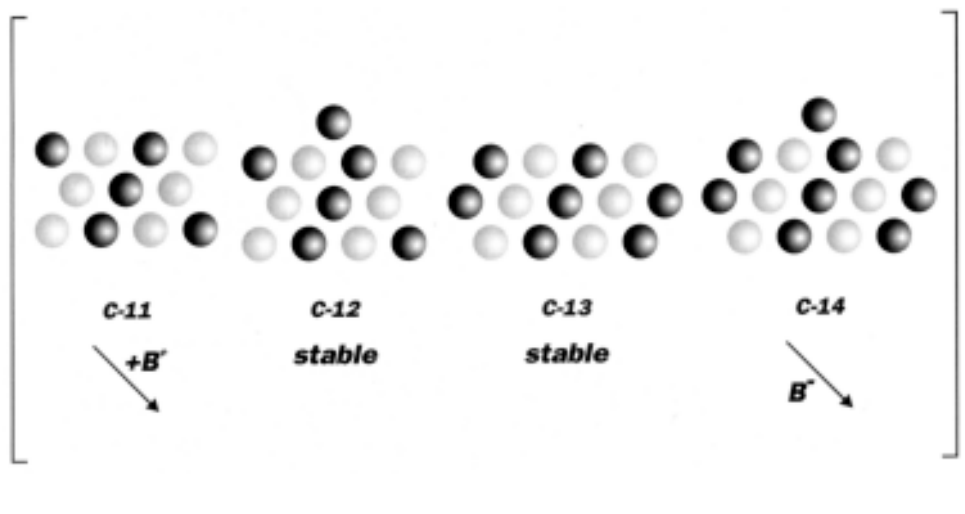


Alpha, Beta and Gamma Radioactivity



When an unstable atom decays it is nearly always by emitting one of the above. For most elements there is a combination of neutrons and protons in the nucleus of the atom that is stable, that is it has not been possible to measure any radioactive decay. In some cases there is more than one combination which gives rise to a stable atom of a given element: these have the same number of protons in the nucleus, but different numbers of neutrons. Such atoms are called isotopes.

Example



All four atoms have 6 protons which makes them carbon atoms, but they have different numbers of neutrons. Both C-12 and C-13 are stable, but C-11 and C-14 are radioactive and decay by emitting beta particles. These four are different isotopes of carbon.

In general, isotopes which have an excess of neutrons, like C-14, decay by emitting negatrons which are negatively charged beta particles. Isotopes with a deficiency of neutrons, like C-11, can decay by emitting

positrons which are positively charged beta particles, or by capturing a negatively charged electron, electron capture. C-11 decays by positron emission.

All elements above lead, Pb, in the Periodic Table have at least one isotope which decays by emitting alpha particles. Alpha decay is relatively rare because it requires a lot of energy to take two neutrons and two protons out of a nucleus. It is only possible in some

Gamma radiation is very common, and occurs when a nucleus is in an excited state. To understand this it is useful to compare energy levels for neutrons and protons with those for electrons in an atom. It is well-known that electrons occupy well-defined energy levels in an atom, and that an electron can be excited to a higher unoccupied level. This atom is then in an excited state.

When the electron falls back to the lower energy level, energy is emitted from the atom in the form of electromagnetic radiation. The energy of this radiation is the difference in energy of the two levels occupied by the electron, and can be UV, visible, IR radiation or X ray.

Neutrons and protons similarly occupy well-defined energy levels in a nucleus, and when a neutron or a proton is excited to a higher unoccupied level the nucleus becomes excited. The excited nucleus decays to a lower energy state (the neutron or proton moves down to a lower energy level), and the difference in energy is emitted as electromagnetic radiation. This energy difference is much larger than in the case of the electrons in atoms, (MeV, million electron volts, compared to a few eV). In the case of the nucleus the electromagnetic radiation is called gamma emission.

cases because a lot of energy is gained by forming the two neutrons and two protons into an alpha particle. This gain in energy is called the binding energy of the nucleons (neutrons and protons).

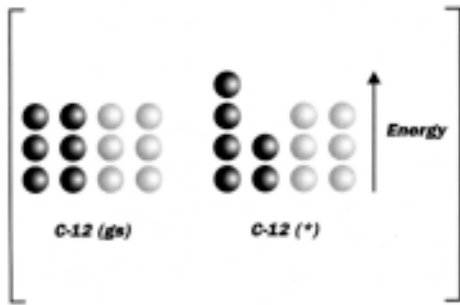
Energies of Beta, Alpha and Gamma decay

Definitions:

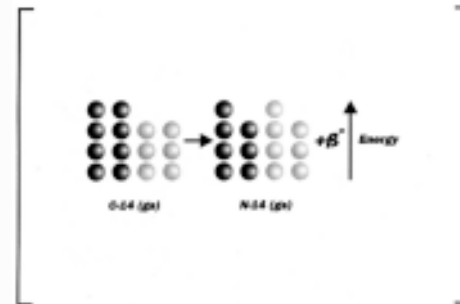
Ground state (gs) is a nucleus in which all the nucleons (neutrons and protons) are in their lowest energy states.

An excited nucleus (*) is one where one or more of the nucleons are in an energy state above the ground state.

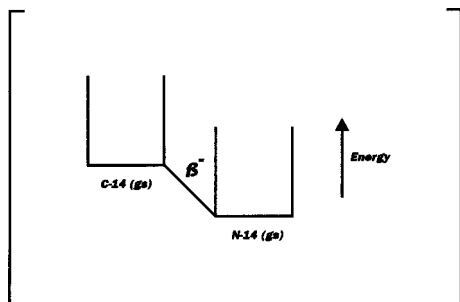
These can be represented pictorially.



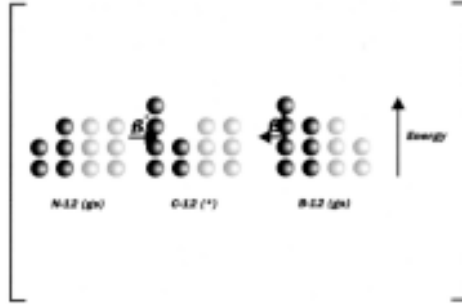
Pure Beta



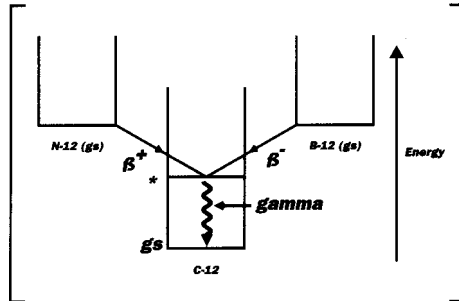
C-14 decays to N-14 by emitting a negative beta particle, that is a neutron converts to a proton. Because both nuclei are in their ground states there is no gamma radiation associated with this decay process.



Beta plus Gamma

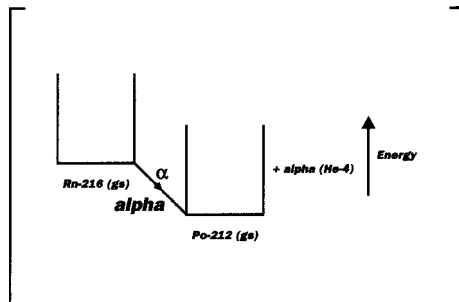


N-12 decays to an excited state of C-12 by emitting a positive beta particle, and B-12 decays to the same excited state of C-12 by emitting a negative beta particle. In the first case a proton changes to a neutron, and in the second case a neutron changes to a proton.



The excited C-12 decays to the gs in both cases by emitting a gamma photon.

Pure Alpha



Alpha plus Gamma

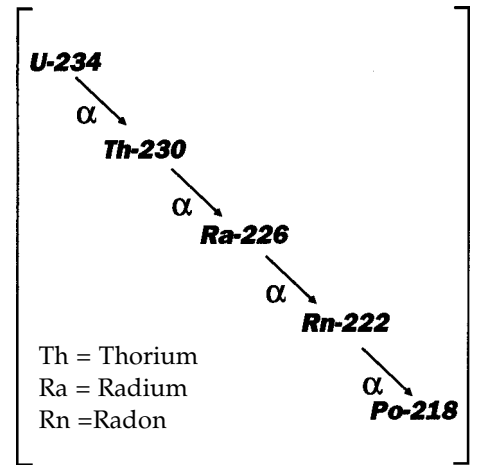
Most isotopes that decay by alpha emission, do so to an excited state of the daughter nucleus; this daughter nucleus then decays to its ground state by emitting one or more gamma rays as in the beta decay above.

The three different modes of decay have very different properties and are detected by different methods.

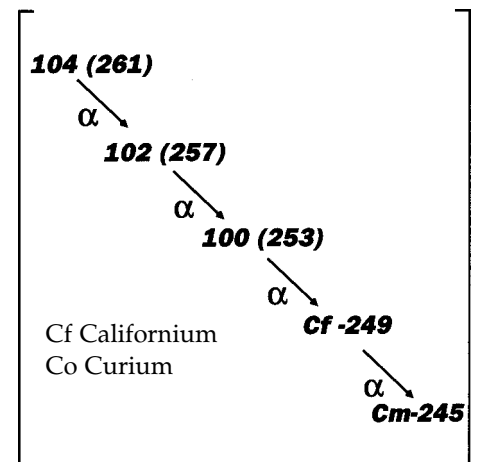
Alpha Particles

Rutherford showed that the alpha particle was the doubly charged nucleus of helium and therefore contained two protons and two neutrons.

Following alpha decay the daughter nucleus has two less protons (also two less neutrons) and therefore moves two places down the Periodic Table. This can happen in a chain, a typical example is Uranium-234 (U-234), the decay product of U-238, this decays in 4 steps to Polonium-218 (Po-218):

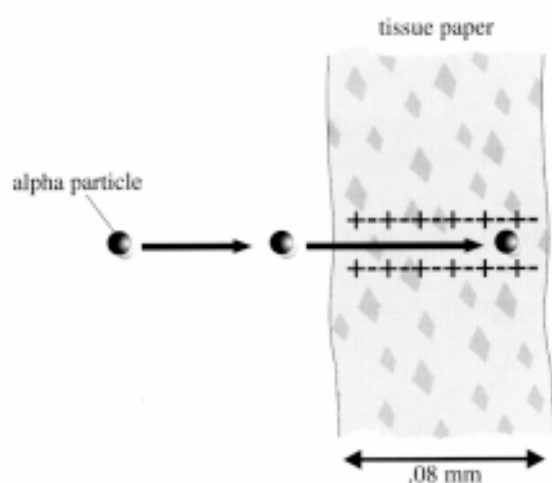


This phenomenon has been used to prove the identity of unknown nuclei, particularly above Z=100. An alpha chain is followed down to a known nucleus, and then the mass of the unknown can be worked out. An example is element 104 of mass 261:

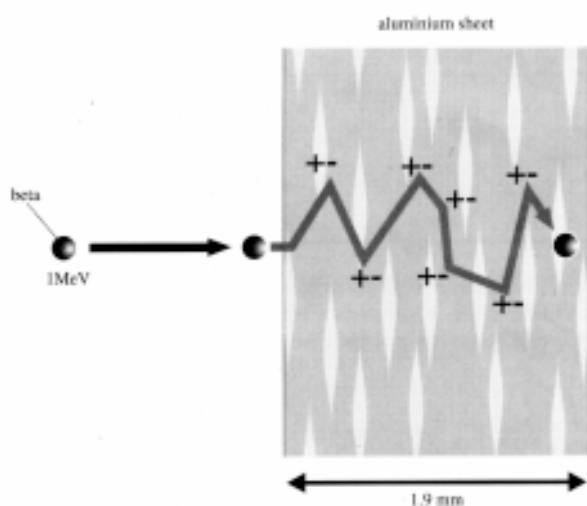


Alpha particles range in energy from 4 to 8 MeV, and have a relatively high atomic mass of 4. For these reasons alpha particles travel in straight lines through matter and deposit their energy over short distances. This means that they do a lot of damage in that short distance. Their main mode of interaction is ionization, knocking electrons off atoms. However as Rutherford showed, in rare cases they can collide and react with the nucleus of an atom, that is they undergo nuclear reactions.

It is easy to protect against alpha particles because they can be stopped with thin layers such as tissue paper. However, if they are ingested or get into open wounds they are very dangerous because they deposit a lot of energy in a small volume which in living tissue results in the destruction of cells. The range of a 4 MeV alpha particle in air is about 2.5 cm and about 14 microns in tissue, whereas an 8 MeV alpha particle would have a range of 7 cm in air and 42 microns in tissue.



Alpha Range



Beta Range

Beta Particles

These are singly negatively charged (negatrons) or singly positively charged (positrons) electrons. They typically have energies from a few KeV to a few MeV and a mass of an electron which is $1/1836$ the mass of a proton. The rest masses of electrons, neutrons and protons are: $9.191 \times 10^{28}g$, $1.675 \times 10^{24}g$ and $1.673 \times 10^{24}g$ respectively. From Einstein's equation $E=mc^2$ these are equivalent to 0.511 MeV, 939.6 MeV and 938.3 MeV respectively.

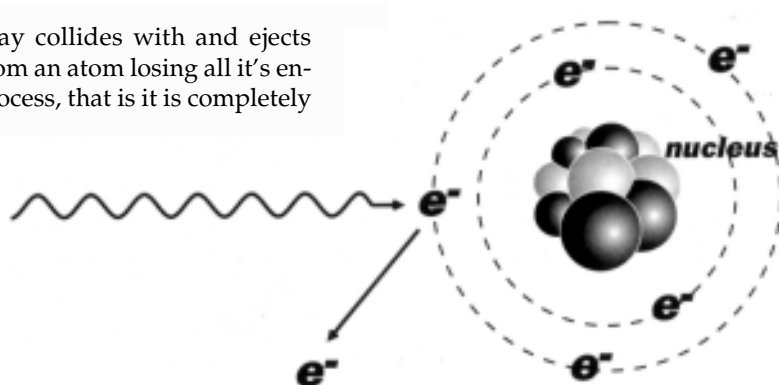
The range of beta particles is greater than alpha particles, and it requires a few mm of Al, or tissue, to stop beta particles of a few MeV energy. (example P-32 beta decay of 1.7 MeV). Because they are relatively light, beta particles do not travel in straight lines but follow a random path through material. This makes the definition of range much more difficult. Beta particles lose energy in matter by ionization.

Gamma Rays

These are very short wave-length electromagnetic radiation with typical energies from 0.1 to 3 MeV in radioactive decay. Because they have no charge they have long ranges. Gamma rays lose energy by three major routes:

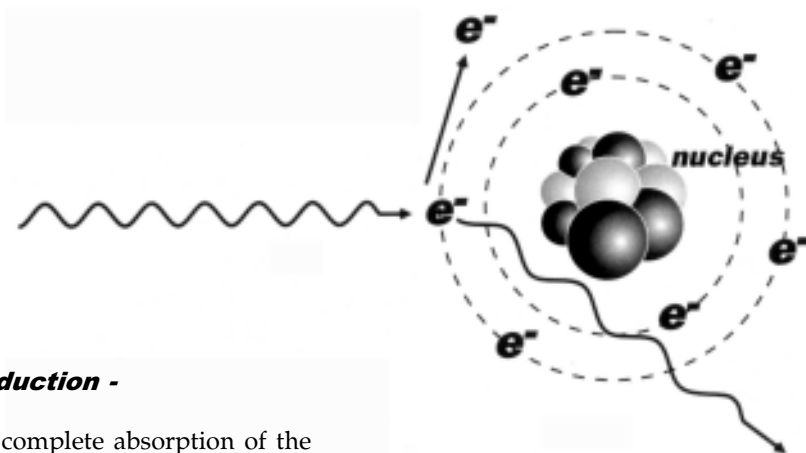
a) Photoelectric Effect -

the gamma ray collides with and ejects an electron from an atom losing all its energy in the process, that is it is completely absorbed.



b) Compton Effect -

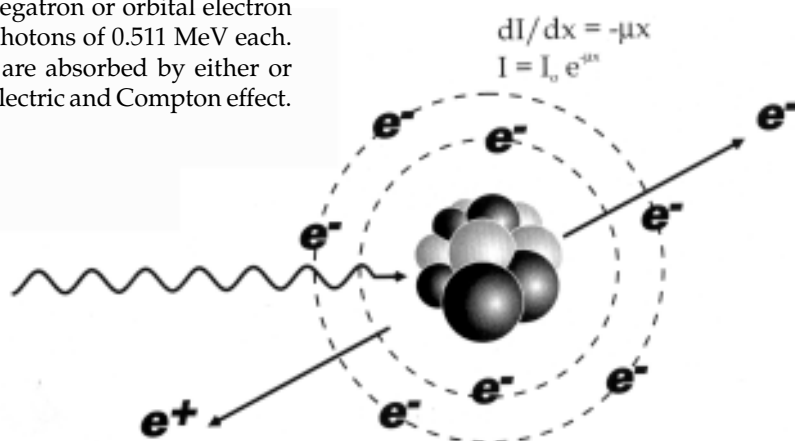
the gamma ray collides with and ejects an electron from an atom and is scattered from the impact with reduced energy.



c) Pair Production -

this involves complete absorption of the gamma photon with the formation of a negatron and a positron. As we saw above the energy of an electron is 0.511 MeV, therefore the energy required to produce two electrons, a negatron and a positron, has to be at least 1.02 MeV. Only gamma rays with energies above 1.02 MeV can cause pair production. The positron annihilates with a negatron or orbital electron releasing two photons of 0.511 MeV each. These photons are absorbed by either or both the photoelectric and Compton effect.

These three processes cause the gamma intensity to decrease with depth in an absorber and is directly proportional to that depth, x.



where I_0 is the intensity at the surface, I the intensity at a depth x , and μ is the absorption coefficient. when $x = 1/\mu$ the intensity is reduced to $1/e$ (0.37) of its value at the surface of the absorber.

Range for gamma photons is therefore expressed in terms of a linear absorption coefficient which is the sum of the three processes mentioned above. Linear absorption coefficients (1/cm) for Al, Pb and tissue are:

	1/cm		cm to reduce by 1/e	
	0.5MeV	2MeV	0.5MeV	2MeV
Al	0.25	0.14	4.00	7.14
Pb	1.7	0.5	0.59	2.00
tissue	0.035	0.031	28.6	32.3

Application of Gamma Activity

The stable isotope of iodine has 53 protons and 74 neutrons, and is 1-127. Isotopes of iodine, such as 1-123 and 131 have been widely used in medicine, particularly in the diagnosis and therapy of thyroid disorders. 1-131 is produced in fission and has a half-life of 8.02 days, because it has a neutron excess over 1-127 it decays by negatron emission together with gamma emission. 1-123 has a deficiency of neutrons compared to 1-127 and therefore can decay by either positron or electron capture, in fact it is electron capture together with gamma emission. The half-life of 1-123 is 13.2 hours. 1-123 is preferred to 1-131 in medical applications because it gives less radiation dose to the patient, and the reason for that is that 1-123:

- a) has a shorter half-life, therefore in the patient for less time.
- b) Emits only one gamma at 159KeV, whereas 1-131 emits several gamma rays of higher energy, and
- c) does not emit a beta particle.

