6/10

THE BETA DECAY LONG TERM ASSIGNMENT

Fundamentals of nuclear engineering and radiological protection

Group 4

Introduction

Not always (Electron Capture)

Beta decay (or β-decay) is a type of radioactive decay in which a beta particle is emitted. The beta particle could be an electron or a positron. For this reason, there are two different types of beta decay. There is Beta minus decay, when an electron and an antineutrino are emitted. And there is Beta plus decay, when the particles which are emitted are the positron and the neutrino.

beta plus decay

There is another type of beta decay which is a competitive process to beta decay plus. It is called electron capture (EC), in this process an electron is captured and only a neutrino is emitted. Neutrinos and antineutrinos are emitted in order to respect the conservation law of Lepton number. They are massless particles but they have energy.

In general, beta decay is a process where the parent and the daughter have the same number of nucleons or mass number (A) but different atomic number (Z). In the beta minus, one neutron is converted in a proton and in the other two processes a proton is converted in a neutron.

The Conservation of Energy

The first step to describe the beta decay process is the conservation of energy. Working on the conservation of energy, the conditions for the three processes to happen are found. Please notice that it uses atomic masses instead of nuclear masses.

a. *Energy balance for beta minus decay*

$$^{A}X \rightarrow \; ^{A}_{+1}Y + \, ^{0}_{-1}e + \, ^{0}_{0}$$ Neutrino!

According to mass and energy conservation, the rest mass of the parent nucleus, $M_X - Zm_e$ is equal to the rest masses of the daughter nucleus, MY – (Z +1) me, and the electron m_e.

NOT CORRECT!!! Nuclear masses

$$M_X - Zm_e = M_Y - (Z+1)m_e + m_e + \frac{Q}{c^2}$$

Where M_X and M_Y are the neutral atomic masses of the parent and daughter nucleus.

$$M_X = M_Y + \frac{Q}{c^2}$$

Therefore, the decay can occur when $M_X > M_Y$

b. *Energy balance for beta plus decay*

$$^{A}X \rightarrow \; {}_{-1}^{A}Y + {}_{+1}^{0}e + {}_{0}^{0}$$

$$M_X - Zm_e = M_Y - (Z-1)m_e + m_e + \frac{Q}{c^2}$$

$$M_X - 2m_e = M_Y + \frac{Q}{c^2}$$

$$2m_e = 1.02 \; MeV$$

β^+ can energetically occur when the mass of the parent atom exceeds the mass of the daughter atom by at least two electron masses (1.02 MeV).

$$M_X - 2m_e > M_Y$$

c. *Energy balance for electron capture process*

$$^{A}X + {}_{-1}^{0}e \rightarrow \; {}_{-1}^{A}Y + {}_{0}^{0}$$

$$m_e + (M_X - Zm_e) = (\,M_Y - (Z-1)m_e) + \frac{Q}{c^2}$$

$$M_X > M_Y$$

Examples of Beta Decay

In Z vs N

There are several nuclides which undergo beta decay. Those which are above the stability region undergo beta plus and EC and those which are below it undergo beta minus in order to achieve a stable nuclei. This is showed in figure 1.

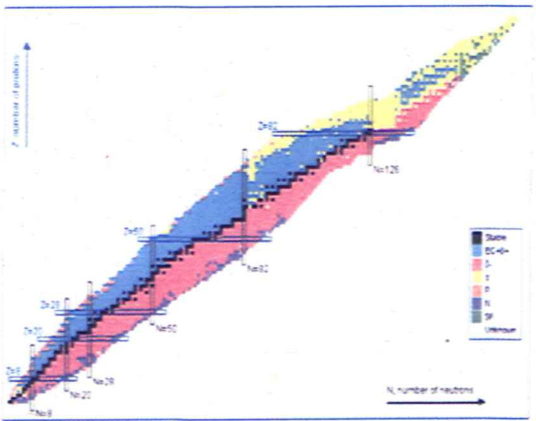

Figure 1: Graphic with all nuclides classified by their decay mode [1]

In a nuclear reactor there are several examples of beta decay processes. The most important of the three is the beta minus. In this case, it is followed the Radium series (4n+2) because it is one of the series which it can be found in the majority of the nuclear reactors. All these reactions are beta minus decays and they are [2]:

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

$$^{234}_{91}Pa \rightarrow ^{234}_{92}U + e^- + v^-$$

(...)

$$^{200}_{81}Tl \rightarrow ^{200}_{82}Pb + e^- + v^-$$

It is achieved Pb-200 which is a stable nuclei and the series decay stops. The other two types of beta decay are difficult to find in a reactor. however. the two followings are found in a nuclear reactor.

$$^{237}_{94}Pu + e^- \rightarrow ^{237}_{93}Np + v$$

$$^{234}_{93}Np \rightarrow ^{234}_{92}U + e^+ + v$$

The Energy Spectra for Beta Particles

Another particularity that is found in the beta decay is the difference in the energy spectra of the beta minus and the energy spectra of the beta plus.

In figure 2. it is showed the two processes which have some differences between them. In these pictures is represented the intensity in front of the kinetic energy in MeV.

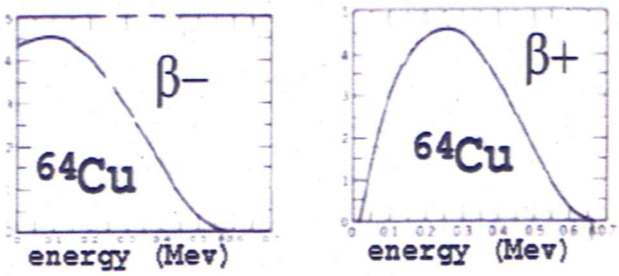

Figure 2: beta decays of Cu-64 [3]

Why is it continuum?

The explanation of these two shapes is that in beta minus the emitted particle is a electron which is attracted by the nucleus. although in beta plus the one which is emitted is a positron which is strongly repelled by the nucleus. When the particle reach the outer shell. the intensity decreases similar in both cases.

An approximate expression for the average energy of electrons as a function of the end point energy of the spectrum is the Fermi theory of beta decay [4]. The Fermi energy of a free-electron gas can be expressed in terms of the number of electrons per unit volume and this is the formula for one particle:

$$E_F^P = (3\pi^2)^{2/3} \cdot \frac{h^2}{2 \cdot m_e} \left(\frac{I}{v}\right)^{2/3}$$

- *EFP* is called the Fermi energy of a particle
- *l/v* is the number of electron per unit volume
- m_e: electron mass.
- *h* is a constant

The average energy of the electron is similar to:

$$E^{P}_{average} = \frac{3}{5} E^{P}_{F}$$

Conclusions

The conclusions which they should be obtained in this report are:

- Two particles are emitted in beta decay, one of them is massless. But in others decays, like alpha and gamma a unique particle is emitted.
- There are two pathways depending on if a proton is converted in a neutron or vice versa, but there are three types of beta decays because two of them achieve the same daughter.
- The spectra of these processes are different because of coulomb interactions and charged particles (electron and positron). The average energy of an electron is more or less the 60% of the Fermi energy of that particle.

Bibliography

Bibliography References

[1]http://en.wikipedia.org/wiki/Beta_decay (last visit: 02/10/14)

[2]NuDat 2.6: http://www.nndc.bnl.gov/nudat2/reCenter.jsp?z=77&n=102 (last visit: 02/10/14)

[3]Energy spectra: http://www.sjsu.edu/faculty/watkins/betadecay.htm (last visit (02/10/14)

[4]Fermi explanation: http://www.eng.fsu.edu/~dommelen/quantum/style_a/cboxfe.html (last visit: 02/10/14)

Complementary Bibliography

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