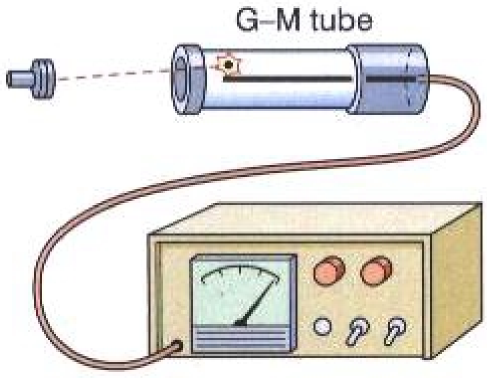
1 RADIOACTIVITY

Videos & questions on the CD ROM



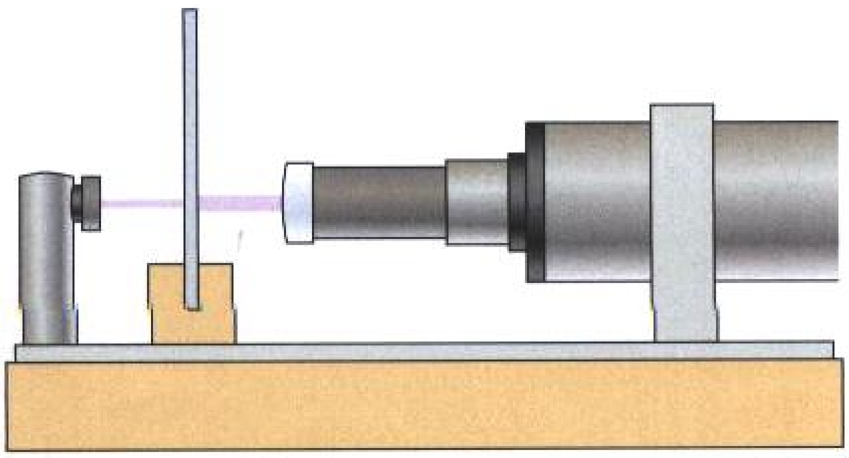
Radioactivity is measured using a Geiger–Müller tube linked to a counter.

Detection of radioactivity

All ionising radiation is invisible to the naked eye, but it affects photographic plates. Individual particles of ionising radiation can be detected using a Geiger–Müller tube.

There is *always* ionising radiation present. This is called **background radiation**. Background radiation is caused by radioactivity in soil, rocks and materials like concrete, radioactive gases in the atmosphere and cosmic rays, which come from somewhere in outer space, though we are still not sure *exactly* where.

Characteristics of the three kinds of emission



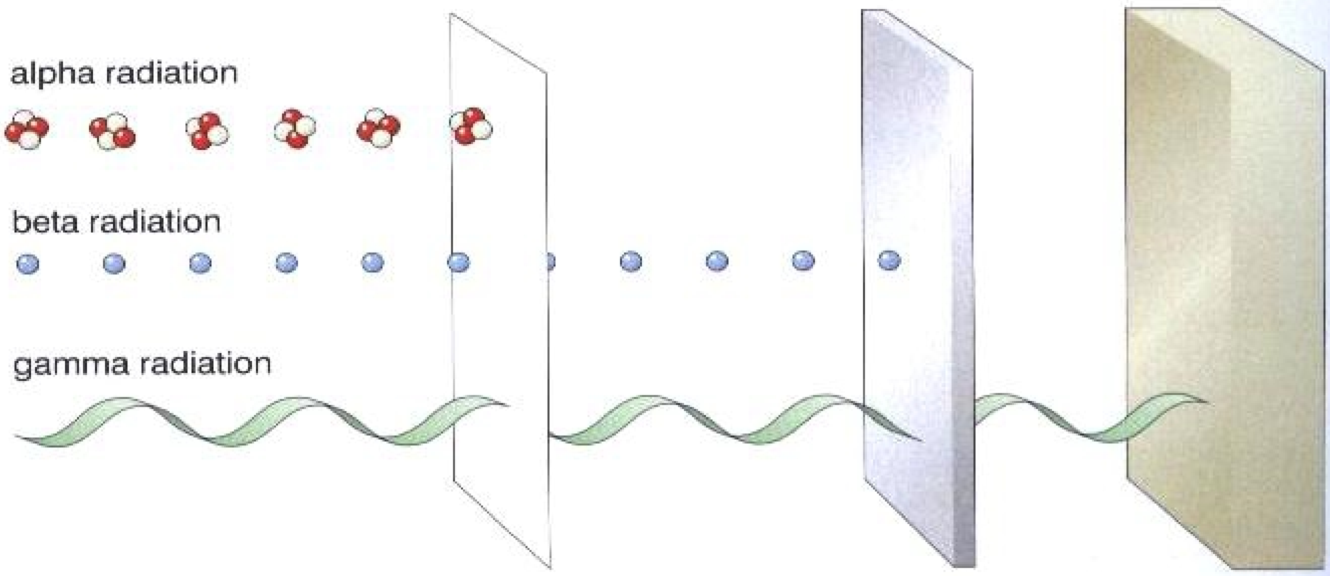
Radiation measurement device with beta emitter, aluminium sheet and meter.

Inside the atom the central **nucleus** of positively charged **protons** and neutral **neutrons** is surrounded by shells, or orbits, of **electrons**. Most nuclei are very stable, but some 'decay' and break apart into more stable nuclei. This breaking apart is called **radioactive decay**. Atoms whose nuclei do this are **radioactive**.

When a radioactive nucleus decays it may emit one or more of the following:

- **alpha (α) particles**
- **beta (β) particles**
- **gamma (γ) rays.**

A stream of these rays is referred to as **ionising radiation** (often called nuclear radiation, or just 'radiation' for short).



	alpha (α)	beta (β)	gamma (γ)
Description	A positively charged particle, identical to a helium nucleus (two protons and two neutrons)	A negatively charged particle, identical to an electron	Electromagnetic radiation. Uncharged
Penetration	4–10 cm of air. Stopped by a sheet of paper	About 1 m of air. Stopped by a few mm of aluminium	Almost no limit in air. Stopped by several cm of lead or several metres of concrete
Effect of electric and magnetic fields	Deflected*	Deflected* considerably	Unaffected – not deflected

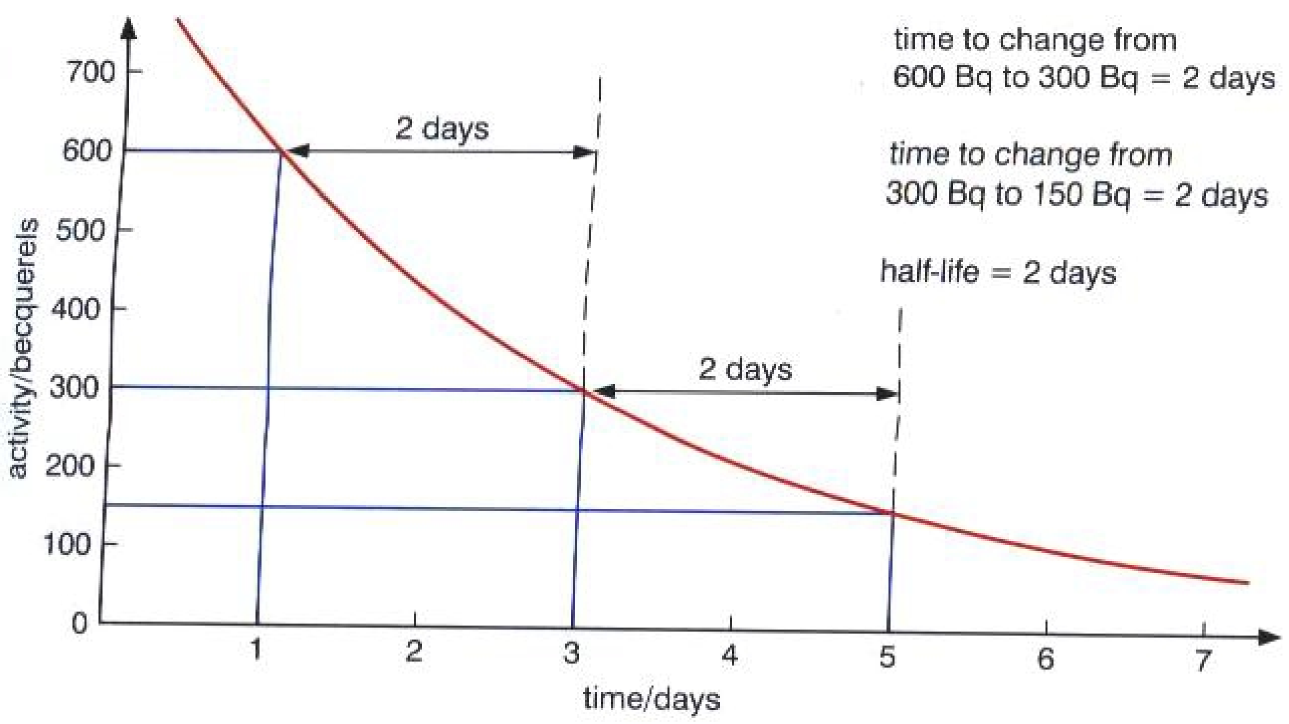
* Note: Alpha particles and beta particles are deflected by magnetic and electric fields in the same manner that electrons are deflected in the cathode ray tube. They are travelling much faster so the deflections are smaller. Beta particles actually are electrons, so they are bent the same way. Alpha particles carry a positive charge, so they are bent the opposite way.

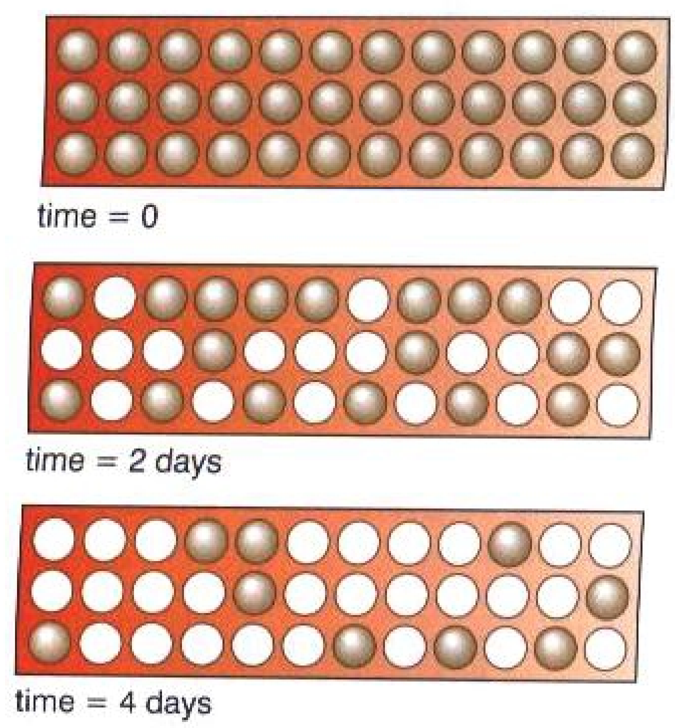
Radioactive decay

The **activity** of a radioactive source is the number of ionising particles it emits each second. Over time, fewer nuclei are left in the source to decay, so the activity drops. The time taken for half the radioactive atoms to decay is called the **half-life**. The activity of a radioactive source is measured in bequerels (Bq).

Half-life

Starting with a pure sample of radioactive nuclei, after one half-life half the nuclei will have decayed. The remaining undecayed nuclei still have the same chance of decaying as before, so after a second half-life half of the remaining nuclei will have decayed. After two half-lives a quarter of the nuclei will remain undecayed.





The half-life is 2 days. Half the number of radioactive nuclei decays in 2 days.

WORKED EXAMPLE

A radioactive element is detected by a Geiger–Müller tube and counter as having an activity of 400 counts per minute. Three hours later the count is 50 counts per minute. What is the half-life of the radioactive element?

Write down the activity and progressively halve it.
Each halving of the activity is one half-life:

0	400 counts
1 half-life	200 counts
2 half-lives	100 counts
3 half-lives	50 counts

3 hours therefore corresponds to 3 half-lives and 1 hour therefore corresponds to 1 half-life.

Safety precautions

Alpha, beta and gamma radiation can all damage living cells. Alpha particles, due to their strong ability to ionise other particles, are particularly dangerous to human tissue. Gamma radiation is dangerous because of its high penetrating power. However, cells have repair mechanisms that make ordinary levels of radiation relatively harmless.

Nevertheless, radiation can be very useful – it just needs to be used *safely.*

Safety precautions for handling radioactive materials include:

- Use forceps to hold radioactive sources – don't hold them directly.
- Do not point radioactive sources at living tissue.
- Store radioactive materials in lead-lined containers – and lock the containers away securely.
- Check the surrounding area for radiation levels above normal background levels.

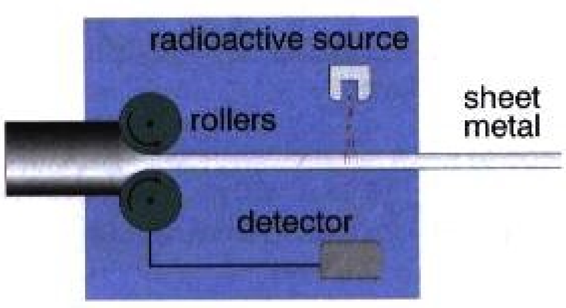
High levels of radiation are extremely hazardous, and people handling highly radioactive materials must wear special film badges (containing photographic film) that monitor the dose that they are receiving. They may need to wear protective clothing, perhaps containing sheets of lead, and they will need to shower and check for radioactivity on their bodies at the end of each shift.

Nuclear power can generate enormous quantities of energy from the radioactivity inside elements, uranium in particular. There are considerable problems still to be overcome on waste disposal.

USES OF RADIOACTIVITY

Gamma rays can be used to kill bacteria. This is used in **sterilising** medical equipment and in preserving food. Due to the ability of gamma rays to penetrate material, the full thickness of the food can be treated even after it has been packaged.

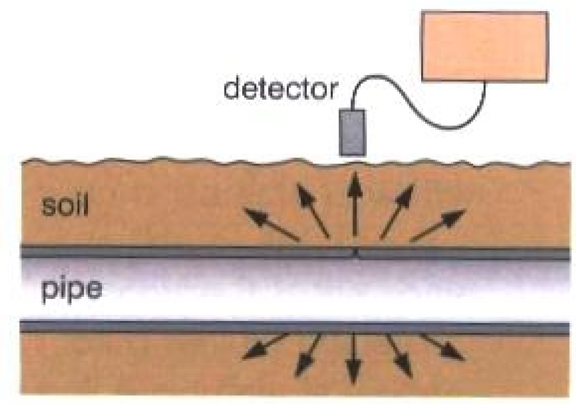
A **smoke alarm** includes a small radioactive source that emits alpha radiation. The radiation produces ions in the air which conduct a small electric current. If a smoke particle absorbs the alpha particles, it reduces the number of ions in the air, and the current drops. This sets off the alarm. Alpha particles must be used because beta or gamma rays would pass through the air without producing enough ions.



Sheet thickness control.

Beta particles are used to monitor the **thickness** of paper or metal. The number of beta particles passing through the material is related to the thickness of the material. Alpha particles would not pass through the paper, and gamma rays would pass through almost unimpeded.

A gamma source is placed on one side of a **weld** and a photographic plate on the other side. Gamma rays pass through the metal, and weaknesses in the weld will show up on the photographic plate.



Tracers detect leaks.

In **radiotherapy** high doses of radiation are fired at cancer cells to kill them. For cancers deep inside the body, gamma rays are used. Here, as in the case of X-rays, the radiation that can cause cancer is also an important tool in treating it.

In all of these above cases the radioactive material used must have a fairly long lifetime so that the device will function for long enough. For example, Americium-241, the material used in smoke detectors, has a half-life of 432 years, which is ample for the life of a smoke detector.

Tracers are radioactive substances with half-lives and radiation types that suit the job they are used for. The half-life must be long enough for the tracer to spread out and to be detected after use but not so long that it stays in the system and causes damage.

- **Medical tracers** are used to detect blockages in vital organs. A gamma camera is used to monitor the passage of the tracer through the body. Doctors often use Technetium-99m, with a half-life of 6 hours.
- **Agricultural tracers** monitor the flow of nutrients through a plant.
- **Industrial tracers** can measure the flow of liquid and gases through pipes to identify leakages.

RADIOACTIVE DATING


This woman's body was preserved in a bog in Denmark. Radioactive carbon-14 dating showed that she had been there for over 2000 years.

Igneous rock contains small quantities of uranium-238 – a type of uranium that decays with a half-life of 4500 million years, eventually forming lead. The ratio of lead to uranium in a rock sample can be used to calculate the age of the rock. For example, a piece of rock with equal numbers of uranium and lead atoms in it must be 4500 million years old – but this would be unlikely as the Earth itself is only 4500 million years old.

Carbon in living material contains a constant, small amount of the radioactive isotope **carbon-14**, which has a half-life of 5700 years. When the living material dies, the remaining carbon-14 atoms slowly decay. The ratio of carbon-14 atoms to the non-radioactive carbon-12 atoms can be used to calculate the age of the plant or animal material. This method is called **radioactive carbon dating**.

REVIEW QUESTIONS

Q1 What type of radiation is used in
a smoke detectors **b** thickness measurement **c** weld checking?

Q2 This question is about tracers.
a What is a tracer?
b The table below shows the half-life of some radioactive isotopes.
Using the information in the table only, state which one of the isotopes is most suitable to be used as a tracer in medicine. Give a reason for your choice.

Radioactive isotope	Half-life
lawrencium-257	8 seconds
sodium-24	15 hours
sulphur-35	87 days
carbon-14	5700 years

Q3 **a** When uranium-238 in a rock sample decays what element is eventually produced?
b Explain how the production of this new element enables the age of the rock sample to be determined.

More questions on the CD ROM

Examination questions are on page 170