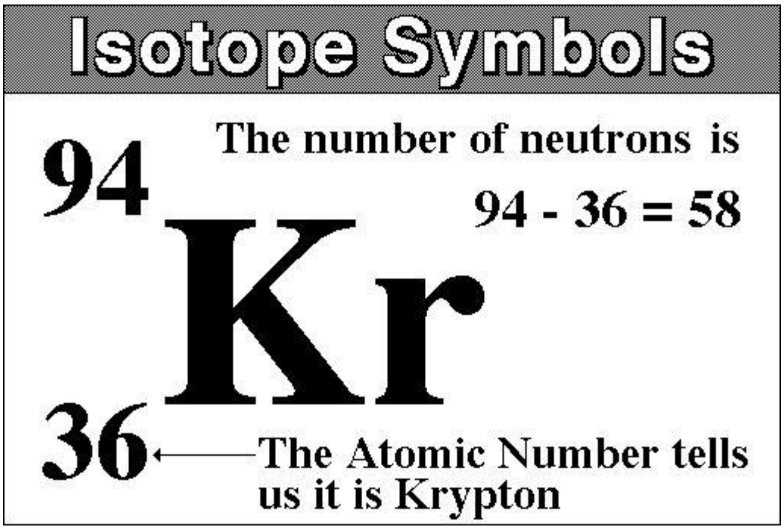
Definitions

Radioactive decay: is the process in which an unstable *atomic nucleus* loses energy by *emitting radiation* in the form of *particles or electromagnetic waves*.

There are numerous types of radioactive decay. The general idea:

An unstable nucleus releases energy to become more stable.

Isotopes: are atoms of the same element that have same number of protons and different number of neutrons.



Radioactive isotopes (radioactive elements): are unstable, they decay and change into different elements over time and sometimes known as radio isotopes.

- **Each element decays into a new element**

C^{14} decays into N^{14}

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 and this particle is known as **positron** or **beta- plus particle**.

These positrons could be called antimatter, they do not exist very long as they quickly combine with a normal electron and annihilate each other and release two gamma rays.

$$P^+ \longrightarrow n^o + e^+$$

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

Radioactive isotope of fluorine.

First of all, let us have a look at fluorine atom. Atomic number of fluorine atom = 9, and the atomic mass = 19

Nucleus of fluorine contains 9 protons and 10 neutrons

$^{19}_{9}F$

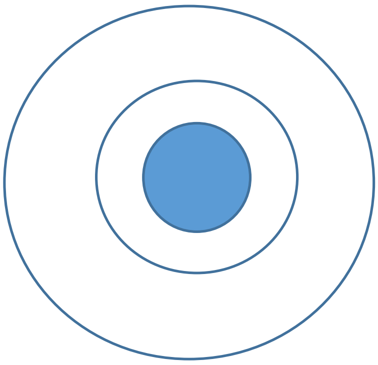


Fig (1): The fluorine atom

However, we can get different isotopes of fluorine atom which means the number of neutron can very.

One example of radioactive isotope of fluorine: ${}^{18}_{9}F$ which has nine neutrons rather than ten.

Let us now discus how it is radioactive and basically emits positron.

${}^{18}_{9}F$ is not stable therefore it decays into oxygen atom and how is that, one of the protons of fluorine radioactive isotope turns into a neutron and now there is ten neutrons and eight protons (and what type of change is that, the change is that, the radioactive isotope changed from being isotope of fluorine to being oxygen). Now there is a problem with this conversion because the proton is positive charge while the neutron is neutral charge, therefore you cannot just turn the proton into a neutron, you have to also create another particle in that conversion and that particle is known as a positron (e^+) which is positively charged and you might see it denoted as β^+. The Positron is antimatter particle for an electron so it is an electron with opposite charge. When electrons meet positrons they will annihilate each other. All what happens they destroy each other and release energy (gamma radiation) according to law of conservation of energy. According to this law of conservation of energy it is not possible to lose energy but the energy is changed from one form into another.

${}^{18}_{9}F \longrightarrow {}^{18}_{8}o + e^+ / \beta^+$ (positron emission of fluorine-18)

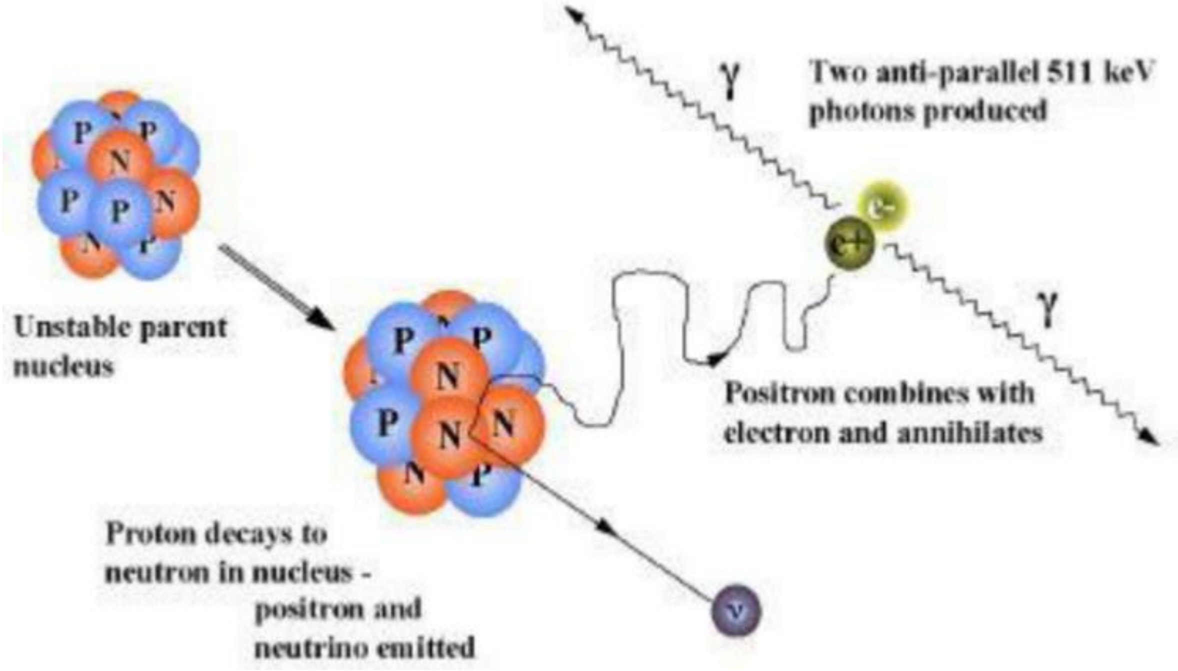


Fig (2): the process of positron emission

When a positron combines with an electron they destroy each other, when they destroyed their kinetic and potential energy has not lost but converted into energy in the form of radiation (two photons). And in what way they are emitted, two photons are being emitted in exactly opposite direction (180^{o} opposite to one another) as shown in Fig. (2). The amount of energy of these photons that is emitted from antimatter annihilation is very high.

PET scan is very general technique; you can use lots of different radio isotopes of different atoms but we are using fluorine radio isotope in this discussion because it is very commonly used one but you could use another one.

Positron Emission Tomography (PET)

PET scan create 3-D images, what we need to do is somehow to inject the radioactive isotope of fluorine into a human being that needs to be scanned but before doing that we firstly have to attach this radioactive isotope of fluorine to a useful molecule that will show us something useful. The molecule that will be used depends on what the doctor is looking for. One of very common molecule that is attached to a fluorine radioactive isotope is glucose, because when it is attached to a glucose, glucose will go where tissues are metabolically active in the body so you will get an accumulation of this radioactive isotope in metabolically active tissues and radioactive isotope of fluorine will decay and release positrons which combine with the surrounding electrons this combination results in the complete annihilation of both particles, releasing two photons that speed of in opposite directions. The detectors in the PET scanner measure these photons and use this information to create an image of the distribution of Fluorodeoxyglucose in the body that can tell us which portions of the body of most metabolically active.

Let us discuss in detail how radioactive isotope of fluorine (^{18}F) is attached to a glucose and creating a Fluorodeoxyglucose which is often abbreviated as ^{18}F - FDG (if ^{18}F radio isotope is used) and sometime abbreviated as FDG.

Normal structure of glucose is shown in figure (3).

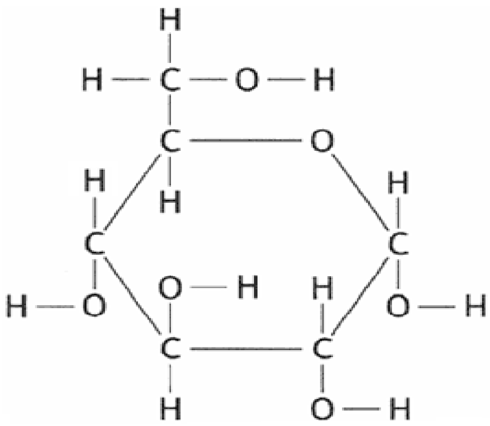


Fig (3): structure of glucose

Now how do we modify this glucose (fig (3)) in order to create fluorodeoxyglucose (^{18}F – FDG), basically we remove one of hydroxyl group (OH) and replace it with our radioactive isotope of fluorine (^{18}F) and then fluorodeoxyglucose (^{18}F - FDG) is created as shown in figure (4). Now ^{18}F - FDG is injected to a person which we suspect has a cancerous tumor. If doctor suspects cancer or monitoring a known cancer's growth, he may use ^{18}F – FDG which get absorbed by tissues that are most metabolically active.

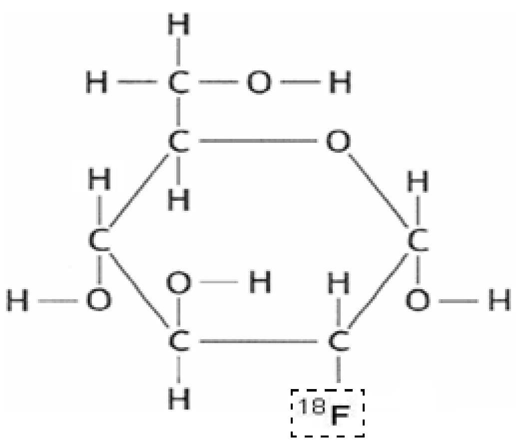


Fig (4): Structure of Fluorodeoxyglucose (^{18}F - FDG).

The PET process works by taking advantage of the way the human body gets its energy from food. When we eat our food, it gets digested and broken down into different products, one of the most important of these products is a substance called glucose, it is one of our body's main sources of energy. The body takes glucose and then travels throughout the body and is delivered as fuel for our organs and muscles as is needed. If you could see glucose as it travels throughout the body you would see it being drawn towards the parts of the body that are the most metabolically active. Because the brain is always active you would expect to see glucose there and likewise in the heart, kidneys and the bladder. Cancer is very metabolically active therefore it absorbs a lot of glucose.

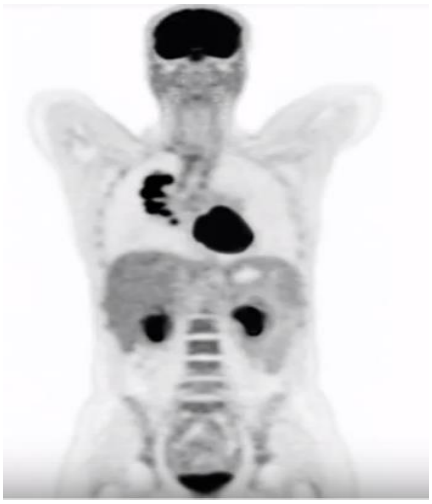


Fig (5): PET image of human body

Here is an actual image taken from a PET scan, any dark areas indicate the presence of glucose. The brain, the heart, the kidneys and the bladder are the darkest as we expect but here there are other dark patches where they shouldn't be, these might very well be cancer. The ability to see and detect glucose in this way is what make a PET scan different from other types of body scans like CT or MRI. The PET scan cannot detect glucose all by itself, for that to happen the glucose first has to be marked with something which does stand out, here is how it works. The only way we can mark the glucose, is to start with glucose and attach it with radioactive isotope and this is before entering the body and then the patient will be given an injection of ^{18}F – FDG.

The radiation itself is nothing to worry about, the exposure level is normal. Once you receive the injection you have to wait for an hour before to continue onto the scan, because it takes this long for the glucose in your body to gather to the fewest possible places.

The general dose of ionizing radiation that you get from having a PET scan is deemed to be within 18 to 25 milli Sievert (SV it is a unit). It tells you how damaging that dose of radiation is. The general dose of radiation we get from background radiation every year is about 3 mSV.

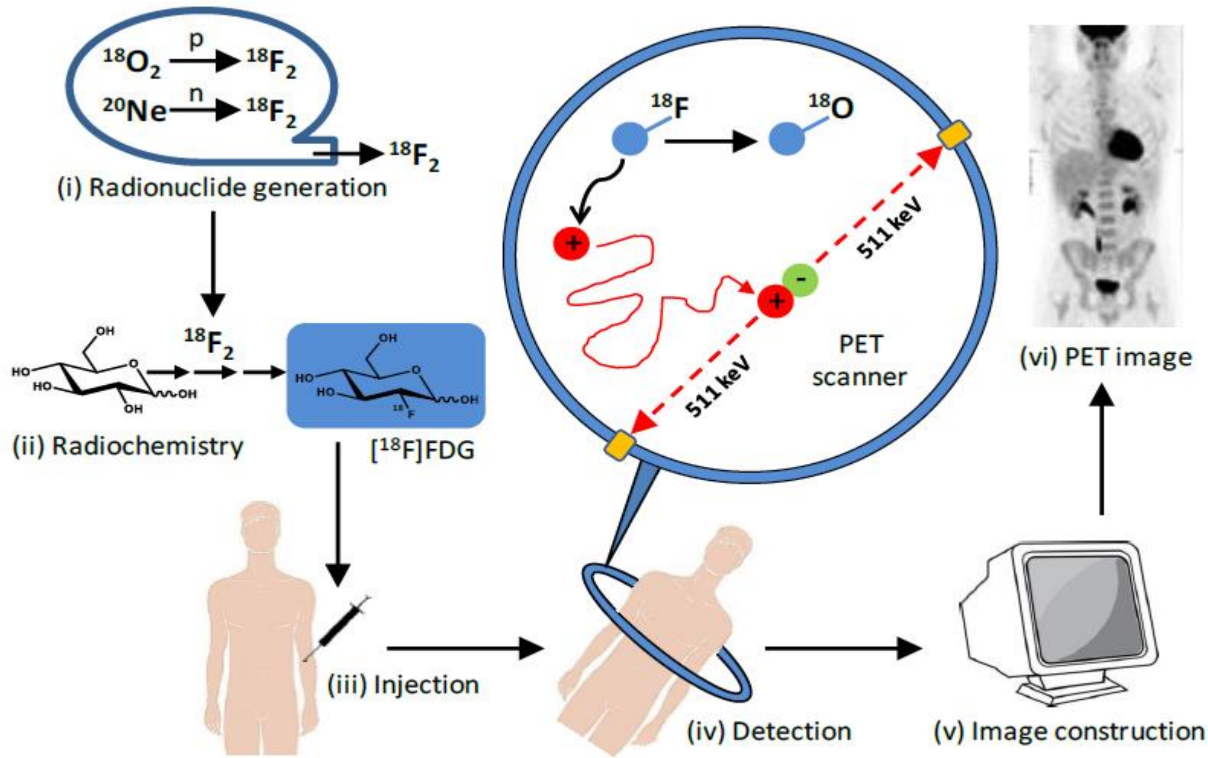


Fig (6): The process of positron emission tomography imaging.