CHAPTER 28

Nuclear Physics

28.1 THE ATOMIC AGE

Radioactivity and nuclear energy have become some of the most important concerns facing society since the Second World War. The benefits to society are immense but so too are the problems they bring. In this chapter we will be examining some aspects of nuclear physics that will help to answer questions such as these:

- When you irradiate food with gamma rays, does the food become radioactive?
- Can you accurately tell the age of bones millions of years old?
- If gamma radiation can go straight through the body, how can it kill cancer tumours?
- Why do you need a fission bomb to start a fusion bomb?
- Why does an airline pilot get exposed to more radiation than an air traveller?
- I thought electrons were negatively charged; how can you get a positive one?

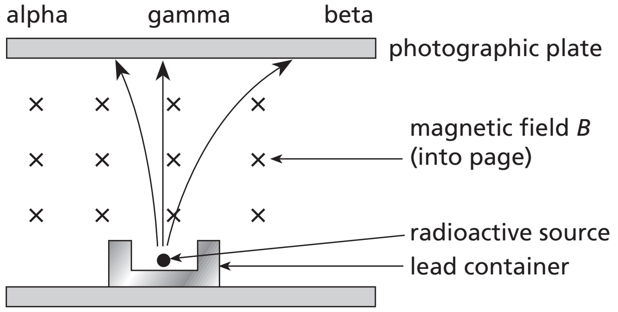
28.2 PROPERTIES OF NUCLEAR RADIATION

In the previous chapter, the history and properties of nuclear radiation were described. Let's expand on these:

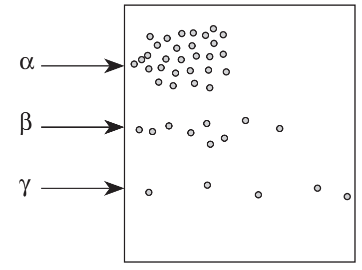
- Any radiation that can remove an electron from an atom and create a heavy positive ion and free electron is termed **ionising radiation**. Ionising radiations include electromagnetic radiation (gamma rays, X-rays, and ultraviolet radiation) as well as energetic particles such as alpha and beta particles. Gamma rays are said to be **nuclear radiation** because they are created within the nucleus; X-rays come from the electron cloud around the nucleus.
- By the early 1900s, the properties of alpha, beta and gamma radiation had been measured, allowing physicists to better understand the process of radioactivity. The deflection of the particles in a magnetic field is shown in Figure 28.1**(a)** and how they pass through matter is shown in Figure 28.1**(b)**.

Figure 28.1
(a) Deflection of alpha, beta and gamma rays by a magnetic field.
(b) Ionising ability.

(a)



(b)



Alpha (α) particles ^4_2He

As they collide with matter, alpha particles slow down, transferring their kinetic energy to the other molecules, shaking many of them apart and leaving a trail of positive and negative ions in their wake.

Beta (β) particles $^0_{-1}e$

Beta particles are electrons moving at high speed ranging from 0.3 to 0.99 times the speed of light (3×10^8 m s^{-1}). Because of their speed and smallness, they are more penetrating than alpha particles and can travel about 1 m in air before slowing down to become just like the surrounding electrons.

Gamma (γ) rays

Gamma radiation differs from alpha and beta radiation in that it is not made up of charged particles and is not deflected in electric or magnetic fields. Instead, gamma rays are electromagnetic radiation of extremely short wavelength (about 10^{-13} m). Since they have no charge they have tremendous penetrating power because they interact with the absorbing material only via a direct head-on collision with an electron or nucleus. Materials such as lead are good absorbers of gamma radiation mainly because of their high electron density. Even so, gamma rays can still penetrate up to 10 cm of lead.

DETECTING NUCLEAR RADIATION 28.3

One of the most common means of detecting radiation is by Geiger–Müller counters but also used are photographic plates, electroscopes, spark chambers and cloud chambers, and by fluorescence.

Fluorescence

When ionising radiation strikes certain substances such as ZnS, diamond or barium platinocyanide, a large number of individual flashes or scintillations can be seen under a microscope. Tedious counting of flashes over a set period was used by Rutherford and his co-workers in the early 1900s. These **scintillation detectors** slowly lost favour until 1947, when **photomultiplier tubes** were developed to count the scintillations electrically. Today, semiconductor detectors are used.

Photographic plates

Becquerel's discovery of radioactive emissions was based on the fogging of photographic plates. As the ionising particles strike the silver chloride or bromide grains in the gelatin emulsion on the plate they change them into silver atoms. On development, the silver is 'fixed' and the unaffected salts are removed. This leaves a permanent photographic record of the particles' tracks.

EI Activity 28.1 PHOTO DETECTIVE

If you print your own photos or know someone who does, you may like to test the effect of nuclear radiation on an unexposed sheet of photographic paper.

1. Place a sheet of the paper in one of the black plastic bags it normally comes in and tape it closed.

2 Under teacher supervision, place three radioactive specimens, one each of α, β and γ-type radiation, on top of the plastic for an hour and record their positions.

3 Develop the paper and see if the results agree with both the penetrating properties mentioned above and the ability of the radiation to fog the paper.

4 Was the image clear? How could you test it without the plastic bag?

Electroscope

Marie Curie measured the activity of fluorescent salts using an electrometer, invented by her husband Pierre and his brother Jacques. It is based on the principle of the **electroscope**, which should be familiar to you (Figure 28.2). When the air surrounding a negatively charged electroscope is ionised, the positive ions will be attracted to the electroscope and cause the leaves to collapse. The rate of collapse will be proportional to the ionisation produced in the air above. The **electrometer** is similar but has a pointer instead of leaves.

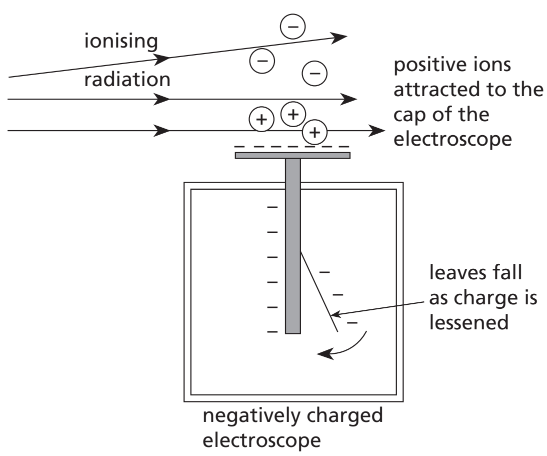


Figure 28.2
A leaf electroscope.

Geiger–Müller counters

Figure 28.3 shows a **Geiger–Müller tube**, commonly known as a **Geiger counter**. It consists of a thin positively charged central wire surrounded by a negatively charged tube filled with a low pressure inert gas. When a radioactive particle enters the tube through the window, it ionises a few atoms. The resulting free electrons are drawn to the positive wire. However, the electric field is so strong that these electrons gain sufficient energy to ionise more atoms of gas. More free electrons are created and the process is repeated many times. This avalanche of electrons is collected by the central wire, creating a signal used to record the passage of the original particle of radiation.

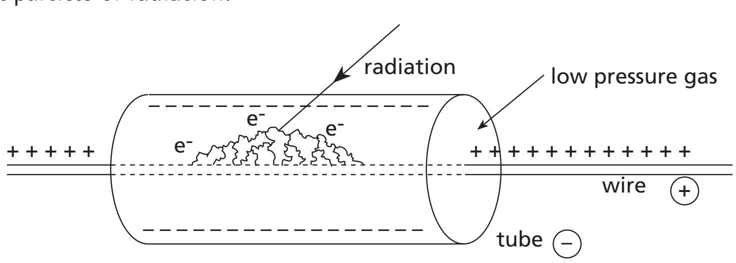


Figure 28.3
A Geiger–Müller tube.

Cloud chambers and bubble chambers

The **cloud chamber** was invented by Scotsman Charles Wilson (1869–1959) and is based on the tendancy of drops of moisture to condense on gaseous ions. When an ionising particle