Alpha Decay and GM Law

By

Dr.Vinod Kumar Singh

Associate Professor Physics K .S. Saket P G College Ayodhya

Email: vks423272@gmail.com

We first describe the sources presently available and follow with how their radiations are detected.

Radioactive Sources:

1. Alpha particles are ^{4}He nuclei and are generally emitted by very heavy nuclei containing too many nucleons to remain stable. The alpha particle source is ^{241}Am (5.49 MeV (85%) and 5.44 MeV (13%) α's) which also gives off γ and x-rays. It has a half-life of 433 yr.

2. Beta particles are fast electrons (or positrons) emitted as a result of the decay of a neutron (or proton) in nuclei which contain an excess of the respective nucleon. Nuclides that decay directly to the ground state are "pure beta emitters." ^{290}Sr/^{90}Y is such a source, emitting a continuous spectrum of fast electrons up to a maximum energy of 0.546/2.27 MeV. The half life is 27.7 yr/64 hr.

3. Gamma rays are electromagnetic radiation emitted by excited nuclei in their transition to lower nuclear energy levels (following beta decay). Like the discreet atomic energy levels which give rise to specific photon energies, the well defined nuclear states are the source of specific gamma ray energies. We use the two most common of such sources: ^{137}Cs, which gives off a 662 keV gamma, and ^{60}Co (1.173 and 1.332 MeV gammas). Half lives are 30.2 and 5.26 yr, respectively.

4. There are no natural isotope sources of neutrons, but by mixing an alpha-emitting isotope with a suitable target material, neutrons can be produced through a nuclear reaction. ^{226}Ra/Be is such a combination. Under bombardment of alphas, beryllium undergoes a number of reactions which leads to the production of free neutrons. The neutron energy spectra of all alpha/Be sources are pretty much similar: 1-13 MeV max, with about 5 MeV average. Two neutron sources are available with neutron flux of 3.2×10^5 n/sec and 6.6×10^4 n/sec. The sources contain 22.5 mg and 10 mg of radium respectively, and give off an appreciable gamma ray background that must be contended with. The half life of Ra-226 is 1602 yr.

Alpha Decay

Alpha decay or α-decay is a type of radioactive decay in which the atomic nucleus emits an alpha particle thereby transforming or decaying into a new atomic nucleus. Here the atomic mass number of the newly formed atom will be reduced by four and the atomic number will be reduced by two. The emitted alpha particle is also known as a helium nucleus. The mass of the alpha particles is relatively large and has a positive charge.

Ernest Rutherford distinguished alpha decay from other forms of radiation by studying the deflection of the radiation through a magnetic field. The deflection of alpha decay would be a positive charge as the particles have a +2e charge.

Alpha decay occurs in very heavy elements like uranium, thorium, and radium. They are called parent nucleus and they are basically unstable. Because the nuclei of these atoms have a lot more neutrons in their nuclei than protons, that is, they have too large a proton to neutron ratio, which makes these elements neutron-rich. This richness makes alpha decay possible. Thus, emitting its two protons and two neutrons in the form of an alpha particle and a forming of new daughter nucleus and attains a very stable configuration. **Alpha decay can be described like this:**

- The nucleus of these nuclei (parent nucleus) rich atoms splits into two parts.

- The alpha particle goes zooming off into space.
- The nucleus left behind (daughter nucleus) has its atomic number reduced by 2 and its mass number reduced by 4.

Gamow Theory of Alpha Decay

The Geiger–Nuttall law or Geiger–Nuttall rule relates to the decay constant of a radioactive isotope with the energy of the alpha particles emitted. This relation also states that half-lives are exponentially dependent on decay energy, so that very large changes in half-life make comparatively small differences in decay energy, and thus alpha particle energy.

As per this rule, short-lived isotopes emit more energetic alpha particles than long-lived ones. This law was stated by Hans Geiger and John Mitchell Nuttall in the year 1911, hence the name was dedicated to these physicists.

Radioactive Decay

The spontaneous decay or breakdown of an atomic nucleus is known as Radioactive Decay. This decay in a nucleus causes the release of energy and matter from the nucleus.

The most common forms of Radioactive decay are:

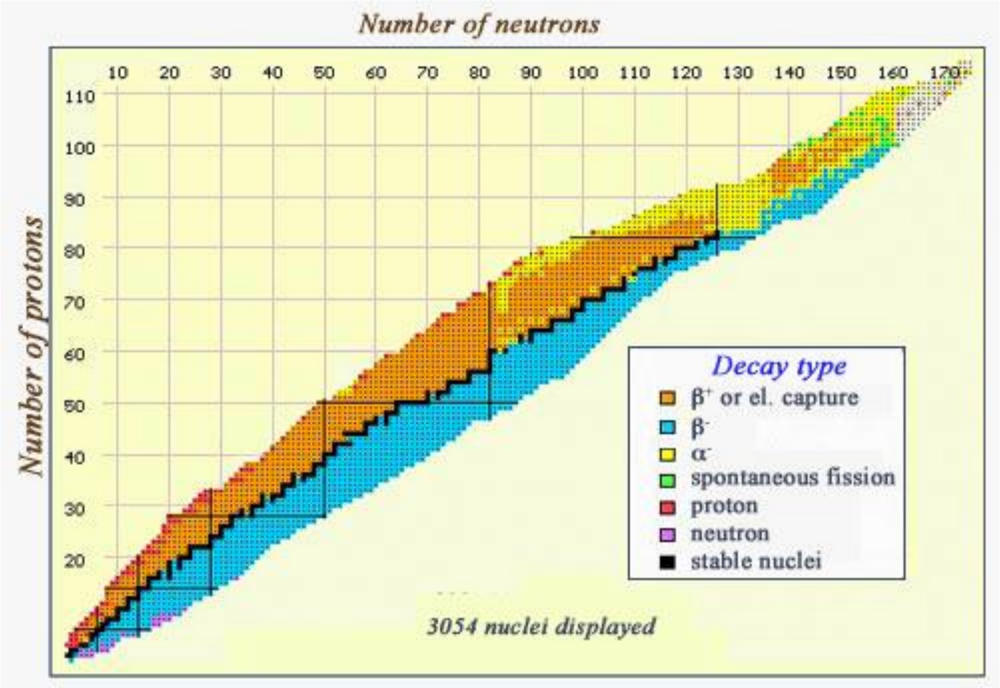
1. Alpha Decay (Helium nucleus is emitted)
2. Beta Decay (Electrons are emitted)
3. Gamma Decay (High energy photons are emitted)

This is also termed as Nuclear Decay or Radioactivity. The element or isotope which emits radiation and undergoes the process of radioactivity is called Radioactive Element.

Alpha Beta Gamma rays

Radioactive nuclei emit three types of radiations

Physicists have called the three types of radiations emitted by nuclei, **alpha**, **beta** and **gamma**, the three first letters of the greek alphabet.



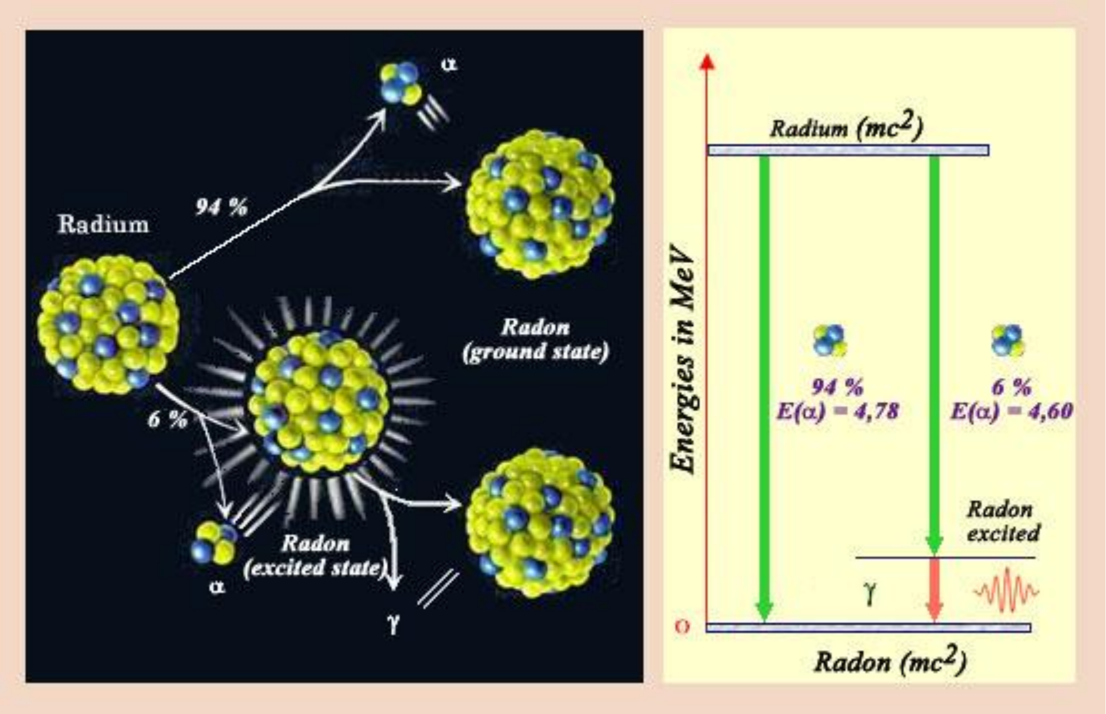
Map of decay modes

This map of the various nuclei is coloured with regards to the types of decay they undergo. Stable nuclei, self-evidently found along the stability line, are in black. The beta-emitters can be found on either side of this curve – beta negatives (in blue) occur in neutron-heavy nuclei, whereas beta-positives (in orange) occur in proton-heavy nuclei. At the right-hand side of the graph, the line of stability is replaced by a zone where alpha-emitters (in yellow) predominate. One can also see some exceedingly heavy particles (very far from the line of stability) which undergo spontaneous fission (in green), and a few nuclei which emit either protons (in red) or neutrons (in purple)

This naming convention of the three types of radiation has been in use since their discovery, and still applies today. The ancient greek alphabet was familar to physicists nourished by classical culture.

Alpha radiation is the name for the emission of an alpha particle in fact an helium nuclei, beta radiation is the emission of electrons or positrons, and gamma radiation is the term used for the emission of energetic photons.

When uranium salts were found in 1896 to produce unknown emissions, two types of radiation, X-rays and cathode rays, have been just discovered. At that time, nuclei, electrons and photons were unknown. It would take decades before the origins of all these rays were properly understood, but a few years to identify their nature. Incidentally cathode rays and X-rays were found to be electrons and photons like beta and gamma radiations.



Disintegration diagram

This nucleus of radium-226, the one discovered by Marie Curie, decays directly in 93 % of the cases in a nucleus of radon by emitting an alpha particle. However in 7 % of the cases, the nucleus is left in an excited state. Very rapidly, the excited radon nucleus get rid of its excess of energy, by emitting a gamma ray. Physicists represents the various decays modes of a nucleus by decay charts similar to the one represented on the right. The emission of gamma very often accompany the transformations of nuclei.

Alpha, beta and gamma decay are a result of the three fundamental forces working in the nucleus – the *'strong'* force, the *'weak'* force and the *'electromagnetic'* force. In all three cases, the emission of radiation increases the nucleus stability, by adjusting its proton/neutron ratio.

In the case of **alpha radiation**, the nucleus attempts to find stability by emitting an 'alpha particle' – identical to a helium nucleus (two protons and two neutrons).

Beta radiation involves the transformation of a neutron into a proton through the emission of an electron, or the reverse process, the transformation of a proton into a neutron through the emission of a positron (similar to an electron, but with a positive charge).

Gamma radiation is simply a loss of energy by the nucleus, a **desexcitation** ; much like an emission of light or X-rays by energetic atoms. Alpha and beta decays almost always leave the nucleus in an excited state. Gamma emission brings the nucleus down to a more stable energetic state.

Alpha and beta decays are often difficult to occur. They can be very slow processes. The lifetimes of some radioactive nuclei are long for the clocks of the infinitely small. They can also be for us. The lifetimes of natural radioactive alpha emitters such as uranium or thorium can extend to several billions of years.

These emissions change the composition of the nucleus, therefore the nature of the atom. Alpha and beta radioactivities do not transform lead into gold, but transmute matter like other nuclear reactions do.

Law of Radioactive Decay

When a radioactive material undergoes α, β or γ-decay, the number of nuclei undergoing the decay, per unit time, is proportional to the total number of nuclei in the sample material. So,

If N = total number of nuclei in the sample and ΔN = number of nuclei that undergo decay in time Δt then,

$\Delta N/ \Delta t \propto N$

Or, $\Delta N/ \Delta t = \lambda N$ … (1)

where λ = radioactive decay constant or disintegration constant. Now, the change in the number of nuclei in the sample is, $dN = - \Delta N$ in time Δt. Hence, the rate of change of N (in the limit $\Delta t \to 0$) is,

$dN/dt = - \lambda N$

Or, $dN/N = - \lambda \, dt$

Now, integrating both the sides of the above equation, we get,

${}^{N}{}_{N0}\int dN/N = \lambda \, {}^{t}{}_{t0}\int dt$ … (2)

Or, $\ln N - \ln N_0 = - \lambda (t - t_0)$ … (3)

Where, N_0 is the number of radioactive nuclei in the sample at some arbitrary time t_0 and N is the number of radioactive nuclei at any subsequent time t. Next, we set $t_0 = 0$ and rearrange the above equation (3) to get,

$\ln (N/N_0) = -\lambda t$

Or, $N(t) = N_0 e^{-\lambda t}$ … (4)

Equation (4) is the Law of Radioactive Decay.