Al-Mustaqbal University Colleg
Medical Physics Department

Medical Imaging

Lecture 9

Radioactive Decay

Second Stage

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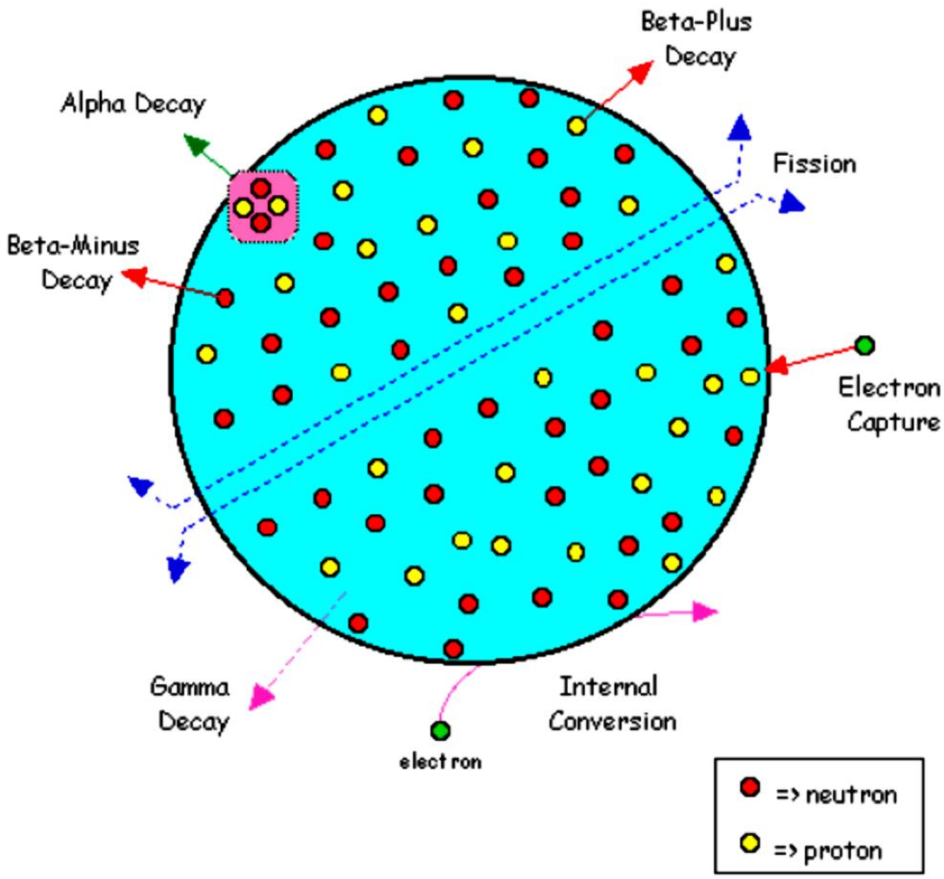
Methods of Radioactive Decay

Rather than considering what happens to individual nuclei it is perhaps easier to consider a hypothetical nucleus that can undergo many of the major forms of radioactive decay. This hypothetical nucleus is shown below:



Firstly, we can see two protons and two neutrons being emitted together in a process called alpha decay. Secondly, we can see that a proton can release a particle in a process called beta-plus decay, and that a neutron can emit a particle in a process called beta-minus decay. We can also see an electron being captured by a proton. Thirdly we can see some energy being emitted which results from a process called gamma-decay as well as an electron being attracted into the nucleus and being ejected again. Finally, there is the rather catastrophic process where the nucleus cracks in half called spontaneous fission. We will now describe each of these decay processes in turn.

Spontaneous Fission

This is a very destructive process which occurs in some heavy nuclei which split into 2 or 3 fragments plus some neutrons. These fragments form new nuclei which are usually radioactive. Nuclear reactors exploit this phenomenon for the production of radioisotopes. Its also used for nuclear power generation and in nuclear weaponry. The process is not of great interest to us here and we will say no more about it for the time being.

Alpha Decay

In this decay process two protons and two neutrons leave the nucleus together in an assembly known as an alpha particle. Note that an alpha particle is really a helium-4 nucleus. So why not call it a helium nucleus? Why give it another name? The answer to this question lies in the history of the discovery of radioactivity. At the time when these radiations were discovered we didn't know what they really were. We found out that one type of these radiations had a double positive charge and it was not until sometime later that we learnt that they were in fact nuclei of helium-4. In the initial period of their discovery this form of radiation was given the name alpha rays (and the other two were called beta and gamma rays), these terms being the first three letters of the Greek alphabet. We still call this form of radiation by the name alpha particle for historical purposes But notice that the radiation really consists of a helium-4 nucleus emitted from an unstable larger nucleus. There is nothing strange about helium since it is quite an abundant element on our planet. So why is this radiation dangerous to humans? The answer to this question lies with the energy with which they are emitted and the fact that they are quite massive and have a double positive charge. So when they interact with living matter they can cause substantial destruction to molecules which they encounter in their attempt to slow down and to attract two electrons to become a neutral helium atom. An example of this form of decay occurs in the uranium-238 nucleus. The equation which represents what occurs is:

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

Here the uranium-238 nucleus emits a helium-4 nucleus (the alpha particle) and the parent nucleus becomes thorium-234. Note that the Mass Number of the parent nucleus has been reduced by 4 and the Atomic Number is reduced by 2 which is a characteristic of alpha decay for any nucleus in which it occurs.

Beta Decay

There are three common forms of beta decay:

(a) Electron Emission

Certain nuclei which have an excess of neutrons may attempt to reach stability by converting a neutron into a proton with the emission of an electron. The electron is called a beta-minus particle -the minus indicating that the particle is negatively charged. We can represent what occurs as follows:

$$n^0 \rightarrow p^+ + e^-$$

here a neutron converts into a proton and an electron. Notice that the total electrical charge is the same on both sides of this equation. We say that the electric charge is conserved. We can consider that the electron cannot exist inside the nucleus and therefore is ejected. Once again there is nothing strange or mysterious about an electron. What is important though from a radiation safety point of view is the energy with which it is emitted and the chemical damage it can cause when it interacts with living matter. An example of this type of decay occurs in the iodine-131 nucleus which decays into xenon-131 with the emission of an electron, that is

$$^{131}_{53}I \rightarrow ^{131}_{54}Xe + ^{0}_{-1}e$$

The electron is what is called a beta-minus particle. Note that the Mass Number in the above equation remains the same and that the Atomic Number increases by 1 which is characteristic of this type of decay.

(b) Positron Emission

When the number of protons in a nucleus is too large for the nucleus to be stable it may attempt to reach stability by converting a proton into a neutron with the emission of a positively-charged electron. That is not a typographical error! An electron with a positive charge also called a positron is emitted. The positron is the beta-plus particle. The history here is quite interesting. A brilliant Italian physicist, Enrico Fermi developed a theory of beta decay and his theory predicted that positively-charged as well as negatively-charged electrons could be emitted by unstable nuclei. These particles could be called pieces of anti-matter and they were subsequently discovered by experiment. They do not exist for very long as they quickly combine with a normal electron and the subsequent reaction called annihilation gives rise to the emission of two gamma rays.

$$p^{+} \rightarrow n^{0} + e^{+}$$

An example of this type of decay occurs in sodium-22 which decays into neon-22 with the emission of a positron:

$$^{22}_{11}Na \rightarrow ^{22}_{10}Ne + ^{0}_{+1}e$$

Note that the Mass Number remains the same and that the Atomic Number decreases by 1

(c) Electron Capture

In this third form of beta decay an inner orbiting electron is attracted into an unstable nucleus where it combines with a proton to form a neutron. The reaction can be represented as:

$$e^{-} + p^{+} \rightarrow n^{0}$$

This process is also known as K-capture since the electron is often attracted from the K-shell of the atom. An example of this type of radioactive decay occurs in iron-55 which decays into manganese-55 following the capture of an electron. The reaction can be represented as follows:

$$^{55}_{26}Fe + ^{0}_{-1}e \rightarrow ^{55}_{25}Mn$$

Note that the Mass Number once again is unchanged in this form of decay and that the Atomic Number is decreased by 1.