Nuclear Physics

Matter is considered to be made up of particles that are referred to as atoms.

Atomic Structure:

Atoms are the smallest particles that are considered to be able to exist freely in nature.

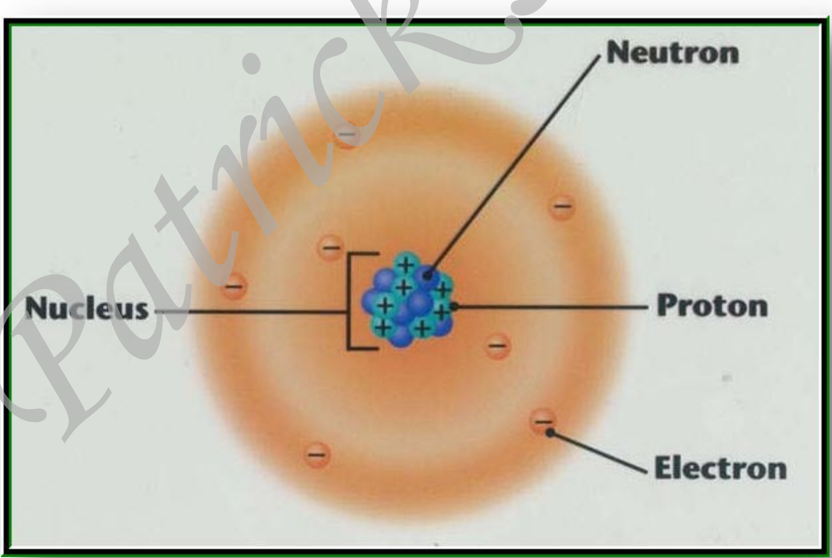
Atoms are themselves composed of other smaller elementary particles that include:

a. The Proton: A Positive particle. Charge +1 residing in the nucleus. Mass 1u (1 unified mass unit)
b. The neutron: A neutral particle. Charge 0 residing in the nucleus. Mass 1u.
c. The electron: A negative particle. Charge -1, orbiting the nucleus. Mass 1/1836 u.

The atom is considered to be made up of two major structures:

The Energy levels or orbits where electrons exist

The Nucleus where the protons and the neutrons reside.



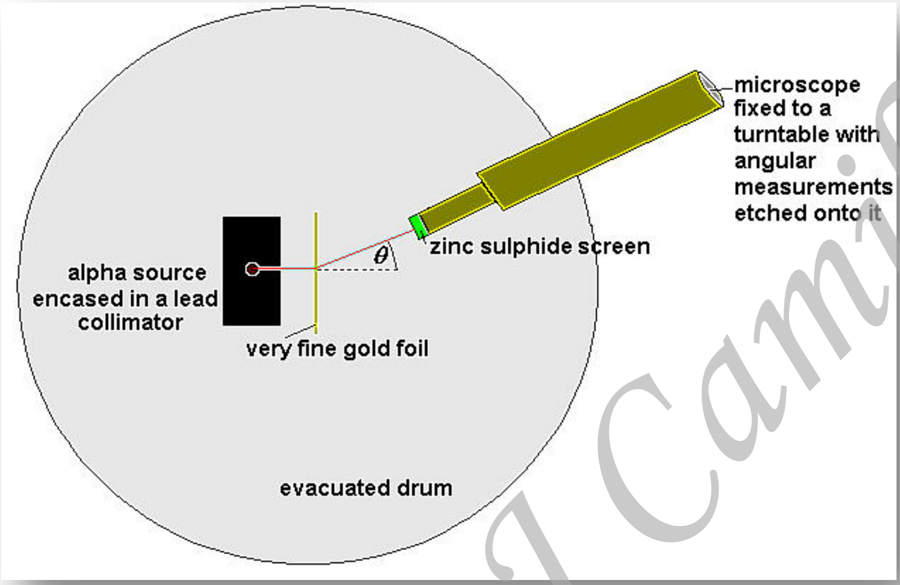
The atomic Radius: Value in the region of 10^{-10} m.

The Nuclear Radius: value in the region of 10^{-15} m.

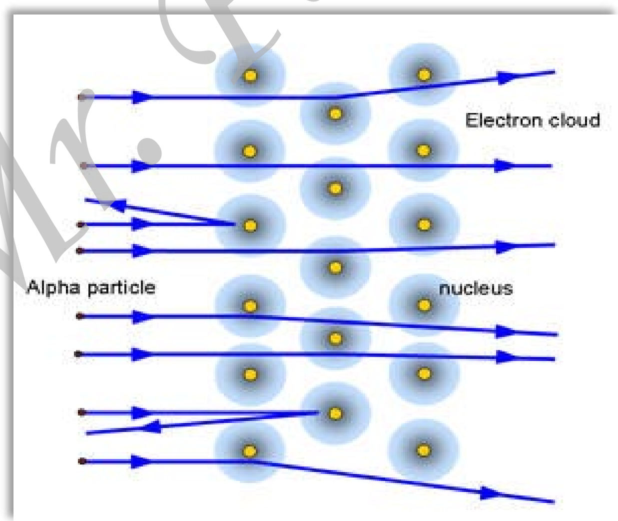
This Model referred to as the Bohr's Atomic Model expresses the atom as composed of a very small/compact nucleus with electrons orbiting around it.

The Alpha Scattering Experiment

It was the experiment that proved the Bohr's atomic structural nature of the atom.



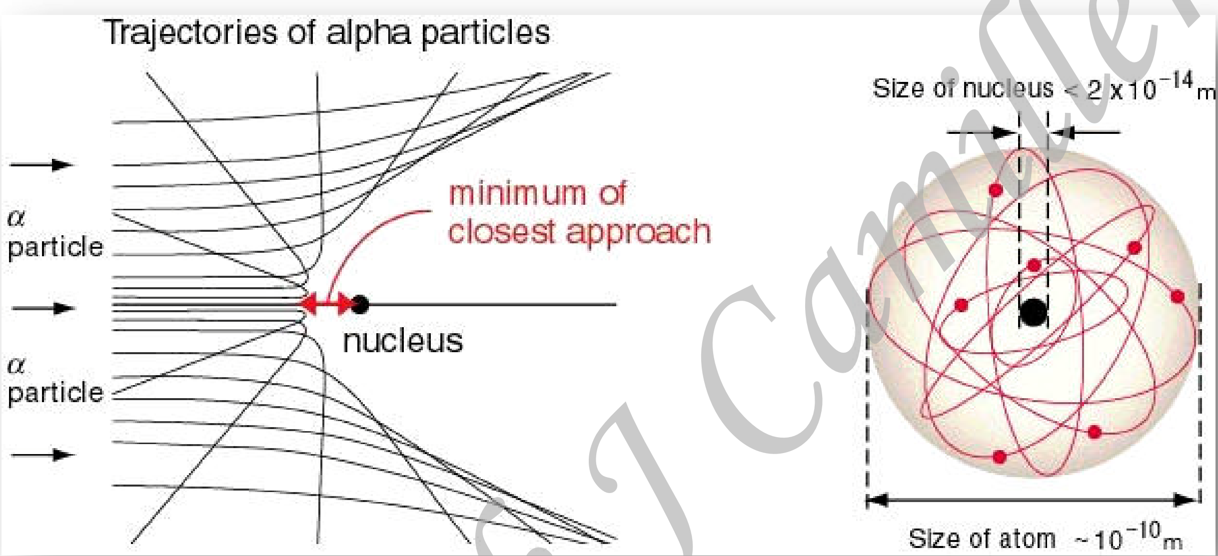
Alpha particles from a radioactive source were allowed to strike a thin gold foil. Alpha particles produce a tiny, but visible flash of light when they strike a fluorescent screen. Surprisingly, alpha particles were found at large deflection angles and some were even found to be back-scattered.



It was observed that a small proportion of the alpha particles were deflected, while an even smaller proportion bounced right back. From analysis of these observations it was concluded that:

Most of the atom was empty space.

- The positive charge was concentrated in a very small space
- The radius of the nucleus was in the order of 3×10^{-15} m.
- The alpha particles that were deflected back (1 out of 8000) had to be travelling in a line with the nucleus.



Radioactivity: Radioactivity is composed of the emission of

a. Radioactive particles that include Alpha (α) and Beta (β) particles.

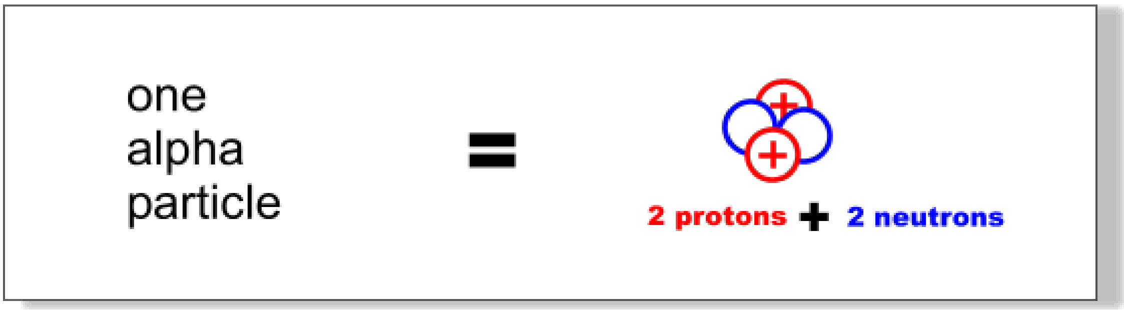
b. Radiation. An electromagnetic radiation (emr) composed of Gamma (Ý)Radiation.

Alpha particles

Alpha particles are relatively slow and heavy compared with other forms of nuclear radiation. They move at approximately 6% the speed of light.

Structure:

Alpha particles are composite particles consisting of two protons and two neutrons tightly bound together (Figure 1). They are emitted from the nucleus of some radio nuclides during a form of radioactive decay, called alpha-decay. An alpha-particle is identical to the nucleus of a normal (atomic mass 4) helium atom or a doubly ionised helium atom.

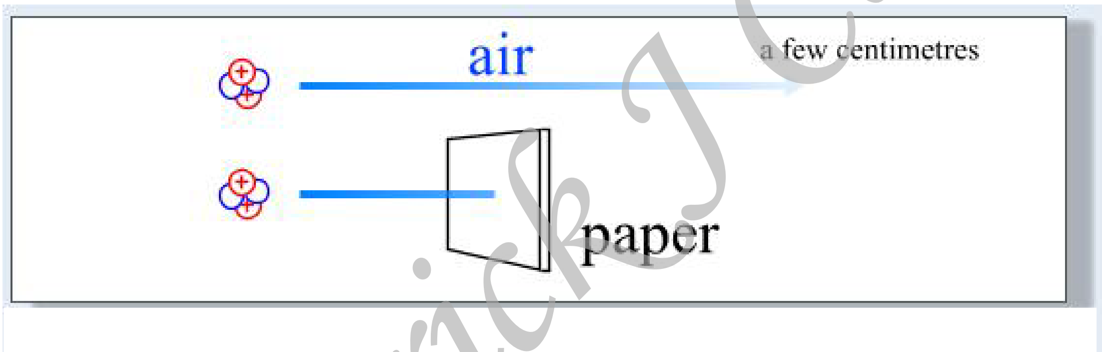


Properties of alpha particles

Alpha particles are highly ionizing because of their double positive charge, large mass (compared to a beta particle) making them relatively slow when compared to other radioactive particles.

They have a very small range in air, less than 10cm.

They have very low penetrating powers. In fact they can be stopped by a thin sheet of paper.

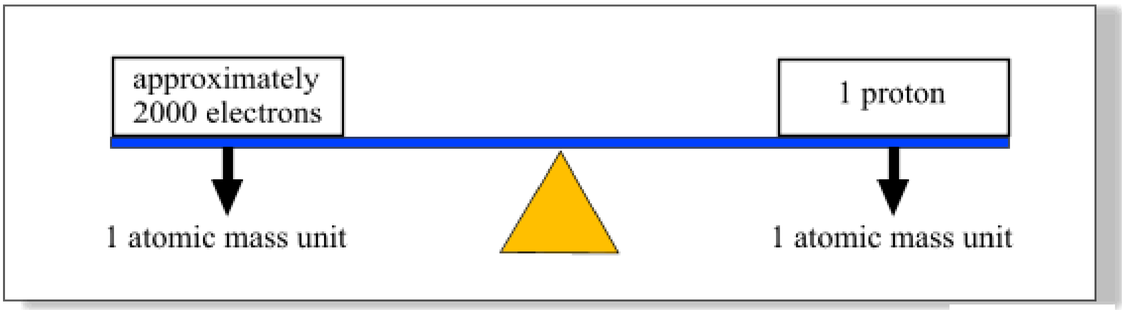


Beta Particles

Beta particles (β^-) are electrons from the nucleus and are ejected by some radio nuclides during a form of radioactive decay called beta-decay. The emission of the electron's antiparticle, the positron or beta plus particle (β^+), is also called beta decay. Beta-decay normally occurs in nuclei that have too many neutrons to achieve stability. It occurs commonly in the radioactive products of nuclear fission and occurs in natural radioactive decay chains following one or more alpha-decays

Properties of beta particles

Beta particles have a much smaller mass which is half of one thousandth of the mass of a proton and carry a single negative charge. Beta particles are much less ionizing that alpha particles and generally do less damage for a given amount of energy deposition.



Beta-particles, being less ionizing than alpha-particles, can travel though many centimetres or even metres or air and though millimetres of skin or tissue. They are stopped by a thin sheet of aluminium or several sheets of paper.

Beta particles being negative are attracted to positively charged plates and being oppositely charged to alpha particles are deflected oppositely to them by a magnetic field.

Gamma Radiation

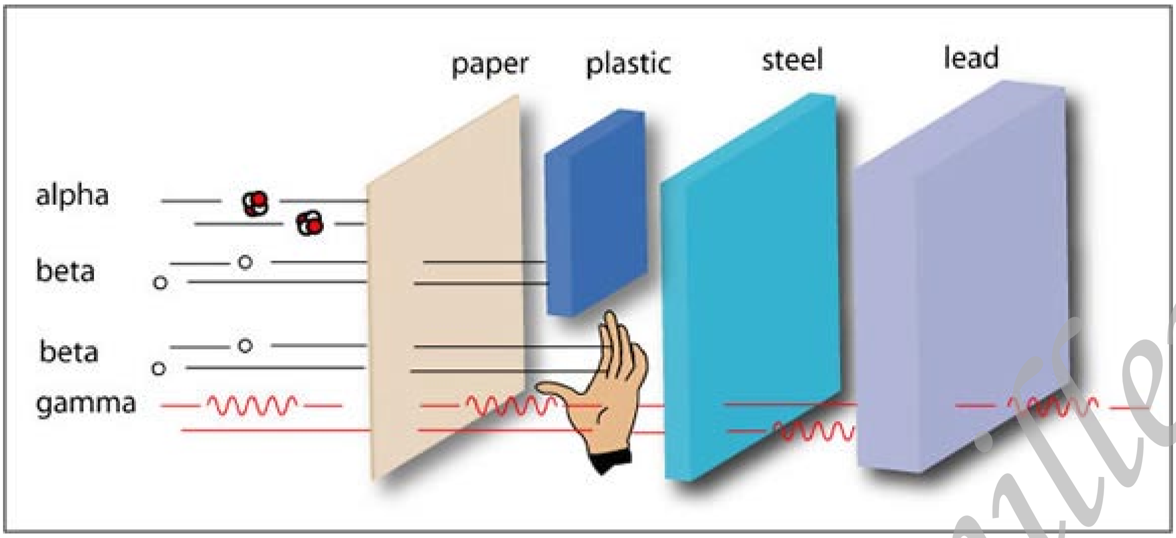
A gamma ray is a packet of electromagnetic energy (photon) emitted by the nucleus of some radio-nuclides following radioactive decay. Gamma photons are the most energetic photons in the electromagnetic spectrum. Their emission commonly occurs within a fraction of a second after radioactive decay but sometimes occurs several hours later.

Properties of gamma rays/radiation

Gamma rays are a form of electromagnetic radiation (EMR). They originate from the nucleus. Electromagnetic radiation can be described in terms of a stream of photons, which are massless particles each traveling in a wave-like pattern and moving at the speed of light. Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons. Gamma-ray photons have the highest energy in the EMR spectrum and their waves have the shortest wavelength.

Having no charge they are unaffected by magnetic and or electric fields.

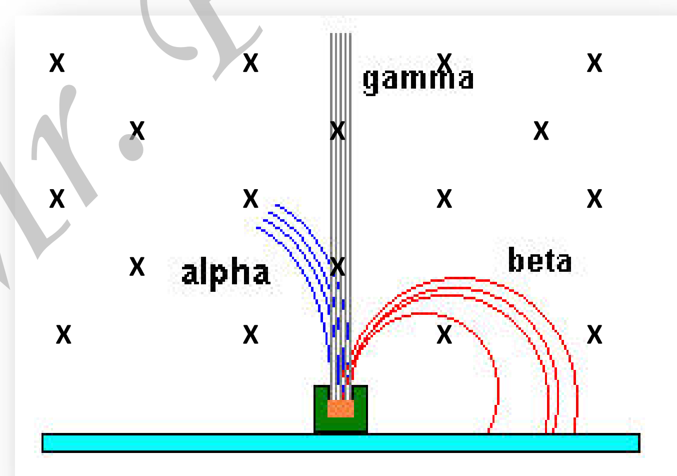
The high energy of gamma rays enables them to pass through many kinds of materials, including human tissue. Very dense materials, such as lead, are commonly used as shielding to slow or stop gamma photons



Uses of radioactive materials:

- measure and control the flow of liquids in numerous industrial processes
- investigate subterranean strata in oil wells
- measure soil density at construction sites
- ensure the proper fill level for packages of food, drugs and other products.
- sterilize medical equipment in hospitals
- pasteurize certain foods and spices
- gauge the thickness of metal in steel mills.
- distance-sensing devices, all of which utilize its gamma radiation.
- The dating of fossils and organic material.

Summary of Properties



Having different charges, alpha and beta are deflected differently in the same magnetic field. Gamma being neutral is not influenced by the magnetic field

Name	Symbols	Identity	Relative Charge	Relative Mass	Penetrating Power	Interaction with Charged Plates	Hazards
Alpha	α, $^{4}_{2}He$	Helium nucleus	2+	4	low - stopped by a sheet of paper	Attracted to negative plate, deflected by positive plate	harmful if ingested
Beta	β, $^{0}_{-1}e$	Electron	1-	$\frac{1}{1836}$	moderate - pass through paper and ½mm aluminium, stopped by ½mm lead	attracted to positive plate, deflected by negative plate	skin burns, harmful if ingested particularly iodine-131 in thyroid & strontium-90 in bones
Gamma	γ	Electromagnetic radiation	0	0	high - only stopped by several cms of lead or many centimetres of concrete	unaffected	most dangerous as these are the most penetrating, as a consequence, gamma rays can be used to sterilize materials & destroy bacteria in food

Precautions in the handling of radioactive materials

Radioactive materials should never be handled with hands.

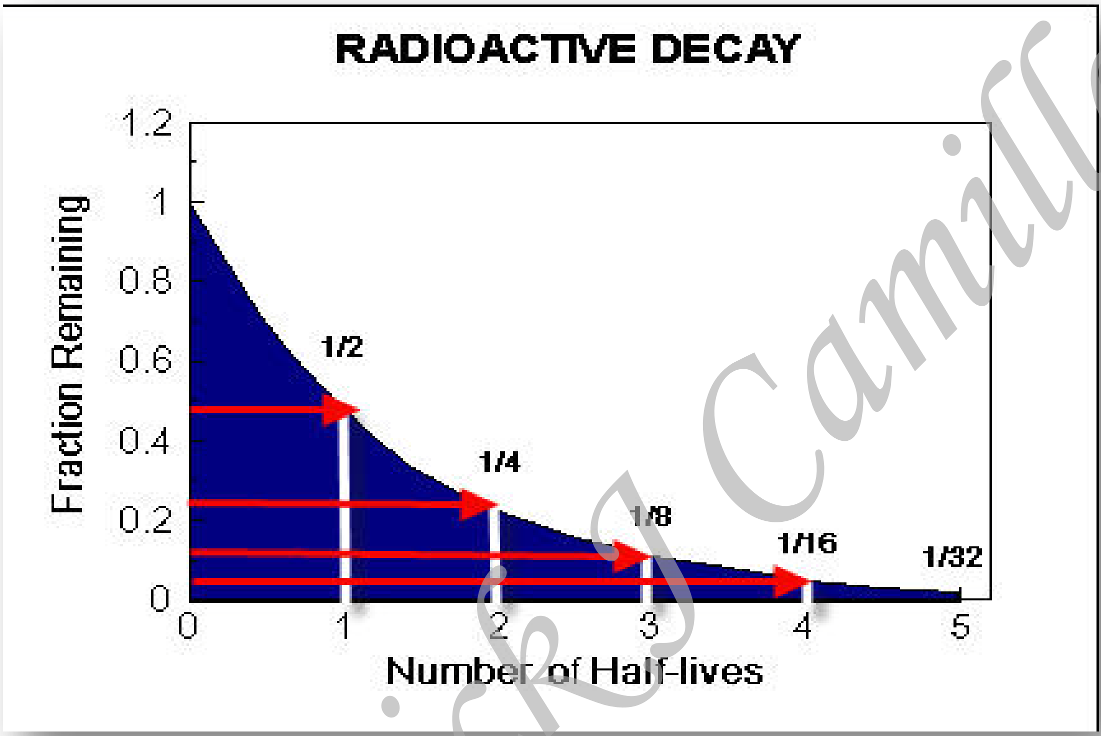
Always stay out of line of radiation.

Wear protective clothing and protect oneself with adequate shielding like concrete walls or barriers lined with lead.

Radioactive Decay

It is a process that takes place when a radioactive nuclide undergoes alpha beta disintegration and gamma emission. Radio active decay is a random process. The rate of radioactive decay cannot be influenced by any physical or chemical process. Still over time a radioactivity pattern that varies from one element to another may be observed. This is referred to as the half life.

The half life is the time required for a radioactivity of a radioactive material to decrease by half or the time taken for a given number of radioactive nuclides to decrease by half.



The half life is a phenomenon that is unique for each and very radioactive element and can vary from a few milliseconds to thousands of years according to the radioactive material in question.

The number of nuclei decays on a time unit is proportional to the number of all nuclei in the sample. The quantity of the number of decays in the period of time in which they proceeded is called the activity of the radioactive source and is represented by the formula:

$$dN/dt = -\lambda N$$

dN/dt (units: s^{-1}) is equivalent to the number of disintegrations per unit time also referred to as the activity A of the radioactive material in question.

N is equivalent to the number of radioactive particles present

λ (units seconds s) is the activity constant equal to $0.6931/T_{1/2}$

Over time the number of active nuclei decreases exponentially causing a decrease in the activity.

The period over which the number of radioactive nuclei becomes half the original amount is referred to as the *half-life period* ($T_{1/2}$) of that radioactive element. This period can be calculated from the formula below:

$$T_{1/2} = 0.6931/\lambda$$

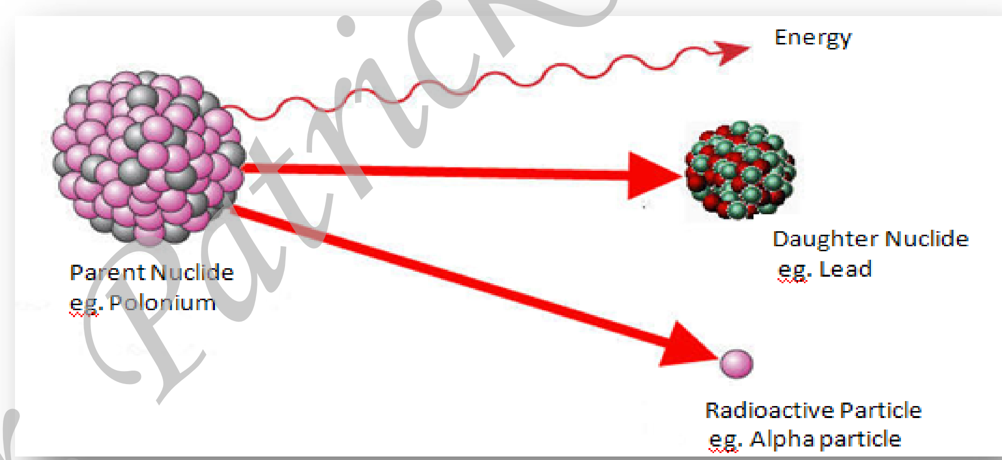
Energy from Radioactivity

In a spontaneous radioactive decay a **parent nuclide** disintegrates into smaller particles that include the **daughter nuclide** accompanied by a **radioactive particle** and at times even gamma radiation.

In the process it is observed that there will be a DECREASE in the mass whose value may be calculated by the equation:

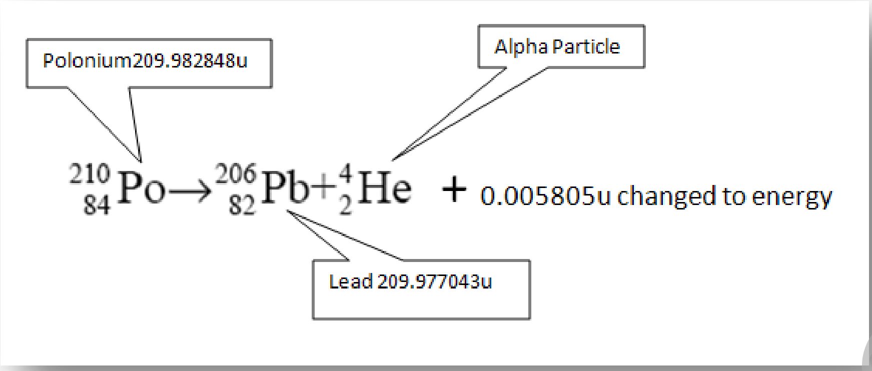
$$E=mc^2$$

For instance this type of decay occurs naturally in Polonium and is an example of "spontaneous decay".



So what has this got to do with $E = mc^2$?

The Polonium atom doesn't just break apart. As it decays, each of the two resulting elements (the Lead and α-particle) fly apart at high speed. In other words they both have kinetic *energy*. What is observed though is that the total mass of the two smaller particles is *less* than the mass of the original uranium particle. Some mass must have been turned into (mostly kinetic) energy, in accordance with $E = mc^2$.



Decrease in Mass from Polonium to its products is of 0.005805u.

1u = 1.66 X 10^{-27}Kg.

0.005805u = ?

0.005805u = 9.64 X 10^{-30}Kg.

If $E=mc^2$ then 9.64 X 10^{-30}KgX $(3x\ 10^8)^2$= 8.7x10^{-13}J