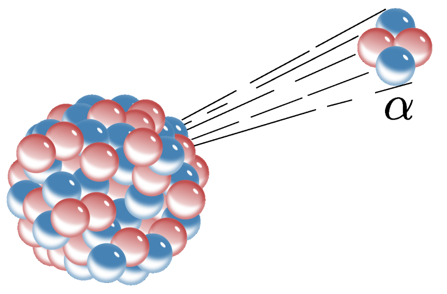
Alpha decay

Alpha decay is a type of radioactive decay in which an atomic nucleus emits an alpha particle and thereby transforms (or 'decays') into an atom with a mass number 4 less and atomic number 2 less. For example:[1]



Alpha decay

$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}^{2+}$

which can also be written as:

$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{Th} + \alpha.$

An alpha particle is the same as a helium-4 nucleus, which has mass number 4 and atomic number 2.

Alpha decay is by far the most common form of cluster decay where the parent atom ejects a defined daughter collection of nucleons, leaving another defined product behind (in nuclear fission, a number of different pairs of daughters of approximately equal size are formed). Alpha decay is the most likely cluster decay because of the combined extremely high binding energy and relatively small mass of the helium-4 product nucleus (the alpha particle).

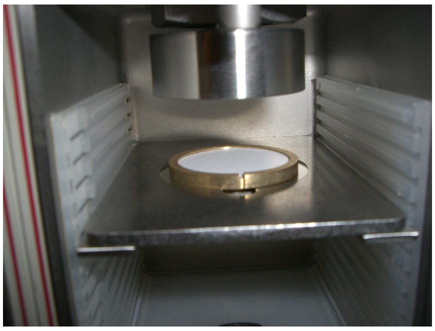
Alpha decay, like other cluster decays, is fundamentally a quantum tunneling process. Unlike beta decay, alpha decay is governed by the interplay between the nuclear force and the electromagnetic force.

Alpha decay typically occurs in the heaviest nuclides. In theory it can occur only in nuclei somewhat heavier than nickel (element 28), where overall binding energy per nucleon is no longer a minimum, and the nuclides are therefore unstable toward spontaneous fission-type processes. In practice, this mode of decay has only been observed in nuclides considerably heavier than nickel, with the lightest known alpha emitter being the lightest isotopes (mass numbers 106–110) of tellurium (element 52).

Alpha particles have a typical kinetic energy of 5 MeV (that is, ≈ 0.13% of their total energy, i.e. 110 TJ/kg) and a speed of 15,000 km/s. This corresponds to a speed of around 0.05 *c*. There is surprisingly small variation around this energy, due to the heavy dependence of the half-life of this process on the energy produced (see equations in the Geiger–Nuttall law).

Because of their relatively large mass, +2 electric charge and relatively low velocity, alpha particles are very likely to interact with other atoms and lose their energy, so their forward motion is effectively stopped within a few centimeters of air.

Most of the helium produced on Earth (approximately 99% of it) is the result of the alpha decay of underground deposits of minerals containing uranium or thorium. The helium is brought to the surface as a byproduct of natural gas production.



Alpha source beneath a radiation detector

History

Alpha particles were first described in the investigations of radioactivity by Ernest Rutherford in 1899, and by 1907 they were identified as He^{2+} ions. For more details of this early work, see Alpha particle#History of discovery and use.

By 1928, George Gamow had solved the theory of the alpha decay via tunneling. The alpha particle is trapped in a potential well by the nucleus. Classically, it is forbidden to escape, but according to the then newly discovered principles of quantum mechanics, it has a tiny (but non-zero) probability of "tunneling" through the barrier and appearing on the other side to escape the nucleus. Gamow solved a model potential for the nucleus and derived from first principles a relationship between the half-life of the decay, and the energy of the emission, which had been previously discovered empirically, and was known as the Geiger–Nuttall law.[2]

Uses

Americium-241, an alpha emitter, is used in smoke detectors. The alpha particles ionize air between a small gap. A small current is passed through that ionized air. Smoke particles from fire that enter the air gap reduce the current flow, sounding the alarm.

Alpha decay can provide a safe power source for radioisotope thermoelectric generators used for space probes and artificial heart pacemakers. Alpha decay is much more easily shielded against than other forms of radioactive decay. Plutonium-238, for example, requires only 2.5 millimetres of lead shielding to protect against unwanted radiation.

Static eliminators typically use polonium-210, an alpha emitter, to ionize air, allowing the 'static cling' to more rapidly dissipate.

Toxicity

Being relatively heavy and positively charged, alpha particles tend to have a very short mean free path, and quickly lose kinetic energy within a short distance of their source. This results in several MeV being deposited in a relatively small volume of material. This increases the chance of cellular damage in cases of internal contamination. In general, external alpha radiation is not harmful since alpha particles are effectively shielded by a few centimeters of air, a piece of paper, or the thin layer of dead skin cells. Even touching an alpha source is usually not harmful, though many alpha sources also are accompanied by beta-emitting radio daughters, and alpha emission is also accompanied by gamma photon emission. If substances emitting alpha particles are ingested, inhaled, injected or introduced through the skin, then it could result in a measurable dose.

The relative biological effectiveness (RBE) of alpha radiation is higher than that of beta or gamma radiation. RBE quantifies the ability of radiation to cause certain biological effects, notably either cancer or cell-death, for equivalent radiation exposure. The higher value for alpha radiation is generally attributable to the high linear energy transfer (LET) coefficient, which is about one ionization of a chemical bond for every angstrom of travel by the alpha particle. The RBE has been set at the value of 20 for alpha radiation by various government regulations. The RBE is set at 10 for neutron irradiation, and at 1 for beta radiation and ionizing photons.

However, another component of alpha radiation is the recoil of the parent nucleus, termed alpha recoil. Due to the conservation of momentum requiring the parent nucleus to recoil, the effect acts much like the 'kick' of a rifle butt when a bullet goes in the opposite direction. This gives a significant amount of energy to the recoiling nucleus, which also causes ionization damage. The total energy of the recoil nucleus is readily calculable, and is roughly the weight of the alpha (4 u) divided by the weight of the parent (typically about 200 u) times the total energy of the alpha. By some estimates, this might account for most of the internal radiation damage, as the recoil nuclei are typically heavy metals which preferentially collect on the chromosomes. In some studies,[3] this has resulted in a RBE approaching 1,000 instead of the value used in governmental regulations.

The largest natural contributor to public radiation dose is radon, a naturally occurring, radioactive gas found in soil and rock.[4] If the gas is inhaled, some of the radon particles may attach to the inner lining of the lung. These particles continue to decay, emitting alpha particles which can damage cells in the lung tissue.[5] The death of Marie Curie at age 66 from leukemia was probably caused by prolonged exposure to high doses of ionizing radiation, but it is not clear if this was due to alpha radiation or X-rays. Curie worked extensively with radium, which decays into radon,[6] along with other radioactive materials that emit beta and gamma rays. However, Curie also worked with unshielded X-ray tubes during World War I, and analysis of her skeleton during a reburial showed a relatively low level of radioisotope burden.

Russian dissident Alexander Litvinenko's 2006 murder by radiation poisoning is thought to have been carried out with polonium-210, an alpha emitter.

References

[1] Suchocki, John. *Conceptual Chemistry*, 2007. Page 119.
[2] For Gamow's derivation of this law, see (http://www.phy.uct.ac.za/courses/phy300w/np/ch1/node38.html)
[3] Winters TH, Franza JR (1982). "Radioactivity in Cigarette Smoke". *New England Journal of Medicine* **306** (6): 364–365. doi:10.1056/NEJM198202113060613.
[4] ANS : Public Information : Resources : Radiation Dose Chart (http://www.ans.org/pi/resources/dosechart/)
[5] EPA Radiation Information: Radon. October 6, 2006, (http://www.epa.gov/radiation/radionuclides/radon.htm), Accessed December 6, 2006
[6] Health Physics Society, "Did Marie Curie die of a radiation overexposure?" (http://www.hps.org/publicinformation/ate/q535.html)

- Alpha emitters by increasing energy (Appendix 1) (http://www.ct.infn.it/~rivel/Didat/SilDet.pdf)

External links

- **The LIVEChart of Nuclides - IAEA** (http://www-nds.iaea.org/livechart) with filter on alpha decay, in **Java** (http://www-nds.iaea.org/livechart) or **HTML** (http://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html)

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