P2 6.1 Observing nuclear radiation

Learning objectives

- What is a radioactive substance?
- What types of radiation are given out from a radioactive substance?
- When does a radioactive source give out radiation (radioactive decay)?
- Where does background radiation come from?

A key discovery

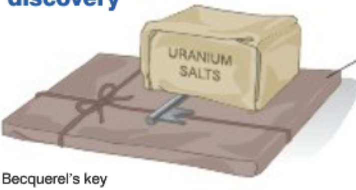

Figure 1 Becquerel's key

If your photos showed a mysterious image, what would you think? In 1896, the French physicist, **Henri Becquerel**, discovered the image of a key on a film he developed. He remembered the film had been in a drawer under a key. On top of that there had been a packet of uranium salts. The uranium salts must have sent out some form of radiation that passed through paper (the film wrapper) but not through metal (the key).

Figure 2 Marie Curie 1867–1934

Marie Curie

Becquerel asked a young research worker, **Marie Curie**, to investigate. She found that the salts gave out radiation all the time. It happened no matter what was done to them. She used the word **radioactivity** to describe this strange new property of uranium.

She and her husband, Pierre, did more research into this new branch of science. They discovered new radioactive elements. They named one of the elements **polonium**, after Marie's native country, Poland.

a You can stop a lamp giving out light by switching it off. Is it possible to stop uranium giving out radiation?

Becquerel and the Curies were awarded the Nobel Prize for the discovery of radioactivity. When Pierre died in a road accident, Marie went on with their work. She was awarded a second Nobel Prize in 1911 for the discovery of polonium and radium. She died in 1934 from leukaemia, a disease of the blood cells. It was probably caused by the radiation from the radioactive materials she worked with.

Practical

Investigating radioactivity

We can use a **Geiger counter** to detect radioactivity. Look at Figure 3. The counter clicks each time a particle of radiation from a radioactive substance enters the Geiger tube.

Figure 3 Using a Geiger counter

What stops the radiation? Ernest Rutherford carried out tests to answer this question about a century ago. He put different materials between the radioactive substance and a detector.

He discovered two types of radiation:

- One type (**alpha radiation**, symbol α) was stopped by paper.
- The other type (**beta radiation**, symbol β) went through the paper.

Scientists later discovered a third type, **gamma radiation** (symbol γ), even more penetrating than beta radiation.

b Can gamma radiation go through paper?

A radioactive puzzle

Why are some substances radioactive? Every atom has a nucleus made up of protons and neutrons. Electrons move about in energy levels (or shells) surrounding the nucleus.

Most atoms each have a stable nucleus that doesn't change. But the atoms of a radioactive substance each have a nucleus that is unstable. An unstable nucleus becomes stable by emitting alpha, beta or gamma radiation. We say an unstable nucleus **decays** when it emits radiation.

We can't tell when an unstable nucleus will decay. It is a **random** event that happens without anything being done to the nucleus.

c Why is the radiation from a radioactive substance sometimes called 'nuclear radiation'?

The origins of background radiation

A Geiger counter clicks even when it is not near a radioactive source. This effect is due to **background radiation**. This is radiation from radioactive substances:

- in the environment (e.g. in the air or the ground or in building materials), or
- from space (cosmic rays), or
- from devices such as X-ray tubes.

Some of these radioactive substances are present because of nuclear weapons testing and nuclear power stations. But most of it is from naturally occurring substances in the Earth. For example, radon gas is radioactive and is a product of the decay of uranium found in the rocks in certain areas.

Summary questions

1 Copy and complete **a** and **b** using the words below. Each word can be used more than once.

protons neutrons nucleus radiation

a The .... of an atom is made up of .... and ....

b When an unstable .... decays, it emits ....

2 a The radiation from a radioactive source is stopped by paper. What type of radiation does the source emit?

b The radiation from a different source goes through paper. What can you say about this radiation?

3 a Explain why some substances are radioactive.

b State two sources of background radioactivity.

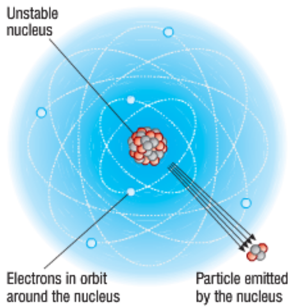

Figure 4 Radioactive decay

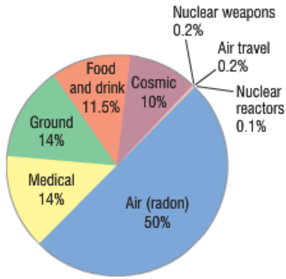

Figure 5 The origins of background radiation

Key points

- A radioactive substance contains unstable nuclei that become stable by emitting radiation.
- There are three main types of radiation from radioactive substances – alpha, beta and gamma radiation.
- Radioactive decay is a random event – we cannot predict or influence when it will happen.
- Background radiation is from radioactive substances in the environment or from space or from devices such as X-ray machines.

P2 6.2 The discovery of the nucleus

Learning objectives

- How was the nuclear model of the atom established?
- Why was the plum pudding model of the atom rejected?
- Why was the nuclear model accepted?

Did you know ...?

Ernest Rutherford was awarded the Nobel Prize in 1908 for his discoveries on radioactivity. His famous discovery of the nucleus was made in 1913. He was knighted in 1914 and made a member of the House of Lords in 1931. He hoped that no one would discover how to release energy from the nucleus until people learned to live at peace with their neighbours. He died in 1937 before the discovery of nuclear fission.

Figure 2 Ernest Rutherford

Practical

Lucky strike!

Fix a small metal disc about 2 cm thick at the centre of a table. Hide the disc under a cardboard disc about 20 cm in diameter. See if you can hit the metal disc with a rolling marble.

Ernest Rutherford made many important discoveries about radioactivity. He discovered that alpha and beta radiation consists of different types of particles. He realised alpha (α) particles could be used to probe the atom. He asked two of his research workers, Hans Geiger and Ernest Marsden, to investigate. They used a thin metal foil to scatter a beam of alpha particles. Figure 1 shows the arrangement they used.

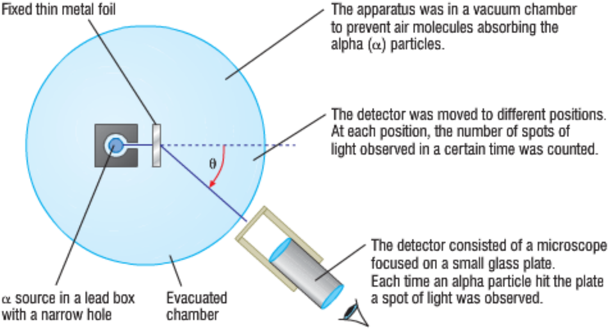

Figure 1 Alpha particle scattering

They measured the number of alpha particles deflected per second through different angles. The results showed that:

- most of the alpha particles passed straight through the metal foil
- the number of alpha particles deflected per minute decreased as the angle of deflection increased
- about 1 in 10 000 alpha particles were deflected by more than 90°.

a If you kicked a football at an empty goal and the ball bounced back at you, what would you conclude?

Rutherford was astonished by the results. He said it was like firing 'naval shells' at tissue paper and discovering the occasional shell rebounds. He knew that α particles are positively charged. He deduced from the results that there is a nucleus at the centre of every atom that is:

- positively charged because it repels α particles (remember that like charges repel and unlike charges attract)
- much smaller than the atom because most α particles pass through without deflection
- where most of the mass of the atom is located.

Using this model, Rutherford worked out the proportion of α particles that would be deflected for a given angle. He found an exact agreement with Geiger and Marsden's measurements. He used his theory to estimate the diameter of the nucleus. He found it was about 100 000 times smaller than the atom.

Rutherford's nuclear model of the atom was quickly accepted because:

- It agreed exactly with the measurements Geiger and Marsden made in their experiments.
- It explains radioactivity in terms of changes that happen to an unstable nucleus when it emits radiation.
- It predicted the existence of the neutron, which was later discovered.

b What difference would it have made if Geiger and Marsden's measurements had not fitted Rutherford's nuclear model?

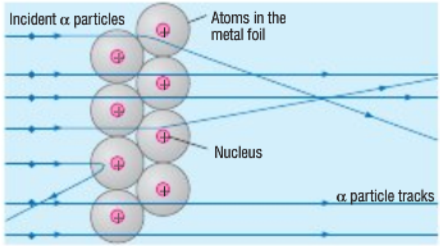

Figure 3 Alpha (α) particle paths

Goodbye to the plum pudding model!

Before the nucleus was discovered in 1914, scientists didn't know what the structure of the atom was. They did know atoms contained electrons and they knew these are tiny negatively charged particles. But they didn't know how the positive charge was arranged in an atom, although there were different models in circulation. Some scientists thought the atom was like a 'plum pudding' with:

- the positively charged matter in the atom evenly spread about (as in a pudding), and
- electrons buried inside (like plums in the pudding).

Rutherford's discovery meant farewell to the 'plum pudding' atom.

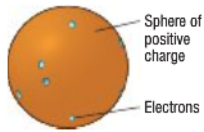

Figure 4 The plum pudding atom

Did you know ...?

Almost all the mass of an atom is in its nucleus. The density of the nucleus is about a thousand million million times the density of water. A matchbox of nuclear matter would weigh about a million million tonnes!

Summary questions

1 Copy and complete **a** to **c** using the words below:

charge diameter mass

a A nucleus has the same type of .... as an alpha particle.
b A nucleus has a much smaller .... than the atom.
c Most of the .... of the atom is in the nucleus.

2 **a** Figure 5 shows four possible paths, labelled A, B, C and D, of an alpha particle deflected by a nucleus. Which path would the alpha particle travel along?
b Explain why each of the other paths in part **a** is not possible.

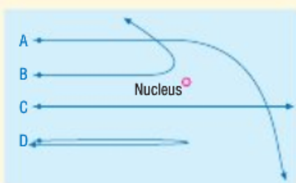

Figure 5

3 **a** Describe two differences between the nuclear model of the atom and the plum pudding model.
b Explain why the alpha-scattering experiment led to the acceptance of the nuclear model of the atom and the rejection of the plum pudding model.

Key points

- **Rutherford used the measurements from alpha-scattering experiments to prove that an atom has a small positively charged central nucleus where most of the mass of the atom is located.**
- **The plum pudding model could not explain why some alpha particles were scattered through large angles.**
- **The nuclear model of the atom correctly explained why the alpha particles are scattered and why some are scattered through large angles.**

P2 6.4 More about alpha, beta and gamma radiation

Learning objectives

- How far can each type of radiation travel in air and what stops it?
- What is alpha, beta and gamma radiation?
- How can we separate a beam of alpha, beta and gamma radiation?
- Why is alpha, beta and gamma radiation dangerous?

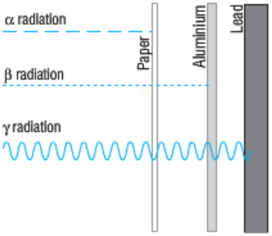

Figure 2 The penetrating powers of α, β and γ radiation

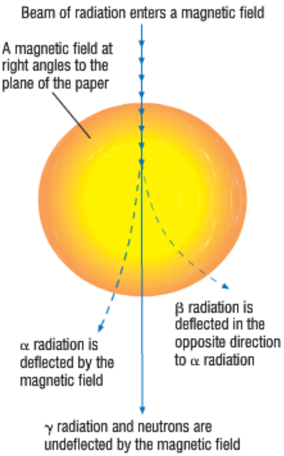

Figure 3 Radiation in a magnetic field

Penetrating power

Alpha radiation can't penetrate paper. But what stops beta and gamma radiation? And how far can each type of radiation travel through air? We can use a Geiger counter to find out, but we must take account of background radiation. To do this we should:

1. Measure the count rate (which is the number of counts per second) without the radioactive source present. This is the background count rate, the count rate due to background radiation.
2. Measure the count rate with the source in place. Subtracting the background count rate from this gives the count rate due to the source alone.

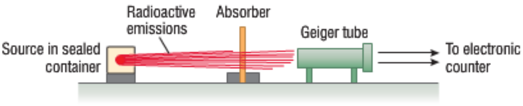

Figure 1 Absorption tests

We can then test absorber materials and the range in air.

- To test different materials, we need to place each material between the tube and the radioactive source. Then we measure the count rate. We can add more layers of material until the count rate due to the source is zero. The radiation from the source has then been stopped by the absorber material.
- To test the range in air, we need to move the tube away from the source. When the tube is beyond the range of the radiation, the count rate due to the source is zero.

The table below shows the results of the two tests.

Type of radiation	Absorber materials	Range in air
alpha (α)	Thin sheet of paper	about 5 cm
beta (β)	Aluminium sheet (about 5 mm thick) Lead sheet (2–3 mm thick)	about 1 m
gamma (γ)	Thick lead sheet (several cm thick) Concrete (more than 1 m thick)	unlimited

Gamma radiation spreads out in air without being absorbed. It does get weaker as it spreads out.

a Why is a radioactive source stored in a lead-lined box?

The nature of alpha, beta and gamma radiation

We can separate these radiations using a magnetic field or an electric field.

Deflection by a magnetic field

- β radiation is easily deflected, in the same way as electrons. So the radiation consists of negatively charged particles. In fact, a β particle is a fast-moving electron. It is emitted by an unstable nucleus that contains too many neutrons.

- α radiation is deflected in the opposite direction to β radiation. So α radiation consists of positively charged particles. α particles are harder to deflect than β radiation. This is because an α particle has a much greater mass than a β particle has. An alpha particle is two protons and two neutrons stuck together, the same as a helium nucleus.
- γ radiation is not deflected by a magnetic field or an electric field. This is because gamma radiation is electromagnetic radiation so is uncharged.

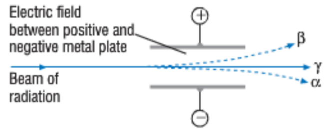

Figure 4 Radiation passing through an electric field

Deflection by an electric field

α and β particles passing through an electric field are deflected in opposite directions, as shown in Figure 4.

- The α particles are attracted towards the negative plate because they are positively charged.
- The β particles are attracted towards the positive plate because they are negatively charged,

In Figures 3 and 4, an alpha particle is deflected much less than the beta particle. The charge of an alpha particle is twice that of a beta particle, so the force is twice as great. But the mass of an alpha particle is about 8000 times that of a beta particle, so the deflection of the alpha particle is much less.

b How do we know that gamma radiation is not made up of charged particles?

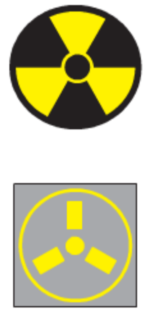

Figure 5 Radioactive warnings

Radioactivity dangers

The radiation from a radioactive substance can knock electrons out of atoms. The atoms become charged because they lose electrons. The process is called **ionisation**. (Remember that a charged particle is called an ion.)

X-rays also cause ionisation. Ionisation in a living cell can damage or kill the cell. Damage to the genes in a cell can be passed on if the cell generates more cells. Strict safety rules must always be followed when radioactive substances are used.

Alpha radiation is more dangerous in the body than beta or gamma radiation. This is because it has a greater ionising effect than beta or gamma radiation.

c Why should long-handled tongs be used to move a radioactive source?

Summary questions

1 Copy and complete **a** and **b** using the words below. Each word can be used more than once.

alpha beta gamma

a Electromagnetic radiation from a radioactive substance is called .... radiation.

b A thick metal plate will stop .... and .... radiation but not .... radiation.

2 Which type of radiation is:

a uncharged **b** positively charged **c** negatively charged?

3 **a** Explain why ionising radiation is dangerous.

b Explain how you would use a Geiger counter to find the range of the radiation from a source of α radiation.

Key points

- **α radiation is stopped by paper, has a range of a few centimetres in air and consists of particles, each composed of two protons and two neutrons.**
- **β radiation is stopped by thin metal, has a range of about a metre in air and consists of fast-moving electrons emitted from the nucleus.**
- **γ radiation is stopped by thick lead, has an unlimited range in air and consists of electromagnetic radiation.**
- **A magnetic or an electric field can be used to separate a beam of alpha, beta and gamma radiation.**
- **Alpha, beta and gamma radiation ionise substances they pass through. Ionisation in a living cell can damage or kill the cell.**