# *Lecture7*: Radioactivity

It is the spontaneous decay of the isotope nucleus with the emission of nuclear particles such as alpha or beta particles and may be accompanied by the emission of a gamma ray. The isotopes that cause this decay are known as radioisotopes.

The process of decay occurs in isotopes, whether in pure form or within chemical, biological or other compounds. The decay process does not depend on natural conditions such as temperature and isotope state.

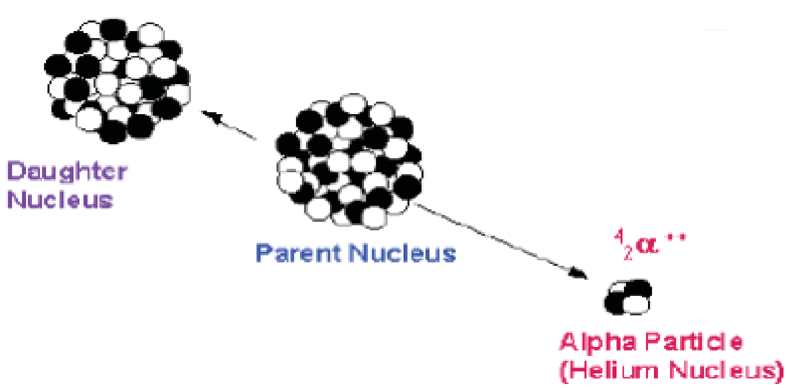
## 1. Alpha decay α

The nuclei of heavy elements "that are heavier than lead" are characterized by the low value of the bonding energy for each nucleon in the nucleus, so these nuclei are unstable and decay into lighter and more stable nuclei, such as the following:

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

$$^{118}_{84}Po \rightarrow {}^{114}_{92}Pb + {}^{4}_{2}He(\alpha)$$

The radioactive nucleus that decays is called the **parent nucleus** while the name of the **daughter nucleus** is called the nucleus resulting from decay.



In order for the nucleus to be radioactive for an alpha particle, its mass must be greater than the sum of the masses of the daughter nucleus and the alpha particle, in other words, in order for the parent nucleus to be able to decay by emitting the alpha particle, the following condition must be fulfilled:

$$\underset{\text{النواة الام}}{M_P} - \left(\underset{\text{النواة الوليدة}}{M_d} + \underset{\text{كتلة جسيم الفا}}{M_\alpha}\right) > 0$$

This condition is only fulfilled for the nuclei of some elements heavier than lead and a very limited number of elements lighter than lead because the nuclei of the lighter elements are stable relative to the emission of alpha particles.

The energy of alpha particles from a given isotope can be calculated using the Einstein **mass-energy** equivalence equation:

$$E = mc^2$$

$$E = [M_P - (M_d + M_\alpha)]c^2$$

This energy is distributed between the alpha particle and the daughter nucleus in opposite proportions to their masses, according to the law of conservation of momentum, meaning that the alpha particle carries the largest part of the energy resulting from decay, while the daughter nucleus carries a small part of this energy.

To calculate the energy of alpha particles:

$$E_\alpha = \frac{M_d}{M_P} E$$

When the daughter nucleus "after its decay from the parent nucleus" is in the ground state, the energy of the alpha particles is one. When the daughter nucleus is in the excited state, the energy of alpha particles has multiple and specific values. Therefore, the spectrum of alpha particles is a spectrum with specific energies and varies from one isotope to another.

## 2. Beta decay β

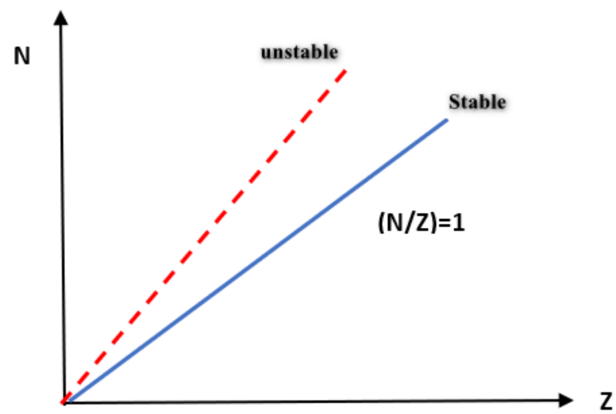
The nuclei of some radioactive isotopes emit other particles known as beta particles, and these particles are **electrons** or **positrons**. A **positron** is a particle whose mass is exactly equal to the mass of an electron but has a positive charge. This type of decay occurs to the nuclei of many isotopes, whether heavy or light.

It is known that in order for the **isotope** to be **stable** with respect to **emitting beta** particles, the ratio between the number of neutrons to the protons (N / Z) in the nucleus of this isotope must be ranging from **one** for the light nucleus and increase until it reaches **1.6** for heavy isotopes such as:

$${}^{12}_{6}C_{6} \qquad \frac{N}{Z} = \frac{6}{6} = 1 \text{ مستقرة}$$

$${}^{14}_{6}C_{8} \qquad \frac{N}{Z} = \frac{8}{6} = 1.333$$

If the ratio between the number of protons and neutrons is within the stability curve, the isotope is stable with respect to the beta decay. However, if this ratio deviates from the curve, then the isotope is active (unstable) with respect to this decay.




The isotope may also be stable with an alpha decay ratio but unstable for beta decay and vice versa. For example, uranium nuclei are stable with respect to beta decay but unstable to alpha decay.

$$^{238}_{92}U_{146} \qquad \frac{N}{Z} = \frac{146}{92} = 1.55$$

$$^{234}_{90}Th_{144} \qquad \frac{N}{Z} = \frac{144}{90} = 1.6$$

That is, the ratio of neutrons to protons deviates from the stability curve, so we find that the thorium nucleus becomes unstable with respect to beta decay with the emission of the beta particle.

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{-}\beta$$

In other words, the nucleus of thorium decays into Protactinium nucleus, while emitting a negative beta particle. It is noticed that as a result of this decay, the number of protons inside the nucleus increased by one proton, while the number of neutrons decreased by one neutron, which becomes 1, and it achieves stability with respect to beta decay.

## Types of Beta decay β