Radon

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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 a decay product of radium. Its most stable isotope, ^{222}Rn, 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 elemental gas under normal conditions that has no stable 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 other radioactive elements called radon progeny (also known as 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, 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 density. It can also occur in water where the water comes from a ground source -e.g. in some spring waters and hot springs.[5]

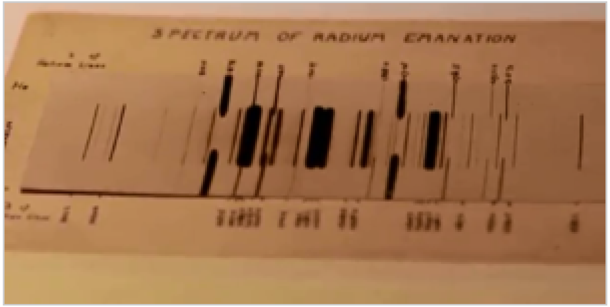
Radon, $_{86}Rn$

Spectral lines of radon

General properties	
Name, symbol	radon, Rn
Appearance	colorless gas, occasionally glows green or red in discharge tubes
Radon in the periodic table	
Atomic number (*Z*)	86
Group, block	group 18 (noble gases), p-block
Period	period 6
Element category	□ noble gas
Standard atomic weight (A_r)	(222)
Electron configuration	[Xe] $4f^{14}\ 5d^{10}\ 6s^2\ 6p^6$
per shell	2, 8, 18, 32, 18, 8
Physical properties	
Phase	gas
Melting point	202 K (−71 °C, −96 °F)
Boiling point	211.5 K (−61.7 °C, −79.1 °F)
Density at stp (0 °C and 101.325 kPa)	9.73 g/L

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]

Characteristics



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

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, about 8 times the density of the Earth's atmosphere at sea level, 1.217 kg/m^3.[7] 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 °C; −96 °F), radon emits a brilliant radioluminescence that turns from yellow to orange-red as the temperature lowers.[8] Upon condensation, radon glows because of the intense radiation it produces.[9] 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

when liquid, at b.p.	4.4 g/cm^3
Critical point	377 K, 6.28 MPa[1]
Heat of fusion	3.247 kJ/mol
Heat of vaporization	18.10 kJ/mol
Molar heat capacity	5R/2 = 20.786 J/(mol·K)

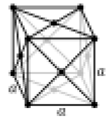
Vapor pressure

P (Pa)	**1**	**10**	**100**	**1 k**	**10 k**	**100 k**
at T (K)	110	121	134	152	176	211

Atomic properties

Oxidation states	6, 2, **0**
Electronegativity	Pauling scale: 2.2
Ionization energies	1st: 1037 kJ/mol
Covalent radius	150 pm
Van der Waals radius	220 pm

Miscellanea

Crystal structure	face-centered cubic (fcc) 
Thermal conductivity	3.61×10^{-3} W/(m·K)
Magnetic ordering	non-magnetic
CAS Number	10043-92-2

History

Discovery	Ernest Rutherford and Robert B. Owens (1899)
First isolation	William Ramsay and

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. Because it is a gas at standard conditions, unlike its parents, it can readily be extracted from them for research.

Robert Whytlaw-Gray (1910)

Most stable isotopes of radon

iso	NA	half-life	DM	DE (MeV)	DP
^{210}Rn	syn	2.4 h	α	6.404	^{206}Po
^{211}Rn	syn	14.6 h	ε	2.892	^{211}At
			α	5.965	^{207}Po
^{222}Rn	trace	3.8235 d	α	5.590	^{218}Po
^{224}Rn	syn	1.8 h	β−	0.8	^{224}Fr

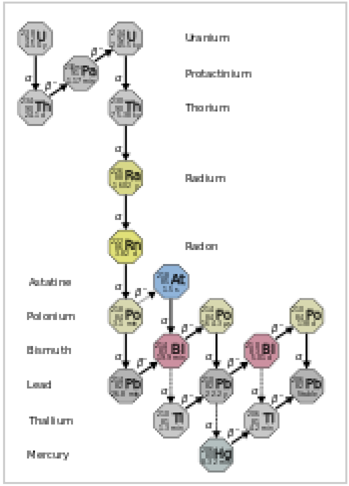
Radon is a member of the zero-valence elements that are called noble gases. It is inert to most common chemical reactions, such as combustion, because the outer valence shell contains eight electrons. This produces a stable, minimum energy configuration in which the outer electrons are tightly bound.[10] 1037 kJ/mol is required to extract one electron from its shells (also known as the first ionization energy).[11] 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).[12]

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 powerful oxidizing agents such as fluorine, thus forming radon difluoride.[13][14] It decomposes back to elements at a temperature of above 250 °C. It has a low volatility and was thought to be RnF_2. 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 Å, and that the compound is thermodynamically more stable and less volatile than its lighter counterpart XeF_2.[15] The octahedral molecule RnF_6 was predicted to have an even lower enthalpy of formation than the difluoride.[16] The higher fluorides RnF_4 and RnF_6 have been claimed,[17] and are calculated to be stable,[18] but it is doubtful whether they have yet been synthesized.[17] The $[RnF]^+$ ion is believed to form by the following reaction:[19]

$$\mathrm{Rn\ (g) + 2\ [O_2]^+[SbF_6]^-\ (s) \rightarrow [RnF]^+[Sb_2F_{11}]^-\ (s) + 2\ O_2\ (g)}$$

Radon oxides are among the few other reported compounds of radon;[20] only the trioxide has been confirmed.[17] Radon carbonyl RnCO has been predicted to be stable and to have a linear molecular geometry.[21] The molecules Rn_2 and RnXe were found to be significantly stabilized by spin-orbit coupling.[22] Radon caged inside a fullerene has been proposed as a drug for tumors.[23] Despite the existence of Xe(VIII), no Rn(VIII) compounds have been claimed to exist; RnF_8 should be highly unstable chemically (XeF_8 is thermodynamically unstable). It is predicted that the most stable Rn(VIII) compound would be barium perradate (Ba_2RnO_6), analogous to barium perxenate.[18] The instability of Rn(VIII) is due to the relativistic stabilization of the 6s shell, also known as the inert pair effect.[18]

Isotopes



The radium or uranium series.

Radon has no stable isotopes. Thirty-six radioactive isotopes have been characterized, with atomic masses ranging from 193 to 228.[24] The most stable isotope is ^{222}Rn, which is a decay product of ^{226}Ra, a decay product of ^{238}U.[25] A trace amount of the (highly unstable) isotope ^{218}Rn is also among the daughters of ^{222}Rn.

Three other radon isotopes have a half-life of over an hour: ^{211}Rn, ^{210}Rn and ^{224}Rn. The ^{220}Rn isotope is a natural decay product of the most stable thorium isotope (^{232}Th), and is commonly referred to as thoron. It has a half-life of 55.6 seconds and also emits alpha radiation. Similarly, ^{219}Rn is derived from the most stable isotope of actinium (^{227}Ac)—named "actinon"—and is an alpha emitter with a half-life of 3.96 seconds.[24] No radon isotopes occur significantly in the neptunium (^{237}Np) decay series, though a trace amount of the (extremely unstable) isotope ^{217}Rn is produced.

Daughters

^{222}Rn 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:[24]

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

- ^{206}Pb, stable.

The radon equilibrium factor[26] 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 (Working Level -a measure of radioactivity commonly used in mining. A detailed explanation of WL is given in Concentration Units). These conditions are not always met; in many homes, the equilibrium fraction is typically 40%; that is, there will be 0.004 WL of daughters for each pCi/L of radon in air.[27] ^{210}Pb 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.[28]

Source

- Wikipedia: Radon (https://en.wikipedia.org/wiki/Radon)