RADIOACTIVITY

Three kinds of radiation:

Historically, the products of radioactivity were called alpha, beta, and gamma when it was found that they could be analysed into three distinct species by either a magnetic field or an electric field.

There are three different main types of radioactivity at this level of study and these are denoted by the Greek letters alpha (**α**), beta (**β**) and gamma (**γ**).

Some radiation is easily absorbed, some has more penetrating power, and others were absorbed only with difficulty.

The heavy, positive, easily absorbed rays are called **α radiation**.

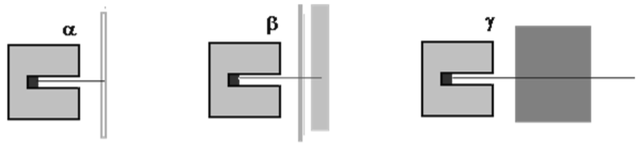
The rays consisting of lighter, negative, not so easily absorbed particles are called **β radiation**.

The rays which were not affected by a magnetic field, and which were most penetrating, are a very high-energy short-wave form of electromagnetic radiation called **γ rays**.

Penetrating power and Ionisation:

In a vacuum the range of alpha, beta or gamma radiation is infinite, since no ionisation occurs (no ions are produced). The intensity of gamma radiation decreases with distance, following the inverse square law since it is electromagnetic radiation.

Three kinds of radiation being absorbed



α	β	γ
absorbed by several cm of air thin paper skin	pass through air, paper; absorbed by a few cm of aluminium	pass through air, paper, aluminium; partly absorbed by several cm of lead.

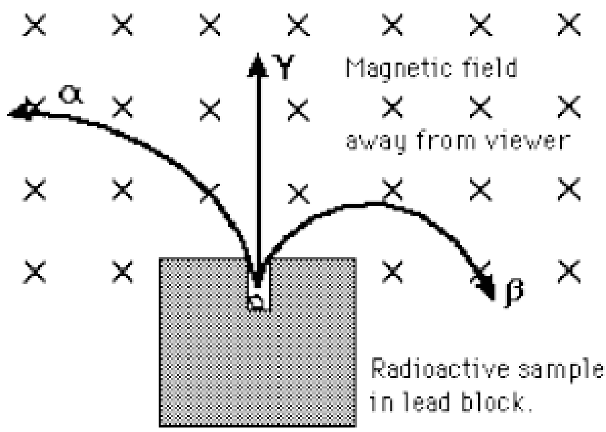
The main effect of radiation passing through a substance is the ionisation of the atoms (the removal of electrons) of that substance. For this reason, these radiations are classed as **ionising radiation.**

Particle	Range in air (mm)	Ionisation (proportional)
α	Up to 100	10000
β	Up to 500	100
γ	Almost infinite	1

Deflection by a magnetic field:

One of the radiations was affected by a magnetic field in the same way as a beam of electrons and was therefore negatively charged. A second was affected in the opposite way and was shown to be positively charged and much heavier. The third radiation was not affected by a magnetic field.

The diagram shows how alpha, beta and gamma radiation would be deflected by a magnetic field acting perpendicular to the path of the particles (if the particles were travelling at about the same speed – which they aren't).

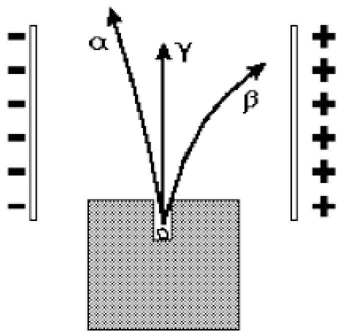


(In the diagram the magnetic field acts into the plane of the paper)

α	β	γ
deflected weakly in the opposite direction to the way electrons would be deflected, because they are heavier, and positive	deflected strongly because they have small mass and negative charge, just like electrons	not deflected at all because they are not charged particles

Alpha particles are deflected a little because of their large mass while beta particles are deflected much more because they are nearly two thousand times lighter. They have a negative charge while alpha particles are positive and so they are deflected in the opposite direction. Gamma rays are not deflected at all – this is because they have no charge.

Deflection by an electric field:



α	β	γ
deflected towards the negative plate because they are positive particles	deflected more strongly towards the positive plate because they are lighter negative particles	not deflected at all because they are not charged particles

	α	β	γ
mass	4	1/2000	0
charge	2+	1-	0

Particle	Symbol	Description	Penetration power	Ionising power	Deflected by magnetic field
Alpha particle α	$^{4}_{2}He$	Helium nucleus made up of 2 protons & 2 neutrons	Stopped by a few cm of air or thin sheet of paper - low penetration.	Very high ionising power	yes
Beta particle β	$^{0}_{-1}e$	High kinetic energy electron	Stopped by a few mm of most metals e.g. aluminium.	Moderate ionising power	yes
Gamma radiation γ	$^{0}_{0}\gamma$	Very high frequency electromagnetic radiation	"Stopped" by several cm of steel or metres of concrete.	Lowest ionising power	no

Nuclear equations:

The changes can be represented as nuclear equations and they must balance in atomic number and mass number. In both α and β a new element is formed which is called the transmutation of one element into another.

When alpha decay occurs, mass no. decreases by 4 and atomic no. decreases by 2.
For beta decay, mass number does not change, atomic number increases by 1.
Gamma decay, a gamma ray is released (energy), no change to mass & atomic number.

Two conservation laws are the "law of conservation of atomic number" (or charge) & the "law of conservation of mass number" (or nucleon number)

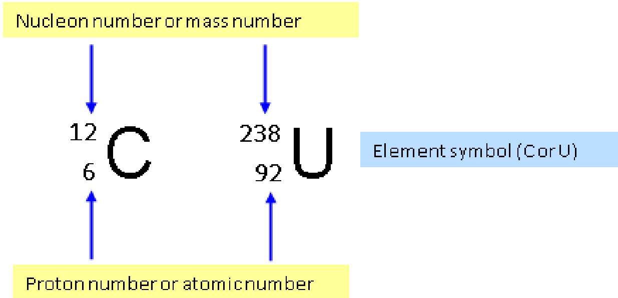
$$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

The total charge on the left hand side of the reaction is zero (88 electrons and 88 protons in the radium atom). On the right hand side of the equation the total charge is still zero (86 protons and electrons in the radon atom and 2 protons and 2 electrons within the helium atom)

Nuclear equations:

As you may know we use a special way of writing the structure of a nucleus so that is easy to see what the proton and nucleon numbers are.

This is how to write down the structure of carbon and uranium:



This means that in the nucleus of a carbon atom there are 6 protons and 6 neutrons making 12 particles (or nucleons). In a uranium atom there are 92 protons and 146 neutrons making 238 nuclear particles (nucleons).

We can use these symbols in the following examples of the three main ways that a nucleus can decay.

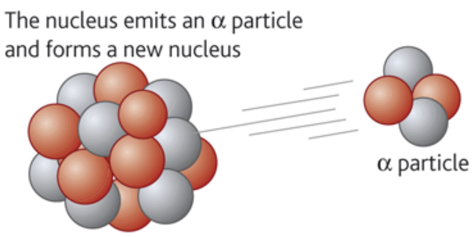
$$^{90}_{38}Sr \longrightarrow {}^{90}_{39}Y + {}^{0}_{-1}e$$ Beta emission

$$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$ Alpha emission

$$^{60}_{27}Co \longrightarrow {}^{60}_{27}Y + {}^{0}_{0}\gamma$$ Gamma emission

Alpha:

Alpha particles are the same as **helium nuclei**, consisting of two protons and two neutrons.



When a nucleus emits an alpha particle it loses two protons and two neutrons. Its mass number will have gone down by 4, and its atomic number will have gone down by 2.

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

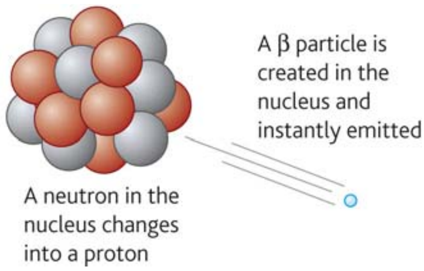
This will form a different element e.g.

$$^{235}_{92}U \rightarrow {}^{231}_{90}Th + {}^{4}_{2}He$$

Law of conservation of atomic number: Here 92 (LHS) = 90 + 2 (RHS).
Law of conservation of mass number: Here 235 (LHS) = 231 + 4 (RHS).

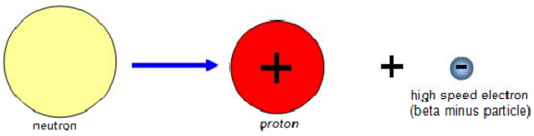
Beta:

Beta particles consist of fast moving **electrons**, with speeds of between about 0.3 and 0.7 times the speed of light.



Because of their wide range of energies, some electrons can pass further through absorbing material than others, unlike the alpha radiation.

A neutron in the nucleus changes spontaneously into a proton and the high kinetic energy electron formed is the emitted beta particle. Since the proton and neutron have a mass of 1 and the electrons mass is negligible, the mass number stays the same, the atomic number rises by 1.



$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta$$

This will form a different element e.g.

$$^{238}_{92}U \rightarrow ^{238}_{93}Np + ^{0}_{-1}e$$

(92 = 93 + -1; 238 = 238 + 0)

Gamma:

The emission of gamma radiation from a nucleus does not involve any change in the atomic (proton) number or mass number. Gamma radiation usually accompanies α and/or β decay.

$$^{99}_{43}Tc \longrightarrow ^{99}_{43}Tc + \gamma$$

This has no effect on the nature of the atom.

Neutron bombardment:

To "make" radioisotopes for use in industry and medicine, stable isotopes are bombarded with neutrons in a nuclear reactor.

$$^{16}_{8}O + ^{1}_{0}n \rightarrow ^{13}_{6}C + ^{4}_{2}He$$