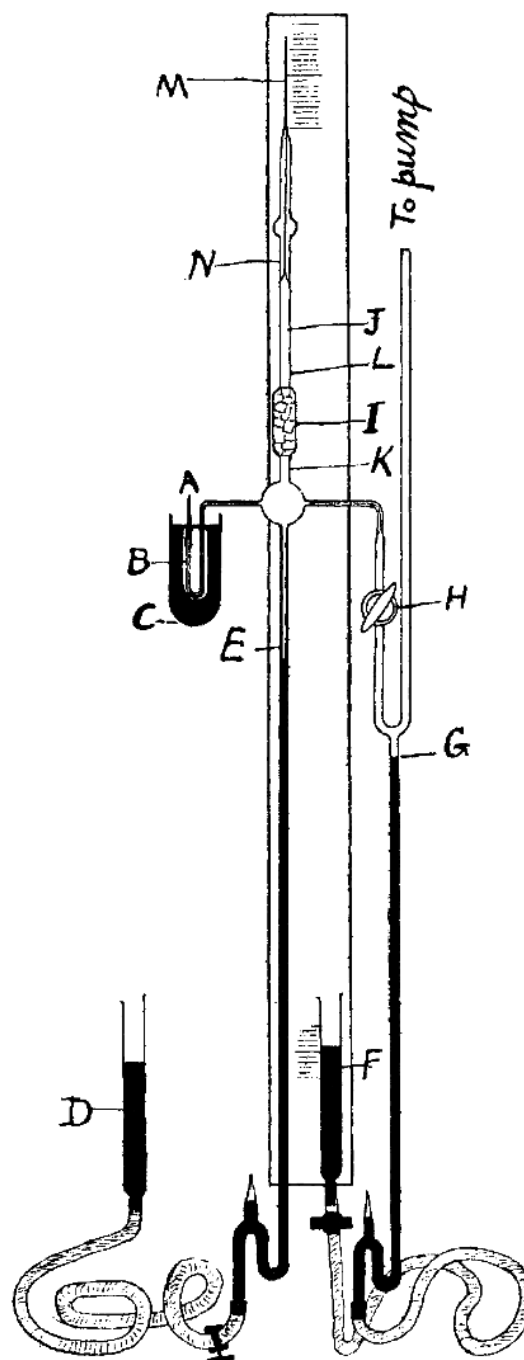
Because of their electrostatic charge, radon progenies adhere to surfaces or dust particles, whereas gaseous radon does not. Attachment removes them from the air, usually causing the equilibrium factor in the atmosphere to be less than one. The equilibrium factor is also lowered by air circulation or air filtration devices, and is increased by airborne dust particles, including cigarette smoke. In high concentrations, airborne radon isotopes contribute significantly to human health risk. The equilibrium factor found in epidemiological studies is 0.4.^[29]

2.6.2 History and etymology

Radon was the fifth radioactive element to be discovered, in 1900 by Friedrich Ernst Dorn,^[30] after uranium, thorium, radium and polonium.^{[31][32][33][34][35]} In 1900 Dorn reported some experiments in which he noticed that radium compounds emanate a radioactive gas he named *Radium Emanation (Ra Em)*.^[36] Before that, in 1899, Pierre and Marie Curie observed that the gas emitted by radium remained radioactive for a month.^[37] Later that year, Robert B. Owens and Ernest Rutherford, at McGill University in Montreal, noticed variations when trying to measure radiation from thorium oxide.^[38] Rutherford noticed that the compounds of thorium continuously emit a radioactive gas that retains the radioactive powers for several minutes, and called this gas *emanation* (from Latin “emanare”—to elapse and “emanatio”—expiration),^[39] and later *Thorium Emanation (Th Em)*. In 1901, he demonstrated that the emanations are radioactive, but credited the Curies for the discovery of the element.^[40] In 1903, similar emanations were observed from actinium by André-Louis Debierne^{[41][42]} and were called *Actinium Emanation (Ac Em)*.

Several names were suggested for these three gases: *exradio*, *exthorio*, and *exactinio* in 1904;^[43] *radon*, *thoron*, and *akton* in 1918;^[44] *radeon*, *thoreon*, and *actineon* in 1919,^[45] and eventually *radon*, *thoron*, and *actinon* in 1920.^[46] The likeness of the spectra of these three gases with those of argon, krypton, and xenon, and their observed chemical inertia led Sir William Ramsay to suggest in 1904 that the “emanations” might contain a new element of the noble gas family.^[43]

In 1910, Sir William Ramsay and Robert Whytlaw-Gray isolated radon, determined its density, and determined that it was the heaviest known gas.^[47] They wrote that “L’expression de l’emanation du radium est fort incommode”, (the expression ‘radium emanation’ is very awkward) and suggested the new name niton (Nt) (from the Latin “nitens” meaning “shining”) to emphasize the radioluminescence property,^[47] and in 1912 it was accepted by the International Commission for Atomic Weights.



Apparatus used by Ramsay and Whytlaw-Gray to isolate radon. *M* is a capillary tube where approximately 0.1 mm^3 were isolated. Rn mixed with H₂ entered the evacuated system through siphon A; mercury is shown in black.

In 1923, the International Committee for Chemical Elements and International Union of Pure and Applied Chemistry (IUPAC) chose among the names radon (Rn), thoron (Tn), and actinon (An). Later, when isotopes were numbered instead of named, the element took the name of the most stable isotope, *radon*, while Tn was renamed ^{220}Rn and An was renamed ^{219}Rn . As late as the 1960s,

the element was also referred to simply as *emanation*.^[48] The first synthesized compound of radon, radon fluoride, was obtained in 1962.^[49]

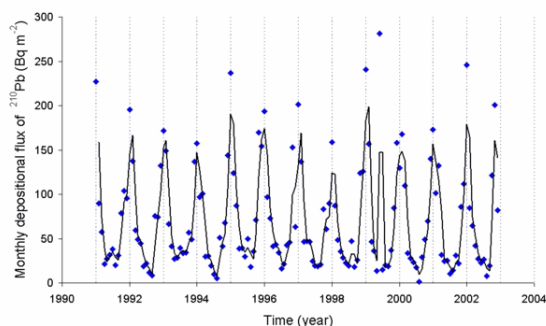
The danger of high exposure to radon in mines, where exposures reaching $1,000,000 \text{ Bq/m}^3$ can be found, has long been known. In 1530, Paracelsus described a wasting disease of miners, the *mala metallorum*, and Georg Agricola recommended ventilation in mines to avoid this mountain sickness (*Bergsucht*).^{[50][51]} In 1879, this condition was identified as lung cancer by Herting and Hesse in their investigation of miners from Schneeberg, Germany. The first major studies with radon and health occurred in the context of uranium mining in the Joachimsthal region of Bohemia.^[52] In the US, studies and mitigation only followed decades of health effects on uranium miners of the Southwestern United States employed during the early Cold War; standards were not implemented until 1971.^[53]

The presence of radon in indoor air was documented as early as 1950. Beginning in the 1970s research was initiated to address sources of indoor radon, determinants of concentration, health effects, and approaches to mitigation. In the United States, the problem of indoor radon received widespread publicity and intensified investigation after a widely publicized incident in 1984. During routine monitoring at a Pennsylvania nuclear power plant, a worker was found to be contaminated with radioactivity. A high contamination of radon in his home was subsequently identified as responsible for the contamination.^[54]

2.6.3 Occurrence

See also: Radium and radon in the environment

Concentration units



²¹⁰Pb is formed from the decay of ²²²Rn. Here is a typical deposition rate of ²¹⁰Pb as observed in Japan as a function of time, due to variations in radon concentration.^[55]

All discussions of radon concentrations in the environment refer to ²²²Rn. While the average rate of produc-

tion of ²²⁰Rn (from the thorium decay series) is about the same as ²²²Rn, the amount of ²²⁰Rn in the environment is much less than that of ²²²Rn because of the short half-life of ²²⁰Rn (55 seconds, versus 3.8 days respectively).^[3]

Radon concentration in the atmosphere is usually measured in becquerel per cubic meter (Bq/m^3), the SI derived unit. Another unit of measurement common in the USA is picocuries per liter (pCi/L); $1 \text{ pCi/L} = 37 \text{ Bq/m}^3$.^[28] Typical domestic exposures average about 48 Bq/m^3 indoors, though this varies widely, and 15 Bq/m^3 outdoors.^[56]

In the mining industry, the exposure is traditionally measured in *working level* (WL), and the cumulative exposure in *working level month* (WLM); 1 WL equals any combination of short-lived ²²²Rn progeny (²¹⁸Po, ²¹⁴Pb, ²¹⁴Bi, and ²¹⁴Po) in 1 liter of air that releases $1.3 \times 10^5 \text{ MeV}$ of potential alpha energy,^[28] one WL is equivalent to $2.08 \times 10^{-5} \text{ joules per cubic meter of air (J/m}^3)$.^[3] The SI unit of cumulative exposure is expressed in joule-hours per cubic meter ($\text{J}\cdot\text{h/m}^3$). One WLM is equivalent to $3.6 \times 10^{-3} \text{ J}\cdot\text{h/m}^3$. An exposure to 1 WL for 1 working month (170 hours) equals 1 WLM cumulative exposure. A cumulative exposure of 1 WLM is roughly equivalent to living one year in an atmosphere with a radon concentration of 230 Bq/m^3 .^[57]

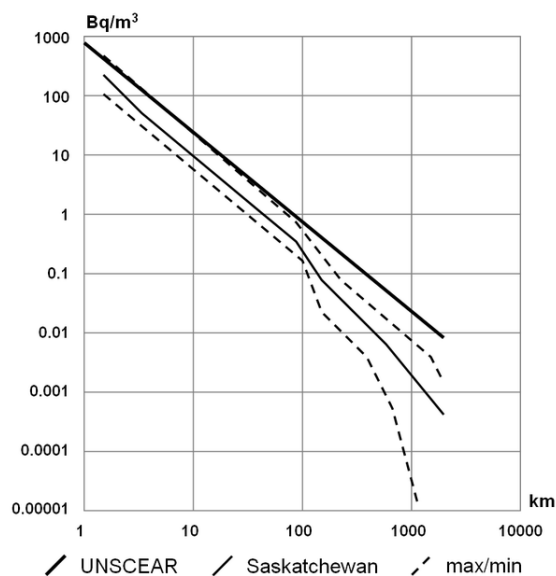
Radon (²²²Rn), decays to ²¹⁰Pb and other radioisotopes. The levels of ²¹⁰Pb can be measured. The rate of deposition of this radioisotope is weather-dependent.

Radon concentrations found in natural environments are much too low to be detected by chemical means. A 1000 Bq/m^3 (relatively high) concentration corresponds to $0.17 \text{ picogram per cubic meter}$. The average concentration of radon in the atmosphere is about 6×10^{-20} atoms of radon for each molecule in the air, or about 150 atoms in each ml of air.^[58] The radon activity of the entire Earth's atmosphere originates from only a few tens of grams of radon, consistently replaced by decay of larger amounts of radium and uranium.^[59]

Natural

Radon is produced by the radioactive decay of radium-226, which is found in uranium ores; phosphate rock; shales; igneous and metamorphic rocks such as granite, gneiss, and schist; and, to a lesser degree, in common rocks such as limestone.^[60] Every square mile of surface soil, to a depth of 6 inches (2.6 km^2 to a depth of 15 cm), contains approximately 1 gram of radium, which releases radon in small amounts to the atmosphere.^[3] On a global scale, it is estimated that 2,400 million curies (90 TBq) of radon are released from soil annually.^[61]

Radon concentration varies widely from place to place. In the open air, it ranges from 1 to 100 Bq/m^3 , even less (0.1 Bq/m^3) above the ocean. In caves or aerated mines, or ill-aerated houses, its concentration climbs to



Radon concentration next to a uranium mine.

20–2,000 Bq/m³.^[62] Radon concentration can be much higher in mining contexts. Ventilation regulations instruct to maintain radon concentration in uranium mines under the “working level”, with 95th percentile levels ranging up to nearly 3 WL (546 pCi ²²²Rn per liter of air; 20.2 kBq/m³, measured from 1976 to 1985).^[3] The concentration in the air at the (unventilated) Gastein Healing Gallery averages 43 kBq/m³ (1.2 nCi/L) with maximal value of 160 kBq/m³ (4.3 nCi/L).^[63]

Radon mostly appears with the decay chain of the radium and uranium series (²²²Rn), and marginally with the thorium series (²²⁰Rn). The element emanates naturally from the ground, and some building materials, all over the world, wherever traces of uranium or thorium can be found, and particularly in regions with soils containing granite or shale, which have a higher concentration of uranium. However, not all granitic regions are prone to high emissions of radon. Being a rare gas, it usually migrates freely through faults and fragmented soils, and may accumulate in caves or water. Owing to its very short half-life (four days for ²²²Rn), radon concentration decreases very quickly when the distance from the production area increases. Radon concentration varies greatly with season and atmospheric conditions. For instance, it has been shown to accumulate in the air if there is a meteorological inversion and little wind.^[64]

High concentrations of radon can be found in some spring waters and hot springs.^[65] The towns of Boulder, Montana; Misasa; Bad Kreuznach, Germany; and the country of Japan have radium-rich springs that emit radon. To be classified as a radon mineral water, radon concentration must be above a minimum of 2 nCi/L (74 kBq/m³).^[66] The activity of radon mineral water reaches 2,000 kBq/m³ in Merano and 4,000 kBq/m³ in Lurisia (Italy).^[63]

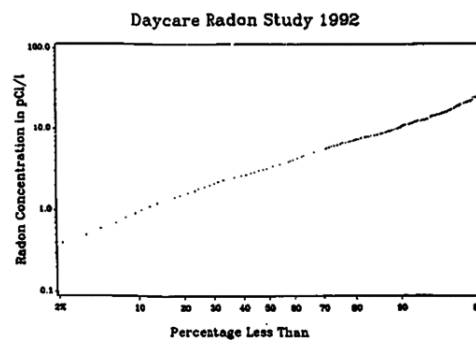
Natural radon concentrations in the Earth’s atmosphere are so low that radon-rich water in contact with the atmosphere will continually lose radon by volatilization. Hence, ground water has a higher concentration of ²²²Rn than surface water, because radon is continuously produced by radioactive decay of ²²⁶Ra present in rocks. Likewise, the saturated zone of a soil frequently has a higher radon content than the unsaturated zone because of diffusional losses to the atmosphere.^{[67][68]}

In 1971, Apollo 15 passed 110 km (68 mi) above the Aristarchus plateau on the Moon, and detected a significant rise in alpha particles thought to be caused by the decay of ²²²Rn. The presence of ²²²Rn has been inferred later from data obtained from the Lunar Prospector alpha particle spectrometer.^[69]

Radon is found in some petroleum. Because radon has a similar pressure and temperature curve to propane, and oil refineries separate petrochemicals based on their boiling points, the piping carrying freshly separated propane in oil refineries can become radioactive because of decaying radon and its products.^[70]

Residues from the petroleum and natural gas industry of ten contain radium and its daughters. The sulfate scale from an oil well can be radium rich, while the water, oil, and gas from a well often contains radon. Radon decays to form solid radioisotopes that form coatings on the inside of pipework.^[70]

Accumulation in houses



Typical log-normal radon distribution in dwellings.

High concentrations of radon in homes were discovered by chance in 1985 after the stringent radiation testing conducted at a nuclear power plant entrance revealed that Stanley Watras, an engineer entering the plant, was contaminated by radioactive substances.^[71] Typical domestic exposures are of approximately 100 Bq/m³ (1.3 pCi/L) indoors. Some level of radon will be found in all homes. Radon mostly enters a home directly from the soil through the lowest level in the home that is in contact with the ground. High levels of radon in the water supply can also increase indoor radon air levels. Typical entry points of radon into homes are cracks in solid foundations, con-

struction joints, cracks in walls, gaps in suspended floors, gaps around service pipes, cavities inside walls, and the water supply.^[2] Radon concentrations in the same location may differ by a factor of two over a period of 1 hour. Also, the concentration in one room of a building may be significantly different from the concentration in an adjoining room.^[3]

The distribution of radon concentrations will generally change from room to room, and the readings are averaged according to regulatory protocols. Indoor radon concentration is usually assumed to follow a **lognormal distribution** on a given territory.^[72] Thus, the **geometric mean** is generally used for estimating the “average” radon concentration in an area.^[73]

The mean concentration ranges from less than 10 Bq/m³ to over 100 Bq/m³ in some European countries.^[74] Typical **geometric standard deviations** found in studies range between 2 and 3, meaning (given the 68–95–99.7 rule) that the radon concentration is expected to be more than a hundred times the mean concentration for 2 to 3% of the cases.

The highest average radon concentrations in the United States are found in Iowa and in the **Appalachian Mountain** areas in southeastern Pennsylvania.^[75] Some of the highest readings ever have been recorded in the Irish town of **Mallow, County Cork**, prompting local fears regarding lung cancer. Iowa has the highest average radon concentrations in the United States due to significant **glaciation** that ground the granitic rocks from the **Canadian Shield** and deposited it as soils making up the rich Iowa farmland.^[76] Many cities within the state, such as **Iowa City**, have passed requirements for radon-resistant construction in new homes.

In a few locations, **uranium tailings** have been used for **landfills** and were subsequently built on, resulting in possible increased exposure to radon.^[3]

Since radon is a colorless, odorless gas the only way to know how much is present in the air or water is to perform tests. In the United States radon test kits are available to the public at retail stores, such as hardware stores, for home use and testing is available through licensed professionals, who are often **home inspectors**. Efforts to reduce indoor radon levels are called **radon mitigation**. In the U.S. the Environmental Protection Agency recommends all houses be tested for radon.

Industrial production

Radon is obtained as a by-product of **uraniferous ores** processing after transferring into 1% solutions of hydrochloric or hydrobromic acids. The gas mixture extracted from the solutions contains H

2, O

2, He, Rn, CO

2, H

2O and **hydrocarbons**. The mixture is purified by passing it over copper at 720 °C to remove the H

2 and the O

2, and then **KOH** and **P**

2O

5 are used to remove the acids and moisture by **sorption**. Radon is condensed by liquid nitrogen and purified from residue gases by **sublimation**.^[77]

Radon commercialization is regulated, but it is available in small quantities for the calibration of ²²²Rn measurement systems, at a price of almost \$6,000 per milliliter of radium solution (which only contains about 15 picograms of actual radon at a given moment).^[78] Radon is produced by a solution of **radium-226** (half-life of 1600 years). Radium-226 decays by alpha-particle emission, producing radon that collects over samples of radium-226 at a rate of about 1 mm³/day per gram of radium; equilibrium is quickly achieved and radon is produced in a steady flow, with an activity equal to that of the radium (50 Bq). Gaseous ²²²Rn (half-life of about four days) escapes from the capsule through diffusion.^[79]

Concentration scale

2.6.4 Applications

Medical

Main article: **Radioactive quackery**

An early-20th-century form of **quackery** was the treatment of maladies in a **radiatorium**.^[83] It was a small, sealed room for patients to be exposed to radon for its “medicinal effects”. The carcinogenic nature of radon due to its ionizing radiation became apparent later on. Radon’s molecule-damaging radioactivity has been used to kill cancerous cells.^[84] It does not, however, increase the health of healthy cells. In fact, the ionizing radiation causes the formation of **free radicals**, which results in genetic and other cell damage, resulting in increased rates of illness, including **cancer**.

Exposure to radon, a process known as **radiation hormesis**, has been suggested to mitigate auto-immune diseases such as **arthritis**.^{[85][86]} As a result, in the late 20th century and early 21st century, “health mines” established in **Basin, Montana** attracted people seeking relief from health problems such as arthritis through limited exposure to radioactive mine water and radon. However, the practice is discouraged because of the well-documented ill effects of high-doses of radiation on the body.^[87]

Radioactive water baths have been applied since 1906 in **Jáchymov, Czech Republic**, but even before radon discovery they were used in **Bad Gastein, Austria**. Radium-rich springs are also used in traditional Japanese **onsen** in **Misasa, Tottori Prefecture**. Drinking therapy is applied in **Bad Brambach, Germany**. Inhalation therapy is car-

ried out in Gasteiner-Heilstollen, Austria, in Świeradów-Zdrój, Czerniawa-Zdrój, Kowary, Łądek Zdrój, Poland, in Harghita Băi, Romania, and in Boulder, United States. In the United States and Europe there are several “radon spas,” where people sit for minutes or hours in a high-radon atmosphere in the belief that low doses of radiation will invigorate or energize them.^{[86][88]}

Radon has been produced commercially for use in radiation therapy, but for the most part has been replaced by radionuclides made in accelerators and nuclear reactors. Radon has been used in implantable seeds, made of gold or glass, primarily used to treat cancers. The gold seeds were produced by filling a long tube with radon pumped from a radium source, the tube being then divided into short sections by crimping and cutting. The gold layer keeps the radon within, and filters out the alpha and beta radiations, while allowing the gamma rays to escape (which kill the diseased tissue). The activities might range from 0.05 to 5 millicuries per seed (2 to 200 MBq).^[84] The gamma rays are produced by radon and the first short-lived elements of its decay chain (^{218}Po , ^{214}Pb , ^{214}Bi , ^{214}Po).

Radon and its first decay products being very short-lived, the seed is left in place. After 12 half-lives (43 days), radon radioactivity is at 1/2000 of its original level. At this stage, the predominant residual activity originates from the radon decay product ^{210}Pb , whose half-life (22.3 years) is 2000 times that of radon (and whose activity is thus 1/2000 of radon’s), and its descendants ^{210}Bi and ^{210}Po .

In the early part of the 20th century in the USA, gold contaminated with ^{210}Pb entered the jewelry industry. This was from gold seeds that had held ^{222}Rn that had been melted down after the radon had decayed.^{[89][90]}

Scientific

Radon emanation from the soil varies with soil type and with surface uranium content, so outdoor radon concentrations can be used to track air masses to a limited degree. This fact has been put to use by some atmospheric scientists. Because of radon’s rapid loss to air and comparatively rapid decay, radon is used in hydrologic research that studies the interaction between ground water and streams. Any significant concentration of radon in a stream is a good indicator that there are local inputs of ground water.

Radon soil-concentration has been used in an experimental way to map buried close-subsurface geological faults because concentrations are generally higher over the faults.^[91] Similarly, it has found some limited use in prospecting for geothermal gradients.^[92]

Some researchers have investigated changes in ground-water radon concentrations for earthquake prediction.^{[93][94][95]} Radon has a half-life of approximately 3.8

days, which means that it can be found only shortly after it has been produced in the radioactive decay chain. For this reason, it has been hypothesized that increases in radon concentration is due to the generation of new cracks underground, which would allow increased ground water circulation, flushing out radon. The generation of new cracks might not unreasonably be assumed to precede major earthquakes. In the 1970s and 1980s, scientific measurements of radon emissions near faults found that earthquakes often occurred with no radon signal, and radon was often detected with no earthquake to follow. It was then dismissed by many as an unreliable indicator.^[96] However, as of 2009, it is under investigation as a possible precursor by NASA.^[97]

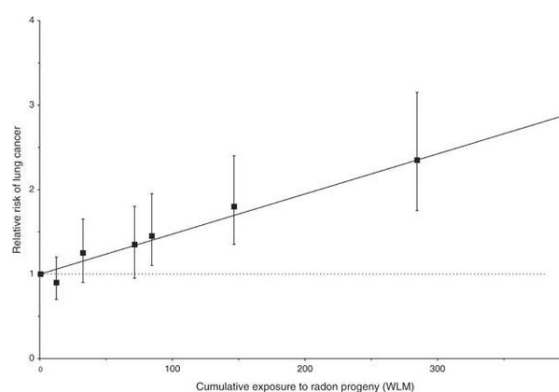
Radon is a known pollutant emitted from geothermal power stations because it is present in the material pumped from deep underground. However, it disperses rapidly, and no radiological hazard has been demonstrated in various investigations. In addition, typical systems re-inject the material deep underground rather than releasing it at the surface, so its environmental impact is minimal.^[98]

In the 1940s and 50s, radon was used for industrial radiography,^{[99][100]} Other X-ray sources, which became available after World War II, quickly replaced radon for this application, as they were lower in cost and had less hazard of alpha radiation.

2.6.5 Health risks

Main article: [Health effects of radon](#)

In mines



Relative risk of lung cancer mortality by cumulative exposure to radon decay products (in WLM) from the combined data from 11 cohorts of underground hard rock miners. Though high exposures (>50 WLM) cause statistically significant excess cancers, the case of small exposures (10 WLM) is inconclusive and appears slightly beneficial in this study.

Radon-222 (actually radon progeny) has been classified

by International Agency for Research on Cancer as being carcinogenic to humans,^[101] and as a gas that can be inhaled, lung cancer is a particular concern for people exposed to high levels of radon for sustained periods of time. During the 1940s and 50s, when safety standards requiring expensive ventilation in mines were not widely implemented,^[102] radon exposure was linked to lung cancer among non-smoking miners of uranium and other hard rock materials in what is now the **Czech Republic**, and later among miners from the Southwestern United States^{[103][104][105]} and **South Australia**.^[106]

Since that time, ventilation and other measures have been used to reduce radon levels in most affected mines that continue to operate. In recent years, the average annual exposure of uranium miners has fallen to levels similar to the concentrations inhaled in some homes. This has reduced the risk of occupationally induced cancer from radon, although health issues may persist for those who are currently employed in affected mines and for those who have been employed in them in the past.^[107] As the relative risk for miners has decreased, so has the ability to detect excess risks among that population.^[108]

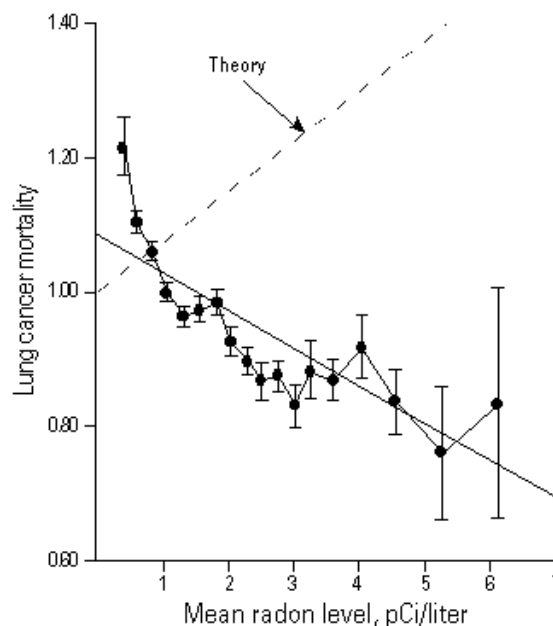
In addition to lung cancer, researchers have theorized a possible increased risk of leukemia due to radon exposure. Empirical support from studies of the general population is inconsistent. However, a study of uranium miners found a noticeable correlation between radon exposure and chronic lymphocytic leukemia.^[109]

Domestic-level exposure

Radon exposure (actually radon progeny) has been linked to lung cancer in numerous case-control studies performed in the United States, Europe and China. There are approximately 21,000 deaths per year in the USA due to radon-induced lung cancers.^[6] One of the most comprehensive radon studies performed in the United States by Dr. **R. William Field** and colleagues found a 50% increased lung cancer risk even at the protracted exposures at the EPA's action level of 4 pCi/L. North American and European Pooled analyses further support these findings.^[110]

Most models of residential radon exposure are based on studies of miners, and direct estimates of the risks posed to homeowners would be more desirable.^[107] Nonetheless, because of the difficulties of measuring the risk of radon relative to other contributors—namely smoking—models of their effect have often made use of them.

Radon has been considered the second leading cause of lung cancer and leading environmental cause of cancer mortality by the United States Environmental Protection Agency.^[114] Others have reached similar conclusions for the United Kingdom^[107] and France.^[115] Radon exposure in homes and offices may arise from certain subsurface rock formations, and also from certain building materials (e.g., some granites). The greatest risk of radon exposure



A controversial epidemiological study showing decreased cancer risk vs. radon domestic exposure (5 pCi/L \approx 200 Bq/m³).^[111] This study lacks individual level controls for smoking and radon exposure, and therefore lacks statistical power to draw definitive conclusions. Because of this the error bars (which simply reflect the raw data variability) are probably too small.^[112] Among other expert panels, the WHO's International Agency for Research on Cancer concluded that these analyses "can be rejected."^[113]

arises in buildings that are airtight, insufficiently ventilated, and have foundation leaks that allow air from the soil into basements and dwelling rooms.

Action and reference level

WHO presented in 2009 a recommended reference level (the national reference level), 100 Bq/m³, for radon in dwellings. The recommendation also says that where this is not possible, 300 Bq/m³ should be selected as the highest level. A national reference level should not be a limit, but should represent the maximum acceptable annual average radon concentration in a dwelling.^[116]

The actionable concentration of radon in a home varies depending on the organization doing the recommendation, for example, the United States Environmental Protection Agency encourages that action be taken at concentrations as low as 74 Bq/m³ (2 pCi/L),^[56] and the European Union recommends action be taken when concentrations reach 400 Bq/m³ (11 pCi/L) for old houses and 200 Bq/m³ (5 pCi/L) for new ones.^[117] On 8 July 2010 the UK's Health Protection Agency issued new advice setting a "Target Level" of 100 Bq/m³ whilst retaining an "Action Level" of 200 Bq/m³.^[118] The same levels (as UK) apply to Norway from 2010; in all new housings preventative measures should be taken against radon accumulation.

Relationship to smoking

Results from epidemiological studies indicate that the risk of lung cancer increases with exposure to residential radon. However, there are always major uncertainties in these studies. A classical and well-known example of source of error is smoking. In addition, smoking is the most important risk factor for lung cancer. In the West, tobacco smoke is estimated to cause about 90% of all lung cancers. There is a tendency for other hypothetical lung cancer risks to drown in the risk of smoking. Results from epidemiological studies must always be interpreted with caution.

According to the EPA, the risk of lung cancer for smokers is significant due to synergistic effects of radon and smoking. For this population about 62 people in a total of 1,000 will die of lung cancer compared to 7 people in a total of 1,000 for people who have never smoked.^[6] It can, however, not be excluded that the risk of non-smokers should be primarily explained by a combination effect of radon and passive smoking (see below).

Radon, like other known or suspected external risk factors for lung cancer, is a threat for smokers and former smokers. This was clearly demonstrated by the European pooling study.^[119] A commentary^[120] to the pooling study stated: “it is not appropriate to talk simply of a risk from radon in homes. The risk is from smoking, compounded by a synergistic effect of radon for smokers. Without smoking, the effect seems to be so small as to be insignificant.”

According to the European pooling study, there is a difference in risk from radon between histological types. Small cell lung carcinoma, which practically only affects smokers have high risk from radon. For other histological types such as adenocarcinoma, the type that primarily affects never smokers, the risk from radon appears to be lower.^{[119][121]}

A study^[122] of radiation from post mastectomy radiotherapy shows that the simple models previously used to assess the combined and separate risks from radiation and smoking need to be developed. This is also supported by new discussion about the calculation method, LNT, which routinely has been used.^[123]

Relationship to passive smoking

An important question is if also passive smoking can cause a similar synergy effect with residential radon. This has been insufficiently studied. The basic data for the European pooling study makes it impossible to exclude that such synergy effect is an explanation for the (very limited) increase in the risk from radon that was stated for non-smokers.

A study^[124] from 2001, which included 436 cases (never smokers who had lung cancer), and a control group (1649

never smokers) showed that exposure to radon increased the risk of lung cancer in never smokers. But the group that had been exposed to passive smoking at home appeared to bear the entire risk increase, while those who were not exposed to passive smoking did not show any increased risk with increasing radon level.

In drinking water

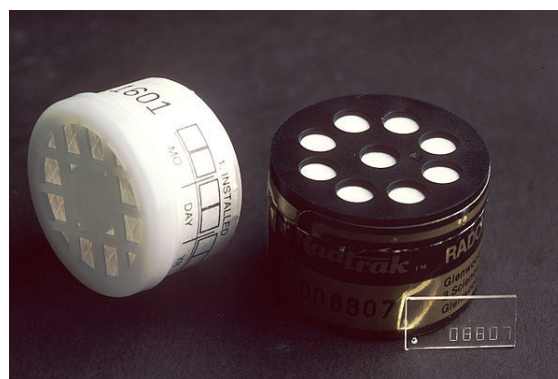
The effects of radon if ingested are similarly unknown, although studies have found that its biological half-life ranges from 30–70 minutes, with 90 percent removal at 100 minutes. In 1999 National Research Council investigated the issue of radon in drinking water. The risks associated with ingestion was considered almost negligible.^[125] Water from underground sources may contain significant amounts of radon depending on the surrounding rock and soil conditions, whereas surface sources generally do not.^[126]

As well as being ingested through drinking water, radon is also released from water when temperature is increased, pressure is decreased and when water is aerated. Optimum conditions for radon release and exposure occur during showering. Water with a radon concentration of 10^4 pCi/L can increase the indoor airborne radon concentration by 1 pCi/L under normal conditions of water use.^[127]

Testing and mitigation

Main article: [Radon mitigation](#)

There are relatively simple tests for radon gas. In some



A radon test kit.

countries these tests are methodically done in areas of known systematic hazards. Radon detection devices are commercially available. The short-term radon test devices used for screening purposes are inexpensive, in some cases free. There are very important protocols for taking short-term radon tests and it is imperative that they be strictly followed. The kit includes a collector that the user hangs in the lowest livable floor of the house for 2 to 7 days. The user then sends the collector to a labora-

tory for analysis. Long term kits, taking collections for up to one year, are also available. An open-land test kit can test radon emissions from the land before construction begins.^[6]

Radon levels fluctuate naturally, due to factors like transient weather conditions, so an initial test might not be an accurate assessment of a home's average radon level. Radon levels are at a maximum during the coolest part of the day when pressure differentials are greatest.^[60] Therefore, a high result (over 4 pCi/L) justifies repeating the test before undertaking more expensive abatement projects. Measurements between 4 and 10 pCi/L warrant a long term radon test. Measurements over 10 pCi/L warrant only another short term test so that abatement measures are not unduly delayed. Purchasers of real estate are advised to delay or decline a purchase if the seller has not successfully abated radon to 4 pCi/L or less.^[6]

Because the half-life of radon is only 3.8 days, removing or isolating the source will greatly reduce the hazard within a few weeks. Another method of reducing radon levels is to modify the building's ventilation. Generally, the indoor radon concentrations increase as ventilation rates decrease.^[3] In a well ventilated place, the radon concentration tends to align with outdoor values (typically 10 Bq/m³, ranging from 1 to 100 Bq/m³).^[6]

Radon levels in indoor air can be lowered in a number of ways, from sub-slab depressurization to increasing the ventilation rate of the building. The four principal ways of reducing the amount of radon accumulating in a house are^{[6][128]}

- Sub-slab depressurization (soil suction) by increasing under-floor ventilation;
- Improving the ventilation of the house and avoiding the transport of radon from the basement into living rooms;
- Installing a radon sump system in the basement;
- Installing a positive pressurization or positive supply ventilation system.

According to the EPA^[6] the method to reduce radon "...primarily used is a vent pipe system and fan, which pulls radon from beneath the house and vents it to the outside," which is also called sub-slab depressurization, active soil depressurization, or soil suction. Generally indoor radon can be mitigated by sub-slab depressurization and exhausting such radon-laden air to the outdoors, away from windows and other building openings. "EPA generally recommends methods which prevent the entry of radon. Soil suction, for example, prevents radon from entering your home by drawing the radon from below the home and venting it through a pipe, or pipes, to the air above the home where it is quickly diluted" and "EPA does not recommend the use of sealing alone to reduce

radon because, by itself, sealing has not been shown to lower radon levels significantly or consistently".^[129]

Positive-pressure ventilation systems can be combined with a heat exchanger to recover energy in the process of exchanging air with the outside, and simply exhausting basement air to the outside is not necessarily a viable solution as this can actually draw radon gas *into* a dwelling. Homes built on a crawl space may benefit from a radon collector installed under a "radon barrier" (a sheet of plastic that covers the crawl space).^{[6][130]} For crawlspaces, the EPA states "An effective method to reduce radon levels in crawlspace homes involves covering the earth floor with a high-density plastic sheet. A vent pipe and fan are used to draw the radon from under the sheet and vent it to the outdoors. This form of soil suction is called submembrane suction, and when properly applied is the most effective way to reduce radon levels in crawlspace homes."^[129]

2.6.6 See also

- International Radon Project
- Lucas cell
- Radiation Exposure Compensation Act
- Radiohalo

2.6.7 References

- [1] Haynes, William M., ed. (2011). *CRC Handbook of Chemistry and Physics* (92nd ed.). Boca Raton, FL: CRC Press. p. 4.122. ISBN 1439855110.
- [2] "A Citizen's Guide to Radon | Radon | US EPA". Epa.gov. 2010-08-05. Retrieved 2012-04-28.
- [3] Toxicological profile for radon, Agency for Toxic Substances and Disease Registry, U.S. Public Health Service, In collaboration with U.S. Environmental Protection Agency, December 1990.
- [4] "Public Health Fact Sheet on Radon — Health and Human Services". Mass.Gov. Archived from the original on 2011-11-21. Retrieved 2011-12-04.
- [5] "Facts about Radon". Facts about. Retrieved 2008-09-07.
- [6] "A Citizen's Guide to Radon". *www.epa.gov*. United States Environmental Protection Agency. October 12, 2010. Retrieved January 29, 2012.
- [7] [http://web.archive.org/web/20110809192552/http://www.allmeasures.com/Formulae/d1/d2/d3/Results2_2.asp?formula=2&material=Radon+{[]Rn] "Radon"]. All Measures. 2004. Retrieved 2008-02-12.
- [8] Williams, David R. (2007-04-19). "Earth Fact Sheet". NASA. Retrieved 2008-06-26.
- [9] "Radon". Jefferson Lab. Retrieved 2008-06-26.

- [10] Thomas, Jens (2002). *Noble Gases*. Marshall Cavendish. p. 13. ISBN 978-0-7614-1462-9.
- [11] Bader, Richard F. W. "An Introduction to the Electronic Structure of Atoms and Molecules". McMaster University. Retrieved 2008-06-26.
- [12] David R. Lide (2003). "Section 10, Atomic, Molecular, and Optical Physics; Ionization Potentials of Atoms and Atomic Ions". *CRC Handbook of Chemistry and Physics* (84th ed.). Boca Raton, Florida: CRC Press.
- [13] Avrorin, V V; Krasikova, R N; Nefedov, V D; Toropova, M A (1982). "The Chemistry of Radon". *Russian Chemical Reviews* **51**: 12. Bibcode:1982RuCRv..51...12A. doi:10.1070/RC1982v051n01ABEH002787.
- [14] Stein, L. (1970). "Ionic Radon Solution". *Science* **168** (3929): 362–4. Bibcode:1970Sci...168..362S. doi:10.1126/science.168.3929.362. PMID 17809133.
- [15] Pitzer, Kenneth S. (1975). "Fluorides of radon and element 118". *J. Chem. Soc., Chem. Commun.* (18): 760–1. doi:10.1039/C3975000760b.
- [16] Meng- Sheng Liao; Qian- Er Zhang (1998). "Chemical Bonding in XeF₂, XeF₄, KrF₂, KrF₄, RnF₂, XeCl₂, and XeBr₂: From the Gas Phase to the Solid State". *The Journal of Physical Chemistry A* **102** (52): 10647. doi:10.1021/jp9825516.
- [17] Filatov, Michael; Cremer, Dieter (2003). "Bonding in radon hexafluoride: An unusual relativistic problem?". *Physical Chemistry Chemical Physics* **5** (6): 1103. Bibcode:2003PCCP....5.1103F. doi:10.1039/b212460m.
- [18] Sykes, A. G. (1998). "Recent Advances in Noble-Gas Chemistry". *Advances in Inorganic Chemistry* **46**. Academic Press. pp. 91–93. ISBN 978-0120236466. Retrieved 2012-11-02.
- [19] Thayer, John S. (2010). "Relativistic Effects and the Chemistry of the Heavier Main Group Elements". p. 80. doi:10.1007/978-1-4020-9975-5_2.
- [20] Holloway, J (1986). "Noble-gas fluorides". *Journal of Fluorine Chemistry* **33**: 149. doi:10.1016/S0022-1139(00)85275-6.
- [21] Avrorin, V. V.; Krasikova, R. N.; Nefedov, V. D.; Toropova, M. A. (1982). "The Chemistry of Radon". *Russ. Chem. Review* **51**: 12. Bibcode:1982RuCRv..51...12A. doi:10.1070/RC1982v051n01ABEH002787.
- [22] Malli, Gulzari L. (2002). "Prediction of the existence of radon carbonyl: RnCO". *International Journal of Quantum Chemistry* **90** (2): 611. doi:10.1002/qua.963.
- [23] Runeberg, Nino; Pyykkö, Pekka (1998). "Relativistic pseudopotential calculations on Xe₂, RnXe, and Rn₂: The van der Waals properties of radon". *International Journal of Quantum Chemistry* **66** (2): 131. doi:10.1002/(SICI)1097-461X(1998)66:2<131::AID-QUA4>3.0.CO;2-W.
- [24] Browne, Malcolm W. (1993-03-05). "Chemists Find Way to Make An 'Impossible' Compound". *The New York Times*. Retrieved 2009-01-30.
- [25] Sonzogni, Alejandro. "Interactive Chart of Nuclides". National Nuclear Data Center: Brookhaven National Laboratory. Retrieved 2008-06-06.
- [26] "Principal Decay Scheme of the Uranium Series". Gulflink.osd.mil. Retrieved 2008-09-12.
- [27] "Why Measure RDPs?". Retrieved 2009-07-07.
- [28] "EPA Assessment of Risks from Radon in Homes" (PDF). Office of Radiation and Indoor Air, US Environmental Protection Agency. June 2003. Archived from the original (PDF) on 2008-02-27.
- [29] *Health effects of exposure to radon, Volume 6 of BEIR (Series)*. National Academies Press. 1999. p. 179. ISBN 0-309-05645-4.
- [30] Dorn, F. E. (1900). "Die von radioactiven Substanzen ausgesandte Emanation" (PDF). *Abhandlungen der Naturforschenden Gesellschaft zu Halle* **23**: 1–15.
- [31] Partington, J. R. (1957). "Discovery of Radon". *Nature* **179** (4566): 912. Bibcode:1957Natur.179..912P. doi:10.1038/179912a0.
- [32] "Timeline of Element Discovery". The New York Times Company. 2008. Retrieved 2008-02-28.
- [33] Partington, J. R. (1957). "Discovery of Radon". *Nature* **179** (4566): 912. Bibcode:1957Natur.179..912P. doi:10.1038/179912a0.
- [34] Schüttmann, W. (1988). "Zur Entdeckungsgeschichte des Radons". *Isotopenpraxis Isotopes in Environmental and Health Studies* **24** (4): 158. doi:10.1080/10256018808623931.
- [35] Brenner, David J. (2000). "Rutherford, the Curies, and Radon". *Medical Physics* **27** (3): 618. Bibcode:2000MedPh..27..618B. doi:10.1118/1.598902. PMID 10757614.
- [36] Dorn, Friedrich Ernst (1900). "Ueber die von radioactiven Substanzen ausgesandte Emanation". *Abhandlungen der Naturforschenden Gesellschaft zu Halle (Stuttgart)* **22**: 155.
- [37] Curie, P.; Curie, Mme. Marie (1899). "Sur la radioactivite provoquee par les rayons de Becquerel". *Comptes rendus hebdomadaires des séances de l'Académie des sciences* **129**: 714–6.
- [38] Rutherford, E.; Owens, R. B. (1899). "Thorium and uranium radiation". *Trans. R. Soc. Can.* **2**: 9–12.: "The radiation from thorium oxide was not constant, but varied in a most capricious manner," whereas "All the compounds of Uranium give out a radiation which is remarkably constant."
- [39] Rutherford, E. (1900). "A radioactive substance emitted from thorium compounds". *Phil. Mag.* **40**: 1–4.
- [40] Rutherford, E.; Brooks, H.T. (1901). "The new gas from radium". *Trans. R. Soc. Can.* **7**: 21–5.

- [41] Giesel, Fritz (1903). “Ueber den Emanationskörper aus Pechblende und über Radium”. *Chemische Berichte* **36**: 342. doi:10.1002/cber.19030360177.
- [42] Debierne, André-Louis (1903). “Sur la radioactivité induite provoquée par les sels d’actinium”. *Comptes rendus hebdomadaires des séances de l’Académie des sciences* **136**: 446.
- [43] Ramsay, Sir William; Collie, J. Normal (1904). “The Spectrum of the Radium Emanation”. *Proceedings of the Royal Society* **73** (488–496): 470–6. doi:10.1098/rspl.1904.0064.
- [44] Schmidt, Curt (1918). “Periodisches System und Genesis der Elemente”. *Z. Anorg. Ch.* **103**: 79–118. doi:10.1002/zaac.19181030106.
- [45] Perrin, J (1919). “Radon”. *Ann. Physique* **11**: 5.
- [46] Adams, Elliot Quincy (1920). “The Independent Origin of Actinium”. *J. Amer. Chem. Soc.* **42** (11): 2205. doi:10.1021/ja01456a010.
- [47] Ramsay, W.; Gray, R. W. (1910). “La densité de l’emanation du radium”. *Comptes rendus hebdomadaires des séances de l’Académie des sciences* **151**: 126–8.
- [48] Grosse, A. V. (1965). “Some physical and chemical properties of element 118 (Eka-Em) and element 86 (Em)”. *Journal of Inorganic and Nuclear Chemistry* (Elsevier Science Ltd.) **27** (3): 509. doi:10.1016/0022-1902(65)80255-X.
- [49] Fields, Paul R.; Stein, Lawrence; Zirin, Moshe H. (1962). “Radon Fluoride”. *J. Amer. Chem. Soc.* **84** (21): 4164. doi:10.1021/ja00880a048.
- [50] Le radon, aspects historiques et perception du risque, Roland Masse.
- [51] Radon Toxicity: Who is at Risk?, Agency for Toxic Substances and Disease Registry, 2000.
- [52] Proctor, Robert N. *The Nazi War on Cancer*. Princeton University Press, 2000 p. 99 ISBN 0691070512.
- [53] Edelstein, Michael R., William J. Makofske. *Radon’s deadly daughters: science, environmental policy, and the politics of risk*. Rowman & Littlefield, 1998, pp. 36–39 ISBN 0847683346.
- [54] Samet, J. M. (1992). “Indoor radon and lung cancer. Estimating the risks”. *The Western journal of medicine* **156** (1): 25–9. PMC 1003141. PMID 1734594.
- [55] Yamamoto, M.; Sakaguchi, A; Sasaki, K; Hirose, K; Igarashi, Y; Kim, C (2006). “Radon”. *Journal of Environmental Radioactivity* **86** (1): 110–31. doi:10.1016/j.jenvrad.2005.08.001. PMID 16181712.
- [56] “Radiation Protection: Radon”. United States Environmental Protection Agency. November 2007. Retrieved 2008-04-17.
- [57] Radon (Rn). CEA. 12 April 2005. (in French)
- [58] “Health hazard data” (PDF). The Linde Group. Retrieved 2008-06-26.
- [59] “Le Radon. Un gaz radioactif naturel”. Retrieved 2009-07-07.
- [60] Thad. Godish, (2001) . “Indoor Environment Quality”. Boca Raton, FL. CRC Press LLC.
- [61] J. H. Harley (1975). *Noble gases*. U.S. Environmental Protection Agency. pp. 109–114.
- [62] Sperrin, Malcolm; Gillmore, Gavin; Denman, Tony (2001). “Radon concentration variations in a Mendip cave cluster”. *Environmental Management and Health* **12** (5): 476. doi:10.1108/09566160110404881.
- [63] Zdrojewicz, Zygmunt; Strzelczyk, Jadwiga (Jodi) (2006). “Radon Treatment Controversy, Dose Response”. *Dose-Response* **4** (2): 106–18. doi:10.2203/dose-response.05-025.Zdrojewicz. PMC 2477672. PMID 18648641.
- [64] Steck, Daniel J.; Field, R. William; Lynch, Charles F. (1999). “Exposure to Atmospheric Radon”. *Environmental Health Perspectives* **107** (2): 123–127. doi:10.2307/3434368. JSTOR 3434368. PMC 1566320. PMID 9924007.
- [65] Field, R. William. “Radon Occurrence and Health Risk” (PDF). Department of Occupational and Environmental Health, University of Iowa. Retrieved 2008-02-02.
- [66] “The Clinical Principles Of Balneology & Physical Medicine”. Retrieved 2009-07-07.
- [67] “The Geology of Radon”. United States Geological Survey. Retrieved 2008-06-28.
- [68] “Radon-222 as a tracer in groundwater-surface water interactions” (PDF). Lancaster University. Retrieved 2008-06-28.
- [69] Lawson, S.; Feldman, W.; Lawrence, D.; Moore, K.; Elphic, R.; Belian, R. (2005). “Recent outgassing from the lunar surface: the Lunar Prospector alpha particle spectrometer”. *J. Geophys. Res.* **110**: 1029. Bibcode:2005JGRE..11009009L. doi:10.1029/2005JE002433.
- [70] “Potential for Elevated Radiation Levels In Propane” (PDF). National Energy Board. April 1994. Retrieved 2009-07-07.
- [71] Roaf, Susan; Fuentes, Manuel & Thomas, Stephanie (2007). *Ecohouse: A Design Guide*. Elsevier. p. 159. ISBN 0-7506-6903-9.
- [72] Numerous references, see for instance Analysis And Modelling Of Indoor Radon Distributions Using Extreme Values Theory or Indoor Radon in Hungary (Lognormal Misticism) for a discussion.
- [73] “Data Collection and Statistical Computations”. Retrieved 2009-07-07.
- [74] “Annex E: Sources to effects assessment for radon in homes and workplaces” (PDF), *Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (2006)* (United Nations) **2**, 2008: 209–10, retrieved 17 August 2013

- [75] Price, Phillip N.; Nero, A.; Revzan, K.; Apte, M.; Gelman, A.; Boscardin, W. John. "Predicted County Median Concentration". Lawrence Berkeley National Laboratory. Archived from the original on 2007-12-31. Retrieved 2008-02-12.
- [76] Field, R. William. "The Iowa Radon Lung Cancer Study". Department of Occupational and Environmental Health, University of Iowa. Retrieved 2008-02-22.
- [77] "Radon Production". Rn-radon.info. 2007-07-24. Archived from the original on 2008-10-28. Retrieved 2009-01-30.
- [78] "SRM 4972 – Radon-222 Emanation Standard". National Institute of Standards and Technology. Retrieved 2008-06-26.
- [79] Collé, R. & R. Kishore (1997). "An update on the NIST radon-in-water standard generator: its performance efficacy and long-term stability". *Nucl. Instrum. Meth. A* **391** (3): 511–528. Bibcode:1997NIMPA.391..511C. doi:10.1016/S0168-9002(97)00572-X.
- [80] *The Mining Safety and Health Act - 30 CFR 57.0*. United States Government. 1977. Retrieved 2014-07-30.
- [81] Thomas, John J.; Thomas, Barbara R.; Overeynder, Helen M. (September 27–30, 1995). *Indoor Radon Concentration Data: Its Geographic and Geologic Distribution, an Example from the Capital District, NY* (PDF). International Radon Symposium. Nashville, TN: American Association of Radon Scientists and Technologists. Retrieved 2012-11-28.
- [82] Upfal, Mark J.; Johnson, Christine (2003). "65 Residential Radon". In Greenberg, Michael I.; Hamilton, Richard J.; Phillips, Scott D.; N.N., Gayla J. *Occupational, industrial, and environmental toxicology* (PDF) (2nd ed.). St Louis, Missouri: Mosby. ISBN 9780323013406. Retrieved 28 November 2012.
- [83] *The Clinique, Volume 34*. Illinois Homeopathic Medical Association. 1913. Retrieved 2011-06-30.
- [84] "Radon seeds". Retrieved 2009-05-05.
- [85] "Radon Health Mines: Boulder and Basin, Montana". Roadside America. Retrieved 2007-12-04.
- [86] Neda, T et al. (2008). "Radon concentration levels in dry CO₂ emanations from Harghita Băi, Romania, used for curative purposes". *Journal of Radioanalytical and Nuclear Chemistry* **277** (3): 685. doi:10.1007/s10967-007-7169-0.
- [87] Salak, Kara; Nordeman, Landon (2004). "59631: Mining for Miracles". *National Geographic* (National Geographic Society). Retrieved 2008-06-26.
- [88] "Jáchymov". Petros. Retrieved 2008-06-26.
- [89] "Poster Issued by the New York Department of Health (ca. 1981)". Oak Ridge Associated Universities. 2007-07-25. Retrieved 2008-06-26.
- [90] "Rings and Cancer". *Time*. 1968-09-13. Retrieved 2009-05-05.
- [91] Richon, P.; Y. Klinger; P. Tapponnier; C.-X. Li; J. Van Der Woerd & F. Perrier (2010). "Measuring radon flux across active faults: Relevance of excavating and possibility of satellite discharges" (PDF). *Radiat. Meas* **45** (2): 211–218. doi:10.1016/j.radmeas.2010.01.019.
- [92] Radon Transect Analysis In Geothermal Reservoirs
- [93] Igarashi, G. & Wakita, H. (1995). "Geochemical and hydrological observations for earthquake prediction in Japan". *Journal of the Physics of the Earth* **43** (5): 585–598. doi:10.4294/jpe1952.43.585.
- [94] Wakita, H., (1996). Earthquake chemistry II, collected papers, edn, Vol. II, Laboratory for Earthquake Chemistry, Faculty of Science, University of Tokyo, Japan
- [95] Richon, P.; Sabroux, J.-C.; Halbwachs, M.; Vandemeulebrouck, J.; Poussielgue, N.; Tabbagh, J.; Punongbayan, R. (2003). "Radon anomaly in the soil of Taal volcano, the Philippines: A likely precursor of the M 7.1 Mindoro earthquake (1994)". *Geophysical Research Letters* **30** (9): 34. Bibcode:2003GeoRL..30i..34R. doi:10.1029/2003GL016902.
- [96] "Expert: Earthquakes Hard To Predict". Retrieved 2009-05-05.
- [97] "EARTH Magazine: Earthquake prediction: Gone and back again".
- [98] "Radon and Naturally Occurring Radioactive Materials (NORM) associated with Hot Rock Geothermal Systems" (PDF). Government of South Australia—Primary Industries and Resources SA. Retrieved 2013-07-16.
- [99] Dawson, J A T (1946). "Radon. Its Properties and Preparation for Industrial Radiography". *Journal of Scientific Instruments* **23** (7): 138. Bibcode:1946JSci...23..138D. doi:10.1088/0950-7671/23/7/301.
- [100] Morrison, A. (1945). "Use of radon for industrial radiography". *Canadian Journal of Research* **23f** (6): 413–419. doi:10.1139/cjr45f-044.
- [101] "Known and Probable Carcinogens". American Cancer Society. Retrieved 2008-06-26.
- [102] Mould, Richard Francis (1993). *A Century of X-rays and Radioactivity in Medicine*. CRC Press. ISBN 0-7503-0224-0.
- [103] "Uranium Miners' Cancer". *Time*. 1960-12-26. ISSN 0040-781X. Retrieved 2008-06-26.
- [104] Tirmarche M; Laurier D; Mitton N & Gelas JM. "Lung Cancer Risk Associated with Low Chronic Radon Exposure: Results from the French Uranium Miners Cohort and the European Project" (PDF). Retrieved 2009-07-07.
- [105] Roscoe, R. J.; Steenland, K.; Halperin, W. E.; Beaumont, J. J.; Waxweiler, R. J. (1989-08-04). "Lung cancer mortality among nonsmoking uranium miners exposed to radon daughters". *Journal of the American Medical Association* **262** (5): 629–33. doi:10.1001/jama.1989.03430050045024. PMID 2746814.

- [106] Woodward, Alistair; Roder, David; McMichael, Anthony J.; Crouch, Philip; Mylvaganam, Arul (1991-07-01). "Radon Daughter Exposures at the Radium Hill Uranium Mine and Lung Cancer Rates among Former Workers, 1952-87". *Cancer Causes & Control* (Springer) **2** (4). Retrieved 2015-05-01.
- [107] Darby, S; Hill, D; Doll, R (2005). "Radon: a likely carcinogen at all exposures". *Annals of Oncology* **12** (10): 1341–51. doi:10.1023/A:1012518223463. PMID 11762803.
- [108] "UNSCEAR 2006 Report Vol. I". United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2006 Report to the General Assembly, with scientific annexes.
- [109] Rericha, V.; Kulich, M.; Rericha, R.; Shore, D. L.; Sandler, D. P. (2007). "Incidence of leukemia, lymphoma, and multiple myeloma in Czech uranium miners: a case-cohort study". *Environmental Health Perspectives* **114** (6): 818–22. doi:10.1289/ehp.8476. PMC 1480508. PMID 16759978.
- [110] Reducing Environmental Cancer Risk – What We Can Do Now. US Department of Health and Human Services. 2008–2009 Annual Report
- [111] Cohen BL (1990). "A test of the linear-no threshold theory of radiation carcinogenesis". *Environ. Res.* **53** (2): 193–220. Bibcode:1990ER.....53..193C. doi:10.1016/S0013-9351(05)80119-7. PMID 2253600.
- [112] Heath CW; Bond PD; Hoel DG; Meinhold CB (2004). "Residential radon exposure and lung cancer risk: commentary on Cohen's county-based study". *Health Phys* **87** (6): 647–55; discussion 656–8. doi:10.1097/01.HP.0000138588.59022.40. PMID 15545771.
- [113] *Ionizing Radiation, Part 2: Some Internally Deposited Radionuclides* (PDF). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans **78**. World Health Organization, International Agency for Research on Cancer. 2001.
- [114] "Health Risks". EPA. Retrieved 2008-06-26.
- [115] Catelinois O; Rogel A; Laurier D; Billon, Solenne; Hemon, Denis; Verger, Pierre; Tirmarche, Margot (2006). "Lung cancer attributable to indoor radon exposure in france: impact of the risk models and uncertainty analysis". *Environ. Health Perspect* **114** (9): 1361–6. doi:10.1289/ehp.9070. PMC 1570096. PMID 16966089.
- [116] WHO Handbook on Indoor Radon. World Health Organization
- [117] "Radon Levels in Dwellings: Fact Sheet 4.6" (PDF). European Environment and Health Information System. December 2009. Retrieved 2013-07-16.
- [118] "HPA issues new advice on radon". UK Health Protection Agency. July 2010. Retrieved 2010-08-13.
- [119] Darby, S; Hill, D; Auvinen, A; Barros-Dios, JM; Baysson, H; Bochicchio, F; Deo, H; Falk, R; Forastiere, F et al. (2005). "Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies". *BMJ* **330** (7485): 223. doi:10.1136/bmj.38308.477650.63. PMC 546066. PMID 15613366.
- [120] Replies to Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. Bmj.com. Retrieved on 2012-04-14.
- [121] President's Cancer Panel, Environmental Factors in Cancer: Radon, December 4, 2008.
- [122] Kaufman, EL; Jacobson, JS; Hershman, DL; Desai, M; Neugut, AI (2008). "Effect of breast cancer radiotherapy and cigarette smoking on risk of second primary lung cancer". *Journal of clinical oncology : official journal of the American Society of Clinical Oncology* **26** (3): 392–8. doi:10.1200/JCO.2007.13.3033. PMID 18202415.
- [123] Dauer, L. T.; Brooks, A. L.; Hoel, D. G.; Morgan, W. F.; Stram, D.; Tran, P. (2010). "Review and evaluation of updated research on the health effects associated with low-dose ionising radiation". *Radiation Protection Dosimetry* **140** (2): 103–36. doi:10.1093/rpd/ncq141. PMID 20413418.
- [124] Lagarde, F; Axelsson, G; Damber, L; Mellander, H; Nyberg, F; Pershagen, G (2001). "Residential radon and lung cancer among never-smokers in Sweden". *Epidemiology (Cambridge, Mass.)* **12** (4): 396–404. doi:10.1097/00001648-200107000-00009. JSTOR 3703373. PMID 11416777.
- [125] Risk Assessment of Radon in Drinking Water. Nap.edu (2003-06-01). Retrieved on 2011-08-20.
- [126] "Basic Information about Radon in Drinking Water". Retrieved 2013-07-24.
- [127] Godish, Thad (2001). *Indoor Environmental Quality*. CRC Press. ISBN 1-56670-402-2.
- [128] World Health Organization. "Radon and cancer, fact sheet 291".
- [129] "Consumer's Guide to Radon Reduction: How to fix your home". EPA. Retrieved 2010-04-03.
- [130] *Building radon out a stepbystep guide on how to build radonresistant homes*. DIANE Publishing. p. 46. ISBN 1-4289-0070-5.

2.6.8 External links

- Radon and radon publications at the United States Environmental Protection Agency
- National Radon Program Services hosted by Kansas State University
- Radon Information from the UK Health Protection Agency

- Frequently Asked Questions About Radon at National Safety Council
- Radon at *The Periodic Table of Videos* (University of Nottingham)
- Radon and Lung Health from the American Lung Association
- Radon's impact on your health – Lung Association
- The Geology of Radon, James K. Otton, Linda C.S. Gundersen, and R. Randall Schumann
- Map referring to radon concentrations in England and Wales
- Home Buyer's and Seller's Guide to Radon An article by the International Association of Certified Home Inspectors (InterNACHI)
- EPA Federal Radon Mitigation Action Plan
- Toxicological Profile for Radon, Draft for Public Comment, Agency for Toxic Substances and Disease Registry, September 2008
- *Health Effects of Exposure to Radon: BEIR VI*. Committee on Health Risks of Exposure to Radon (BEIR VI), National Research Council available online
- UNSCEAR 2000 Report to the General Assembly, with scientific annexes: Annex B: Exposures from natural radiation sources.
- Should you measure the radon concentration in your home?, Phillip N. Price, Andrew Gelman, in *Statistics: A Guide to the Unknown*, January 2004.

2.7 Ununoctium

Ununoctium is the temporary IUPAC name^[11] for the transactinide element with the atomic number 118 and temporary element symbol **Uuo**. It is also known as **ekaradon** or **element 118**, and on the periodic table of the elements it is a p-block element and the last one of the 7th period. Ununoctium is currently the only synthetic member of group 18. It has the highest atomic number and highest atomic mass of all the elements discovered so far.

The radioactive ununoctium atom is very unstable, due to its high mass, and since 2005, only three or possibly four atoms of the isotope ²⁹⁴Uuo have been detected.^[12] Although this allowed very little experimental characterization of its properties and possible compounds, theoretical calculations have resulted in many predictions, including some unexpected ones. For example, although ununoctium is a member of group 18, it may possibly not be a noble gas, unlike all the other group 18 elements.^[1] It was formerly thought to be a gas under normal conditions but is now predicted to be a solid due to relativistic effects.^[1]

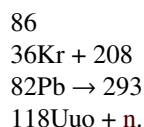
2.7.1 History

See also: Discoveries of the chemical elements

Unsuccessful synthesis attempts

In late 1998, Polish physicist Robert Smolańczuk published calculations on the fusion of atomic nuclei towards the synthesis of superheavy atoms, including ununoctium.^[13] His calculations suggested that it might be possible to make ununoctium by fusing lead with krypton under carefully controlled conditions.^[13]

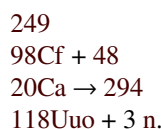
In 1999, researchers at Lawrence Berkeley National Laboratory made use of these predictions and announced the discovery of livermorium and ununoctium, in a paper published in *Physical Review Letters*,^[14] and very soon after the results were reported in *Science*.^[15] The researchers reported to have performed the reaction



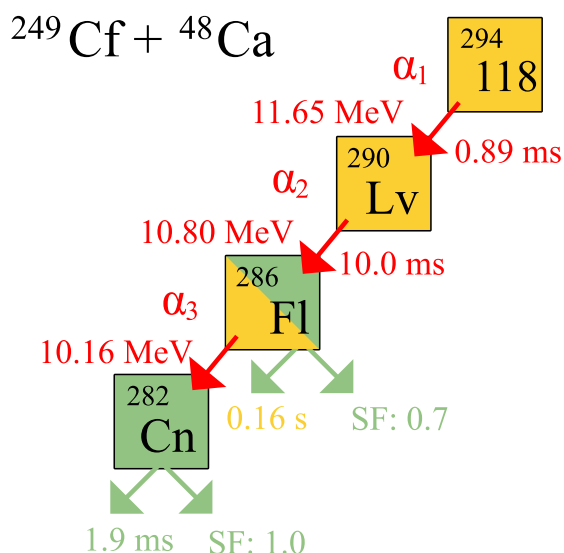
The following year, they published a retraction after researchers at other laboratories were unable to duplicate the results and the Berkeley lab itself was unable to duplicate them as well.^[16] In June 2002, the director of the lab announced that the original claim of the discovery of these two elements had been based on data fabricated by principal author Victor Ninov.^{[17][18]}

Discovery reports

The first decay of atoms of ununoctium was observed at the Joint Institute for Nuclear Research (JINR) by Yuri Oganessian and his group in Dubna, Russia, in 2002.^[19] On October 9, 2006, researchers from JINR and Lawrence Livermore National Laboratory of California, US, working at the JINR in Dubna, announced^[10] that they had indirectly detected a total of three (possibly four) nuclei of ununoctium-294 (one or two in 2002^[20] and two more in 2005) produced via collisions of californium-249 atoms and calcium-48 ions.^{[21][22][23][24][25]}



In 2011, IUPAC evaluated the 2006 results of the Dubna-Livermore collaboration and concluded: "The three events reported for the Z = 118 isotope have very good



Radioactive decay pathway of the isotope ununoctium-294.^[10] The decay energy and average half-life is given for the parent isotope and each daughter isotope. The fraction of atoms undergoing spontaneous fission (SF) is given in green.

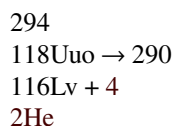
internal redundancy but with no anchor to known nuclei do not satisfy the criteria for discovery”.^[26]

Because of the very small fusion reaction probability (the fusion cross section is $\sim 0.3\text{--}0.6$ pb or $(3\text{--}6)\times 10^{-41}$ m²) the experiment took four months and involved a beam dose of 4×10^{19} calcium ions that had to be shot at the californium target to produce the first recorded event believed to be the synthesis of ununoctium.^[9] Nevertheless, researchers are highly confident that the results are not a false positive, since the chance that the detections were random events was estimated to be less than one part in 100000.^[27]

In the experiments, the alpha-decay of three atoms of ununoctium was observed. A fourth decay by direct spontaneous fission was also proposed. A half-life of 0.89 ms was calculated: 294

Uuo decays into 290

Lv by alpha decay. Since there were only three nuclei, the half-life derived from observed lifetimes has a large uncertainty: 0.89 ± 1.07 – 0.31 ms.^[10]



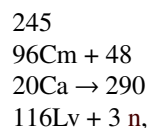
The identification of the 294

Uuo nuclei was verified by separately creating the putative daughter nucleus 290

Lv directly by means of a bombardment of 245

Cm with 48

Ca ions,



and checking that the 290

Lv decay matched the decay chain of the 294

Uuo nuclei.^[10] The daughter nucleus 290

Lv is very unstable, decaying with a lifetime of 14 milliseconds into 286

Fl, which may experience either spontaneous fission or alpha decay into 282

Cn, which will undergo spontaneous fission.^[10]

In a quantum-tunneling model, the alpha decay half-life of 294

Uuo was predicted to be 0.66 ± 0.23

– 0.18 ms^[28] with the experimental Q-value published in 2004.^[29] Calculation with theoretical Q-values from the macroscopic-microscopic model of Muntian–Hofman–Patyk–Sobiczewski gives somewhat low but comparable results.^[30]

2.7.2 Naming

Until the 1960s ununoctium was known as *eka-emanation* (emanation is the old name for radon).^[31] In 1979 the IUPAC published recommendations according to which the element was to be called *ununoctium*,^[32] a systematic element name, as a placeholder until the discovery of the element is confirmed and the IUPAC decides on a name.

Before the retraction in 2002, the researchers from Berkeley had intended to name the element *ghiorsium* (Gh), after Albert Ghiorso (a leading member of the research team).^[33]

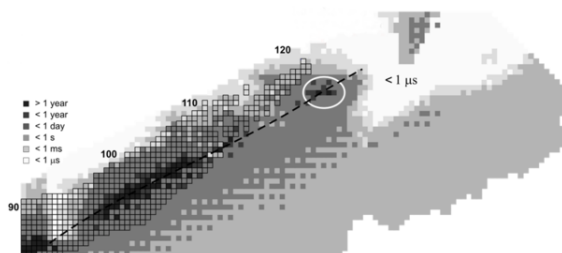
The Russian discoverers reported their synthesis in 2006. In 2007, the head of the Russian institute stated the team were considering two names for the new element: *flyorium*, in honor of Georgy Flyorov, the founder of the research laboratory in Dubna; and *moskovium*, in recognition of the Moscow Oblast where Dubna is located.^[34] He also stated that although the element was discovered as an American collaboration, who provided the californium target, the element should rightly be named in honor of Russia since the Flerov Laboratory of Nuclear Reactions at JINR was the only facility in the world which could achieve this result.^[35] These names were later proposed for element 114 (flerovium) and element 116 (moscovium).^[36] However, the final name proposed for element 116 was instead *livermorium*.^[37]

No name has yet been officially suggested for the element as no claims for discovery have yet been accepted by the IUPAC. According to current guidelines from IUPAC, the ultimate name for all new elements should end in “-ium”, which means the name for ununoctium will almost certainly end in “-ium”, not “-on”, even if ununoctium turns out to be a noble gas, which traditionally have names

ending in "-on" (with the exception of helium, which was not known to be a noble gas when it was discovered).^[38]

2.7.3 Characteristics

Nuclear stability and isotopes



Ununoctium (row 118) is slightly above the "island of stability" (white circle) and thus its nuclei are slightly more stable than otherwise predicted.

Main article: [Isotopes of ununoctium](#)
See also: [Island of stability](#)

The stability of nuclei decreases greatly with the increase in atomic number after plutonium, the heaviest primordial element, so that all isotopes with an atomic number above 101 decay radioactively with a half-life under a day, with an exception of dubnium—268. No elements with atomic numbers above 82 (after lead) have stable isotopes.^[39] Nevertheless, because of reasons not very well understood yet, there is a slightly increased nuclear stability around atomic numbers 110–114, which leads to the appearance of what is known in nuclear physics as the "island of stability". This concept, proposed by University of California professor Glenn Seaborg, explains why superheavy elements last longer than predicted.^[40] Ununoctium is radioactive and has a half-life that appears to be less than a millisecond. Nonetheless, this is still longer than some predicted values,^{[28][41]} thus giving further support to the idea of this "island of stability".^[42]

Calculations using a quantum-tunneling model predict the existence of several neutron-rich isotopes of ununoctium with alpha-decay half-lives close to 1 ms.^{[43][44]}

Theoretical calculations done on the synthetic pathways for, and the half-life of, other isotopes have shown that some could be slightly more stable than the synthesized isotope ²⁹⁴Uuo, most likely ²⁹³Uuo, ²⁹⁵Uuo, ²⁹⁶Uuo, ²⁹⁷Uuo, ²⁹⁸Uuo, ³⁰⁰Uuo and ³⁰²Uuo.^{[28][45]} Of these, ²⁹⁷Uuo might provide the best chances for obtaining longer-lived nuclei,^{[28][45]} and thus might become the focus of future work with this element. Some isotopes with many more neutrons, such as some located around ³¹³Uuo could also provide longer-lived nuclei.^[46]

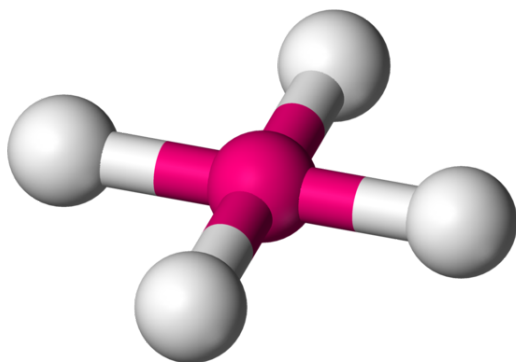
Calculated atomic and physical properties

Ununoctium is a member of group 18, the zero-valence elements. The members of this group are usually inert to most common chemical reactions (for example, combustion) because the outer valence shell is completely filled with eight electrons. This produces a stable, minimum energy configuration in which the outer electrons are tightly bound.^[47] It is thought that similarly, ununoctium has a closed outer valence shell in which its valence electrons are arranged in a $7s^27p^6$ configuration.^[1]

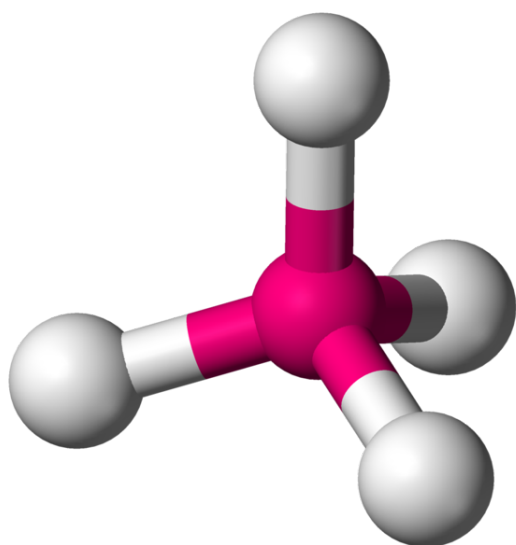
Consequently, some expect ununoctium to have similar physical and chemical properties to other members of its group, most closely resembling the noble gas above it in the periodic table, radon.^[48] Following the periodic trend, ununoctium would be expected to be slightly more reactive than radon. However, theoretical calculations have shown that it could be quite reactive, so that it probably cannot be considered a noble gas.^[6] In addition to being far more reactive than radon, ununoctium may be even more reactive than elements flerovium and copernicium.^[1] The reason for the apparent enhancement of the chemical activity of ununoctium relative to radon is an energetic destabilization and a radial expansion of the last occupied 7p-subshell.^{[1][lower-alpha 1]} More precisely, considerable spin-orbit interactions between the 7p electrons with the inert $7s^2$ electrons, effectively lead to a second valence shell closing at flerovium, and a significant decrease in stabilization of the closed shell of element 118.^[1] It has also been calculated that ununoctium, unlike other noble gases, binds an electron with release of energy—or in other words, it exhibits positive electron affinity.^{[49][50][lower-alpha 2]}

Ununoctium is expected to have by far the broadest polarizability of all elements before it in the periodic table, and almost twofold of radon.^[1] By extrapolating from the other noble gases, it is expected that ununoctium has a boiling point between 320 and 380 K.^[1] This is very different from the previously estimated values of 263 K^[51] or 247 K.^[52] Even given the large uncertainties of the calculations, it seems highly unlikely that ununoctium would be a gas under standard conditions,^{[1][lower-alpha 3]} and as the liquid range of the other gases is very narrow, between 2 and 9 kelvins, this element should be solid at standard conditions. If ununoctium forms a gas under standard conditions nevertheless, it would be one of the densest gaseous substances at standard conditions (even if it is monatomic like the other noble gases).

Because of its tremendous polarizability, ununoctium is expected to have an anomalously low ionization energy (similar to that of lead which is 70% of that of radon^[5] and significantly smaller than that of flerovium^[53]) and a standard state condensed phase.^[1]

*XeF*

4 has a square planar configuration.

*UuoF*

4 is predicted to have a tetrahedral configuration.

Predicted compounds

No compounds of ununoctium have been synthesized yet, but calculations on theoretical compounds have been performed since 1964.^[31] It is expected that if the ionization energy of the element is high enough, it will be difficult to oxidize and therefore, the most common oxidation state will be 0 (as for other noble gases);^[54] nevertheless, this appears not to be the case.^[7]

Calculations on the diatomic molecule Uuo₂ showed a bonding interaction roughly equivalent to that calculated for Hg₂, and a dissociation energy of 6 kJ/mol, roughly 4 times of that of Rn₂.^[1] But most strikingly, it was calculated to have a bond length shorter than in Rn₂ by 0.16 Å, which would be indicative of a significant bonding interaction.^[1] On the other hand, the com-

pound UuoH⁺ exhibits a dissociation energy (in other words proton affinity of Uuo) that is smaller than that of RnH⁺.^[1]

The bonding between ununoctium and hydrogen in UuoH is predicted to be very limp and can be regarded as a pure van der Waals interaction rather than a true chemical bond.^[5] On the other hand, with highly electronegative elements, ununoctium seems to form more stable compounds than for example copernicium or flerovium.^[5] The stable oxidation states +2 and +4 have been predicted to exist in the fluorides UuoF₂ and UuoF₄.^[55]

The +6 state would be less stable due to the strong binding of the 7p_{1/2} subshell.^[7] This is a result of the same spin-orbit interactions that make ununoctium unusually reactive. For example, it was shown that the reaction of ununoctium with F₂ to form the compound UuoF₂ would release an energy of 106 kcal/mol of which about 46 kcal/mol come from these interactions.^[5] For comparison, the spin-orbit interaction for the similar molecule RnF₂ is about 10 kcal/mol out of a formation energy of 49 kcal/mol.^[5]

The same interaction stabilizes the tetrahedral T_d configuration for UuoF₄, as distinct from the square planar D_{4h} one of XeF₄, which RnF₄ is also expected to have.^[55]

The Uuo–F bond will most probably be ionic rather than covalent, rendering the UuoFn compounds non-volatile.^{[6][56]} UuoF₂ is predicted to be partially ionic due to ununoctium's high electropositivity.^[57] Unlike the other noble gases (except possibly xenon),^{[58][59]} ununoctium was predicted to be sufficiently electropositive^[57] to form a Uuo–Cl bond with chlorine.^[6]

2.7.4 See also

- Transactinide element
- Transuranic element


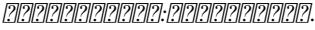
2.7.5 Notes

- [1] The actual quote is “The reason for the apparent enhancement of chemical activity of element 118 relative to radon is the energetic destabilization and radial expansion of its occupied 7p_{3/2} spinor shell.”
- [2] Nevertheless, quantum electrodynamic corrections have been shown to be quite significant in reducing this affinity by decreasing the binding in the anion Uuo[−] by 9%, thus confirming the importance of these corrections in superheavy elements. See Pyykkö.
- [3] It is debatable if the name of the group “noble gases” will be changed if ununoctium is shown to be non-volatile.

2.7.6 References

- [1] Nash, Clinton S. (2005). "Atomic and Molecular Properties of Elements 112, 114, and 118". *Journal of Physical Chemistry A* **109** (15): 3493–3500. doi:10.1021/jp050736o. PMID 16833687.
- [2] Haire, Richard G. (2006). "Transactinides and the future elements". In Morss; Edelstein, Norman M.; Fuger, Jean. *The Chemistry of the Actinide and Transactinide Elements* (3rd ed.). Dordrecht, The Netherlands: Springer Science+Business Media. p. 1724. ISBN 1-4020-3555-1.
- [3] Bonchev, Danail; Kamenska, Verginia (1981). "Predicting the Properties of the 113–120 Transactinide Elements". *Journal of Physical Chemistry (American Chemical Society)* **85** (9): 1177–1186. doi:10.1021/j150609a021.
- [4] Eichler, R.; Eichler, B., *Thermochemical Properties of the Elements Rn, 112, 114, and 118* (PDF), Paul Scherrer Institut, retrieved 2010-10-23
- [5] Han, Young-Kyu; Bae, Cheolbeom; Son, Sang-Kil; Lee, Yoon Sup (2000). "Spin-orbit effects on the transactinide p-block element monohydrides MH (M=element 113–118)". *Journal of Chemical Physics* **112** (6): 2684. Bibcode:2000JChPh.112.2684H. doi:10.1063/1.480842.
- [6] Kaldor, Uzi; Wilson, Stephen (2003). *Theoretical Chemistry and Physics of Heavy and Superheavy Elements*. Springer. p. 105. ISBN 140201371X. Retrieved 2008-01-18.
- [7] Fricke, Burkhard (1975). "Superheavy elements: a prediction of their chemical and physical properties". *Recent Impact of Physics on Inorganic Chemistry* **21**: 89–144. doi:10.1007/BFb0116498. Retrieved 4 October 2013.
- [8] Chemical Data. Ununocium - Uuo, Royal Chemical Society
- [9] "Ununocium". WebElements Periodic Table. Retrieved 2007-12-09.
- [10] Oganessian, Yu. Ts.; Utyonkov, V. K.; Lobanov, Yu. V.; Abdullin, F. Sh.; Polyakov, A. N.; Sagaidak, R. N.; Shirokovsky, I. V.; Tsyganov, Yu. S.; Voinov, A. A.; Gulbekian, G. G.; Bogomolov, S. L.; Gikal, B. N.; Mezentssev, A. N.; Iliev, S.; Subbotin, V. G.; Sukhov, A. M.; Subotic, K.; Zagrebaev, V. I.; Vostokin, G. K.; Itkis, M. G.; Moody, K. J.; Patin, J. B.; Shaughnessy, D. A.; Stoyer, M. A.; Stoyer, N. J.; Wilk, P. A.; Kenneally, J. M.; Landrum, J. H.; Wild, J. F.; Loughheed, R. W. (2006-10-09). "Synthesis of the isotopes of elements 118 and 116 in the ^{249}Cf and $^{245}\text{Cm}+^{48}\text{Ca}$ fusion reactions". *Physical Review C* **74** (4): 044602. Bibcode:2006PhRvC..74d4602O. doi:10.1103/PhysRevC.74.044602. Retrieved 2008-01-18.
- [11] Wieser, M.E. (2006). "Atomic weights of the elements 2005 (IUPAC Technical Report)". *Pure Appl. Chem.* **78** (11): 2051–2066. doi:10.1351/pac200678112051.
- [12] "The Top 6 Physics Stories of 2006". Discover Magazine. 2007-01-07. Retrieved 2008-01-18.
- [13] Smolanczuk, R. (1999). "Production mechanism of superheavy nuclei in cold fusion reactions". *Physical Review C* **59** (5): 2634–2639. Bibcode:1999PhRvC..59.2634S. doi:10.1103/PhysRevC.59.2634.
- [14] Ninov, Viktor (1999). "Observation of Superheavy Nuclei Produced in the Reaction of ^{86}Kr with ^{208}Pb ". *Physical Review Letters* **83** (6): 1104–1107. Bibcode:1999PhRvL..83.1104N. doi:10.1103/PhysRevLett.83.1104.
- [15] Service, R. F. (1999). "Berkeley Crew Bags Element 118". *Science* **284** (5421): 1751. doi:10.1126/science.284.5421.1751.
- [16] Public Affairs Department (2001-07-21). "Results of element 118 experiment retracted". Berkeley Lab. Retrieved 2008-01-18.
- [17] Dalton, R. (2002). "Misconduct: The stars who fell to Earth". *Nature* **420** (6917): 728–729. Bibcode:2002Natur.420..728D. doi:10.1038/420728a. PMID 12490902.
- [18] Element 118 disappears two years after it was discovered. Physicsworld.com. Retrieved on 2012-04-02.
- [19] Oganessian, Yu. T. et al. (2002). "Results from the first 249 Cf+48 Ca experiment" (PDF). *JINR Communication* (JINR, Dubna).
- [20] Oganessian, Yu. T. et al. (2002). "Element 118: results from the first 249Cf + 48Ca experiment". Communication of the Joint Institute for Nuclear Research.
- [21] "Livermore scientists team with Russia to discover element 118". Livermore press release. 2006-12-03. Retrieved 2008-01-18.
- [22] Oganessian, Yu. T. (2006). "Synthesis and decay properties of superheavy elements". *Pure Appl. Chem.* **78** (5): 889–904. doi:10.1351/pac200678050889.
- [23] Sanderson, K. (2006). "Heaviest element made – again". *Nature News* (Nature). doi:10.1038/news061016-4.
- [24] Schewe, P. & Stein, B. (2006-10-17). "Elements 116 and 118 Are Discovered". *Physics News Update*. American Institute of Physics. Retrieved 2008-01-18.
- [25] Weiss, R. (2006-10-17). "Scientists Announce Creation of Atomic Element, the Heaviest Yet". Washington Post. Retrieved 2008-01-18.
- [26] Barber, Robert C.; Karol, Paul J.; Nakahara, Hiromichi; Vardaci, Emanuele; Vogt, Erich W. (2011). "Discovery of the elements with atomic numbers greater than or equal to 113 (IUPAC Technical Report)". *Pure and Applied Chemistry* **83** (7): 1. doi:10.1351/PAC-REP-10-05-01.
- [27] "Element 118 Detected, With Confidence". Chemical and Engineering news. 2006-10-17. Retrieved 2008-01-18. I would say we're very confident.

- [28] Chowdhury, Roy P.; Samanta, C.; Basu, D. N. (2006). " α decay half-lives of new superheavy elements". *Phys. Rev. C* **73**: 014612. arXiv:nucl-th/0507054. Bibcode:2006PhRvC..73a4612C. doi:10.1103/PhysRevC.73.014612.
- [29] Oganessian, Yu. Ts.; Utyonkov, V.; Lobanov, Yu.; Abdullin, F.; Polyakov, A.; Shirokovsky, I.; Tsyganov, Yu.; Gulbekian, G.; Bogomolov, S.; Gikal, B. N. et al. (2004). "Measurements of cross sections and decay properties of the isotopes of elements 112, 114, and 116 produced in the fusion reactions $^{233,238}\text{U}$, ^{242}Pu , and $^{248}\text{Cm}+^{48}\text{Ca}$ ". *Physical Review C* **70** (6): 064609. Bibcode:2004PhRvC..70f4609O. doi:10.1103/PhysRevC.70.064609.
- [30] Samanta, C.; Chowdhury, R. P.; Basu, D.N. (2007). "Predictions of alpha decay half-lives of heavy and superheavy elements". *Nucl. Phys. A* **789**: 142–154. arXiv:nucl-th/0703086. Bibcode:2007NuPhA.789..142S. doi:10.1016/j.nuclphysa.2007.04.001.
- [31] Grosse, A. V. (1965). "Some physical and chemical properties of element 118 (Eka-Em) and element 86 (Em)". *Journal of Inorganic and Nuclear Chemistry* (Elsevier Science Ltd.) **27** (3): 509–19. doi:10.1016/0022-1902(65)80255-X.
- [32] Chatt, J. (1979). "Recommendations for the Naming of Elements of Atomic Numbers Greater than 100". *Pure Appl. Chem.* **51** (2): 381–384. doi:10.1351/pac197951020381.
- [33] "Discovery of New Elements Makes Front Page News". Berkeley Lab Research Review Summer 1999. 1999. Retrieved 2008-01-18.
- [34] "New chemical elements discovered in Russia's Science City". 2007-02-12. Retrieved 2008-02-09.
- [35] Yemel'yanova, Asya (2006-12-17). "118-й элемент назовут по-русски (118th element will be named in Russian)" (in Russian). vesti.ru. Retrieved 2008-01-18.
- [36] "Российские физики предложат назвать 116 химический элемент московием (Russian Physicists Will Suggest to Name Element 116 Moscovium)" (in Russian). rian.ru. 2011. Retrieved 2011-05-08.
- [37] "News: Start of the Name Approval Process for the Elements of Atomic Number 114 and 116". *International Union of Pure and Applied Chemistry*. Retrieved 2011-12-02.
- [38] Koppenol, W. H. (2002). "Naming of new elements (IUPAC Recommendations 2002)" (PDF). *Pure and Applied Chemistry* **74** (5): 787. doi:10.1351/pac200274050787.
- [39] de Marcillac, Pierre; Coron, Noël; Dambier, Gérard; Leblanc, Jacques; Moalic, Jean-Pierre (April 2003). "Experimental detection of α -particles from the radioactive decay of natural bismuth". *Nature* **422** (6934): 876–878. Bibcode:2003Natur.422..876D. doi:10.1038/nature01541. PMID 12712201.
- [40] Considine, Glenn D.; Kulik, Peter H. (2002). *Van Nostrand's scientific encyclopedia* (9th ed.). Wiley-Interscience. ISBN 978-0-471-33230-5. OCLC 223349096.
- [41] Oganessian, Yu. T. (2007). "Heaviest nuclei from 48Ca-induced reactions". *Journal of Physics G: Nuclear and Particle Physics* **34** (4): R165–R242. Bibcode:2007JPhG...34..165O. doi:10.1088/0954-3899/34/4/R01.
- [42] "New Element Isolated Only Briefly". *The Daily Californian*. 2006-10-18. Retrieved 2008-01-18.
- [43] Chowdhury, Roy P.; Samanta, C.; Basu, D. N. (2008). "Search for long lived heaviest nuclei beyond the valley of stability". *Physical Reviews C* **77** (4): 044603. arXiv:0802.3837. Bibcode:2008PhRvC..77d4603C. doi:10.1103/PhysRevC.77.044603.
- [44] Chowdhury, R. P.; Samanta, C.; Basu, D.N. (2008). "Nuclear half-lives for α -radioactivity of elements with $100 \leq Z \leq 130$ ". *At. Data & Nucl. Data Tables* **94** (6): 781–806. arXiv:0802.4161. Bibcode:2008ADNDT..94..781C. doi:10.1016/j.adt.2008.01.003.
- [45] Royer, G.; Zbiri, K.; Bonilla, C. (2004). "Entrance channels and alpha decay half-lives of the heaviest elements". *Nuclear Physics A* **730** (3–4): 355–376. arXiv:nucl-th/0410048. Bibcode:2004NuPhA.730..355R. doi:10.1016/j.nuclphysa.2003.11.010.
- [46] Duarte, S. B.; Tavares, O. A. P.; Gonçalves, M.; Rodríguez, O.; Guzmán, F.; Barbosa, T. N.; García, F.; Dimarco, A. (2004). "Half-life predictions for decay modes of superheavy nuclei". *Journal of Physics G: Nuclear and Particle Physics* **30** (10): 1487–1494. Bibcode:2004JPhG...30.1487D. doi:10.1088/0954-3899/30/10/014.
- [47] Bader, Richard F.W. "An Introduction to the Electronic Structure of Atoms and Molecules". McMaster University. Retrieved 2008-01-18.
- [48] "Ununoctium (Uuo) – Chemical properties, Health and Environmental effects". Lenntech. Archived from the original on January 16, 2008. Retrieved 2008-01-18.
- [49] Goidenko, Igor; Labzowsky, Leonti; Eliav, Ephraim; Kaldor, Uzi; Pyykko, Pekka (2003). "QED corrections to the binding energy of the eka-radon ($Z=118$) negative ion". *Physical Review A* **67** (2): 020102(R). Bibcode:2003PhRvA..67b0102G. doi:10.1103/PhysRevA.67.020102.
- [50] Eliav, Ephraim; Kaldor, Uzi; Ishikawa, Y; Pyykko, P (1996). "Element 118: The First Rare Gas with an Electron Affinity". *Physical Review Letters* **77** (27): 5350–5352. Bibcode:1996PhRvL..77.5350E. doi:10.1103/PhysRevLett.77.5350. PMID 10062781.
- [51] Seaborg, Glenn Theodore (1994). *Modern Alchemy*. World Scientific. p. 172. ISBN 981-02-1440-5.
- [52] Takahashi, N. (2002). "Boiling points of the superheavy elements 117 and 118". *Journal of Radioanalytical and Nuclear Chemistry* **251** (2): 299–301. doi:10.1023/A:1014880730282.

- [53] Nash, Clinton S.; Bursten, Bruce E. (1999). "Spin-Orbit Effects, VSEPR Theory, and the Electronic Structures of Heavy and Superheavy Group IVA Hydrides and Group VIIIA Tetrafluorides. A Partial Role Reversal for Elements 114 and 118". *Journal of Physical Chemistry A* **1999** (3): 402–410. doi:10.1021/jp982735k.
- [54] "Ununoctium: Binary Compounds". WebElements Periodic Table. Retrieved 2008-01-18.
- [55] Han, Young-Kyu; Lee, Yoon Sup (1999). "Structures of RgFn (Rg = Xe, Rn, and Element 118. n = 2, 4.) Calculated by Two-component Spin-Orbit Methods. A Spin-Orbit Induced Isomer of (118)F₄". *Journal of Physical Chemistry A* **103** (8): 1104–1108. doi:10.1021/jp983665k.
- [56] Pitzer, Kenneth S. (1975). "Fluorides of radon and element 118". *Journal of the Chemical Society, Chemical Communications* (18): 760–761. doi:10.1039/C3975000760b.
- [57] Seaborg (c. 2006). "transuranium element (chemical element)". Encyclopædia Britannica. Retrieved 2010-03-16.
- [58]  (November 1991).  Beijing: Science Press. pp. P72. ISBN 7-03-002238-6.
- [59] Proserpio, Davide M.; Hoffmann, Roald; Janda, Kenneth C. (1991). "The xenon-chlorine conundrum: van der Waals complex or linear molecule?". *Journal of the American Chemical Society* **113** (19): 7184. doi:10.1021/ja00019a014.

2.7.7 Further reading

- Eric Scerri, *The Periodic Table, Its Story and Its Significance*, Oxford University Press, New York, 2007.

2.7.8 External links

- Element 118: experiments on discovery, archive of discoverers' official web page
- Chemistry Blog: Independent analysis of 118 claim
- It's Elemental: Ununoctium
- Ununoctium at *The Periodic Table of Videos* (University of Nottingham)
- On the Claims for Discovery of Elements 110, 111, 112, 114, 116, and 118 (IUPAC Technical Report)
- "Element 118, Heaviest Ever, Reported for 1,000th of a Second", NYTimes.com.
- WebElements: Ununoctium

Chapter 3

Text and image sources, contributors, and licenses

3.1 Text

- **Noble gas** *Source:* <http://en.wikipedia.org/wiki/Noble%20gas?oldid=660819900> *Contributors:* AxelBoldt, Carey Evans, Derek Ross, LC-enwiki, Mav, Tarquin, Andre Engels, Christian List, DrBob, Fonzy, Hephaestos, Olivier, Edward, Shellreef, Ahoerstemeier, Jimfbleak, Rlandmann, Salsa Shark, Nikai, GCarty, Smack, Lenaic, Stone, Jake Nelson, Tero-enwiki, Paul-L-enwiki, Taoster, Betterworld, Fvw, Shantavira, Donarreiskoffer, Gentgeen, Robbot, Sander123, Jakohn, Romanm, Merovingian, Rfc1394, Flauto Dolce, Meelar, Mervyn, Hadal, JackofOz, Robinh, Lupo, Dina, Giftlite, DocWatson42, Herbee, Monedula, Karn, Everyking, Slyguy, Kandar, Quackor, Andycjp, Antandrus, 1297, Icairns, Sam Hocevar, Gscshoyru, Deglr6328, Adashiel, Mike Rosoft, DanielCD, Discospinster, Rich Farmbrough, Vsmith, Ponder, Paul August, NeilTarrant, Geoking66, RJHall, El C, Dnwq, Shanes, Remember, Sietse Snel, Art LaPella, Femto, Marco Polo, Shenme, Viriditas, SpeedyGonsales, Severious, Obradovic Goran, Haham hanuka, Nsaa, Eddideigel, Orangemarlín, Ranveig, Jumbuck, Alansohn, Gary, Jared81, Keenan Pepper, Plumbago, Cjthellama, InShanee, Suruena, Vuo, Gene Nygaard, Feline1, Kay Dekker, Boothy443, Woohookitty, Cimex, TarmoK, LOL, Pol098, WadeSimMiser, Mpatel, Wayward, Shanedidona, Palica, Stevey7788, Paxsimius, Graham87, David Levy, DePiep, Canderson7, Rjwilmsi, Mfwills, Vary, HappyCamper, Matjlav, Vuong Ngan Ha, RobertG, Latka, NihilTres, Strangnet, RexNL, Mjp797, DevastatorIIC, Goudzovski, Scerri, Kri, King of Hearts, Chobot, DVdm, Bgwhite, Eamon-nPKeane, YurikBot, Chaser, Ollie holton, Yyy, NawlinWiki, Bachrach44, Jaxl, Adamn, Semperf, Zirland, Bota47, T-rex, Thetoaster3, Wknight94, Tetracube, Leptictidium, Phgao, Zzuuzz, Adilch, Scoutersig, Keepiru, HereToHelp, Katieh5584, NeilN, GrinBot-enwiki, DVD R W, Tom Morris, That Guy, From That Show!, Itub, Anthony Duff, SmackBot, FocalPoint, Tarret, KnowledgeOfSelf, Shoy, Kilo-Lima, Edgar181, Gaff, Aksi great, Gilliam, Isaac Dupree, Pslawinski, Durova, Bluebot, Bduke, SchfiftyThree, Moshe Constantine Hassan Al-Silverburg, CSWarren, Robth, DHN-bot-enwiki, DARTH Panda, Gyrobo, Tsca.bot, Eric Olson, MJCdetroit, Rrburke, Aldaron, Nakon, Eganev, Pwjb, Smokefoot, DMacks, Wizardman, The undertow, SashatoBot, Lambiam, Krashlandon, Titus III, John, Zaphrad, Jaganath, Breno, Anoop.m, IronGargoyle, JHunterJ, Slakr, Beetstra, Noah Salzman, Optimale, Kpengboy, SandyGeorgia, AdultSwim, MTSbot-enwiki, BranStark, Iridescent, StephenBuxton, Jaksmata, Tawkerbot2, Swampgas, JForget, Irwangatot, Ruslik0, CompRhetoric, Dorothybaez, Bentleymrk, Gogo Dodo, A Softer Answer, Hibou8, SteveMcCluskey, Mattisse, Thijs!bot, Epr123, Kablammo, Headbomb, JaimeAnnaMoore, Straussian, Werdnanoslen, Dantheman531, Mentifisto, AntiVandalBot, Luna Santin, Opelio, Cinnamon42, Scepia, LibLord, Xnuiem, Gökhan, IanOsgood, Nicholas Tan, Easchiff, Animaly2k2, Magioladitis, Bongwarrior, VoABot II, Hasek is the best, Ling.Nut, LorenzoB, Thibbs, Vssun, DerHexer, JaGa, Awolnetdiva, Mattinbgn, Hdt83, ChemNerd, Polartsang, CommonsDelinker, AlexiusHoratius, Leyo, J.delanoy, Pharaoh of the Wizards, Phillip.northfield, Hans Dunkelberg, Dhruv17singhal, Uncle Dick, Jeri Aulurtve, Extransit, Cpiral, Bombhead, Wandering Ghost, Shay Guy, Coppertwig, Plasticup, Andraaide, Belovedfreak, Acey365, NewEnglandYankee, Najlepszy, Numerjeden, Matthardingu, KChiu7, WinterSpw, Brvman, Wilhelm meis, Squids and Chips, Idioma-bot, Wikieditor06, Deor, VolkovBot, Eakka, JGHowes, Jeff G., Chris Dybala, AlnoktaBOT, Nousearnamesleft, Philip Trueman, Photonikonman, TXiKiBoT, Tavix, GimmeBot, Muro de Aguas, Rei-bot, Slysplace, Enigmaman, Davidmwhite, CephasE, Sylent, TinribsAndy, Owainbut, AlleborgoBot, Surfrat60793, SieBot, Calliopejen1, OTAVIO1981, Graham Beards, BotMultichill, ToePeu.bot, Jauerback, Nathan, Triwbe, Agesworth, Keilana, The Evil Spartan, Arbor to SJ, Sohelpme, Scorpion451, Enok Walker, Lightmouse, OKBot, Nielg, Nimbusania, Nergaal, Escape Orbit, PerpetualSX, Runtishpaladin, UKe-CH, Martarius, ClueBot, Artichoker, The Thing That Should Not Be, Cygnis insignis, Manbearpig4, Franamax, Blanchardb, Piledhigheranddeeper, ChandlerMapBot, Puchiko, DragonBot, Excirial, Sidias300, GngstrMKNKY, Jusdafax, Finch-HIMself, Estirabot, Poigol5043, Cenarium, Zomno, Jotterbot, Bellax22, Chaser (away), Werson, Boatcolour, SeanFarris, Thingg, Aitias, Dank, Versus22, Rexas, Boleyn, Neuralwarp, Feinoha, Little Mountain 5, Skarebo, Froot, Freestyle-69, CalumH93, Addbot, Mr0t1633, Roentgenium111, DOI bot, Theleftorium, Popopee, Ronhjones, Jncraton, Mooshadley, CanadianLinuxUser, AnnaFrance, Jasper Deng, Alchemist-hp, Numbo3-bot, Tide rolls, Zorrobot, Angrysockhop, Arimareiji, Legobot, Seresin.public, Luckas-bot, ZX81, Yobot, IsFari, TaBOT-zerem, Rshire3, Bloody Mary (folklore), KamikazeBot, Widey, Synchronism, Andme2, AnomieBOT, Lol-copter666, Jcsdude, Navneethmohan, Jim1138, IRP, Law, MaterialsScientist, Citation bot, E2eamon, Maxis ftw, ArthurBot, Xqbot, Capricorn42, Nickkid5, Tad Lincoln, Turk oĝlan, NocturneNoir, Lop242438, Pmlineditor, GrouchoBot, Doulos Christos, Antonjad, Jilkmarine, Smot94, Robo37, OgreBot, Citation bot 1, AstaBOTh15, Pinethicket, HRoestBot, Calmer Waters, I own in the bed, Marine79, Double sharp, TobeBot, Yopure, Navy101, Reach Out to the Truth, Minimac, DARTH SIDIOUS 2, AXRL, RjwilmsiBot, Japheth the Warlock, Ripchip Bot, Salvio giuliano, Deagle AP, EmausBot, WikitanvirBot, RA0808, Jordan776, Wikipelli, P. S. F. Freitas, AvicBot, ZéroBot, Fingerginger1, Maxviwe, StringTheory11, H3llBot, Makecat, Wagino 20100516, L Kensington, Donner60, Whoop whoop pull up, JohnM-Crain, Mjbrbot, Special Cases, Washington Irving Esquire, ClueBot NG, Rich Smith, Jack Greenmaven, Hon-3s-T, Skoot13, Ethanpiot, Lanthanum-138, Widr, Lolm8, Bibcode Bot, Swampphlosion, Lowercase sigmabot, Gluonman, TCN7JM, Iankhou, Sandbh, MusikAnimal, Altaïr, WikisucksKNOBLEgasses, VictorParker, Jimbo2440, Tycho Magnetic Anomaly-1, Softballbaby984, ThomasRules, BattyBot,

Justincheng12345-bot, Abilinin, ChrisGualtieri, EuroCarGT, Dexbot, Webclient101, TwoTwoHello, King jakob c, RandomLittleHelper, Reatlas, Cteung, Ugog Nizdast, Ginsuloft, Noyster, DudeWithAFeud, Skr15081997, Matthewweber12, HotHabenero, Hotta stuffu, Sony Vark XIII, Monkbot, HiYahhFriend, ZYjacklin, Narky Blert, Jodihe93, Selimozd20, Anbgsm07, UZawMoeNaing, SandKitty256 and Anonymous: 586

- Helium** Source: <http://en.wikipedia.org/wiki/Helium?oldid=660903207> Contributors: Kpjas, CYD, Mav, Bryan Derksen, The Anome, Ap, Malcolm Farmer, Andre Engels, Josh Grosse, Christian List, William Avery, Roadrunner, SimonP, Ktsquare, Fonzy, Edward, Patrick, RTC, D, Erik Zachte, Breakpoint, Tannin, Ixfd64, Dcljr, GTBacchus, Gbleem, Eric119, Iluvcapra, Minesweeper, Tregoweth, Ahoerstemeier, Pjamescowie, Ronz, Mgimpel-enwiki, Theresa knott, Snoyes, CatherineMunro, TUF-KAT, Suisui, Bueller 007, Darkwind, Aarchiba, Александър, Julesd, Susurrrus, Kwekubo, Andres, Evercat, Palmpilot900, Mxn, BRG, Schneelocke, Arteitle, Emperorbma, Malbi, EL Willy, Stone, David Latapie, Fuzheado, Doradus, Selket, Maximus Rex, Sboehringer, Furrykef, Grendelkhan, SEWilco, Fibonacci, Omegatron, Thomasedavis, Thue, Traroth, Pstudier, Pakaran, Pumpie, Denelson83, Twang, Phil Boswell, Chuunen Baka, Donarreiskoffer, Robbot, Fredrik, Altenmann, Netizen, Nurg, Romann, Naddy, Smallweed, Merovingian, Lsy098-enwiki, Rurus, Auric, Blainster, DataSurfer, Raeky, Xanzzibar, Pengo, Carnildo, Davidcannon, David Gerard, Matt Gies, Centrx, Giftlite, Smjg, Graeme Bartlett, Mat-C, Art Carlson, Lupin, Aphaia, Herbee, Cool Hand Luke, Mark.murphy, Xerxes314, Everyking, Aoi, Jorend, Varlaam, F. Delpierre, Guanaco, Fak119, Darrien, PlatinumX, Jackol, Pne, Bobblewik, Tagishsimon, ALargeElk, Isidore, Utorsch, Pgan002, Zeimusu, Slowing Man, Yath, Quadell, Antandrus, Beland, Blazotron, Jossi, Exigentsky, H Padleckas, Tomruen, Lawnchair, Icairns, Karl-Henner, Sam Hocevar, J0m1e1sler, Elwell, Iantresman, Urhixidur, Joyous!, Wyllium, Andy Christ, Deglr6328, Adashiel, Jimaginator, Freakofnurture, Mindspillage, Noisy, Discospinster, Rich Farmbrough, Guanabot, Qutezuze, TrbleClef, Vsmith, Uppland, Paul August, SpookyMulder, DcoetzeeBot-enwiki, Bender235, Sunborn, BlueNight, Syp, RJHall, El C, Kwamikagami, Remember, Sietse Snel, RoyBoy, Femto, CDN99, Diamonddavej, Bobo192, Army1987, Harley peters, Fir0002, Apollo2011, Adrian-enwiki, Daniel Medina, Redquark, A2Kafir, Passw0rd, Alansohn, DaniellC, Plumbago, Sl, AzaToth, Lightdarkness, Viridian, Dark Shikari, Mlm42, Bantman, KingTT, Rebroad, Suruena, Mikeo, Vuo, Itsmine, Gene Nygaard, Netkinetic, Mow-Cow-enwiki, Ceyockey, Forderud, Kay Dekker, Adrian.benko, Ron Ritzman, Flying fish, Dejvid, Megan1967, Woohookitty, Henrik, JarlaxleArtemis, LOL, Pinball22, Adamgarrigus, Swiftblade21, Benbest, Ruud Koot, MONGO, Stevedegrace, Sdgjake, Asdert, The Jacobin, Steinbach, Sengkang, BlaiseFEgan, El Suizo, SDC, Jimstoic, Brendanconway, Wayward, Mandarax, Jan.bannister, Ashmoo, Graham87, Magister Mathematicae, Jan van Male, DePiep, Pmj, Saperaud-enwiki, Rjwilmsi, Isaac Rabinovitch, Joffan, Jibco, Strait, Ikh, MZMcBride, SpNeo, Oblivious, HappyCamper, Ligulem, Tintazul, Brighterorange, Krash, Cryonic Mammoth, Splarka, RobertG, Ground Zero, Old Moonraker, Musser, Nihiltres, JiFish, Nivix, RexNL, Gurch, Joedeshon, Srleffler, Physchim62, Alphus, King of Hearts, Chobot, Flying Jazz, Jaraalbe, Gwernol, The Rambling Man, MDM, Wavelength, KKM, JWB, Rt66lt, Jimp, Joborrett, Bergsten, SpuriousQ, Stephenb, Gaius Cornelius, CambridgeBayWeather, Shaddack, Rsrkanth05, Wimt, GeeJo, K.C. Tang, NawlinWiki, Wiki alf, Janke, Badagnani, Jaxl, LiamE, Brian Crawford, Daniel Mietchen, Raven4x4x, Dank235, Gerard.Newman, Misza13, Semperf, Tony1, Aaron Schulz, BOT-Superzerocool, Gadget850, Bigrich, Elkman, Somoza, Stefan Udrea, Tetracube, Mütze, J. Nguyen, Mythobeast, GreatAlfredini, Zzuuzz, Ageekgal, Theda, Closedmouth, Nemu, Petri Krohn, Luiscolorado, Curpsbot-unicodify, Johnpseudo, Allens, TLSuda, Whitehat101, Airconswitch, Mejor Los Indios, DVD R W, AndrewWTaylor, ChemGadener, Itub, SmackBot, Theasus, Unschool, Ashill, Reedy, KnowledgeOfSelf, Pgg, Davewild, AndreasJS, Piksi, Jfurr1981, KVDP, Delddot, Veestic, Canthusus, Jpvinall, Edgar181, HalfShadow, Alsandor, Iantnm, Ravenmasterq, Ohnoitsjamie, Aaron of Mpls, Andy M. Wang, Pslawinski, Wikicali00, Chris the speller, Michbich, IvanAndreevich, Agateller, Persian Poet Gal, Dr bab, Thumperward, Ph7five, Droll, Moshe Constantine Hassan Al-Silverburg, Delinck, ARM-enwiki, DHN-bot-enwiki, Sbharris, Colonies Chris, William Allen Simpson, DARTH Panda, Gyrobo, MaxSem, Scwlong, Xchbla423, Shalom Yechiel, Njål, Vladislav, Gurps npc, Rrburke, TKD, Ddbd, Mbertsch, Addshore, Kcordina, Aldaron, Robma, Cybercobra, Khukri, Nakon, IrisKawling, Andrew c, BrentRockwood, DMacks, Jeremyb, Acdx, PeterJeremy, Triforce of Power, Captainbeefart, Pilotguy, Kukini, Drunken Pirate, Deathregis, Nishkid64, Xdamr, Archimerged, Soap, Richard L. Peterson, John, Timdownie, Scientizzle, Matanzb, Shadowlynk, Anoop.m, JorisvS, Niczar, Ocatecir, Jrouquie, Eivind F Øyangen, Smith609, Volatileacid, Slakr, Werdan7, Beetstra, Bendzh, Stizz, SandyGeorgia, Mets501, Jose77, Caiaffa, Norm mit, Ossipewsk, Iridescent, Electrified mocha chinchilla, Pooua, Ewulp, Buckyboy314, Courcelles, Thricecube, Pjbflynn, Tawkerbot2, Dlohcierekim, Cryptic C62, Poolkris, Randroide, HDCase, KangKnight, Xcentaur, JForget, Ericlaw02, Scohoust, Megaboz, Ruslik0, DeepSkyFrontier, NickW557, Smallpond, Skybon, Myasuda, Cydebot, Abeg92, Reywas92, Dominicanpapi82, Rifleman 82, Not me, Llort, Ericagol, Racecarr, DumbBOT, Chrislk02, Iempleh, Daven200520, Brad101, Omicronpersei8, Tunheim, Thijs!bot, Eprb123, Opabinia regalis, Pajz, Headbomb, Frank, Electron9, James086, Doyley, Tellyaddict, Grayshi, CharlotteWebb, Greg L, Sikkema, DPdH, Dr. Zaret, Natalie Erin, RoboServien, Escarbot, AntiVandalBot, Luna Santin, Widefox, Opelio, QuiteUnusual, VmoSW, James Slezak, Tmpoksin, Tjmayerinsf, Gregorof, Badocher, Dougher, Corey Bryant, Zidane tribal, Myanov, Canadian-Bacon, Res2216firestar, JAnDbot, Dan D. Ric, Defective, Em3ryguy, Davewho2, Scasey1960, MER-C, Plantsurfer, ZZninepluralZalpha, QuantumEngineer, Andonic, Igodard, Belg4mit, Denimadept, Samjohnson, Karlhahn, Swikid, Bennybp, VoABot II, Hasek is the best, JamesBWatson, Kajasudhakarababu, بیاسم, Eng02019-enwiki, Nyttend, Baccyak4H, Avicennasis, Dirac66, Sultanofsurreal, User A1, Musicloudball, Scot.parker, Vssun, DerHexer, Edward321, Textorus, Labmunkay, MartinBot, Ariel., Arjun01, Nikpapag, Jay Litman, Gsrzdl, CommonsDelinker, AlexiusHoratius, Leyo, Jacobst, Cyrus Andiron, Watch37264, J.delanoy, DrKiernan, Trusilver, Clyrenternal, Bogeyp97, Keithkml, L337 kyblmstr, Gzkn, FrummerThanThou, RichardEil, Bot-Schafter, LordAnubisBOT, Gman124, McSly, Slippeded sleep, Skier Dude, Toadburger, Coptertwig, ColinClark, Bumble11, HiLo48, Rossenglish, Warut, Belovedfreak, WaltTFB, Trilobitealive, Richard Wolf VI, Atropos235, Puddytang, Tvbrichmond, Moondoll, Mike V, JavierMC, Ronbo76, Dissfigured, Xiahou, Squids and Chips, Aznhellboi, Steel1943, DraxusD, Idioma-bot, Harrison.grant, Nuala, Vitamins13, Geosultan4, Black Kite, EcoRover, Legoland12342, Deor, Derain, VolkovBot, Thedjatclubrock, Rose10, Jeff G., Indubitably, Chris Dybala, Alexandria, AlnoktaBOT, Cadby Waydell Bainbrydge, Gene Hobbs, Philip Trueman, TXiKiBoT, Dajwilkinson, DUBJAY04, GroveGuy, Rett Mikhal, Technopat, Tomsega, Rei-bot, Anonymous Dissident, Piperh, Lexington50, Lradrama, Gekritzl, LeaveSleaves, Psyche825, Seb az86556, Bobthellemu, Hrundi Bakshi, Senilebiker, Evil-Azn-Imperial, Evil dude69, Madhero88, Plazak, Daryan-enwiki, Viktor-viking, Deansinclair, Falcon8765, Enviroboy, Spinningspark, Davidsaker, WatermelonPotion, Ceranthor, Edkollin, Sue Rangell, LuigiManiac, NHRHS2010, EmxBot, SieBot, Jauerback, Krawi, Dragonic2020, Jbmurray, Caltas, RJaguar3, Triwbe, Keilana, Happysailor, Radon210, Aravindk editing, Arjen Dijkman, Oxymoron83, Enok Walker, Lightmouse, Techman224, Grunkhead, Maelgwnbot, Kutera Genesis, Tesi1700, Hyperionsteel, Dabomb87, PerryTachett, Nergaal, Denisarona, A.C. Norman, Jacob Myers, The sunder king, SallyForth123, FaithlessTheWonderboy, Martarius, ClueBot, Safebreaker, Robcat2075, Deanlaw, The Thing That Should Not Be, Blatv, John.D.Ward, Hongthay, Zach4636, Arakunem, Wdavis1911, LUUSAP, Richerman, Piledhigheranddeeper, Masterblooregard, Giantcalledgrawp, Neverquick, Ottawa Rima, Ky Tran, DragonBot, Jusdafax, Mrmuile, PixelBot, Adimovk5, Feline Hymnic, Maseracing, Shinkolobwe, Estirabot, Parsec96, Nascarboy38, Tdq11, Chemkid1, LarryMorseDCOhio, Ember of Light, Patrik Andersson, Thehelpfulone, Calor, Aitias, Plasmic Physics, Me20078888, Apparition11, DumZiBoT, Darkicebot, Rexas, Nettings, BarretB, Foxfoil, BodhisattvaBot, Adrian kubesh, Facts707, Skarebo, Noctibus, Airplaneman, Thatguyflint, MrOt1633, Roentgenium111, C6541, DOI bot, Dragnos2, Ronjhones, Fieldday-sunday, SpillingBot, CarsracBot, Ccacsms, Debresser, Favonian, Lucian Sunday, LemmeyBOT, LinkFA-Bot, Alchemist-hp, 84user, Numbo3-bot, VASANTH S.N., Tide rolls, Fishbirdman, Sionnach1, Gail,

Zorrobot, Bpiks, Luckas-bot, Yobot, Felixmonk1, Tohd8BohathuGh1, Librsh, II MusLiM HyBRiD II, Rrokkedd, Pogo da, THEN WHO WAS PHONE?, OmriSama, AnomieBOT, A More Perfect Onion, Rubinbot, Killiondude, IRP, Gizmo323, Richnotts, Adishesha, Luciee lololololol, Materialscientist, Edguy99, Citation bot, OllieFury, Knuthove, Vuerqex, JohnnyB256, Hastenjason, Frankenpuppy, BIONICLE233, ArthurBot, LovesMacs, LihHelpa, Crashnelms, Xqbot, Capricorn42, Ryomaandres, Nickkid5, Vexedd, Aa77zz, Inferno, Lord of Penguins, Srich32977, Jhbdel, OSU1994, RibotBOT, Klknolles, Nedim Ardoğa, Dougofborg, Legobot III, Jatosado, Tobby72, Pepper, AK2AK2, FrankMJohnson, Cs32en, Stolengood, Citation bot 1, Redrose64, AstaBOTH15, Pinethicket, HROestBot, Jivee Blau, Jonesey95, Tom.Reding, Hellknorz, Games 101 wiki, A8UDI, Isofox, Mikespedia, Pbsouthwood, Xeworlebi, Awolthuis11, FoxBot, Aeseisgod, Double sharp, TobeBot, Kc0hds, Moscow Connection, SingingZombie, Tobias1984, Yoiloper, Baravara, Oniony97, Mttcmbs, Jhenderon777, Nascar1996, Tbhotch, Lord of the Pit, Underseaker, RjwilmsiBot, Ripchip Bot, Skatesdgallday, Noommos, NerdyScienceDude, Death567, Hiiamapie, Elium2, Nyxaus, DASHBot, Pizdamatii, Nerdathon3000, EmausBot, Cricobr, Nima1024, WikitanvirBot, JJADuP, Dewritech, Sambodyer64, GoingBatty, JustinTime55, Bumblebee113, Mrkbh12, Muqtasidmansoor, MarkBenvenuto, Kerokero21, Amberdown43, Wikipelli, P. S. F. Freitas, Hhhippo, ZéroBot, Cogiati, Mistman97, ElationAviation, Dondervogel 2, CrimsonDemon, H3llBot, Joshlepaknpa, ALD-Holcroft, Wayne Slam, ChemMater, Demiurge1000, D3333b, Civilian knowledge, L Kensington, Ego White Tray, Mentibot, Peter Karlsen, 1234qwerzxcv, DASHBotAV, Whoop whoop pull up, ClueBot NG, KLindblom, Rezabot, Nesan101, Mishraran, Diyar se, Bibcode Bot, Lowercase sigmabot, BG19bot, Hodeken, Pamlegend, IraChesterfield, Meczech, Aranea Mortem, Detedagowa, Im Rick James Biotch, Acratta, BattyBot, DarafshBot, ChrisGualtieri, Adwaele, JYBot, BrightStarSky, Dexbot, JZNIOSH, Cerabot-enwiki, TwoTwoHello, Jnargus, Ariadavid, Reatlas, Sheepzi, Totalllgeek, Pi3.124, Balgontork, Stunguy3000, BruceBlaus, Ramendocor, Ed Oppty, Anrnusna, The Northamptonshire pins, Meteor sandwich yum, DayleLucy101, G S Palmer, Mahusha, Amortias and Anonymous: 1013

- Neon Source:** <http://en.wikipedia.org/wiki/Neon?oldid=659643139>
Contributors: Kpjas, CYD, Vicki Rosenzweig, Mav, Koyaanis Qatsi, Andre Engels, LA2, William Avery, SimonP, DrBob, Heron, Jaknouse, Fonzy, Ubiquity, RTC, Tim Starling, Erik Zachte, Lxor, Ixf064, Sannse, Eric119, Minesweeper, Dgrant, Looxix-enwiki, Ahoerstemeyer, Mgimpel-enwiki, Suisui, Александр, Poor Yorick, Andres, Cratbro, Evercat, Mxn, BRG, Raven in Orbit, Epo-enwiki, Schneelocke, Hashar, Emperorbma, EL Willy, Stone, David Latapie, Tpradbury, Grendelkhan, Finlay McWalter, Robbot, Moondyne, Kowey, Romanm, Naddy, Jondel, Wikibot, Ungvichian, Raeky, Anthony, Dina, Carnildo, Dave6, Giftlite, Christopher Parham, Marnanel, Robin Patterson, Misterkillboy, Lupin, Herbee, Everyking, Solipsist, Dastien, SWAdair, Yath, Quadell, Antandrus, Vina, Rdsmith4, Sebbe, Icairns, Sfoskett, Karl-Henner, CanSpice, Edsantville, Jcw69, Wyllium, Deglr6328, Adashiel, Trevor MacInnis, Venu62, Indosaurus, Discospinster, Pak21, Vsmith, Paul August, Bender235, ESKog, Sunborn, Yinon, FrankCostanza, Calair, Dataphile, RJHall, CanisRufus, Phrozenfire, Joanjoc-enwiki, Kwamikagami, Mwanner, Remember, Sietse Snel, Femto, Bobo192, Elipongo, Ker-Jar Song, A2Kafir, Jumbuck, Alansohn, Gary, PaulHanson, Mo0, Mário e Dário, Sl, Cloud Strife-enwiki, Lightdarkness, Snowwolf, Wtmitchell, Jobe6, RJJFR, Sciurinae, BlastOButter42, Pderryh, Feline1, HenryLi, Adrian.benko, RyanGerbil10, Kelly Martin, Camw, Davidkazuhiro, Miss Madeline, Sengkang, TheAlphaWolf, Wayward, Palica, Pflstad, Magister Mathematicae, Chun-hian, FreplySpang, DePiep, Grammarbot, Sjö, Saperaud-enwiki, Rjwilmsi, Koavf, Jake Wartenberg, Vary, Strait, MZM-cBride, The wub, Yamamoto Ichiro, FlaBot, Nihilres, Sanbeg, Hyphz, Nivix, Kerowyn, RexNL, Gurch, Alphachimp, Tedder, Sreffefer, Chobot, Jaraalbe, Hall Monitor, Gwernol, The Rambling Man, YurikBot, Huw Powell, Red Slash, Sarranduin, SpuriousQ, Hellbus, RadioFan, Stephenb, Yyy, Shaddock, Theelf29, Pseudomonas, Cryptic, Wimt, NawlinWiki, Grafen, Johann Wolfgang, David.Gross, Nick, Anetode, RL0919, Tim Goodwyn, Maerk, ManoaChild, DeadEyeArrow, Bota47, Derek.cashman, Nlu, Wknight94, Tetracube, Zzuuzz, Lt-wiki-bot, Closedmouth, Black-Velvet, GraemeL, Aeon1006, Croat Canuck, Anclation-enwiki, Emc2, Xiornik-enwiki, GrinBot-enwiki, Selmo, Dupz, SmackBot, Tarret, Royalguard11, Bomac, AndreasJS, Delldot, Batmanbb, PJM, Edgar181, Yamaguchi, Gilliam, Ohnoit-sjamie, Skizzik, LostArtilleryman, Michbich, Master Jay, Persian Poet Gal, Thumperward, MalafayaBot, Delinck, Baronnet, Labot2001, DHN-bot-enwiki, Sbharris, Colonies Chris, Konstable, Darth Panda, Iago4096, Gracenotes, Gyrobo, Can't sleep, clown will eat me, Gurps npc, TheKMan, Underorbit, LouScheffer, Rsm99833, SundarBot, Cybercobra, Nakon, T-borg, VegaDark, RJN, Dreadstar, Polonium, DMacks, PeterJeremy, Mion, Vina-iwbot-enwiki, Thistheman, Kukini, SashatoBot, ArglebargleIV, Krashlandon, Archimerge, Dbtzf, Kuru, John, Jan.Smolik, Gobonobo, Shlomke, Anoop.m, Goodnightmush, JohnWittle, Majorclanger, Aleenf1, Ckatz, Beetstra, George The Dragon, Peter12220, Aeluwas, Speedy11, Dicklyon, TastyPoutine, AEMoreira042281, Zapvet, Jose77, BranStark, Vanished user, Iridescent, J Di, StephenBuxton, Casull, Thricecube, Tawkerbot2, Pi, Nicholas.miniaci, Cryptic C62, Poolkris, MightyWarrior, JForget, Mrtobacco, Utelprob, Deon, Ale jrb, Sir Vicious, Megaboz, R9tgokunks, Basawala, Electricmic, SelfStudyBuddy, Casper2k3, Doctorevil64, Oden, Equendil, Doctormatt, Cydebot, Meno25, Michaelas10, Gogo Dodo, Travelbird, Odie5533, Tawkerbot4, Roberta F., DumbBOT, Chrisk02, Mooseofshadows, FastLizard4, Omicronpersei8, Vanished user jdksfajlasd, Nol888, Gimmetrow, Independent Journalist, Thijs!bot, Epr123, Opabinia regalis, Ucanlookitup, Gamer007, Wompa99, Headbomb, Marek69, Vertium, Electron9, James086, Cool Blue, Big Bird, Escarbot, Mentifisto, Thadius856, AntiVandalBot, Letstalk, Jj137, LibLord, Farosdaughter, Malcolm, Badoctor, Res2216firestar, JAnDbot, Deflective, Leuko, MER-C, Instinct, Hut 8.5, PhilKnight, Helge Skjveland, MSBOT, Jbom1, anacondabot, Easchiff, Karlhahn, Pedro, Bongwarrior, VoABot II, Saifiyaseen, JNW, CTF83!, Eng02019-enwiki, Bubba hotep, Catgut, Indon, Dirac66, Cpl Syx, Vssun, DerHexer, Pax:Vobiscum, Lost tourist, S3000, BunsenH, Jemijohn, MartinBot, Arjun01, ChemNerd, Wikiman123321, Anaxial, Kostisl, CommonsDelinker, Alexandervering, LedgendGamer, Watch37264, J.delanoy, Trusilver, Rgoodermote, Bogyey97, Jack312, Uncle Dick, Mike Winters, Yonidebot, Cocoaguy, Vanished user 342562, Gzkn, TheChrisD, McSly, Poodle90254, Dfoofnik, Fredpf, Pyrospirit, Plasticup, NewEnglandYankee, SJP, Mufka, Shoesss, TottyBot, Luke Green, Doctorblaze, Jdurg, Bye bye now, Dorftrottel, Therearewordstubes, Useight, Zelky, SoCalSuperEagle, Squids and Chips, Upex, CardinalDan, Xnuala, Wikieditor06, X1, 28bytes, VolkovBot, ABF, DSRH, Science4sail, Hersfold, Chris Dybala, AlnoktaBOT, TheOtherJesse, L111812842, Chitrapa, Wolfnix, Philip Trueman, Fffhfhfh, TXiKiBoT, Anonymous Dissident, GcSwRhIc, Qxz, Cosmium, Vanished user ikjeirw34iuaeolaseriffic, Anna Lincoln, Jackfork, LeaveSleaves, Psyche825, Seb az86556, PDFbot, Tityboy, Ilovetractors, Planes&mustangs510, BeaverMonkey, Lamro, Synthobot, Falcon8765, Enviroboy, 000lynx, Euicho, Sue Rangell, AlleborgoBot, Nagy, MrChupon, Rugbyhelp, Kbrose, Bexxx x3, SieBot, PlanetStar, Jeanettedugas, Caltas, Keilana, Toddst1, Tiptoety, Oxymoron83, Antonio Lopez, K10102898, Harry-enwiki, Light-mouse, Kookid654, Hak-ká-ngin, StaticGull, WikiLaurent, Pinkadelica, Nergaal, Snail Doom, Asher196, Aadgray, Loren.wilton, Tanvir Ahmed, ClueBot, Snigbrook, Mada48, Foxj, The Thing That Should Not Be, Zach4636, Arakunem, Polyamorph, Truco, LizardJr8, ChandlerMapBot, Rockfang, DragonBot, Yela0, Robert Skyhawk, Excirial, Quercus basaseachicensis, Alexbot, Jusdafax, PixelBot, Aristotle28, Abrech, Turtle726, NuclearWarfare, OmegaSpacePirate, Arjayay, Jotterbot, LarryMorseDCOhio, Razorflame, Zaphrost, Thingg, Aitias, Plasmic Physics, Versus22, Teleomatic, PCHS-NJROTC, SoxBot III, BarretB, XLinkBot, Zackfield100, Aaron north, Fastily, Swirl-Boy39, Fashiondebz, Noctibus, NHJG, ZooFari, RyanCross, CalumH93, TreyGeek, Pdj1961, Briscanator, Massimo Catarinella, Proof-reader77, Zyntolaz, Willking1979, AVand, Some jerk on the Internet, DOI bot, Jojhutton, Guoguo12, Fyrael, Non-dropframe, Buttchug, TutterMouse, Jayeararwhy, Jncraton, Fieldday-sunday, Cst17, CarsracBot, Glane23, AndersBot, Favonian, Chuggo, AtheWeatherman, Splodgeness, Berkunt, Alchemist-hp, PoliteCarbide, Numbo3-bot, Igksb, Tide rolls, BrianKnez, Luckas Blade, Luckas-bot, Yobot, Fraggle81, OneAhead, KamikazeBot, Amicon, Tempodivalse, DemocraticLuntz, Message From Xenu, 05clareb, Piano non troppo, Adjust-Shift, Kingpin13, Richnotts, NickK, Crystal whacker, Materialscientist, Dendlai, Citation bot, Vuerqex, GB fan, Neurolysis, Arthur-

Bot, Xqbot, KP Shadowww, Cureden, Addihockey10, Capricorn42, Pontificalibus, Mononomic, DSisyphBot, Srich32977, Ute in DC, Frankie0607, Lop7685, RibotBOT, TonyHagale, Numshullet, Doulos Christos, E0steven, Darkakatsuki, Bobbyjoe58963, Alexco creator11, Nenyia17, Frozenevolution, George2001hi, Yellowweasel, Aperram, Dogposter, Ace of Spades, Cappybara21, Alarics, Tharthan, TampAGS, Citation bot 1, AstaBOTH15, Pinethicket, I dream of horses, Vicenarian, Elockid, Jonesey95, Rameshngbot, Tom.Reding, Rebecca Pringle08, Calmer Waters, RedBot, Pikiwyn, Jademckit, SpaceFlight89, Neoncicy, Xeworlebi, Jauhienij, Double sharp, TobeBot, DixonDBot, Thestraycat57, Larsadams, Diannaa, JenVan, Tbhotch, Daddybabby34567890, DARTH SIDIOUS 2, RjwilmsiBot, TjBot, Alph Bot, Noommos, NerdyScienceDude, Slon02, LcawteHuggle, DASHBot, Vinnyzz, EmausBot, Cricobr, Orphan Wiki, Acather96, WikitanvirBot, Immunize, Erikgunby, Sambodyer64, GoingBatty, RenamedUser01302013, Slightsmile, Tommy2010, Wikipelli, K6ka, Kaimakides, Thecheesykid, ZéroBot, Magnetizzle, StringTheory11, JacobyMorrice, Jacobymorrice2, H3llBot, Christina Silverman, Mancomewin, Wayne Slam, Jay-Sebastos, Kill me when i die, Donner60, Pulpkk, Puffin, Autoerrant, Carmichael, Oisinisio, Jshru, Catsanddogs444, Lighttex, DASHBotAV, 28bot, Unknown1321, Petrb, Reconhunter, Mikhail Ryazanov, ClueBot NG, Jack Greenmaven, Baylea10, Gilderien, Jksaintsfan, Primergrey, 123Hedgehog456, Rezabot, Widr, Abdurahab almassapiy, Jessicap17, Helpful Pixie Bot, Lowercase sigmabot, S.R.Madden, Lolojore, RandomTwitterGuy, Jeffreyhenry3, TomeHale, Justincheng12345-bot, Kharaz2, Dexbot, Coolkidneon, Xcoopax, Gsmanu007, Totalstooge, Lugia2453, Frosty, Jamesj12345, Jnargus, Reatlas, Vanamonde93, Eyesnore, Anoop Manakkalath, Buffbills7701, BruceBlaus, Ramendoctor, DudeWithAFeud, Ethan morgan X., Mai141Ww, TheEpTic, Elliebmc, Patribre000, Bibty123, Kalledenseje, Wordytitan9, XvxAnonymousvX, Da'Keia Curry and Anonymous: 1184

- Argon** Source: <http://en.wikipedia.org/wiki/Argon?oldid=660291943> Contributors: CYD, Mav, Bryan Derksen, Dave McKee, Gorm, Andre Engels, LA2, Rmhermen, Christian List, William Avery, SimonP, Heron, Jaknouse, Fonzy, Youandme, RTC, Erik Zachte, Lexor, Shellreef, lxdf64, Delirium, Eric119, Iluvcapra, Minesweeper, Dgrant, Ahoerstemeier, Mgimpel-enwiki, Suisui, Darkwind, Andres, Grin, BRG, Schneelocke, Mulad, Emperorbma, EL Willy, Ec5618, Jonadab-enwiki, Stone, David Latapie, Selket, Markhurd, Vancouverguy, Jake Nelson, Grendelkhan, Saltine, SEWilco, Wilbern Cobb-enwiki, Donarreiskoffer, Robbot, RedWolf, Kowey, Nurg, Roman, Naddy, Merovingian, Flauto Dolce, Hadal, Wikibot, Carnildo, Alan Liefthing, Giftlite, Marnanel, Awolf002, Wolfkeeper, Bkonrad, Curps, Beardo, Redux, Solipsist, Foobar, Brockert, Darrien, Jackol, Bobblewik, Gubbubu, ChicXulub, StuartH, Auximines, Yath, ConradPino, Quadell, Antandrus, HorsePunchKid, Jossi, Rdsmith4, DragonflySixtyseven, Anárior, Icairns, Karl-Henner, Kmweber, B.d.mills, TonyW, Iantresman, Urhixidur, Edsanville, Deglr6328, Adashiel, Trevor MacInnis, Mike Rosoft, N328KF, Indosauros, Discospinster, Guanabot, Vsmith, Eric Shalov, Guanabot2, Alistair1978, Arthur Holland, Quistnix, Paul August, MarkS, Night Gyr, ESKog, PP Jewel, Sunborn, JoeSmack, Brian0918, Kaszeta, Livajo, MBisanz, El C, Joanjoc-enwiki, Kwamikagami, Remember, Art LaPella, Femto, Bobo192, BW, Shenme, RAM, Apostrophe, Llywelyn, Azn king28, Sam Korn, Haham hanuka, Hawaii fiveoh, Nsaa, Passw0rd, Jumbuck, Alansohn, Anthony Appleyard, Mitsuhamma, Atlant, Sl, Sligocki, Rwendland, Wtmitchell, BRW, Kaiser matias, SteinbDJ, Gene Nygaard, Kazvorpal, Alvis, TigerShark, Staphylococcus, Sengkang, M412k, M100, Palica, Mandarax, Pfunk42, Graham87, Magister Mathematicae, Qwertyus, FreplySpang, DePiep, Sjö, Drbogdan, Saperaud-enwiki, Rjwilmsi, Coemgenus, Magu2k, Rschen7754, MZMcBride, Vegaswikian, Matt Deres, Ptdecker, Yamamoto Ichiro, Vuong Ngan Ha, Titoxd, FlaBot, Naraht, Nihiltres, RexNL, Gurch, TheDJ, Fresheneesz, Goudzovski, King of Hearts, Chobot, Jaraalbe, Gwernol, Whosasking, YurikBot, Wavelength, Klingoncowboy4, Jimp, Anonymous editor, Bergsten, Hydrargyrum, Stephenb, Yyy, Merlincooper, Dsmouse, Wimt, Thane, NawlinWiki, Bachrach44, Janke, Shaun F, Bobbo, Brandon, PhilipO, Number 57, Misza13, Nick C, Graydonflatt, Derek.cashman, Elkmn, Wknight94, Tetracube, Mugunghur, Zzuuz, Lt-wiki-bot, Gtdp, Closedmouth, Donald Albury, Extraordinary, E Wing, KGasso, Dspradua, Tevildo, JoanneB, Dschor, Ilmari Karonen, Junglecat, GrinBot-enwiki, Groyolo, Minnesota1, Itub, SmackBot, Bobet, Tarret, KnowledgeOfSelf, Hydrogen Iodide, Basil.bourque, Messs17, Bomac, Jacek Kendysz, KocjoBot-enwiki, AndreasJS, Ddcampayo, Jab843, Edgar181, Yamaguchi, Gilliam, Pslawinski, Sinblox, Mossman93, Bluebot, Kurykh, Vmatikov, Jprg1966, Thumperward, SchfiftyThree, Delinck, Baa, DHN-bot-enwiki, Sbharris, Iago4096, Gyrobo, Jehan UK, Can't sleep, clown will eat me, Dillona, TheKMan, Rrburke, LouScheffer, Addshore, Mr.Z-man, Aldaron, Krich, Nakon, Funky Monkey, Archfiendweazel, Geoffr, PeterJeremy, Ohconfucius, SashatoBot, Archmerged, John, Scientizzle, Computermix, Spikeman, Anoop.m, CaptainVindaloo, IronGargoyle, Ckatz, Hvn0413, Beetstra, Mr Stephen, Dicklyon, Funnybunny, Novangelis, Jose77, BranStark, Sfgagnon, Iridescent, S0me l0ser, Thief111362, CapitalR, Thricecube, Tawkerbot2, Cryptic C62, Poolkris, JForget, Stifynsemons, Patrick Berry, Ale jrb, Aherunar, Dgw, ShelfSkewed, Lyoko is Cool, WeggeBot, Casper2k3, No1lakersfan, Pewwer22, Cydebot, Peripitus, Rifleman 82, Clayoquot, Corpx, Pascal.Tesson, Ksbrown, Chuto, Kozuch, MayaSimFan, Gcsuchemistry, Thijs!bot, Epr123, Opabinia regalis, Tsgo3, Keraunos, Headbomb, Marek69, Tapir Terrific, Nezzadar, X201, Natalie Erin, CTZMSC3, Escarbot, Tham153, AntiVandalBot, Sepharius, Quintote, Jj137, Farosdaughter, Badocter, Elaragirl, Res2216freestar, JANdbot, Deflective, MER-C, Plantsurfer, Kaabi, Seddon, Hut 8.5, PhilKnight, FaerieInGrey, Karlhahn, VoABot II, Dannyc77, Ling.Nut, Jespinos, Eng02019-enwiki, Twsx, KConWiki, Catgut, Indon, DeadShort, Animum, Dirac66, Sultanofsurreal, Vssun, DerHexer, JaGa, WLU, Video game fan11, BunsenH, MartinBot, BetBot-enwiki, Arjun01, ChemNerd, Paracel63, Anaxial, Kostisl, CommonsDelinker, Static-XJ, Watch37264, J.delanoy, Tlim7882, All Is One, Daemon Reborn, LordAnubisBOT, Gman124, Jayden54, Plasticup, NewEnglandYankee, Neonfrank, SJP, Juliancolton, STBotD, Tomwzhang95, WinterSpw, TheNewPhobia, Squids and Chips, JimWhitaker, Idioma-bot, Funandtrvl, 28bytes, VolkovBot, TreasuryTag, Thedjatclubrock, ABF, Chris Dybala, Gene Hobbs, Philip Trueman, TXiKiBoT, RyanB88, Rei-bot, Anonymous Dissident, Lradrama, LeaveLeaves, Psyche825, Seb az86556, UnitedStatesian, Cremepuff222, Dhall12345, Lamro, Poltair, ObjectivismLover, Emmy.rocks, Insanity Incarnate, Ceranthor, Pierre.laloë, LuigiManiac, Jokah49, Tim McDaniel, SieBot, PlanetStar, Weeliljimmy, Plinkit, Caltas, Trigger820, Tiptoety, JetLover, Oxymoron83, Avidallred, Enok Walker, Steven Zhang, Lightmouse, Tombomp, Techman224, Hak-kâ-ngin, Grunkhead, Nancy, PrimaryDragon, Sean.hoyland, Mygerardromance, Dabomb87, Nergaal, Francvs, TheCatalyst31, Riflewhipu, Sfan00 IMG, ClueBot, S lijn, Foxj, The Thing That Should Not Be, Rodhullandemu, Jagun, JanInad, Zach4636, Taroaldo, CristianCantoro, Eric Armengaud, AirdishStraus, Brooknet, Neverquick, Lamanatasa, Excirial, Erebus Morgaine, Eeekster, Aristotle28, Abrech, Gtstricky, Leonard^Bloom, Aurora2698, Salty1984, Mr45acp, Deasington, Woodster93, Bald Zebra, Aitias, Horselover Frost, Plasmic Physics, Versus22, DumZi-BoT, Kuithei-enwiki, RextxS, Crazy Boris with a red beard, SouthernSunShine, Little Mountain 5, Avoided, Alexius08, Noctibus, RyanCross, Freestyle-69, Antidisestablishmentarianism, Willking1979, Some jerk on the Internet, DOI bot, Pearl's sun, Hda3ku, TutterMouse, Wikimichael22, Leszek Jańczuk, WFPM, Wang Ivan, Cst17, Download, CarsracBot, Glane23, Thej42, Chzz, Favianian, LinkFA-Bot, Any Moose, Jasper Deng, Alchemist-hp, Numbo3-bot, Cyclist 1977, Tide rolls, Lightbot, Luckas-bot, Yobot, 2D, II MusLiM HyBRiD II, KamikazeBot, IW.HG, Jprefect, Ari639, AnomieBOT, John Holmes II, A More Perfect Onion, Jim1138, IRP, Piano non troppo, Kingpin13, Richnotts, Flewis, MaterialsScientist, The High Fin Sperm Whale, Citation bot, Frankenpuppy, ArthurBot, Mistyfrog, Xqbot, Sionus, Cureden, Addihockey10, DSisyphBot, Humormekil, AbigailAbernathy, Srich32977, Zm786, Champlax, Thefirstgolffoffer, GrouchoBot, Abce2, Shadowdude77, Brandon5485, SassoBot, Doulos Christos, Rolof1991, Misortie, Elemesh, GT5162, FrescoBot, Wikidoug, Dogposter, StaticVision, Ryanh1994, Kwiki, Citation bot 1, Nirmos, AstaBOTH15, Gaba p, Pinethicket, Jonesey95, Tom.Reding, Mikespedia, Robvanvee, Double sharp, Speciman00, Peppoj, Dinamik-bot, 777sms, Robbin' Knowledge, Tbhotch, DARTH SIDIOUS 2, Andyfinn94, RjwilmsiBot, Ripchip Bot, LcawteHuggle, Enauspeaker, DASHBot, EmausBot, WikitanvirBot, Az29, Craig is a Pikey, NotAnonymous0, Tommy2010, Wikipelli, K6ka, P. S. F. Freitas, Trinidade, StringTheory11, Andyman1125, Hazard-SJ, Arbnos, A930913, H3llBot, GeaVox, Joshlepkpnpsa, Vanrevel97, Hippopotomanman, Donner60, ChuispastonBot, Peter Karlson, Noob4000, Whoop whoop pull

- up, JonRichfield, ClueBot NG, Rich Smith, Jack Greenmaven, CocuBot, A520, Theimmaculatechemist, Widr, Tyler12369, Johnwest1999, පිටි කවි, Bibcode Bot, ElphiBot, AwamerT, Snow Blizzard, NotWith, TomeHale, Whybotherknow, Octopus5650, USH Peirce, Idenshi, Cunieformboy, Ingvar in newyork, ChrisGualtieri, GoShow, Bachware, Selene Scott, MadGuy7023, Dexbot, Fiery3033, Webclient101, Mysterious Whisper, Mogism, Tony Mach, King jakob c, Jnargus, Reatlas, Darth Sitges, Anthony5099, Epicgenius, Surfer43, DavidLeighEllis, J.meija, LieutenantLatvia, Ginsuloft, Ramendoctor, HamiltonFromAbove, Param Mudgal, DudeWithAFeud, Anrusna, Darkrip, TheEpTic, Dakotajm25, Monkbot, Uberparticle, Octopus41, La2O3, Aih1013, Dasitmaaane, Usernameishoyeh, Bubbycat, Wynstol, Halo12344, Mahirislam64, Houseofbanter and Anonymous: 933
- Krypton** *Source:* <http://en.wikipedia.org/wiki/Krypton?oldid=660255639> *Contributors:* CYD, Mav, Bryan Derksen, Jeronimo, Malcolm Farmer, BenBaker, Andre Engels, William Avery, SimonP, Jaknouse, Fonzy, RTC, Tim Starling, Erik Zachte, Ledor, Sannse, Minesweeper, Dgrant, Ahoerstemeier, Mgimpel-enwiki, Suisui, Aarchiba, Александр, Julesd, Andres, BRG, Schneelocke, Hashar, Emperorbma, Stone, Stismail, El-enwiki, David Latapie, RichardB-enwiki, Grendelkhan, Thue, Lord Emsworth, Michael Rawdon, GPHemsley, Shafei, Donarreiskoffer, Robbot, Kowey, Yelyos, Nurg, Romanm, Naddy, Carnildo, Giftlite, Muke, FrYGUY, Skagedal, Yekrats, Egomaniac, Darrien, Utursch, Antandrus, Kesac, Kevin B12, Icairns, Edsanville, Dcandeto, Indosauros, Discospinster, Vsmith, DcoetzeeBot-enwiki, Ngchen, Sunborn, Kbh3rd, El C, Joanjoc-enwiki, Kwamikagami, Remember, Femto, Bobo192, Longhair, Smalljim, Reuben, Deryck Chan, 99of9, Jumbuck, Danski14, Alansohn, Anthony Appleyard, Sl, Snowolf, Vellela, Axeman89, Stephen, Veemonkamiya, Woohookitty, Mindmatrix, Yansa, Benbest, Pol098, WadeSimMiser, Sengkang, Palica, Dysepsion, Mandarax, Deltabeignet, DePiep, Enzo Aquarius, Saperaud-enwiki, Koavf, MarSch, Quiddity, Mike s, ErikHaugen, SMC, Bushido Hacks, Yamamoto Ichiro, Vuong Ngan Ha, FlaBot, Nihiltres, RexNL, Gurch, Goudzovski, Zotel, Physchim62, King of Hearts, Chobot, Jaraalbe, The Rambling Man, YurikBot, Phantomsteve, Yyy, Pseudomonas, Ellimist, NawlinWiki, SEWilcoBot, RazorICE, Dureo, Nick, Nick C, Mysid, Derek.cashman, Elkmam, Wknight94, Tetracube, Deville, Imaninjapirate, Livitup, BorgQueen, GraemeL, JoanneB, Levil, Anclation-enwiki, Junglectat, JTYler, DVD R W, Minnesotal, Itub, SmackBot, MattieTK, Tarret, KnowledgeOfSelf, Pkg, AndreasJS, Delldot, Edgar181, Gilliam, Skizzik, Kurykh, Keegan, Jprg1966, Thumperward, Bethling, Delink, Dlohcierekim's sock, DHN-bot-enwiki, Sbarris, Darth Panda, Iago4096, Rlevse, Gyrobo, Brideshead, Can't sleep, clown will eat me, Writtenright, Ctjj.stevenson, Jjjsixsix, SundarBot, Cameron Nedland, Iapetus, Cybercobra, Khukri, Dreadstar, Weregibil, Polonium, Astroview120mm, PeterJeremy, Triforce of Power, SashatoBot, Robomaeyhem, Harryboyles, Archimerged, John, AmiDaniel, Scientistzle, Anoop.m, Beetstra, Fedallah, Waggars, Anakinjmt, Therealsquee, Jose77, KJS77, Iridescent, R-enwiki, Bruinfan12, MrBoo, Thricecube, Tawkerbot2, Cryptic C62, Poolkris, AbsolutDan, Nutster, Stifynsemons, Ale jrb, Van helsing, Scohous, SiriusGrey, Maximilli, Casper2k3, TJDday, Mike Christie, Gogo Dodo, TicketMan, Red Director, JFreeman, Frosty0814snowman, Benjiboi, Q43, Tawkerbot4, Roberta F., DumbBOT, Jay32183, Kozuch, Zalgo, UberScienceNerd, Epbr123, Opabinia regalis, Auror, Hazmat2, Mojo Hand, Oliver202, Headbomb, Marek69, John254, Crzycheetat, Tellyaddict, Davidhorman, Bigvis, CharlotteWebb, Blathnaid, MichaelMaggs, Escarbot, Hmrox, AntiVandalBot, Luna Santin, Quintote, DarkAudit, Jj137, TimVickers, Badocter, JAnDbot, Deflective, Husond, Plantsurfer, Sheitan, Instinct, Andonic, Beaumont, .anacondabot, Bencherlite, Magioladitis, Bongwarrior, VoABot II, AuburnPilot, Eng02019-enwiki, Aka042, EvilFred, Indon, Giggy, Animum, 28421u2232nfencenc, Edward321, Johnbrownsbody, MartinBot, ChemNerd, NReitzel, Partnerintime12, RiddG07, CommonsDelinker, Pekaje, Cyrus Andiron, Watch37264, J.delanoy, Andrei901, Pharaoh of the Wizards, Trusilver, TimBuck2, Uncle Dick, C.A.T.S. CEO, Mike Winters, Matts computer, Killawolf, Katalavon, Stan J Klimas, Ignatzmice, Boyofus, Will dogson, Warut, SJP, Cobi, Pundit, TottyBot, Juliancolton, STBotD, Kvdveer, Keenman76, Alan012, Pdcok, Squids and Chips, Idioma-bot, Split Infinity, Wikieditor06, X1, Deor, 28bytes, VolkovBot, ABF, Jeff G., Jmrowland, Chitrapa, Philip Trueman, TXiKiBoT, GDonato, Rixshk, Rossdaboss50, Captain Wikify, Qxz, Someguy1221, Pendragonneo, Crazy British Kid, Martin451, JhsBot, LeaveLeaves, Mattbaileysneat, Jvbishop, Ma335019, Superman1560, NodnarbLlad, Finnigall, Jason Leach, Rodney Ruff, AlleborgoBot, LuigiManiac, NHRHS2010, 8v, EJF, C66, SieBot, Cunaay, PlanetStar, Tiddly Tom, Qwertyasfgh, Dawn Bard, Wideyedraven, GlassCobra, Keilana, Flyer22, Tiptoety, Exert, Hxhbot, Wilder22, Oxymoron83, Antonio Lopez, AngelOfSadness, Steven Zhang, Hak-kàngin, Danimations, Hatster301, Pre1mj, Joshschr, Nergaal, Chem-awb, TheCatalyst31, Loren.wilton, ClueBot, Trojancowboy, Avenged Eightfold, The Thing That Should Not Be, AirdishStraus, CounterVandalismBot, Blanchardb, Harland1, Shakowski, MasterXC, Somno, DragonBot, Buttman12345, Excirial, Jusdafax, WikiZorro, LordFoppington, Abrech, GreenGourd, Tjmage1, Jotterbot, LarryMorseD-COho, Bleubeatle, DisorderedOne, BOTarate, Pifreak94, Plasmic Physics, Versus22, RextxS, Against the current, Singergirl350, Stickee, Ost316, SilvonenBot, Noctibus, ApsbaMd2, BrucePodger, Pplz4ever, ERK, Proofreader77, Willking1979, Some jerk on the Internet, DOI bot, Joghutton, Tcncv, Yoshie310, Fieldday-sunday, Mr. Wheely Guy, CanadianLinuxUser, Ka Faraq Gatri, Cst17, CarsracBot, Inmsan, 5 albert square, Alchemist-hp, Guitarlord123, Numbo3-bot, Mah213, Tide rolls, Lightbot, Nadando, Arbitrarily0, Lucas-bot, 2D, THEN WHO WAS PHONE?, KamikazeBot, Amicon, Lukemynds, Tempodivale, Martin-vogel, Marauder40, Howieju, 9258fahsflkh917fas, Piano non troppo, Macuser678, AdjustShift, Kingpin13, Wrenchelle, Greenknight04, Materialschemist, RobertEves92, Druiddude2384, The High Fin Sperm Whale, Danno uk, GB fan, Frankenpuppy, Neurolysis, ArthurBot, Clark89, Xqbot, Zad68, Jeffwood12, JimVC3, Kgreg10, Jeffrey Mall, Mecee, Teddks, Srich32977, Smallzman, XxLayoutax, AeroChemistry, Doulos Christos, Cekli829, Con soccer13, Ryanh1994, ZenerV, Deadskull56, HamburgerRadio, Citation bot 1, AstaBOTH15, Pinethicket, Dtkey, Cool Stuff Is Cool, Tom.Reding, Fish.chips+mushypeas, Achaemenes, Gypsykpd, Meaghan, Kangxi emperor6868, Xeworlebi, December21st2012Freak, Jauhienji, Double sharp, Vrenator, Haven812, Reaper Eternal, 4, Jeffrd10, Calcvids, Tbotch, Minimac, Brnnrngl, DARTH SIDIOUS 2, Rjwilmsi-Bot, CalicoCatLover, Spidey1215, EmausBot, WikitanvirBot, RA0808, Tommy2010, Wikipelli, AsceticRose, Thecheesykid, Shearonink, Ronk01, StringTheory11, Alpha Quadrant (alt), H3llBot, Rails, QEDK, Wayne Slam, MrKevzMatz, Donner60, Autoerrant, DASHBotAV, PetrB, ClueBot NG, Satellizer, Expelled-enwiki, Millerkm, Dillpickle911, Muchograzioso, Widr, Helpful Pixie Bot, Bibcode Bot, Lowercase sigmabot, Belromain, ElphiBot, Kabjdb10, Mark Arsten, Joydeep, 3.14159265358pi, Xaiverjack12, Robotcgeek, Anbu121, Tinmoran, Mdann52, EuroCarGT, Dexbot, Jamesx12345, T42N24T, Reatlas, Zec99, DavidLeighEllis, My name is not dave, Ramendoctor, Pepepe123, 123456789qwertyuiopas, Monkbot, HiYahhFriend and Anonymous: 803
 - Xenon** *Source:* <http://en.wikipedia.org/wiki/Xenon?oldid=660132551> *Contributors:* AxelBoldt, CYD, Mav, Bryan Derksen, Robert Merkel, Malcolm Farmer, Csx, Andre Engels, Eclecticology, LA2, Christian List, William Avery, SimonP, Jaknouse, Fonzy, RTC, Tim Starling, Erik Zachte, Ledor, Ixfd64, GTBacchus, Minesweeper, Dgrant, Egil, Ahoerstemeier, Mgimpel-enwiki, Aarchiba, Александр, Schneelocke, Arteilte, Ideyal, Emperorbma, Dino, Stone, David Latapie, Hannibal (usurped), Zoicon5, Tpbroadbury, Grendelkhan, Fvw, Pstudier, Gakrivas, Donarreiskoffer, SpikeMolec, Robbot, Kowey, Romanm, Ajd, Naddy, Meelar, Acegikmo1, Bkell, HaeB, Carnildo, Giftlite, Karn, Michael Devore, AJim, Yekrats, Jorge Stolfi, Darrien, Jaan513, Erich gasboy, Bact, Antandrus, MisfitToys, Eregli bob, MacGyverMagic, Maximaximax, Icairns, Sam Hocevar, Deglr6328, Adashiel, Danh, Mike Rosoft, Mernen, Robophilosopher, DanielCD, Felix Wan, Discospinster, Rich Farmbrough, Pjacobi, Vsmith, Edibobb, RJHall, El C, Cap'n Refsmaat, Joanjoc-enwiki, Kwamikagami, Evand, Remember, RoyBoy, Femto, Bobo192, Bradkittenbrink, Dreish, Phidauex, Ivansanchez, Azn king28, MPerel, Jonathunder, Jumbuck, Alansohn, Anthony Appleyard, Qrc, Benjah-bmm27, Sl, Riana, Walkerma, PAR, Wtshymanski, Vuo, SteinbDJ, Stepheno, Gene Nygaard, Kay Dekker, BerserkerBen, Sennard, Bratsche, Benbest, ^demon, MONGO, Sengkang, GregorB, Graham87, V8rik, Galwhaa, DePiep, Nanite, Sjö, Saperaud-enwiki, Rjwilmsi, Coemgenus, Dar-Ape, Fish and karate, Vuong Ngan Ha, FlaBot, Splarka, RobertG, Nihiltres, RexNL, Enon, Alphachimp, Chobot, Visor, Jaraalbe, DanielDeGraaf, YurikBot, Wavelength, Spacepotato, Bhny, Berg-

sten, LightSabre, Akamad, Stephenb, Friedfish, Gaius Cornelius, Yyy, Shaddock, Tavis, Big Brother 1984, Notchcode, Wiki alf, Dalziel 86, Bucketsofg, Syrthiss, Bota47, Wknight94, Tetracube, Kelovy, Lt-wiki-bot, Nikkimaria, BorgQueen, Petri Krohn, Anclation-enwiki, KJBracey, NeilN, GrinBot-enwiki, Marquez-enwiki, Ndaisley, Itub, Anthony Duff, SmackBot, Unschool, Gruber76, Tarret, VigilancePrime, AndreasJS, ScaldingHotSoup, AnOddName, Edgar181, Cazort, Yamaguchi, Cool3, Gilliam, Amatulic, GoneAwayNowAndRetired, Chris the speller, Kurykh, Persian Poet Gal, Thumperward, Moshe Constantine Hassan Al-Silverburg, DHN-bot-enwiki, Shharris, Iago4096, Gyrobo, Zsinj, Can't sleep, clown will eat me, Vladislav, LouScheffer, Addshore, SundarBot, Zirconscoot, Cybercobra, Trieste, DMacks, Raphael s, PeterJeremy, SashatoBot, AThing, Archimerged, Kuru, John, Sfuerst, Iliev, Tomhubbard, Anoop.m, JorisvS, IronGargoyle, Saseigel, Smith609, Slakr, Hvn0413, Beetstra, Noah Salzmann, Mr Stephen, Dicklyon, Condem, Jose77, BranStark, Vanished user, Ossipewsk, Peter M Dodge, CzarB, Thricecube, Poolkris, Fvasconcellos, JForget, Stifynsemons, Casahueten, Tanthalas39, Barnaclese, JohnCD, Randalllin, Ruslik0, Meodipt, Tim1988, Borislav.dopudja, Icek-enwiki, A876, Gogo Dodo, Corpx, ST47, MyLegAlta, My Flatley, Christian75, Roberta F., Chrisk02, Duccio, Kozuch, Gcsuchemistry, Thijs!bot, Epbr123, Opabinia regalis, Columbo2, Headbomb, Marek69, John254, Electron9, James086, Bricheja, SusanLesch, Viralmemesis, Escarbot, Mentifisto, AntiVandalBot, Luna Santin, BigMitch741, Just Chilling, Jj137, TimVickers, Mohsen4465, LibLord, Badocter, Aliwalla, Arx Fortis, Deflective, Savant13, Acroterion, Magioladitis, WolfmanSF, Karlhahn, Bongwarrior, VoABot II, AuburnPilot, JNW, Eng02019-enwiki, Klausok, Wrwhiteal, Baccyak4H, Jvhertum, Animum, Ksanyi, Dirac66, Allstarecho, LorenzoB, DerHexer, Scottalter, MartinBot, Andre.holzner, RP88, ChemNerd, Jim.henderson, Rettetast, Kostisl, CommonsDelinker, Nono64, Leyo, Watch37264, J.delanoy, Pharaoh of the Wizards, DrKiernan, TruSilver, DandyDan2007, Uncle Dick, Ryan Postlethwaite, Spinach Dip, NewEnglandYankee, STBotD, Vanished user 39948282, AndreasJSbot, Squids and Chips, Idioma-bot, Funandtrvl, Xenonice, ACSE, 28bytes, VolkovBot, ABF, Alexandria, Soliloquial, Philip True-man, Mercurywoodrose, Cdpl, Qxz, Anna Lincoln, Corvus cornix, Raymondwin, UnitedStatesian, Mraandy, Jason Leach, Wikifreak09, Truthanado, Pierre.laloë, Logan, LuigiManiac, Flaquito1979, SieBot, Sonicology, PlanetStar, Dkelley123, Tlslights, Parhamr, Dawn Bard, Yintan, Agesworth, Keilana, Tiptoety, Oxymoron83, Smilesfozwood, Jeremiah Mountain, Lightmouse, OKBot, Adam11010, Grrahnbahr, Randomblue, Nergaal, Lloydpick, Chem-awb, Aadgray, Velvetron, Leranedo, TheodoreB, ClueBot, PipepBot, The Thing That Should Not Be, EelkeSpaak, Nnemo, FileMaster, Arakunem, Mild Bill Hiccup, CounterVandalismBot, Paperlan, DragonBot, Excirial, Parisian-Blade, NuclearWarfare, Jotterbot, Chininazu12, ChrisHodgesUK, Deasington, Thingg, Chiloa, JDPhD, SoxBot III, -Jade healer-, ClanCC, BassT0theFace, RmFan1, BodhisattvaBot, Wikiusers100, Nepenthes, Avoided, Denton22, Andrew Kanode, Babooche, WikiDao, Iidigsz, SimonKSK, C6541, DOI bot, Neucom, 4inarow, Incraton, Eutactic, Harrymiph, CarsracBot, LinkFA-Bot, Alchemist-hp, Tassedethe, Chethanyk, Numbo3-bot, Apteve, Folypeelarks, Megaman en m, Yinweichen, Lucas-bot, Yobot, Amicon, DiverDave, AnomieBOT, Metalhead94, Glenfarclas, MaterialsScientist, Citation bot, Maxis ftw, Neurolysis, ArthurBot, Bobthebuilder32, LilHelpa, Andrei.hagiescu, Xqbot, Nappyrootslister, Greathl, Srich32977, ProtectionTaggingBot, Mayor mt, Doulos Christos, Joaquin008, Some standardized rigour, Dougofborg, Dave3457, FrescoBot, Mjkper, Citation bot 1, Gezora12, Olaymaster888, AstaBOTH15, Pinethicket, Abductive, 10metreh, Tom.Reding, ZeDestructor, Jomanted, Xeworlebi, Mr.Yim, FoxBot, Double sharp, SingingZombie, Kayla dude, 4, Jeffrd10, Vera.tetrix, L3oombox, Tbhotch, Squishum, Reach Out to the Truth, DARTH SIDIOUS 2, RjwilmsiBot, TjBot, Ripchip Bot, Flym4zt3r, 1234567890whydoesgreensauce, DASHBot, EmausBot, John of Reading, Helium4, GoingBatty, Wikipelli, Kaley12345678910, Shirlyso, Solomonfromfinland, ZéroBot, Éric Junior Wouters, StringTheory11, Hazard-SJ, H3llBot, Joshlepaknpa, AManWithNoPlan, Jarodalien, Whoop whoop pull up, ClueBot NG, KLindblom, Lhb1239, Ulflund, Joefromrandb, Nicolas Seufert, Hispeedtoo, Widr, Kaz Shadows, Bibcode Bot, Jreye, ElphiBot, Elite6809, Rob Hurt, BattyBot, Sciencegeek10188, Dja1979, TylerDurden8823, JYBot, Dexbot, Mrwrtarheel, Webclient101, Mysterious Whisper, Thepasta, JamesMoose, DavidLeighEllis, -اوی رای ش گر-, Connor Kinney, Owllord97, Physicsmichael, SpeedEvil, Monkbot, Lasbotellas, KingOfNerds73, RazorFries, Medgirl131, Johnnyredeye, Azand222, Seargentkailone and Anonymous: 555

- Radon** *Source:* <http://en.wikipedia.org/wiki/Radon?oldid=660719761> *Contributors:* CYD, Mav, Bryan Derksen, Jeronimo, Andre Engels, LA2, William Avery, SimonP, Ellmist, Heron, Jaknouse, Fonzy, Olivier, Dwmyers, Michael Hardy, Erik Zachte, Dominus, Sannse, Minesweeper, Looxix-enwiki, Ellywa, Ahoerstemeier, Suisui, Julesd, Glenn, Whkoh, Cherkash, Schneelocke, Emperorbma, Greatpatton, Stone, Stismail, David Latapie, Greenrd, TpbBradbury, Svante-enwiki, Samsara, Pakaran, David.Monnaux, Twang, Donarreiskoffler, Robbot, Chocolateboy, ZimZalaBim, Altenmann, Romanm, Naddy, Danhuby, Yosri, Bkell, Hadal, UtherSRG, Mushroom, Netjeff, Lupo, MikeCapone, Carnildo, Marc Venot, Alexwovington, Gifflite, DocWatson42, Fastfission, Peruvianllama, Michael Devore, Aoi, Jfdwolff, Fjarlq, Yekrats, Bobblewik, Antandrus, Beland, Wiml, Icairns, Sam Hocevar, Joyous!, Deglr6328, Adashiel, Trevor MacInnis, Mike Rosoft, Rich Farmbrough, Vsmith, Xgenei, Roodog2k, Pavel Vozenilek, Robertbowerman, DcoetzeeBot-enwiki, Bender235, ESKog, Plugwash, RjHall, Kaszeta, CanisRufus, El C, Joanjoc-enwiki, Kwamikagami, Mwanner, Shanes, Remember, Femto, Diamonddavej, BalanceUT, Bobo192, O18, Smalljim, Nk, Mjager, Carl S Bj, Jumbuck, Storm Rider, Alansohn, Gary, Atlant, Keenan Pepper, Sl, Axl, Walkerma, Dennis, Malo, Ummregg, Gene Nygaard, Stemonitis, Henrik, LOL, Miss Madeline, Kelisi, Kmg90, Senggang, GregorB, Brendanconway, E090, DePiep, Grammarbot, Saperaud-enwiki, Martinevos-enwiki, Rjwilmsi, Koavf, Wanblee-enwiki, Zbxgscqf, Edholden, Lockley, Joffan, PinchasC, Jehochman, Redecke-enwiki, FlaBot, Nihiltes, Itinerant1, RexNL, Gurch, ChongDae, Kolbasz, Anirudh.shastri, Stevenfruitsmaak, Rrenner, Preslethe, Zotel, CJLL Wright, Chobot, Jaraalbe, Simesa, The Rambling Man, YurikBot, Wavelength, RobetE, RussBot, Anonymous editor, Captaindan, Limulus, Ytrottier, Hellbus, Stephen, Yyy, Big Brother 1984, Anomalocariss, Wiki alf, Gafen, Joel7687, Misza13, Bota47, RyanJones, Stefan Udea, Tetracube, Coupdeforce, Lt-wiki-bot, Reyk, CharlesHBennett, JoanneB, Junglecat, GrinBot-enwiki, Hiddekel, Itub, SmackBot, Hux, Tarret, KnowledgeOfSelf, Olorin28, KocjoBot-enwiki, AndreasJS, Jrockley, Boris Barowski, Edgar181, Cazort, Gilliam, Aaron of Mpls, Skizzik, Amatulic, Chris the speller, Agateller, RDBrown, Jprg1966, Thumperward, MalafayaBot, EdgeOfEpsilon, Oatmeal batman, Gyrobo, Gsp8181, Tscabot, TheKMan, VMS Mosaic, Xyzzylugh, Cybercobra, Nakon, Rajrajmarley, Brainyiscool, Kellyprice, DMacks, PeterJeremy, Kukini, SashatoBot, Anlace, JunCTionS, Srikeit, John, Ourai, Euchiasmus, Jim Derby, Coastergeekperson04, Starhood, Mr. Lefty, RomanSpa, W.p.dean, Davemcarlson, Beetstra, AdultSwim, CapitalR, Esumnir, Civil Engineer III, Tawkerbot2, Cryptic C62, Poolkris, Kaze0010, JForget, RSido, Stifynsemons, Ale jrb, Jacobking, Benwildeboer, Simply south, Myasuda, Dr Zak, Danapit, ST47, Benjiboi, Roberta F., DumbBOT, Chrisk02, Rbanzai, Epbr123, Kablammo, Headbomb, Electron9, Tellyaddict, Hcobb, Escarbot, Hmrox, AntiVandalBot, Herne nz, Tjmayerinsf, Mack2, Endimion17, Badocter, H.D.Wardle, Myanw, Deflective, Tombarrister, MER-C, Inks.LWC, Instinct, Hut 8.5, Justinnerd, Helge Skjeveland, Ronstock, Bongwarrior, VoABot II, Anonymous, Ishikawa Minoru, Paulking11, Liverpool Scouse, JNW, Remodeling101, Vernon39, Jim Douglas, Baccyak4H, Aka042, Dustin4m3, Dougz1, Animum, Cgingold, Huseyx2, Dirac66, Allstarecho, LorenzoB, JaGa, WLU, Shadesofgrey, The freddinator, MartinBot, Retteast, Mike6271, Kostisl, CommonsDelinker, Dogsdiner, Artaxiad, Watch37264, J.delanoy, Captain panda, Bogy97, Eliz81, 12dstring, Gammabetaalpha, Royalhistorian, Trumpet marietta 45750, (jarbarf), Warut, Rominandrey, Crazy coyote, Tanaats, Tinsman, Pdcoc, Vynbos, Squids and Chips, Jeff Miner, 28bytes, VolkovBot, Jeff G., JohnBlackburne, Jmrowland, Nburden, LeilaniLad, TXiKiBoT, Zidonuke, Michelet, Qxz, LeaveSleeves, Bodybagger, PDFbot, Cremepuff222, Plazak, Synthebot, Lpag01, Insanity Incarnate, Alcmaeonid, AlleborgoBot, Logan, LuigiManiac, EAPIII, Kbrose, SieBot, Claar, PlanetStar, YonaBot, Euryalus, Winchelsea, Caltas, Lucasfbfbot, Calabraxthis, Bentogoa, Samak47, Yerpo, Pedroviltero, Scavenger348, Oxymoron83, Lightmouse, Ealdgyth, Hak-kâ-ngin, Danimations, Wii Wiki, WikiLaurent, Nergaal, Kreag, Escape Orbit, Tuntable, Loren.wilton, Sfan00 IMG, FlamingSilmaril, ClueBot, Trojancowboy, The

Thing That Should Not Be, Valerielgreen, CounterVandalismBot, Blanchardb, MC Scared of Bees, Skihatboatbike, DragonBot, Jusdafax, Sugarsnap240, John Nevard, Abrech, Gtstricky, MNNE, Bvaught07, Zachrush2, Kaiba, Brittenn, Zachrush3, Pifreak94, Footballfan190, Dremos, DumZiBoT, InternetMeme, XLinkBot, Opaldragon1, BodhisattvaBot, Rror, Turtleboy0, Nepenthes, Avoided, Danimes-enwiki, Kbdankbot, HexaChord, Roentgenium111, Dabby, DOI bot, MrSpectacles, Danblum, C3r4, Ronhjones, Ajcooler, CarsracBot, Glane23, Nick&Jacqui, Jasper Deng, Numbo3-bot, Lightbot, Luckas-bot, Yobot, Jamacfarlane, Kilom691, KamikazeBot, AnomieBOT, Nutrivog, Kristen Eriksen, VX, JackieBot, Piano non troppo, AdjustShift, Crystal whacker, Materialschemist, Inthend9, Citation bot, Kalamkaar, Felyza, Vuerqex, ArthurBot, Xqbot, Zad68, Capricorn42, Kennethcleary, Sdcoonce, Srich32977, Mrcscientistman, GrouchoBot, Call me Bubba, Jameygelina, Shadowjams, AlimanRuna, Wikiniton, Cekli829, Biem, FrescoBot, Protocol: Noir, Wervo, Rewd70, Deadskull56, Citation bot 1, Pinethicket, I dream of horses, Notedgrant, Jonesey95, Rameshngbot, Tom.Reding, A8UDI, Gypsypkd, Meaghan, Safwanmoosa, Lineslarge, Roserens, Xeworlebi, Owen 1965, Jauhienij, Lightlowemon, Double sharp, ManfromButtonwillow, Time2getpwned, Kopernagel, WHO2005, Damp geek, Tophediter, Weedwhacker128, DARTH SIDIOUS 2, RjwilmsiBot, Mid137, Ripchip Bot, Natick-townie, Billben74, DASHBot, EmausBot, WikitanvirBot, Lucien504, Solarra, Jsjs1111, Josve05a, Globorunner1973, StringTheory11, Chemicalinterest, H3llBot, Aflafla1, Albinoni67, Givenatoms, KGBart94, Puffin, Whoop whoop pull up, Jno3881, Will Beback Auto, ClueBot NG, Cwmhiraeth, T020, Lanthanum-138, Bsmithuf, Markabe69, Reify-tech, Jenilyn834, CiaranKinf, Pluma, FluorineGas, Maxwys, Helpful Pixie Bot, Bibcode Bot, Vagobot, Blake Burba, ElphiBot, Altair, Petersmarty, Qzh00k, YumOooze, Wgyd, KSal9, Glacialfox, 3.141592653589pi, ConradMayhew, Cengime, SeljukEmpire, Chrislikes p, YFdyh-bot, Khazar2, Illia Connell, JYBot, TopGarbageCollector, RAB1900, Windows.dll, Rot511a, Natecra, Numbermaniac, Lugia2453, The Anonymouse, Jthomson030, Debouch, Jacek, Ilk-ered123, J.meija, Camaraw1, Ugog Nizdast, Wislong, DudeWithAFeud, Anrnusna, Stamptrader, Boilerbuilder72, Galt42, Monkbot, Bast gaga, Trackteur, Antoninus73, ReN-DoG1234, RENCAT1234, TerryAlex, The Cheeky Little Blighter, Crystallizedcarbon, M12345678a, Jozaaar, Infernus 780, Tymon.r, Ravenlogos, Ethanjackson, Palter5, Bbopdd77 and Anonymous: 671

- Ununoctium** *Source:* <http://en.wikipedia.org/wiki/Ununoctium?oldid=659794445> *Contributors:* Vicki Rosenzweig, Mav, Bryan Derksen, Danny, Rmhermen, Ortolan88, William Avery, SimonP, Heron, Camembert, Fonzy, Michael Hardy, Ixf64, GTBacchus, Eric119, Iluvcapra, Golthar, Ahoerstemeier, Andres, Jiang, Rawr, Mxn, Schneelocke, Gamma-enwiki, Hashar, Emperorbma, Timwi, Rbraunwa, RickK, Stone, Lfh, David Latapie, Dysprosia, Furrykef, Fvw, Finlay McWalter, Lumos3, Robbot, Altenmann, Naddy, COGDEN, Merovingian, Henrygb, Mushroom, Seth Ilys, Alan Liefting, Fabifinor, Alerante, Brouhaha, Brian Kendig, Herbee, Michael Devore, Yekrats, Pascal666, Siroxo, Darrien, Piotrus, Lesgles, Almit39, Zfr, Adashiel, Jimaginor, Mike Rosoff, Atrian, Noisy, Twinxor, Rich Farnbrough, NrDg, Vsmith, Bender235, RJHall, El C, Joanjoc-enwiki, Kwamikagami, Art LaPella, RoyBoy, Femto, Minghong, Ed-dideigel, Lysdexia, Honeycake, Anthony Appleyard, Gerweck, Trollinator, Miranche, Atlant, Sl, Andrew Gray, Mac Davis, Rathlan, Wtmitchell, HenkvD, Oghmoir, Wimvanderst, Cmapm, Vuo, Matthew kokai, Jess Cully, Nightstallion, Sturmde, Dismas, Sk4p, Zntrip, Mcsee, CaptainMike, Woohookitty, David Haslam, Benbest, Rickjpellg, Mpatel, Miss Madeline, KFan II, GregorB, Dionyziz, Isnow, Zzyzx11, Graham87, Elvey, Wachholder0, DePiep, Grammarbot, Saperaud-enwiki, Rjwilmsi, JLM-enwiki, Strait, Mitchandre, Brighterorange, Bensin, Naraht, RobertG, Margosbot-enwiki, Nihiltres, Short Verses, Goudzovski, Laur, Chobot, YurikBot, Wavelength, Borgx, RobotE, Neitherday, Jimp, Xoloz, Micahbrwn, Eleassar, Expensivehat, Bmdavll, Lexicon, Raven4x4x, RUL3R, Obey, Zwobot, Bota47, Tetracube, Leptictidium, Aja-Oki, Super Rad!, TheMadBaron, Reyk, Oscarcwk, Lewis R, Physicsdavid, GrinBot-enwiki, D Monack, One, Itub, SmackBot, Tarret, Anarchist42, KocjoBot-enwiki, Xblx, Boris Barowski, Edgar181, Xaosflux, Yamaguchi, Gorman, Hugo-cs, Chris the speller, Kurykh, Grimhelm, MalafayaBot, Timneu22, Nozzleman, DHN-bot-enwiki, Grandmasterka, Gyrobo, WDGraham, Can't sleep, clown will eat me, Shalom Yechiel, Oscar Bravo, Vanished User 0001, VMS Mosaic, Addshore, Julius Sahara, Kingdon, Hateless, Cybercobra, Daniel bg, GaiusTimiusAwesomus, Copysan, DDima, Chymicus, SashatoBot, John, JorisvS, Hans van Deukeren, Olin, Mr. Lefty, Slakr, Negrulio, Iridescent, Igoldste, Amakuru, Bobamnertiopsis, Happy-melon, Dlohcierekim, Poolkris, Gveret Tered, Cacahueten, Wafulz, Black and White, Shandris, Act333, Nilfanion, Error411, Reywas92, Diftuoroethene, Christian75, Mallanox, Blindman shady, Omicronpersei8, Lo2u, CieloEstrellado, Malleus Fatuorum, Thijs!bot, Jeffreyfisher, Pampas Cat, Headbomb, EdJohnston, AntiVandalBot, Jared Hunt, PJY, Deflective, MER-C, QuantumEngineer, East718, .anacondabot, Baccy4H, YA1YB4FIGKYITQ0FB8AR, BilCat, Styrofoam1994, Frotz, DerHexer, Stevebeck, GregU, Iwoelbern, Nono64, SETI3, Go-yeer, DrKiernan, Numbo3, Hans Dunkelberg, Maurice Carbonaro, Man123123, Iamthewalrus36, NerdyNSK, Hules001, Dispenser, Crazy coyote, Treisijs, TheNewPhobia, Idioma-bot, X!, 28bytes, VolkovBot, Chris Dybala, TXiKiBoT, GimmeBot, A4bot, Cosmos, Zimbaro Cookie Experiment, Mouse is back, Woosie roxs, AlleborgoBot, Rknasc, Natox, SieBot, PlanetStar, Gerakibot, RJaguar3, Lightmouse, RandoBLUE, Synthetic element, Dabomb87, Nergaal, Gold257, ClueBot, Leapmark, The Thing That Should Not Be, Drmies, Blanchardb, Michał Sobkowski, LizardJr8, Piledhigheranddeeper, NuclearVacuum, Excirial, Duphus2, Socram, NuclearWarfare, Aurora2698, ChrisHodgesUK, Thingg, Pifreak94, NERIC-Security, Drjezza, AgnosticPreachersKid, Richyhan, SkyLined, Dfoxvog, Roentgenium111, DOI bot, Devleenasamanta, CarsracBot, AndersBot, LinkFA-Bot, AgadaUrbanit, PoliteCarbide, VASANTH S.N., C933103, Luckasbot, Yobot, Donfbreed, Amirobot, THEN WHO WAS PHONE?, Shootbamboo, Materialschemist, Citation bot, Vuerqex, Frankenpuppy, ArthurBot, Xqbot, Ryomaandres, Pontificalibus, Jeffrey Mall, Srich32977, Mrcscientistman, Millar153, Prozacchiwawa, RibotBOT, 78.26, Multixer, Bhangranuch, Spellage, AlimanRuna, Ogel6000, Erik9bot, R8R Gtrs, HJ Mitchell, Outback the koala, Citation bot 1, Hal-lucegenia, Biker Biker, Rameshngbot, Angstorm, Tom.Reding, Efficiency1101e, MastiBot, Σ, Mikespedia, Xeworlebi, Jauhienij, Double sharp, Trappist the monk, Ghjthgh, Walter giardino 987, Cfsfgds, 99faith11, Tshotch, TjBot, DASHBot, EmausBot, WikitanvirBot, Super48paul, Slightsmile, Emma364, Josve05a, StringTheory11, Flag cloud, H3llBot, Capricorn4049, ChuispastonBot, Transnebula, N8er568, Mikhail Ryazanov, ClueBot NG, Lanthanum-138, HazelAB, Zakblade2000, Helpful Pixie Bot, Yanting999, Calabe1992, Bibcode Bot, Pine, HReuter, Writ Keeper, Insidiae, Power2793, Minsbot, BattyBot, Justincheng12345-bot, Mdann52, Neumannjo, Kumioko, Dexbot, G.Kiruthikan, Lugia2453, Frosty, Poopy2810, Reatlas, Abc347834, DudeWithAFeud, Monkbot, Saadk822, Eremium, Keylimepiez, Banclark86 and Anonymous: 293

3.2 Images

- File:2_Helium.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/3/3f/2_Helium.png *License:* Public domain *Contributors:* Transferred from en.wikipedia; transferred to Commons by User:Liftarn using CommonsHelper. *Original artist:* Original uploader was Vuerqex at en.wikipedia
- File:Ac-system_2.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/0/0b/Ac-system_2.jpg *License:* CC BY 3.0 *Contributors:* Own work *Original artist:* Baravara
- File:ArTube.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/2/2f/ArTube.jpg> *License:* CC BY-SA 2.5 *Contributors:* user-made *Original artist:* User:Pslawinski

- **File:Argon-fluorohydride-3D-vdW.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/3/31/Argon-fluorohydride-3D-vdW.png> *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:Argon-glow.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/5/53/Argon-glow.jpg> *License:* CC BY 3.0 *Contributors:* <http://images-of-elements.com/argon.php> *Original artist:* Jurii
- **File:Argon.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/f/fa/Argon.jpg> *License:* Attribution *Contributors:* My Opera devblog *Original artist:* William Viker
- **File:Argon_Spectrum.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/3/37/Argon_Spectrum.png *License:* CC BY-SA 3.0 *Contributors:* Own work <http://goiphone5.com/> *Original artist:* Abilanin
- **File:Argon_discharge_tube.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/8/87/Argon_discharge_tube.jpg *License:* GFDL 1.2 *Contributors:* Own work *Original artist:* Alchemist-hp ([User talk:Alchemist-hp](http://commons.wikimedia.org/wiki/User_talk:Alchemist-hp)) (www.pse-mendeleejew.de)
- **File:Argon_ice_1.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/0/0d/Argon_ice_1.jpg *License:* CC-BY-SA-3.0 *Contributors:* ? *Original artist:* ?
- **File:Binding_energy_curve_-_common_isotopes.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/5/53/Binding_energy_curve_-_common_isotopes.svg *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:Buckminsterfullerene-perspective-3D-balls.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/0/0f/Buckminsterfullerene-perspective-3D-balls.png> *License:* Public domain *Contributors:* Own work *Original artist:* Benjah-bmm27
- **File:Circle_frame.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/1/18/Circle_frame.svg *License:* Public domain *Contributors:* Own work *Original artist:* PleaseStand
- **File:Commons-logo.svg** *Source:* <http://upload.wikimedia.org/wikipedia/en/4/4a/Commons-logo.svg> *License:* ? *Contributors:* ? *Original artist:* ?
- **File:CsCrystals.JPG** *Source:* <http://upload.wikimedia.org/wikipedia/commons/1/11/CsCrystals.JPG> *License:* CC BY 3.0 *Contributors:* Own work *Original artist:* Dnn87
- **File:Cubic-face-centered.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/c/c9/Cubic-face-centered.svg> *License:* CC-BY-SA-3.0 *Contributors:* Cubic, face-centered.png *Original artist:* Original PNGs by Daniel Mayer and DrBob, traced in Inkscape by User:Stannered
- **File:Decay_chain(4n+2,_Uranium_series).svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/6/65/Decay_chain%284n%2B2%2C_Uranium_series%29.svg *License:* CC BY 3.0 *Contributors:* File:Decay chain(4n+2, Uranium series).PNG *Original artist:* User:Tosaka
- **File:Discovery_of_neon_isotopes.JPG** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/e6/Discovery_of_neon_isotopes.JPG *License:* Public domain *Contributors:* *Original artist:* ?
- **File:Electron_shell_010_Neon_-_no_label.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/3/3e/Electron_shell_010_Neon_-_no_label.svg *License:* CC BY-SA 2.0 uk *Contributors:* http://commons.wikimedia.org/wiki/Category:Electron_shell_diagrams (corresponding labeled version) *Original artist:* commons:User:Pumbaa (original work by commons:User:Greg Robson)
- **File:Endohedral fullerene.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/e1/Endohedral_fullerene.png *License:* GFDL *Contributors:* Own work *Original artist:* Hajv01
- **File:Ethanol-3D-balls.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/b/b0/Ethanol-3D-balls.png> *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:Flag_of_Russia.svg** *Source:* http://upload.wikimedia.org/wikipedia/en/f/f3/Flag_of_Russia.svg *License:* PD *Contributors:* ? *Original artist:* ?
- **File:Flag_of_the_United_States.svg** *Source:* http://upload.wikimedia.org/wikipedia/en/a/a4/Flag_of_the_United_States.svg *License:* PD *Contributors:* ? *Original artist:* ?
- **File:Fluoroheliate-ion-3D-vdW.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/f/f4/Fluoroheliate-ion-3D-vdW.png> *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* Whoop whoop pull up
- **File:Folder_Hexagonal_Icon.svg** *Source:* http://upload.wikimedia.org/wikipedia/en/4/48/Folder_Hexagonal_Icon.svg *License:* Cc-by-sa-3.0 *Contributors:* ? *Original artist:* ?
- **File:Glovebox.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/8/85/Glovebox.jpg> *License:* CC-BY-SA-3.0 *Contributors:* Wikipedia-en: [w:en:Image:Glovebox.jpg](http://en.wikipedia.org/wiki/File:Image:Glovebox.jpg) *Original artist:* [w:en>User:Rune.welsh](http://en.wikipedia.org/wiki/User:Rune.welsh)
- **File:Gnome-mime-sound-openclipart.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/8/87/Gnome-mime-sound-openclipart.svg> *License:* Public domain *Contributors:* Own work. Based on File:Gnome-mime-audio-openclipart.svg, which is public domain. *Original artist:* User:Eubulides
- **File:Goodyear-blimp.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/2/2a/Goodyear-blimp.jpg> *License:* Public domain *Contributors:* user-made *Original artist:* Derek Jensen (Tysto)
- **File:HeTube.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/1/1f/HeTube.jpg> *License:* CC BY-SA 2.5 *Contributors:* user-made *Original artist:* User:Pslawinski
- **File:Helium-II-creep.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/b/b7/Helium-II-creep.svg> *License:* CC BY-SA 3.0 *Contributors:* Redrawn after Aarchiba's Helium-II-creep.png *Original artist:* Design: Aarchiba; SVG rendering: Júlio Reis
- **File:Helium-glow.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/0/00/Helium-glow.jpg> *License:* CC BY 3.0 *Contributors:* <http://images-of-elements.com/helium.php> *Original artist:* Jurii
- **File:Helium-hydride-ion-3D-SF.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/0/03/Helium-hydride-ion-3D-SF.png> *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* CCoil ([User talk:CCoil](http://commons.wikimedia.org/wiki/User_talk:CCoil)) ([User talk:CCoil](http://commons.wikimedia.org/wiki/User_talk:CCoil))

- **File:Helium.ogg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/1/16/Helium.ogg> *License:* CC-BY-SA-3.0 *Contributors:*
- Derivative of Helium *Original artist:* **Speaker:** The Jacobin
Authors of the article
- **File:Helium_article_read_with_helium.ogg** *Source:* http://upload.wikimedia.org/wikipedia/commons/9/9c/Helium_article_read_with_helium.ogg *License:* CC-BY-SA-3.0 *Contributors:* <http://en.wikipedia.org/wiki/Helium> *Original artist:* BlueNight
- **File:Helium_atom_QM.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/2/23/Helium_atom_QM.svg *License:* CC-BY-SA-3.0 *Contributors:* Own work *Original artist:* User:Yzmo
- **File:Helium_discharge_tube.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/8/82/Helium_discharge_tube.jpg *License:* GFDL 1.2 *Contributors:* Own work *Original artist:* Alchemist-hp (talk) (www.pse-mendeleejew.de)
- **File:Helium_spectra.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/c/c3/Helium_spectra.jpg *License:* Public domain *Contributors:* Transferred from en.wikipedia; transferred to Commons by User:João Sousa using CommonsHelper. *Original artist:* (teravolt (talk)). Original uploader was Teravolt at en.wikipedia
- **File:Helium_spectrum.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/8/80/Helium_spectrum.jpg *License:* Public domain *Contributors:* http://imagine.gsfc.nasa.gov/docs/teachers/lessons/xray_spectra/worksheet-specgraph2-sol.html *Original artist:* NASA
- **File:Hexagonal_close_packed.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/c/cb/Hexagonal_close_packed.svg *License:* CC BY-SA 3.0 *Contributors:* http://en.wikipedia.org/wiki/File:Hexagonal_close_packed.png *Original artist:* User:Dornelf
- **File:Ionization_energies.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/2/27/Ionization_energies.png *License:* Public domain *Contributors:* Self-made; based on data from: Martin, W. C.; Wiese, W. L. (1996) *Atomic, Molecular, & Optical Physics Handbook*, American Institute of Physics ISBN 156396242X *Original artist:* RJHall
- **File:Island_of_Stability_derived_from_Zagrebaev.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/0/06/Island_of_Stability_derived_from_Zagrebaev.png *License:* Public domain *Contributors:* Modified version of [https://commons.wikimedia.org/wiki/File:Island_of_stability_\(Zagrebaev\).png](https://commons.wikimedia.org/wiki/File:Island_of_stability_(Zagrebaev).png) that does not include unnecessary graphics. Shows the nuclear physics island of stability *Original artist:* N/A not eligible for copyright
- **File:Isolation_of_Argon.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/f/f4/Isolation_of_Argon.png *License:* Public domain *Contributors:* Encyclopædia Britannica Eleventh Edition, Vol. 2, Page 476 *Original artist:* Encyclopædia Britannica
- **File:KrTube.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/e/e7/KrTube.jpg> *License:* CC BY-SA 2.5 *Contributors:* user-made *Original artist:* User:Pslawinski
- **File:Krypton-glow.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/9/9c/Krypton-glow.jpg> *License:* CC BY 3.0 *Contributors:* <http://images-of-elements.com/krypton.php> *Original artist:* Jurii
- **File:Krypton_Spectrum.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/a/a6/Krypton_Spectrum.jpg *License:* Public domain *Contributors:* en wikipedia ([1]) *Original artist:* Mrgoogfan
- **File:Krypton_discharge_tube.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/5/50/Krypton_discharge_tube.jpg *License:* GFDL 1.2 *Contributors:* Own work *Original artist:* Alchemist-hp (talk) (www.pse-mendeleejew.de)
- **File:Lead210inairatjapan.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/e/e8/Lead210inairatjapan.png> *License:* Public domain *Contributors:* w:Image:Lead210inairatjapan.jpg *Original artist:* wikipedia:en:user:Cadmium
- **File:Mill_Mountain_Star_Neon_Lights.JPG** *Source:* http://upload.wikimedia.org/wikipedia/commons/8/83/Mill_Mountain_Star_Neon_Lights.JPG *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* TampAGS, for AGS Media
- **File:Modern_3T_MRI.JPG** *Source:* http://upload.wikimedia.org/wikipedia/commons/b/bd/Modern_3T_MRI.JPG *License:* CC-BY-SA-3.0 *Contributors:* Photographed by User:KasugaHuang on Mar 27, 2006 at Tri-Service General Hospital, Taiwan. *Original artist:* User:KasugaHuang
- **File:NeTube.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/8/88/NeTube.jpg> *License:* CC BY-SA 2.5 *Contributors:* user-made *Original artist:* User:Pslawinski
- **File:Neon-glow.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/f/f8/Neon-glow.jpg> *License:* CC BY 3.0 *Contributors:* <http://images-of-elements.com/neon.php> *Original artist:* Jurii
- **File:Neon_discharge_tube.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/4/46/Neon_discharge_tube.jpg *License:* GFDL 1.2 *Contributors:* Own work *Original artist:* Alchemist-hp (talk) (www.pse-mendeleejew.de)
- **File:Neon_emission.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/3/35/Neon_emission.png *License:* CC BY 3.0 *Contributors:* Own work *Original artist:* Deo Favente
- **File:Neon_spectra.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/9/99/Neon_spectra.jpg *License:* Public domain *Contributors:* Transferred from en.wikipedia *Original artist:* Teravolt at en.wikipedia
- **File:Nitrous-oxide-3D-balls.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/9/93/Nitrous-oxide-3D-balls.png> *License:* Public domain *Contributors:* Own work *Original artist:* Ben Mills
- **File:Nuvola_apps_edu_science.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/5/59/Nuvola_apps_edu_science.svg *License:* LGPL *Contributors:* <http://ftp.gnome.org/pub/GNOME/sources/gnome-themes-extras/0.9/gnome-themes-extras-0.9.0.tar.gz> *Original artist:* David Vignoni / ICON KING
- **File:Office-book.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/a/a8/Office-book.svg> *License:* Public domain *Contributors:* This and myself. *Original artist:* Chris Down/Tango project
- **File:Portal-puzzle.svg** *Source:* <http://upload.wikimedia.org/wikipedia/en/f/fd/Portal-puzzle.svg> *License:* Public domain *Contributors:* ? *Original artist:* ?

- **File:Radon_Concentration_next_to_Uranium_Mine.PNG** *Source:* http://upload.wikimedia.org/wikipedia/commons/c/cb/Radon_Concentration_next_to_Uranium_Mine.PNG *License:* Public domain *Contributors:* Own work *Original artist:* Tungsten
- **File:Radon_Lognormal_distribution.gif** *Source:* http://upload.wikimedia.org/wikipedia/commons/7/71/Radon_Lognormal_distribution.gif *License:* Public domain *Contributors:* <http://www.ndhealth.gov/daq/daq/radon/day9192.htm> *Original artist:* Dakota Department of Human Services
- **File:Radon_and_Cancer_by_Cohen.GIF** *Source:* http://upload.wikimedia.org/wikipedia/commons/0/08/Radon_and_Cancer_by_Cohen.GIF *License:* Public domain *Contributors:* <http://www.ehponline.org/members/1998/Suppl-1/363-368pollycove/full.html> *Original artist:* Myron Pollycove, U.S. Nuclear Regulatory Commission, Washington, DC
- **File:Radon_apparatus.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/0/0b/Radon_apparatus.png *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:Radon_spectrum.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/0/0d/Radon_spectrum.png *License:* Public domain *Contributors:* <http://www.periodicvideos.com/videos/086.htm> *Original artist:* Ernest Rutherford
- **File:Radon_test_kit.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/7/7f/Radon_test_kit.jpg *License:* Public domain *Contributors:* <http://visualsonline.cancer.gov/details.cfm?imageid=2344> *Original artist:* Unknown
- **File:STS-135_Atlantis_rollout_1.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/7/7c/STS-135_Atlantis_rollout_1.jpg *License:* Public domain *Contributors:* <http://mediaarchive.ksc.nasa.gov/detail.cfm?mediaid=53271> *Original artist:* NASA/Kim Shiflett
- **File:Sound-icon.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/4/47/Sound-icon.svg> *License:* LGPL *Contributors:* Derivative work from Silsor's versio *Original artist:* Crystal SVG icon set
- **File:Speakerlink-new.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/3/3b/Speakerlink-new.svg> *License:* CC0 *Contributors:* Own work *Original artist:* Kelvinsong
- **File:Square-planar-3D-balls.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/5/5b/Square-planar-3D-balls.png> *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:Stylised_Lithium_Atom.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/e1/Stylised_Lithium_Atom.svg *License:* CC-BY-SA-3.0 *Contributors:* based off of Image:Stylised Lithium Atom.png by Halfdan. *Original artist:* SVG by Indolences. Recoloring and ironing out some glitches done by Rainer Klute.
- **File:Symbol_book_class2.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/8/89/Symbol_book_class2.svg *License:* CC BY-SA 2.5 *Contributors:* Mad by Lokal_Profil by combining: *Original artist:* Lokal_Profil
- **File:Tetrahedral-3D-balls.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/f/fb/Tetrahedral-3D-balls.png> *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:Transparent.gif** *Source:* <http://upload.wikimedia.org/wikipedia/commons/c/ce/Transparent.gif> *License:* Public domain *Contributors:* Own work *Original artist:* Edokter
- **File:Ununoctium-294_nuclear.svg** *Source:* http://upload.wikimedia.org/wikipedia/commons/4/43/Ununoctium-294_nuclear.svg *License:* CC BY-SA 3.0 *Contributors:* Created based on File:Ununoctium-294 nuclear.png by Nergaal at English Language Wikipedia *Original artist:* Tkgd2007 at English Language Wikipedia
- **File:WLM-Cancer_risk.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/ec/WLM-Cancer_risk.jpg *License:* Public domain *Contributors:* The cancer epidemiology of radiation, *Oncogene* (2004) 23, 6404–6428. doi:10.1038/sj.onc.1207896 <http://www.nature.com/onc/journal/v23/n38/full/1207896a.html> *Original artist:* Richard Wakeford
- **File:Wikibooks-logo-en-noslogan.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/d/df/Wikibooks-logo-en-noslogan.svg> *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* User:Bastique, User:Ramac et al.
- **File:Wikibooks-logo.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/f/fa/Wikibooks-logo.svg> *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* User:Bastique, User:Ramac et al.
- **File:Wikinews-logo.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/2/24/Wikinews-logo.svg> *License:* CC BY-SA 3.0 *Contributors:* This is a cropped version of Image:Wikinews-logo-en.png. *Original artist:* Vectorized by Simon 01:05, 2 August 2006 (UTC) Updated by Time3000 17 April 2007 to use official Wikinews colours and appear correctly on dark backgrounds. Originally uploaded by Simon.
- **File:Wikiversity-logo.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/9/91/Wikiversity-logo.svg> *License:* CC BY-SA 3.0 *Contributors:* Snorky (optimized and cleaned up by verdyp) *Original artist:* Snorky (optimized and cleaned up by verdyp)
- **File:Wiktionary-logo-en.svg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/f/f8/Wiktionary-logo-en.svg> *License:* Public domain *Contributors:* Vector version of Image:Wiktionary-logo-en.png. *Original artist:* Vectorized by Fvasconcellos (talk · contribs), based on original logo tossed together by Brion Vibber
- **File:William_Ramsay_working.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/d/d2/William_Ramsay_working.jpg *License:* Public domain *Contributors:* ? *Original artist:* ?
- **File:XeF2.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/2/27/XeF2.png> *License:* Public domain *Contributors:* user-made *Original artist:* User:Smokefoot
- **File:XeTube.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/5/59/XeTube.jpg> *License:* CC BY-SA 2.5 *Contributors:* user-made *Original artist:* User:Pslawinski
- **File:Xenon-flash.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/2/2a/Xenon-flash.jpg> *License:* CC-BY-SA-3.0 *Contributors:* Own work by the original uploader, based on file:Xenon-flash small.gif *Original artist:* The original uploader was C3o at English Wikipedia
- **File:Xenon-glow.jpg** *Source:* <http://upload.wikimedia.org/wikipedia/commons/5/5d/Xenon-glow.jpg> *License:* CC BY 3.0 *Contributors:* <http://images-of-elements.com/xenon.php> *Original artist:* Jurii
- **File:Xenon-tetrafluoride-3D-vdW.png** *Source:* <http://upload.wikimedia.org/wikipedia/commons/e/e3/Xenon-tetrafluoride-3D-vdW.png> *License:* Public domain *Contributors:* user-made *Original artist:* User:Benjah-bmm27

- **File:Xenon_Spectrum.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/6/67/Xenon_Spectrum.jpg *License:* Public domain *Contributors:* Transferred from en.wikipedia; transferred to Commons by User:Homer Landskirty using CommonsHelper. *Original artist:* Teravolt (talk). Original uploader was Teravolt at en.wikipedia
- **File:Xenon_discharge_tube.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/d/d7/Xenon_discharge_tube.jpg *License:* FAL *Contributors:* Own work *Original artist:* Alchemist-hp (talk) (www.pse-mendelejew.de)
- **File:Xenon_ion_engine_prototype.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/7/7e/Xenon_ion_engine_prototype.png *License:* Public domain *Contributors:* <http://www.jpl.nasa.gov/pictures/solar/ds1ion.html> *Original artist:* NASA
- **File:Xenon_short_arc_1.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/9/9e/Xenon_short_arc_1.jpg *License:* CC BY 2.5 *Contributors:* user-made *Original artist:* provided that proper attribution of my copyright is made. - Atlant 19:15, 26 August 2005 (UTC)
- **File:Xenon_tetrafluoride.JPG** *Source:* http://upload.wikimedia.org/wikipedia/commons/d/d7/Xenon_tetrafluoride.JPG *License:* Public domain *Contributors:*
- [Xenon_tetrafluoride.gif](#) *Original artist:* [Xenon_tetrafluoride.gif](#): User:Paginazero

3.3 Content license

- Creative Commons Attribution-Share Alike 3.0