RADIOACTIVITY

Radioactivity is the spontaneous emissions from the nucleus of certain atoms, of either alpha, beta or gamma radiation. These radiations are emitted when the nuclei of the radioactive substance breaks down to form a new and more stable nuclei.

One of the early workers with this phenomenon was Marie Curie. She experimented with uranium compounds and discovered new elements such as polonium and radium. These substances emitted invisible radiation that eventually killed her in 1934 from overexposure.

Nature of Radioactive Emissions

Alpha particles (α) are helium nuclei. They have 2 protons and 2 neutrons existing together. [$^{4}_{2}He$]

Beta particles (β) are electrons moving at high speeds.

Gamma rays (γ) are electromagnetic waves of very short wavelengths.

SUMMARY OF PROPERTIES OF RADIOACTIVE EMISSIONS				
RADIATION	CHARGE	MASS	SPEED	PENETRATING ABILITY
Alpha particle	+2e	4 units	Approx. 1/20 speed of light	Stopped by thin paper
Beta particle	-e	1/1840 unit	Ranges from 3 - 99% of speed of light	Stopped by an aluminum plate
Gamma ray	0 No Charge	Almost zero mass	speed of light, c	Stopped by thick lead

Cloud Chamber

Radioactivity can be detected by using by using a device called the diffusion cloud chamber. The device consists of a cylinder chamber under which dry ice is placed. Inside the chamber is filled with alcohol vapour, which is cooled about –65 ^{o}C by using dry ice.

When the radioactive source is placed close to the base, the inside is illuminated with white vapour trails, which can be seen shooting from the source. The vapour trails formed, shows the paths taken by the radiation and can be used to distinguish the type

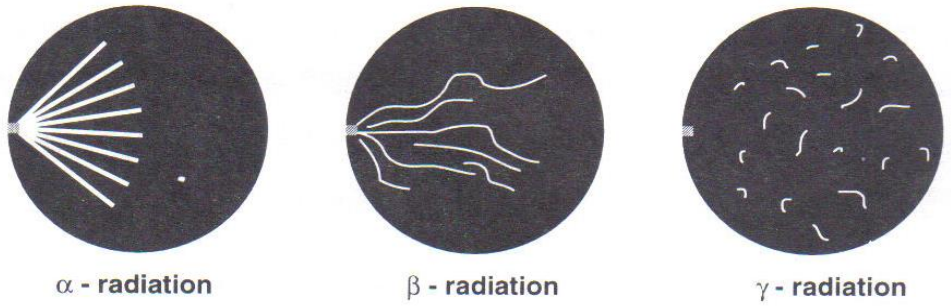

Fig. 13.4 Trails in a Cloud Chamber

of radiation present.

The Effect of Magnetic Fields on Radioactive Emissions

Some radioactive emissions are deflected by both electric and magnetic fields; the diagram below shows the effects of magnetic fields on **α particles, β particles and γ rays.**

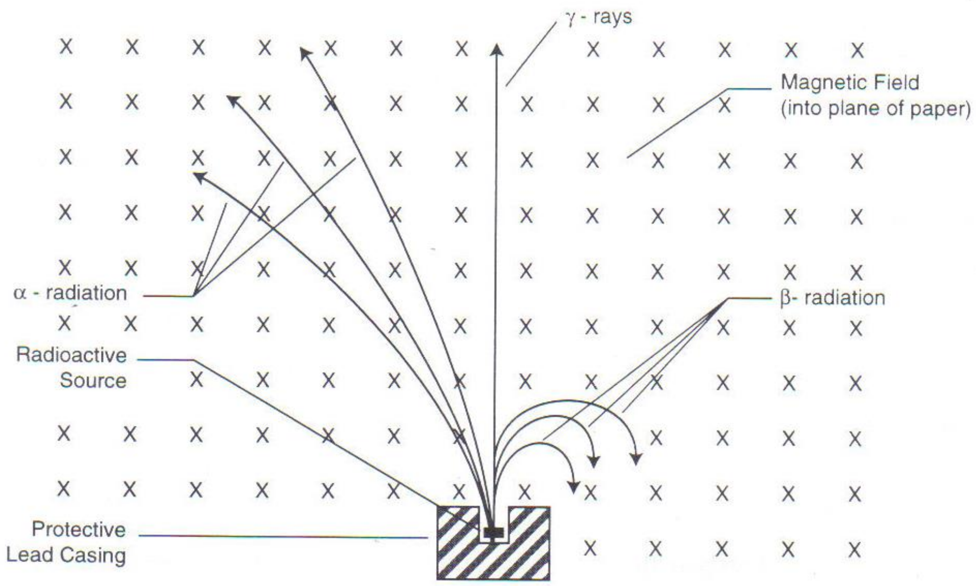

Fig. 13.5 Effect of Magnetic Field on Radioactive Emissions

Gamma **(γ)** rays are not affected by magnetic fields since they have no charge, hence they do not deflect.

Alpha (α) particles show a slight deviation to the left as shown in the diagram above. By using Fleming Left Hand Rule we can determine that the alpha particles are positively charged.

Beta **(β)** particles deviate to the right, which shows that they have a negative charge.

Note that alpha particles deviate less than beta particles because they are massive compared to beta particles.

Nuclear Reactions

There are several types of nuclear reactions. These are

(i) Radioactivity decay,
(ii) Fusion and
(iii) Fission.

Radioactive Decay

If an isotope is radioactive it has an unstable arrangement in its nuclei. The emission of alpha or beta particles can make the isotope more stable. This type of reaction however alters the number of protons or neutrons in the nucleus making the nucleus of a different element. The original nucleus is called the ***parent nucleus*** and the new nucleus is called the ***daughter nucleus***. (N.B. Further decay can also produce a ***granddaughter nucleus.)*** The daughter nucleus and the emitting products are called ***decay products***.

Alpha Particle Decay

When a nucleus decays by emitting alpha **(α)** particles, its atomic mass number **(Z)** decreases by two and its mass number **(A)** decreases by four.

General Equation:

$$^{A}_{Z}\mathbf{X} \longrightarrow {}^{A-4}_{Z-2}\mathbf{Y} + {}^{4}_{2}\mathbf{He} + \mathbf{ENERGY}$$

parent nuclide	daughter nuclide	alpha particle

Examples

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}\alpha + Energy$$

$$^{212}_{84}Po \rightarrow {}^{208}_{82}Pb + {}^{4}_{2}He + Energy$$

Beta Particle Decay

Beta emission causes the proton number **(Z)** to increase by 1, but the nucleon number **(A)** does not change.

General Equation:

$$^{A}_{Z}\mathbf{X} \longrightarrow {}^{A}_{Z+1}\mathbf{Y} + {}^{0}_{-1}\boldsymbol{\beta} + \textbf{ENERGY}$$

parent nuclide	daughter nuclide	beta particle

Examples

$$^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + \text{energy}$$

$$^{131}_{53}\mathrm{I} \longrightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\beta + \text{energy}$$

Gamma Ray Emissions

With some isotopes the emission of alpha particles and/ or beta particles leaves the neutrons and protons in an excited arrangement. As the protons and neutrons arrange themselves into a more stable arrangement they lose energy. This energy is emitted as a burst of gamma radiation. Gamma radiation does not cause changes in the mass number **(A)** or the atomic number **(Z)** of the isotope.

Half-Life

The half-life of a radioactive substance is the time taken for half of the unstable atoms to decay (decrease by half of its original mass).

N.B.

Radioactive decay occurs randomly, hence there is no way of predicting when a particular nucleus will degrade.

The radioactive process is not affected by temperature change, pressure change or chemical change.

Table of Half-Life of Some Radioactive Isotopes

ISOTOPE	HALF-LIFE
Boron-12	0.92 seconds
Radon-220	52 seconds
Iodine-128	25 minutes
Radon-222	3.8 days
Radium-226	1602 years
Carbon-14	5730 years
Plutonium-239	24400 years
Uranium-238	$5.5*10^9$ years

Examples

1. A radioactive source has a half-life of 3 minutes. At a given moment a radiation detector records a count rate of 128 counts from it. What will be the count rate after (i) 3 minutes, (ii) 6 minutes and (iii) 15 minutes?

2. A radioactive substance has a half-life of 20 minutes. Initially there were 8000 nuclei present. How long has lapsed until the number of nuclei falls to 1000?

3. Iodine-131 is a radioactive substance which is used as a medical treatment, has a half-life of 8 days. A patient is given a dose of 10 mg of Iodine-131. How much of the isotope will remain in her body after 24 days assuming none is expelled form the body?

Decay Curve

If a radioactive source has a short half-life, apparatus can be used to obtain data to plot a decay curve. It is not easy to measure the number of nuclei in a sample of radioactive material but the rate of decay can be used to indicate how much of the nuclei is present.

To plot a radioactive decay curve we need to find the value for the background count, this would be subtracted from each reading obtained. Readings are then taken at regular intervals and the corrected count rate is plotted against the time. We can then use the graph to find the half-life of the substance.

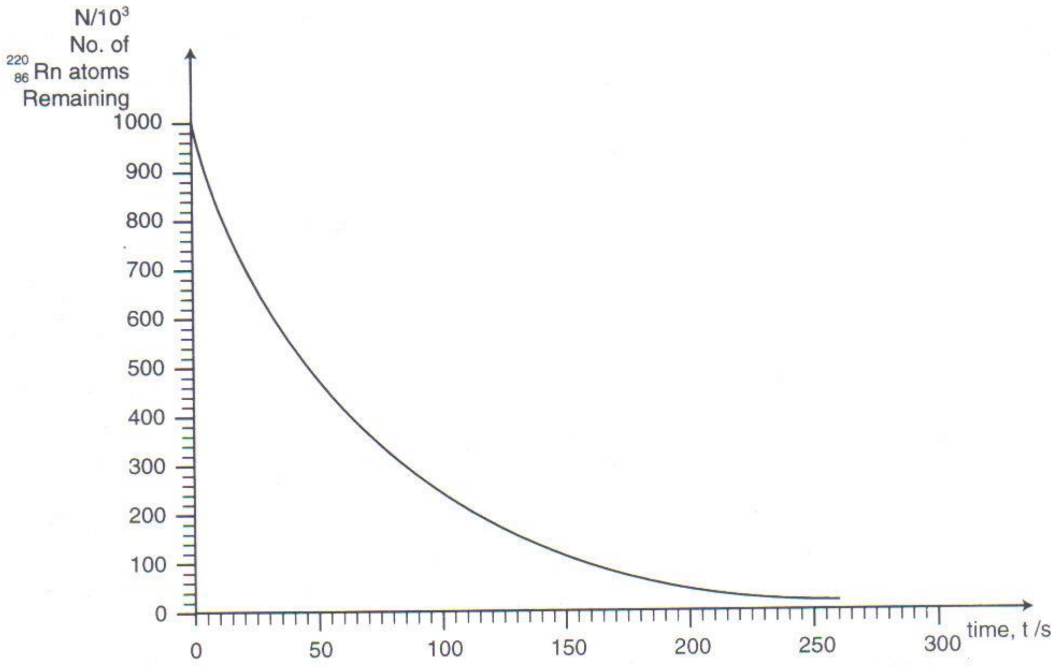

Fig. 13.6 *Typical Corrected Decay Curve for Radon-220* $^{220}_{86}\mathrm{Rn}$ ($t_{\frac{1}{2}} \approx 52$ s)

Fusion and Fission

Fusion
This occur when two small nuclei join together to form a larger one. Energy is released in the process and Einstein's formula can be used to calculate the energy released.

In fusion:

two small particles → one large particle + Energy

Fission
This occurs when a large nucleus splits into two roughly equal smaller ones with the release of energy. This energy is the result of matter converting into energy. We can

therefore use Einstein’s equation to calculate the amount of energy to the quantity of matter converted. ***($E = mc^2$)***

In fission:

1 light particle + 1 heavy particle → 2 less heavy particles about the same mass + energy

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n$$

(energy appears as kinetic energy)

Read and make notes:

PFC **Page 362 - 363**

- Radioactive dating
- Radiation and people

PFC ***Page 375 - 385***

- Nuclear energy
- Fission and Fusion