Radioactivity
and
Radioactive Decay

Radioactivity

We go back in time again.

The beginning of the events leading to our modern understanding of how the nucleus works can be taken back to 1896. That is about thirteen years *before* Rutherford asked Geiger and Marsden to look for back-scattered alpha particles.

In that year Henri Bequerel left a sample of a chemical compound of uranium (uranyl potassium sulfate) in a drawer with a sealed packet of photographic film.

He found that the film was fogged.

It had somehow been exposed while inside the sealed, light-tight packet.

After a number of experiments he established that some sort of penetrating but invisible radiation was emitted by the uranium salt.

This radiation had penetrated through the packaging and exposed the film.

Radioactivity

This penetrating radiation was called *radioactivity*.

It was found that radioactivity is a characteristic of a number of naturally occurring elements such as uranium, thorium, polonium and radium.

Note

These are often called NORM (Naturally Occurring Radioactive Materials).

Radioactivity

The Curies managed to separate out elements that exhibited this *radioactivity*, but what was it?

For instance, what was the *nature* of the radiation emitted?

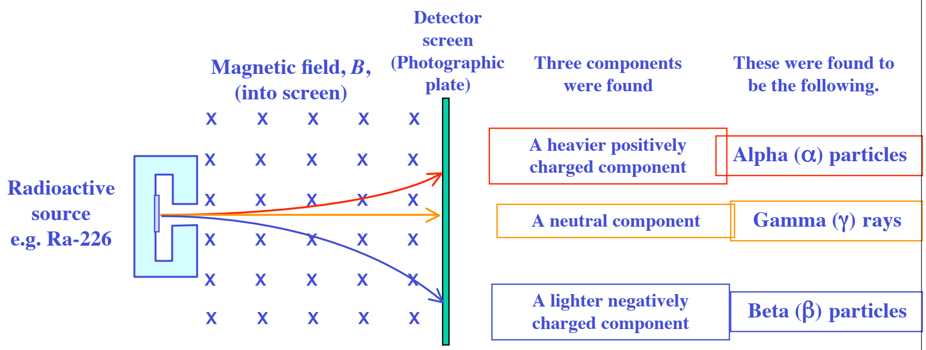
Well, how do you find out what it is?
You do experiments.

You let it go through a magnetic field and see what happens. The *path* will tell you whether the radiation is charged and about the ratio of charge to mass.

You put things in front of the source and find out if the radiation goes through them. How *penetrating* is it?

Radioactivity

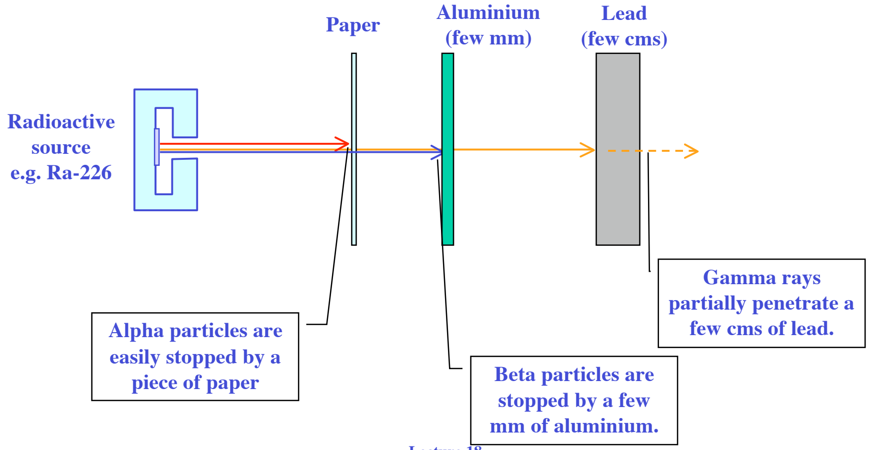
Experimental analysis of radioactivity from a source e.g. Ra-226.



Radioactivity

Experimental analysis of radioactivity from a source e.g. Ra-226.

Penetrating powers.



Radioactivity

It was established later that:

Alpha (α) particles are the nuclei of helium: $^{4}_{2}He$.

Gamma (γ) rays are very energetic *electromagnetic radiation* with energies in the range up to several MeV.

Negative beta (β) particles are actually *electrons* emitted during radioactive (beta) decay. [Both β^- particles (electrons) and β^+ particles (positrons) are emitted during different kinds of beta decay.]

Radioactivity

It was found that a number of nuclei are radioactive.

Some of these occur naturally in the three naturally occurring radioactive series

- **The *uranium series* starts with the most abundant isotope of uranium, ^{238}U and ends with ^{206}Pb.**
- **The so-called *actinium series* starts with the isotope of uranium, ^{235}U (with an abundance of only 0.7%) and ends with ^{207}Pb.**
- **The *thorium series* starts with the isotope of thorium, ^{232}Th and ends with ^{208}Pb.**

There are other naturally occurring radioactive isotopes such as ^{14}C (which is used for radiocarbon dating) and ^{40}K.

The products of many nuclear reactions are also radioactive, as are many *fission products*.

Radioactivity

For example the radioactive nuclide ^{24}Na is produced by neutron capture in the naturally occurring isotope of sodium, ^{23}Na.

The radioactive ^{24}Na then β^- decays to ^{24}Mg (as we saw before).

$$^{24}\text{Na} \xrightarrow{\beta^-} {}^{24}\text{Mg}$$

This decay has a half-life of 15.4 hours.

How much energy is released in the decay?

Just as in the case of a nuclear reaction, we calculate this from the masses as found from tables.

Radioactivity

The following are *atomic* masses taken from the 4th edition of "Modern Physics" by Arthur Beiser.

$$m\left({}^{24}_{11}\text{Na}\right) = 23.990963 \text{ u} \qquad m\left({}^{24}_{12}\text{Mg}\right) = 23.985045 \text{ u}$$

The *atomic mass* of ^{24}Na, i.e. the mass of the ^{24}Na *nucleus* plus the mass of *eleven electrons*.

The *atomic mass* of ^{24}Mg, i.e. the mass of the ^{24}Mg *nucleus* plus the mass of *twelve electrons*.

So the energy released in this decay is just:

$$(23.990963 - 23.985045) \times 931.494 = 5.51 \text{ MeV}$$

[The mass of the emitted β^- is included in the *atomic* mass of the ^{24}Mg.]

$$\left[m(\beta^-) = 0.0005486 \text{ u}\right]$$

Exercise 20

1. In the β^- decay of ^{60}Co two gamma rays with energies of 1173.4 keV and 1332.4 keV are emitted in cascade.

   Find out what "in cascade" means.

   Work out the energy of the emitted β^- particle that feeds this cascade.