CHAPTER 5 INTERACTION OF RADIATION WITH MATTER

Introduction

We have focussed in previous chapters on the source of radiation and the types of radiation. We are now in a position to consider what happens when this radiation interacts with matter. Our main reason for doing this is to find out what happens to the radiation as it passes through matter and also to set ourselves up for considering how to detect radiation. Since all radiation detectors are made from some form of matter it is useful to first of all know how radiation interacts so that we can exploit the effects in the design of such detectors.

Before we do this let us first remind ourselves of the physical characteristics of the major types of radiation. We have covered this material in some detail in the first chapter and it are summarised below for convenience:

Radiation	Mass	Electric Charge	Velocity
Alpha Particles	relatively heavy	double positive	relatively slow
Beta Particles	about 8,000 times lighter	negative	less than the velocity of light
Gamma Rays	None	None	3x 108 m/s in free space

We will now consider the passage of each type of radiation through matter with most attention given to gamma-rays because they are the most common type used in nuclear medicine. One of the main effects that you will notice irrespective of the type of radiation is that ions are produced when radiation interacts with matter. It is for this reason that it is called **ionizing radiation**.

Before we start though you might find an analogy useful to help you with your thinking. This analogy works on the basis of thinking about matter as an enormous mass of atoms (that is nuclei with orbiting electrons) and that the radiation is a particle/photon passing through this type of environment. So the analogy to think about is a spaceship passing through a meteor storm like you might see in a science-fiction movie where the spaceship represents the radiation and the meteors represent the atoms of the material through which the radiation is passing. One added feature to bring on board however is that our spaceship sometimes has an electric charge depending on the type of radiation.

Alpha Particles

We can see from the table above that **alpha-particles** have a double positive charge and we can therefore easily appreciate that they will exert considerable electrostatic attraction on the outer orbital electrons of atoms near which they pass. The result is that some electrons will be attracted away from their parent atoms and that ions will be produced. In other words, ionizations occur.

We can also appreciate from the table that alpha-particles are quite massive relative to the other types of radiation and also to the electrons of atoms of the material through which they are passing. As a result, they travel in straight lines through matter except for rare direct collisions with nuclei of atoms along their path.

A third feature of relevance here is the energy with which they are emitted. This energy in the case of alpha-particles is always distinct. For example, ^{221}Ra emits an alpha-particle with an energy of 6.71 MeV. Every alpha-particle emitted from this radionuclide has this energy. Another example is ^{230}U which emits three alpha-particles with energies of 5.66, 5.82, 5.89 MeV.

Finally, it is useful to note that alpha-particles are very damaging biologically and this is one reason why they are not used for in-vivo diagnostic studies. We will therefore not be considering them in any great detail in this wikibook.

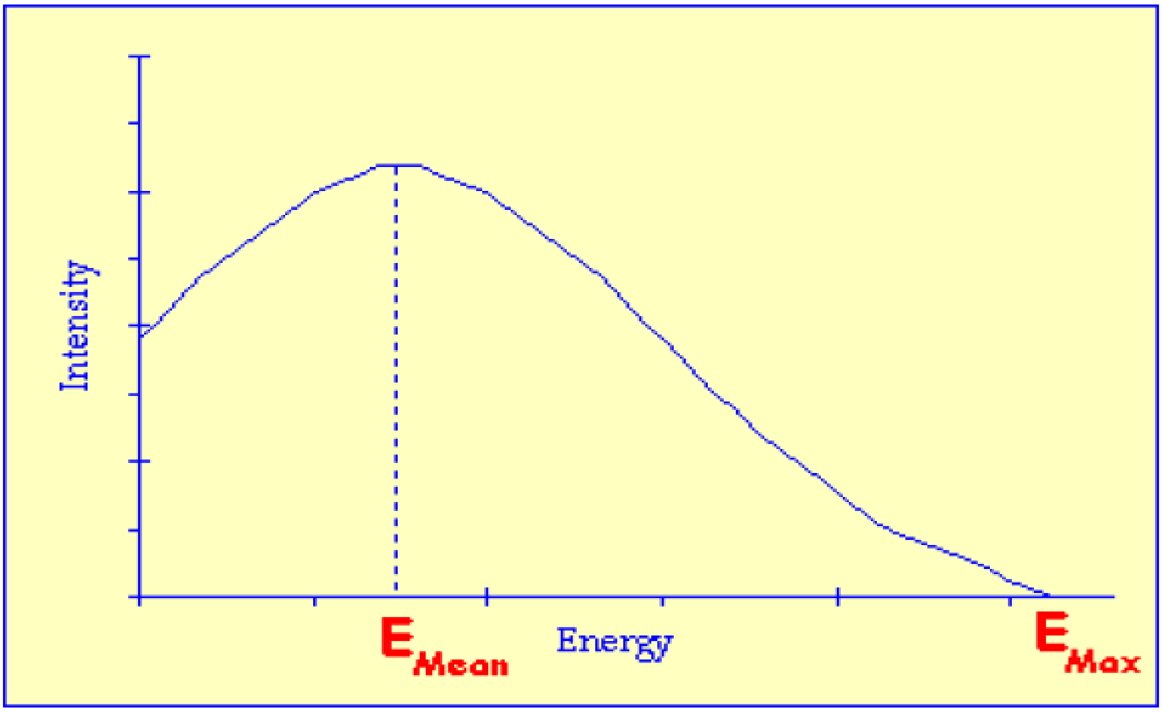
Beta Particles

We can see from the table that **beta-particles** have a negative electric charge. Notice that positrons are not considered here since as we noted in **chapter 2** these particles do not last for very long in matter before they are annihilated. Beta-minus particles last considerably longer and are therefore the focus of our attention here.

Because of their negative charge they are attracted by nuclei and repelled by electron clouds as they pass through matter. The result once again without going into great detail is ionization.

The path of beta-particles in matter is often described as being tortuous, since they tend to ricochet from atom to atom.

A final and important point to note is that the energy of beta-particles is never found to be distinct in contrast to the alpha-particles above. The energies of the beta-particles from a radioactive source forms a spectrum up to a maximum energy - see figure below. Notice from the figure that a range of energies is present and features such as the mean energy, E_{mean}, or the maximum energy, E_{max}, are quoted.



The question we will consider here is: why should a spectrum of energies be seen? Surely if a beta particle is produced inside a nucleus when a neutron is converted into a proton, a single distinct energy should result. The answer lies in the fact that two particles are actually produced in beta-decay. We did not cover this in our treatment in chapter 2 for fear of complicating things too much at that stage of this wikibook. But we will cover it here briefly for the sake of completeness.

The second particle produced in beta-decay is called a **neutrino** and was named by **Enrico Fermi** is quite a mysterious particle possessing neither mass nor charge and we are still researching its properties today. The difficulty with them is that they are very hard to detect and this has greatly limited our knowledge about them so far.

The beta-particle energy spectrum can be explained by considering that the energy produced when a neutron is converted to a proton is shared between the beta-particle and the neutrino. Sometimes all the energy is given to the beta-particle and it receives the maximum energy, E_{max}. But more often the energy is shared between them so that for example the beta-particle has the mean energy, E_{mean} and the neutrino has the remainder of the energy.

Finally, it is useful to note that beta-particles are quite damaging biologically and this is one reason why they are not used for in-vivo diagnostic studies. We will therefore not consider them in any great detail in this wikibook.

Gamma Rays

Since we have been talking about energies above let us first note that the energies of **gamma-rays** emitted from a radioactive source are always distinct. For example, ^{99m}Tc emits gamma-rays which all have an energy of 140 keV and ^{51}Cr emits gamma-rays which have an energy of 320 keV.

Gamma-rays have many modes of interaction with matter. Some of those which are not important to nuclear medicine imaging are:

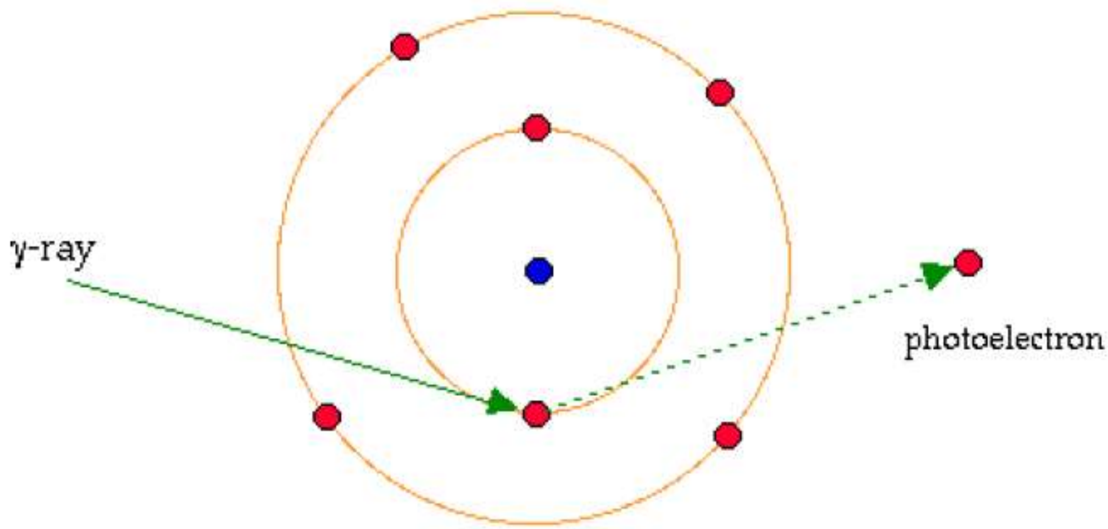
- **Mössbauer Effect**
- **Coherent Scattering**
- **Pair Production**

and will not be described here.

Those which are very important to nuclear medicine imaging, are the Photoelectric **Effect** and the **Compton Effect**. We will consider each of these in turn below. Note that the effects described here are also of relevance to the interaction of X-rays with matter since as we have noted before X-rays and gamma-rays are essentially the same entities. So the treatment below is also of relevance to radiography.

Photoelectric Effect

When a gamma-ray collides with an orbital electron of an atom of the material through which it is passing it can transfer all its energy to the electron and cease to exist - see figure below. On the basis of the **Principle of Conservation of Energy** we can deduce that the electron will leave the atom with a kinetic energy equal to the energy of the gamma-ray less that of the orbital binding energy. This electron is called a photoelectron.



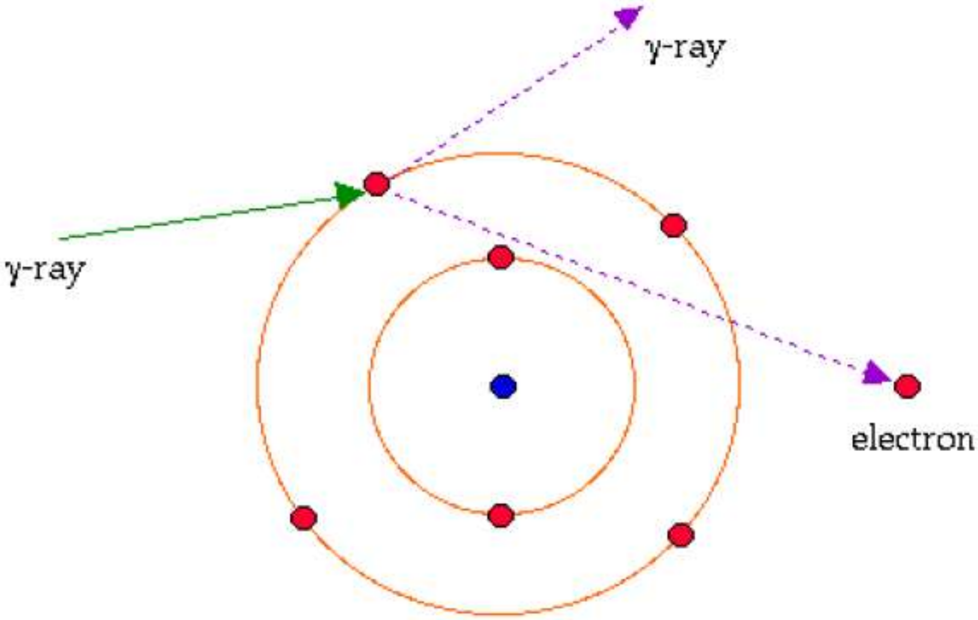
Note that an ion results when the photoelec
tron leaves the atom. Also note that the gamma-ray energy is totally absorbed in the process.

Two subsequent points should also be noted. Firstly, the photoelectron can cause ionisations along its track in a similar manner to a beta-particle. Secondly X-ray emission can occur when the vacancy left by the photoelectron is filled by an electron from an outer shell of the atom. Remember that we came across this type of feature before when we dealt with Electron Capture in **Chapter 2**.

Compton Effect

This type of effect is somewhat akin to a cue ball hitting a coloured ball on a pool table. Here a gamma-ray transfers only part of its energy to a valance electron which is essentially free - see figure below. Notice that the electron leaves the atom and may act like a beta-particle and that the gamma-ray deflects off in a different direction to that with which it approached the atom. This deflected or scattered gamma-ray can undergo further Compton Effects within the material

Note that this effect is sometimes called Compton Scattering.



Attenuation

The two effects we have just described give rise to both absorption and scattering of the radiation beam. The overall effect is referred to as attenuation of gamma-rays. We will investigate this feature from an analytical perspective in the following chapter.