Cambridge IGCSE Physics
Atomic Physics

By: Chaoyang Chu

Radioactivity

1 Radioactivity all around
2 The microscopic picture
3 Radioactive decay
4 Using radioisotopes

Radioactivity

1 **Radioactivity all around**
2 The microscopic picture
3 Radioactive decay
4 Using radioisotopes

Review

Caesium-133 is a stable isotope of the element caesium, but caesium-135 is radioactive.

A nucleus of caesium-133 contains 78 neutrons and a nucleus of caesium-135 contains 80 neutrons.

Put **one** tick in each row of the table to indicate how the number of particles in a neutral atom of caesium-133 compares with the number of particles in a neutral atom of caesium-135.

The first row has been completed already.

	particles in caesium-133				
	2 more than caesium-135	1 more than caesium-135	equal to caesium-135	1 fewer than caesium-135	2 fewer than caesium-135
number of neutrons					✓
number of protons					
number of nucleons					
number of electrons					

[2]

Review

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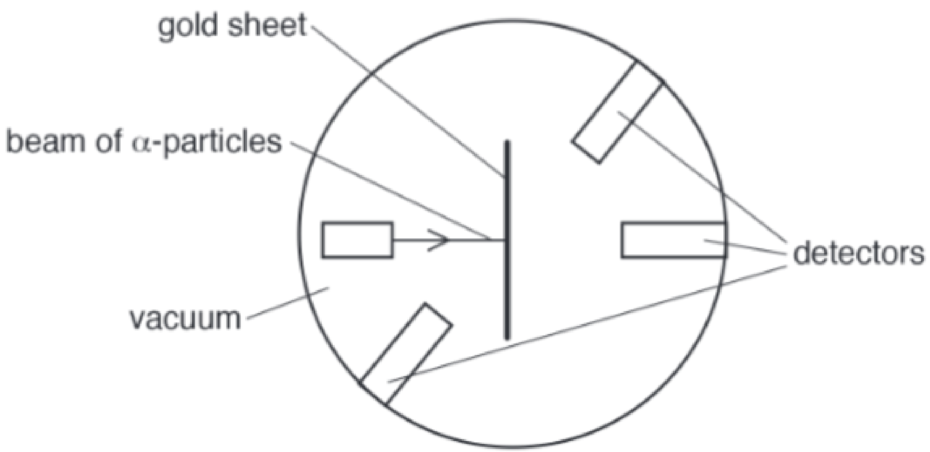
number of neutrons					✓
number of protons			✓		
number of nucleons					✓
number of electrons			✓		

[2]

Review

The diagram shows a beam of α-particles moving towards a thin sheet of gold in a vacuum.



Detectors in the region surrounding the thin gold sheet detect the α-particles and determine the number of particles that travel in various directions.

State and explain what can be deduced from the following observation.

A very small number of α-particles are deflected through very large angles or return back the way they came.

deduction ....

explanation ....

.... [2]

[Total: 2]

Review

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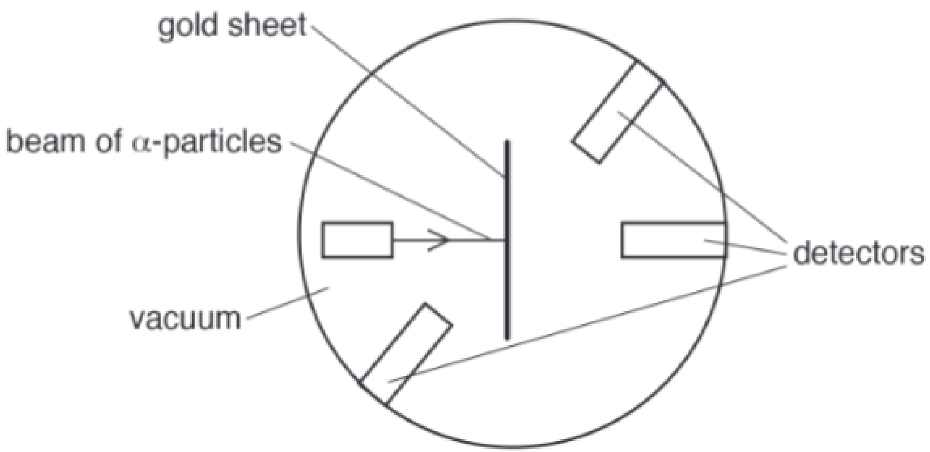


Detectors in the region surrounding the thin gold sheet detect the α-particles and determine the number of particles that travel in various directions.

State and explain what can be deduced from the following observation.

A very small number of α-particles are deflected through very large angles or return back the way they came.

deduction Nucleus is very small; The nucleus carries most of the atom's mass

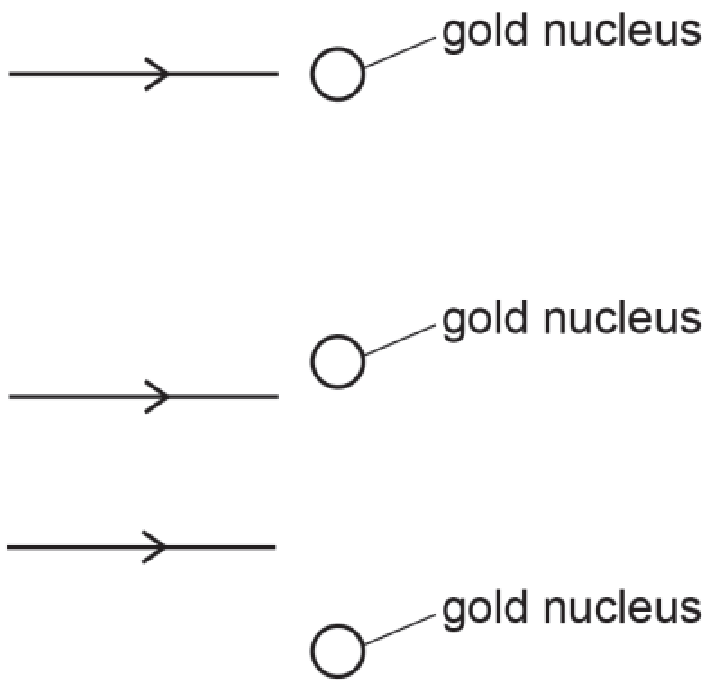
explanation very few α-particles hit or pass near to a nucleus

.... [2]

[Total: 2]

Review

The arrows in the diagram show the paths of three α-particles moving towards gold nuclei in a thin foil.



On the diagram, complete the paths of the three α-particles.

[3]

Review

top: any path to the left with 45° horizontal middle: path to the right and deflected down (ending in a straight line) bottom: path not deflected **OR** path to the right and deflected up <u>much</u> less than middle path	**3**

Radioactive Substance & Radiation

- Many naturally occurring substances are radioactive. Usually these are not very concentrated, so that they do not cause a problem.

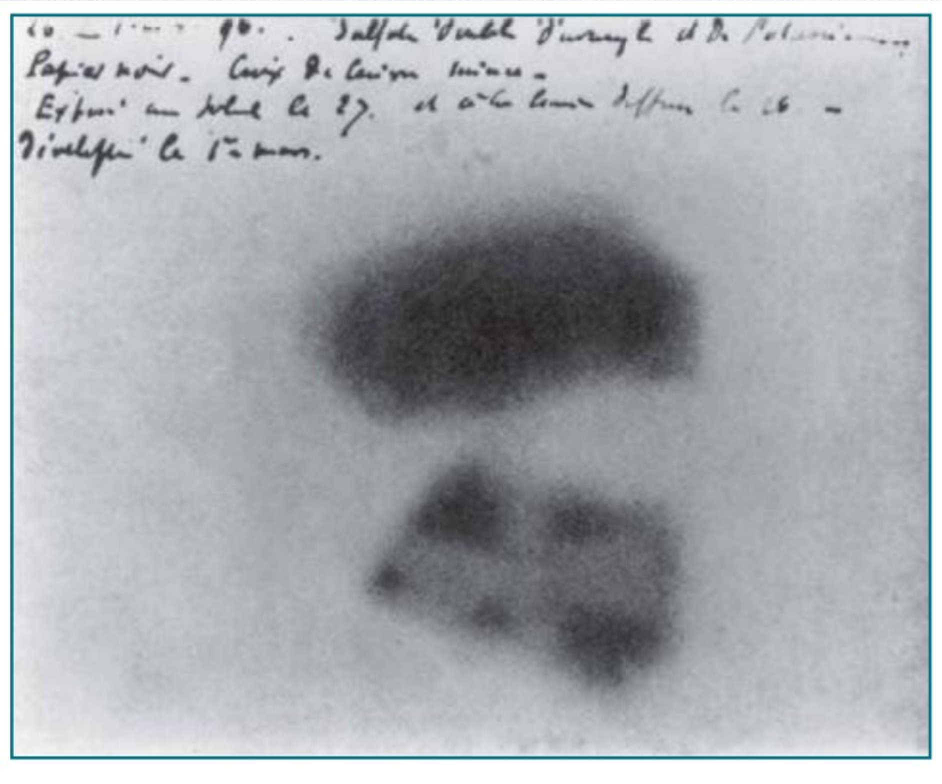
- There are 2 ways in which radioactive substances can cause us problems:
  - ✓ **Contamination** is radioactive particles getting onto objects. If you touch a radioactive source without wearing gloves, your hands would be contaminated.
  - ✓ Exposure to radiation is called **irradiation,** we say that we have received a dose of radiation. We have been **irradiated**.

- In fact, we are exposed to low levels of radiation all the time – this is known as **background radiation**. In addition, we may be exposed to **radiation from artificial sources**, such as the radiation we receive if we have a medical X-ray.

Sources of Background Radiation

- **Background radiation** is everywhere all the time. There's low-level background nuclear radiation all around us all the time.
- The **sources** that make a significant contribution to background radiation including:
  - ✓ **Substances on Earth**:
    - ❖ radon gas (in the air)
    - ❖ rocks and buildings
    - ❖ food and drink
  - ✓ **Radiation from space (cosmic rays): mostly from the Sun**
  - ✓ **Living things**
  - ✓ Radiation due to **human activity** – e.g. fallout from nuclear explosions, or nuclear waste (though this is usually a tiny proportion of the total background radiation).

Detecting Radiation



Radioactivity was discovered by a French physicist, Henri Becquerel, in **1896**.

One of Henri Becquerel's first photographic records of the radiation produced by uranium. The two black blobs are the outlines of two crystals containing uranium. To show that the radiation would pass through metal, he placed a copper cross between one of the crystals and the photographic film.

You can see the 'shadow' of the cross on the photograph. The writing is Becquerel's. The last line says 'développé le 1er mars' – developed on 1st March (1896).

Detection of radioactivity

- ***Geiger-Muller detector (G-M detector) or* G-M tube**:
  - ✓ G-M tube detects ions produced when alpha, beta, or gamma radiation enters the tube
  - ✓ It is attached to a counter that registers a count each time a radioactive particle is detected
  - ✓ **Counter rate** measured in **counts / s** or **counts / minute**
- **Photographic film**
  - ✓ Photographic film is blackened by the presence of ionizing radiation
  - ✓ The higher the number of radioactive particles, the blacker it becomes

Detection of radioactivity - Geiger counter

- A **Geiger–Muller detector** detects nuclear radiation by **measuring the emission of ionizing radiation** of alpha particles, beta particles and gamma rays. Also referred to as a **radiation detector**, a Geiger counter consists of two main elements: the **processing electronics** and the **Geiger tube**.
- For a quicker measurement of radiation, we can use a **Geiger–Muller detector,** which is held close to a suspected source of radiation. The radiation enters the tube, which produces an *electrical pulse* every time it detects any radiation. The electronic counter adds up these pulses. It can give *a click or beep* for each pulse.

The randomness of radioactive decay

- Radioactive decay is a **random process**.

- If you study a sample of a radioactive material, you cannot predict when the next atom will decay. Atoms decay randomly over time.

- Similarly, it is impossible to point at an individual atom and say that it will be the next one to decay.

- Radioactive decay occurs randomly **over space and time**.

THANK YOU

Radioactivity

1 Radioactivity all around

2 The microscopic picture

3 Radioactive decay

4 Using radioisotopes

Review

What is correct for an electron?

	electron charge	position of electron in atom
A	negative	outside the nucleus
B	negative	part of the nucleus
C	positive	outside the nucleus
D	positive	part of the nucleus

[1]

Review

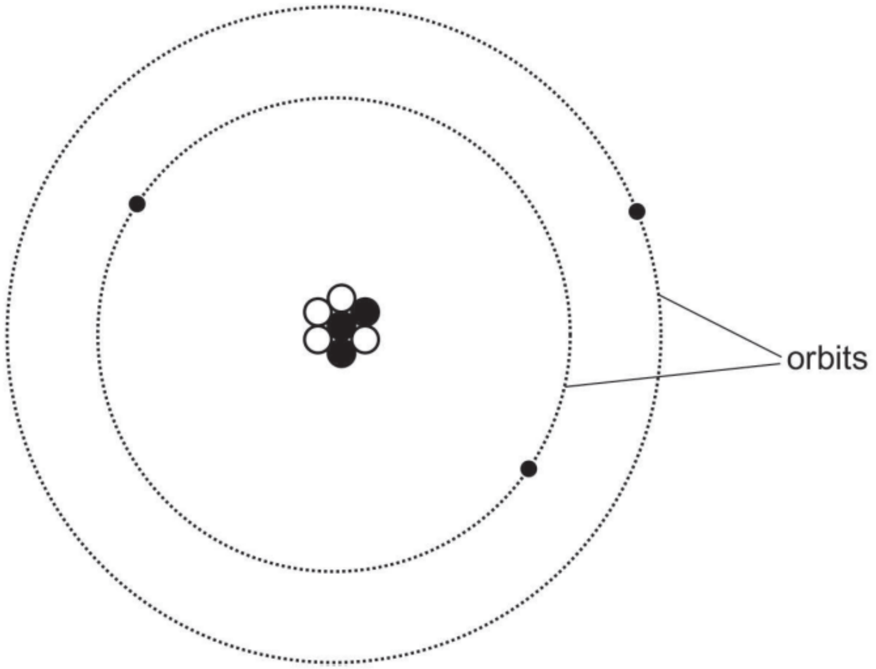
What is correct for an electron? **A**

	electron charge	position of electron in atom
A	negative	outside the nucleus
B	negative	part of the nucleus
C	positive	outside the nucleus
D	positive	part of the nucleus

[1]

Review

The diagram represents the particles in a neutral lithium atom.



Use the information in the diagram of the neutral lithium atom to answer **(a)**, **(b)** and **(c)**.

(a) Determine the number of electrons. .... [1]

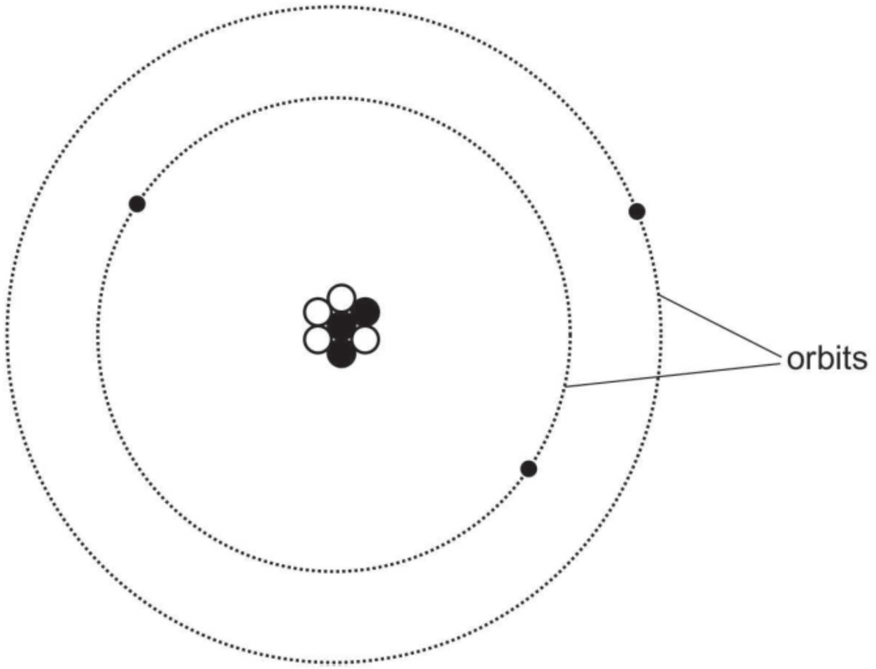
(b) Determine the value of the nucleon number. .... [1]

(c) Determine the number of neutrons. .... [1]

[Total: 3]

Review

The diagram represents the particles in a neutral lithium atom.



Use the information in the diagram of the neutral lithium atom to answer **(a)**, **(b)** and **(c)**.

(a) Determine the number of electrons. ....**3**........ [1]

(b) Determine the value of the nucleon number. ....**7**........ [1]

(c) Determine the number of neutrons. ....**4**........ [1]

[Total: 3]

Review

State what is meant by the term *isotopes*. Use the terms proton number and nucleon number in your explanation.

....

....

....

....

.... [3]

[Total: 3]

Review

versions owtte of same element owtte	**B1**
(isotopes of same element have) same proton number/number of protons/atomic number/Z	**B1**
(isotopes of same element have) different nucleon numbers/number of neutrons/mass number/A	**B1**

Review

State what is meant by the term *isotopes*. Use the terms proton number and nucleon number in your explanation.

Isotopes are same element, which have same number of proton (atomic number). Due to they have different neutron number, the mass (nucleon) number is different. ***OR***

Isotopes of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in nucleon number.

[3]

[Total: 3]

Review

The diagram shows a geologist holding a radiation detector near a rock.

She holds the detector in a fixed position and records the readings shown in the table.

time / minutes	0	1	2	3	4	5
detector reading / counts / minute	16	14	17	13	17	15

Explain the changes in the detector readings.

....

....

....

.... [2]

[Total: 2]

Review

radiation from background/rock/air/outer space/cosmic rays random variation owtte	**2**

Review

A radiation detector is set up in a laboratory where there are no radioactive samples.

On **six** separate occasions, the detector is switched on for 1.0 minute and the background count is recorded. The counts are:

23 27 25 24 20 25

State why the readings are **not** all identical.

.... [1]

Suggest a possible source for this background radiation.

.... [1]

Review

A radiation detector is set up in a laboratory where there are no radioactive samples.

On **six** separate occasions, the detector is switched on for 1.0 minute and the background count is recorded. The counts are:

23 27 25 24 20 25

State why the readings are **not** all identical.

Radiation is random.

.... [1]

Suggest a possible source for this background radiation.

rocks/buildings/soils/air/outer space/cosmic rays/sun/nuclear waste

.... [1]

Review

radioactive emission / (background) radiation / decay is random	**1**
any **one** from: rocks / buildings / soil / Earth space / cosmic rays / Sun radon / nuclear waste / weapons testing	**1**

Radioactive Decay

Why are some atoms radioactive while others are not?
What is the nature of the radiation they produce?

Radiation is emitted by the nucleus of an atom. We say that the nucleus is unstable.

An unstable nucleus emits radiation in an attempt to become more stable. This is known as **radioactive decay**. Fortunately, most of the atoms around us have stable nuclei.

3 types of radiation

There are three types of radiation emitted by radioactive substances.

- **Alpha (α) particle**: is made up of 2 protons and 2 neutrons (this is the same as the nucleus of a helium atom, ${}^{4}_{2}He$). Because it contains protons, it is positively (+ve) charged.

- **Beta (β) particle**: is an electron. It is not one of the electrons that orbit the nucleus – it comes from inside the nucleus. It is negatively (-ve) charged, and its mass is much less than that of an alpha particle.

- **Gamma (γ) ray**: is a form of electromagnetic (EM) radiation. We can think of it as a wave with a very short wavelength (similar to an X-ray, but even more energetic). Alternatively, we can picture it as a 'photon', a particle of electromagnetic energy.

3 types of radiation

Name	Symbol	Made of	Mass	Charge	Speed / m/s
alpha	α or ^4_2He	2 protons + 2 neutrons	approx. (mass of proton) × 4	+2	$\sim 3 \times 10^7$
beta	β or $^0_{-1}e$	an electron	$\frac{\text{approx. (mass of proton)}}{1840}$	−1	$\sim 2.9 \times 10^8$
gamma	γ	photon of electromagnetic radiation	0	0	3×10^8

3 types of radiation

Speed

- **Alpha particles** have a much greater mass than **beta particles**, so they travel more slowly.

- **Gamma rays** travel at the speed of light.

- When an atom of a radioactive substance decays, it becomes an atom of another element. This is because, **in alpha and beta decay, the number of protons in the nucleus changes.**

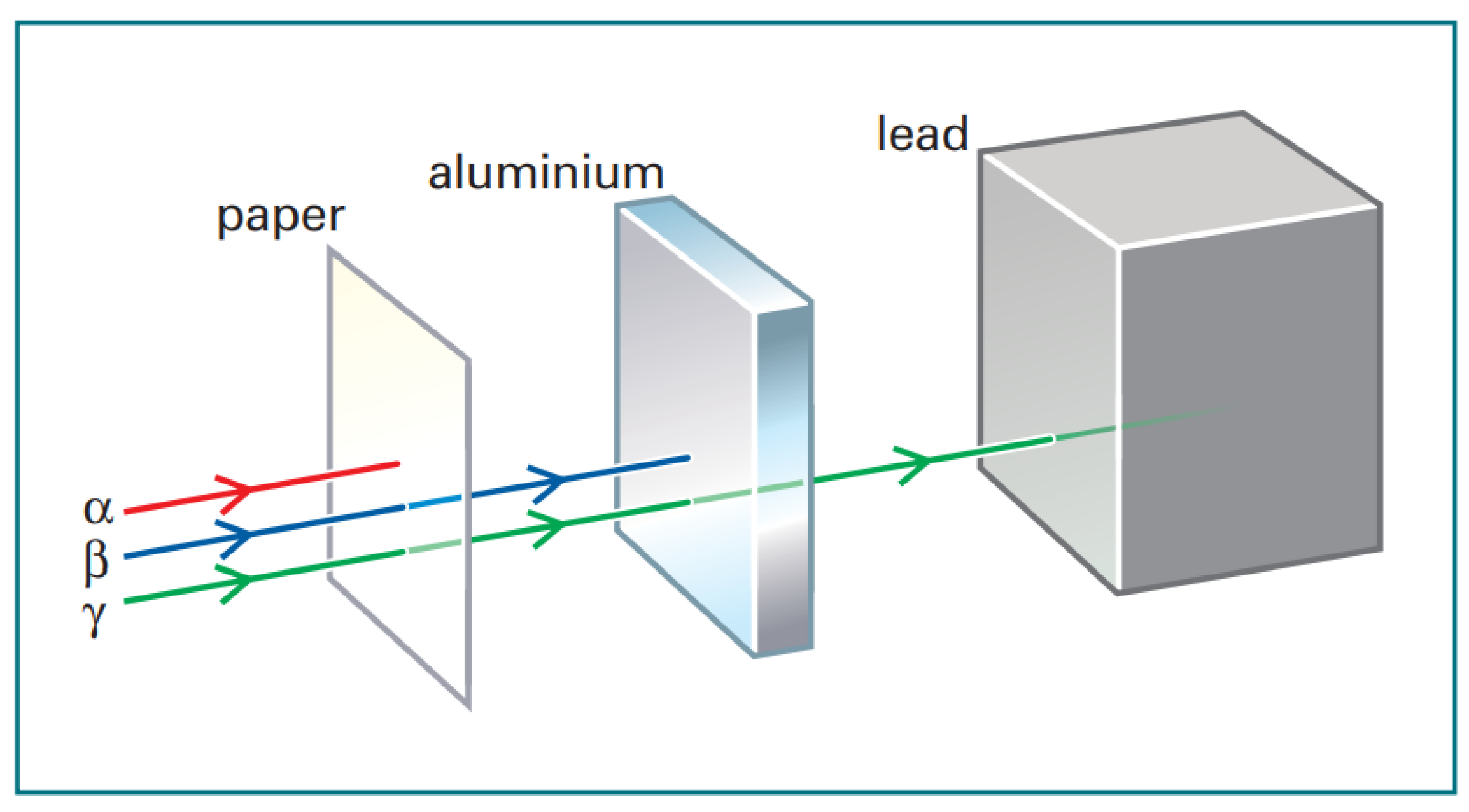
Characteristics of radioactive particles

Energy released

- Radioactive substances release energy when they decay. Before they decay, this energy is stored in the **nucleus** of the atom. When it is released, it is in two forms:
  - ✓ An **alpha or beta** particle is fast-moving. The nucleus that has emitted it recoils. Both particles have **kinetic energy**.
  - ✓ A **gamma ray** transfers energy as **electromagnetic radiation.**

Characteristics of radioactive particles

Penetrating power



Characteristics of radioactive particles

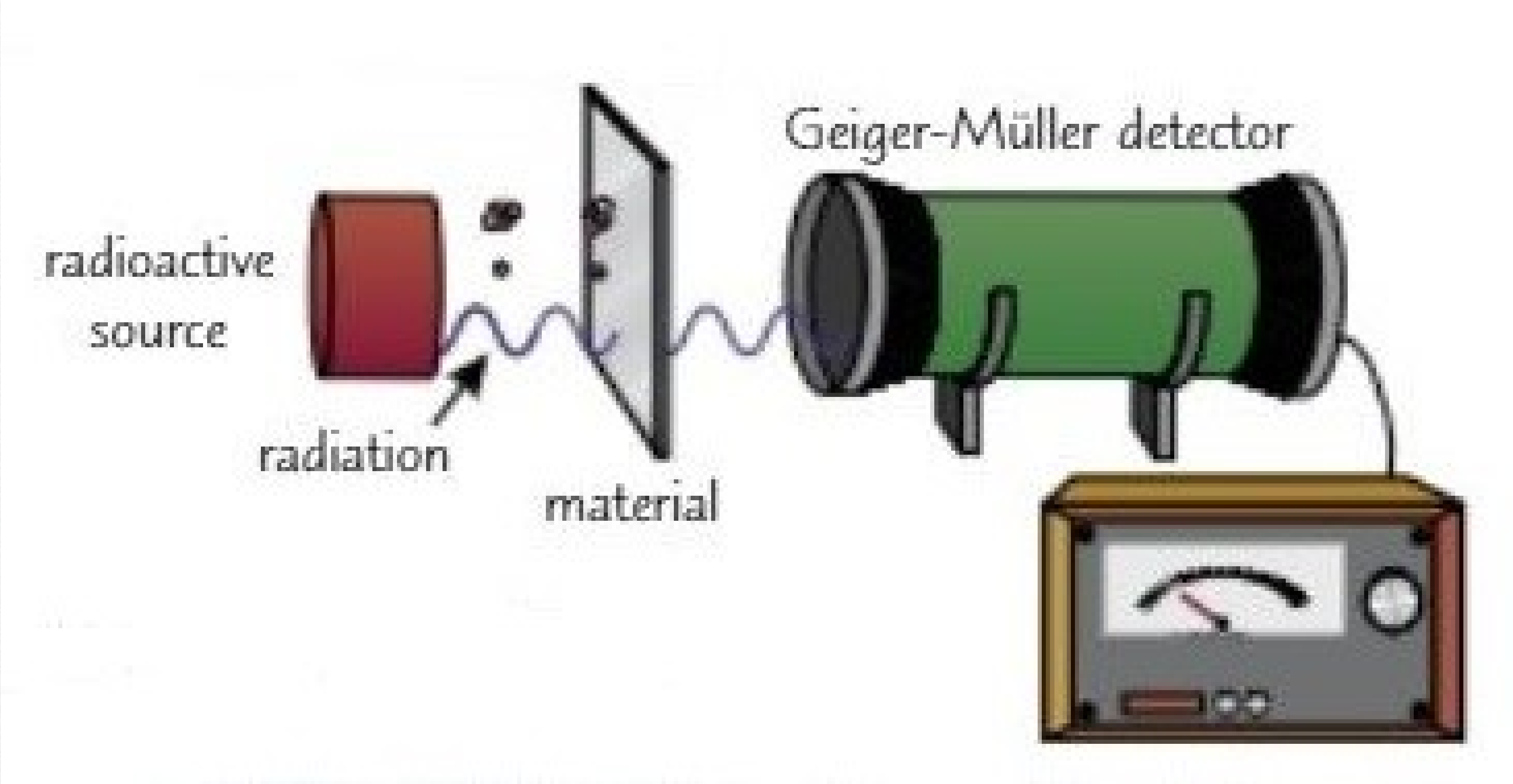
Penetrating power

Different types of radiation can penetrate different thicknesses of materials.

- **Alpha particles** are the most easily absorbed. They can travel about 5 cm in air before they are absorbed. They are **absorbed by a thin sheet of paper**.
- **Beta particles** can travel fairly easily through air or paper. But they are absorbed by **a few millimetres of metal**.
- **Gamma radiation** is the most penetrating. It takes **several centimetres of a dense metal like lead, or several metres of concrete**, to absorb most of the gamma radiation.

Detection of radioactivity

Identify the type of radiation by its penetrating power



Detection of radioactivity

Identify the type of radiation by its penetrating power

Geiger-Muller detector:

- Gives a **counter rate**: the number of radioactive particles reaching it per second
- When nothing is placed between the source and detector, the counter records a high count rate.
- If the count rate **remains** about the same when the material is inserted, then the **radiation can penetrate the material**. If it **drops** by a large amount, then the radiation is being **absorbed and blocked** by the material. If it **drops to zero** after the background count is subtracted, the radiation is being **completely absorbed**.

Characteristics of radioactive particles

Ionisation:

When radiation passes through air, it may interact with air molecules, knocking electrons from them, so that the air molecules become charged. We say that the air molecules have become ionised.

The relative ionizing effects are as follows:

- **alpha particles** are **the most ionizing**

Because the radiation from radioactive substances causes ionisation of the materials that absorb it, it is often known as **ionising radiation**.

Characteristics of radioactive particles

How ionisation happens

Consider an **alpha particle** passing through the air. An alpha particle is the slowest moving of all the three radiations and has the largest charge. As the alpha particle collides with an air molecule, it may knock an electron from the air molecule, so that it becomes charged. The alpha particle loses a little of its energy. It must ionise thousands of molecules before it loses all of its energy and comes to stop.

Nonetheless, **alpha radiation is the most strongly ionising radiation**.

Characteristics of radioactive particles

How ionisation happens

A **beta particle** can similarly ionise air molecules. However, it is less ionising for two reasons: 1) **its charge is less than that of an alpha particle**, and 2) it is **moving faster**, so that it is more likely to travel straight past an air molecule without interacting with it. This is why beta radiation can travel further through air without being absorbed.

Gamma radiation is **uncharged** and it **moves fastest of all**, so it is the least readily absorbed in air, and therefore is the least ionising.

Characteristics of radioactive particles

How ionisation happens

X-rays also cause ionisation in the materials they pass through, and so they are also classed as ionizing radiation.

X-rays are very similar to gamma rays. But X-rays usually have less energy (longer wavelength) than gamma rays, and they are produced by X-ray machines, stars and so on, rather than by radioactive substances.

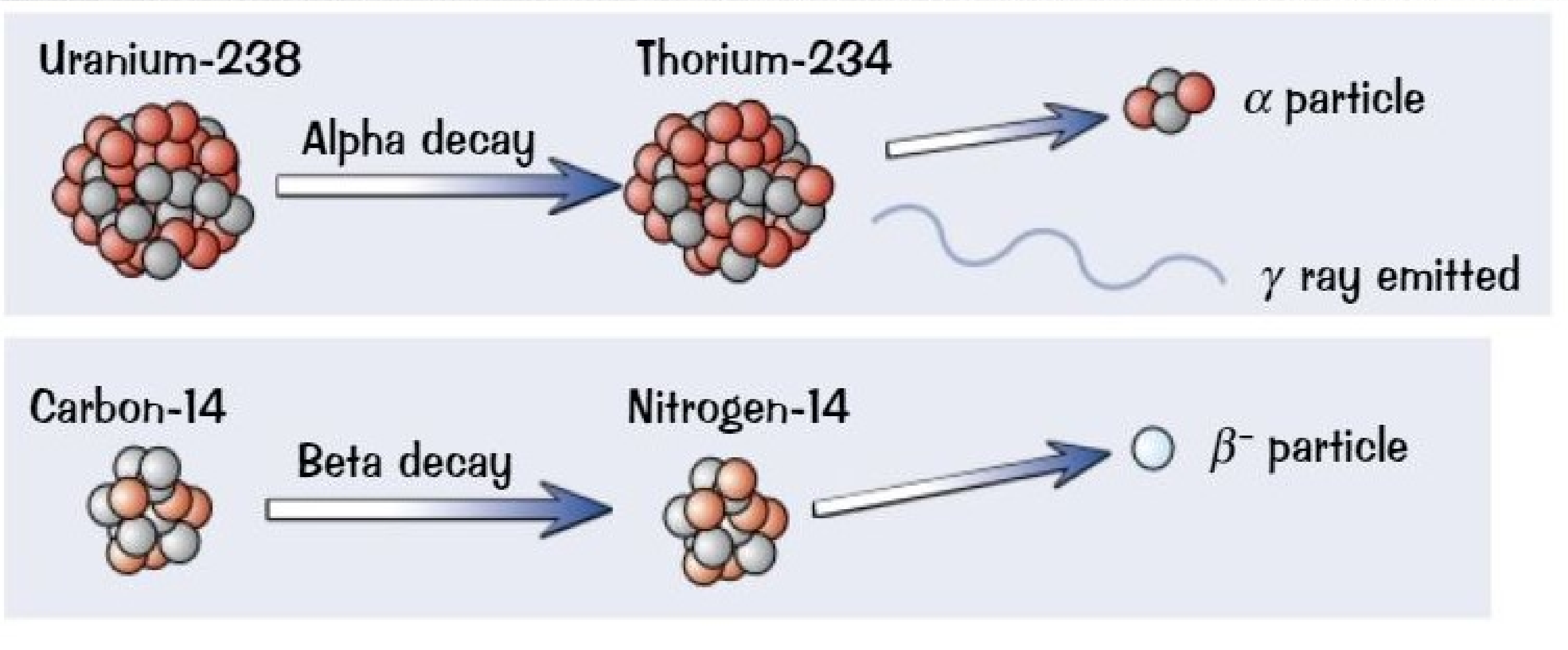
Characteristics of radioactive particles

How ionisation happens

You should be able to see the pattern linking **ionising power and absorption**:

- ✓ **Alpha radiation** is the most strongly ionising, so it is the most easily absorbed and the least penetrating.
- ✓ **Gamma radiation** is the least strongly ionising, so it is the least easily absorbed and the most penetrating.

Radioactive decay

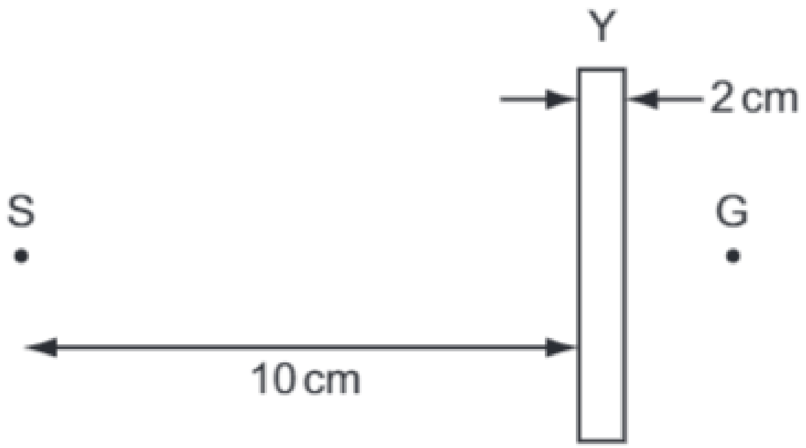


3 types of radiation

	(α)	(β)	(γ)
Identity	Helium nucleus (2p+2n)	Fast moving electron	Electromagnetic wave
Relative charge	+2	-1	0
Relative mass	4	1/1800	0
Ionizing effect	Strong	Weak	Very weak
Penetration	Weak penetration. Absorbed by a few cm of air or few sheets of paper	Greater penetration. Absorbed by a few mm of aluminium metal	Strong penetration. Even lead and thick concrete cannot fully absorb this.
Behaviour in electric and magnetic fields	Deflected by electric and magnetic fields	Deflected by electric and magnetic fields but to a **greater extent** and in the **opposite direction** from alpha	Not deflected by electric or magnetic fields

Review

S is a radioactive source emitting α, β and γ-radiations. Y is a sheet of aluminium 2 cm thick placed 10 cm from S.



Which radiations can be detected at G?

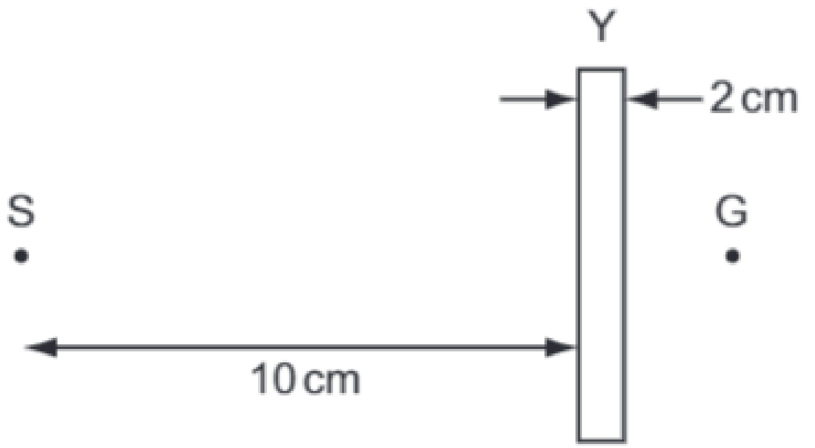
A α only **B** α and β **C** γ only **D** γ and β

[1]

[Total: 1]

Review

S is a radioactive source emitting α, β and γ-radiations. Y is a sheet of aluminium 2 cm thick placed 10 cm from S.



Which radiations can be detected at G? C

A α only

B α and β

C γ only

D γ and β

[1]

[Total: 1]

Review

State the type of radioactive emission that causes the proton number of a nuclide to increase by 1.

.... [1]

[Total: 1]

Review

State the type of radioactive emission that causes the proton number of a nuclide to increase by 1.

β-particle

.... [1]

[Total: 1]

Review

An isotope of an element is radioactive. It decays by emitting a β-particle.

β-particles ionise the air they pass through less strongly than the same number of α-particles.

Suggest why this is so.

....

....

.... [3]

[Total: 3]

Review

An isotope of an element is radioactive. It decays by emitting a β-particle.

β-particles ionise the air they pass through less strongly than the same number of α-particles.

Suggest why this is so.

β-particles have charge of smaller size. Besides, they have smaller mass, and

travel faster than α-particles.

[3]

[Total: 3]

Review

State the relative ionising effects of α-particles, β-particles and γ-rays. Suggest an explanation for the differences.

....

....

....

.... [3]

[Total: 3]

Review

State the relative ionising effects of α-particles, β-particles and γ-rays. Suggest an explanation for the differences.

Ionising effect of α-particles greater than β-particles, and β-particles is greater than γ-rays

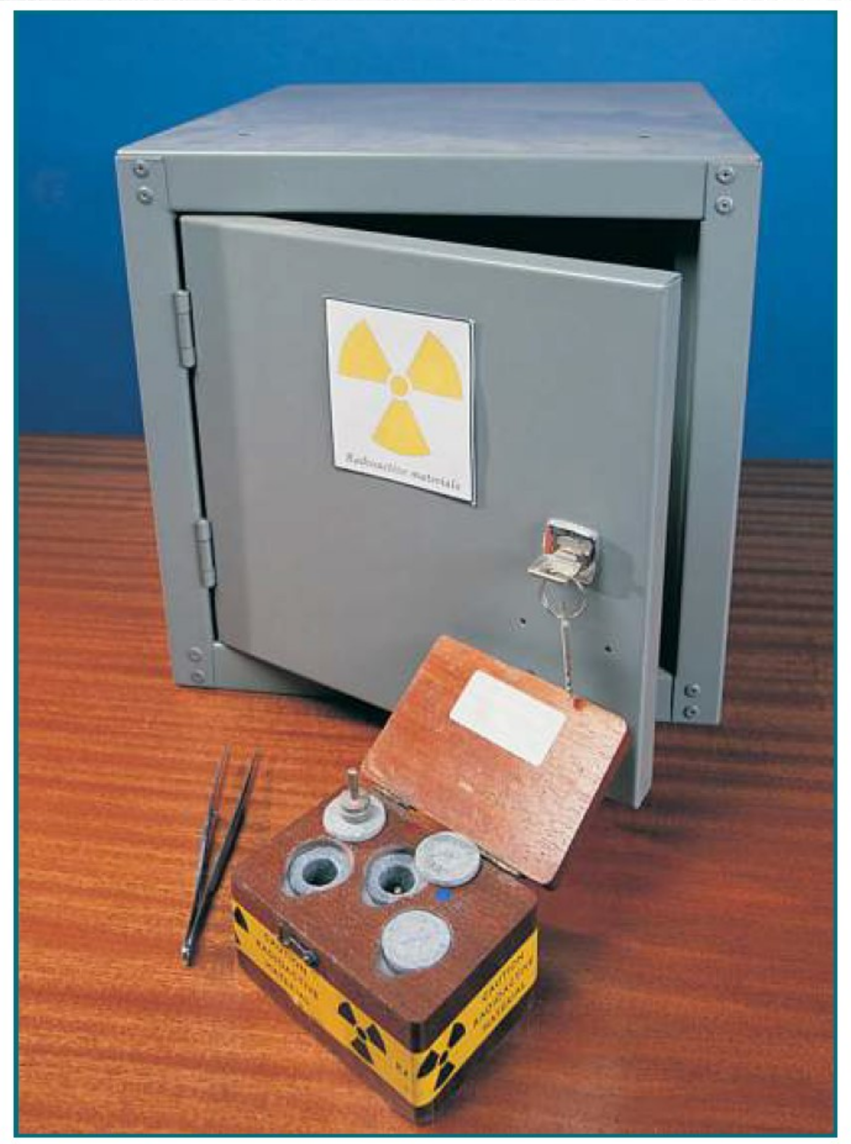
mass α > mass β > mass γ

charge α > charge β > charge γ [3]

speed γ > speed β > speed α [Total: 3]

Note*: this is just one way to state the differences among the 3 types of radiation.

Safe handling



Safe handling

- Radioactive sources should **be stored in a container** that will absorb as much as possible of the radiation coming from them.
- **Lead** is a good material for this, as it is a strong absorber of all 3 types of radiation. Each source is kept in its own **lead-lined compartment**, and the whole box should **be stored in a metal cabinet** with **a hazard warning sign**.
- When sources are not in their protective container, they should be handled carefully. **To avoid contamination**, **tongs** can be used so that the user does not come into direct contact with the source.
- During any experiment, the user should **stand at a safe distance** from the source.

Safety Precautions

- Ionizing radiation can **kill or damage human cells and tissues**, this can cause DNA **mutation** that can eventually lead to **cancer.**
- It is therefore important for people that are working with this sort of radiation to **keep safe** from it.
- Radiation workers wear **film badges**, which **monitors the dose of radiation exposed**. This allows them to ensure that they are **not exposed to levels that are unsafe.**
- Safety precautions for all ionizing radiation:
  - ✓ **reducing exposure time**
  - ✓ **increasing distance** between source and living tissue,
  - ✓ **using shielding** to absorb radiation

Study Question

A technician is handling a solid radioactive sample that emits α-particles and β-particles.

The technician wears thick rubber gloves.

Explain why this may provide some protection from the radiation, but it is not sufficient protection.

....

....

....

.... [2]

[Total: 2]

Study Question

A technician is handling a solid radioactive sample that emits α-particles and β-particles.

The technician wears thick rubber gloves.

Explain why this may provide some protection from the radiation, but it is not sufficient protection.

Thick gloves would stop alpha, however, β-radiation would penetrate gloves and reach other body parts, so wearing thick rubber gloves is insufficient protection.

[2]

[Total: 2]

Radioactive decay equations

We can represent any radioactive decay by an equation.

In radioactive decay, **nucleon number and proton number are conserved**.

$$^{241}_{94}\mathrm{Am} \rightarrow {}^{237}_{92}\mathrm{U} + {}^{4}_{2}\mathrm{He} + \text{energy}$$

This represents the decay of an americium-241 **nucleus**, the isotope used in **smoke detectors**. It emits **an alpha particle** (represented as a helium nucleus) and becomes **an isotope of uranium**.

Notice that the numbers in this equation must balance, because we cannot lose mass or charge.

Radioactive decay equations

Here is an example of an equation for **beta decay**:

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \text{energy}$$

This is the decay that is used in **radiocarbon dating**.

A carbon-14 **nucleus** decays to become a nitrogen-14 nucleus. If we could see inside the nucleus, we would see that **a single neutron has decayed to become a proton**.

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

Nuclear Equations

Study question:

1. What type of radiation is given off in this decay? ${}^{8}_{3}Li \rightarrow {}^{8}_{4}Be + radiation$

2. Write the nuclear equation for ${}^{219}_{86}Rn$ *decaying to polonium (Po) by emitting an alpha particles.*

Nuclear Equations

Study question:

1. What type of radiation is given off in this decay? ${}^{8}_{3}Li \rightarrow {}^{8}_{4}Be + radiation$

Beta particle

2. Write the nuclear equation for ${}^{219}_{86}Rn$ *decaying to polonium (Po) by emitting an alpha particles.*

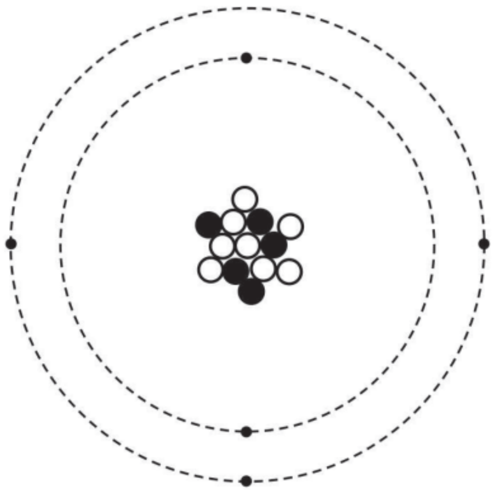
$${}^{219}_{86}Rn \rightarrow {}^{215}_{84}Po + {}^{4}_{2}\alpha$$

Radioactive decay - Summary

- Radioactivity decay is a *spontaneous transformation of an unstable* **nucleus** *which releases radiation* in the form of **alpha particles**, **beta particles**, or **gamma rays**.
- In **alpha decay**, alpha particles are emitted from the original nucleus
  - ✓ Each alpha particle is equal to a helium **nucleus**: **2 protons** & **2 neutrons**, i.e. Z = 2 & A = 4
  - ✓ $^{222}_{88}Ra \rightarrow {}^{4}_{2}He + {}^{218}_{86}Rn$
- In **beta decay**, a **neutron** is converted into **a proton** and **an electron**
  - ✓ The electron is fired out of the nucleus whilst the proton remains
  - ✓ Neutron number therefore decreases by 1 and proton number increases by 1
  - ✓ $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$
- In **gamma decay**, the number of protons and neutrons are **unchanged**
  - ✓ The gamma ray takes away some of the excess energy after the nucleus has emitted an alpha or beta particle
  - ✓ $^{99}_{43}Tc \rightarrow {}^{99}_{43}Tc + \Upsilon$

Study Question

The diagram represents a neutral atom of an isotope of element X.



The isotope of element X is radioactive. It decays to form an isotope of element Y by emitting a β-particle.

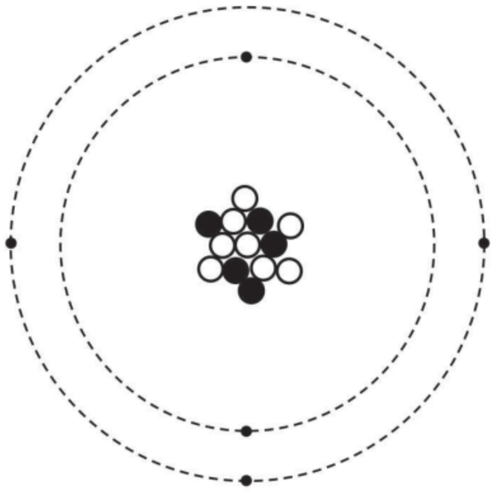
Using the diagram, deduce the nuclide notation for the isotope of Y produced by this decay.

nuclide notation: $^{......}_{......}Y$

C. Chu

Study Question

The diagram represents a neutral atom of an isotope of element X.



$^{13}_{5}X$

The isotope of element X is radioactive. It decays to form an isotope of element Y by emitting a β-particle.

Using the diagram, deduce the nuclide notation for the isotope of Y produced by this decay.

$^{13}_{6}Y$

$^{0}_{-1}\beta$

nuclide notation: $^{\ldots\ldots}_{\ldots\ldots}Y$

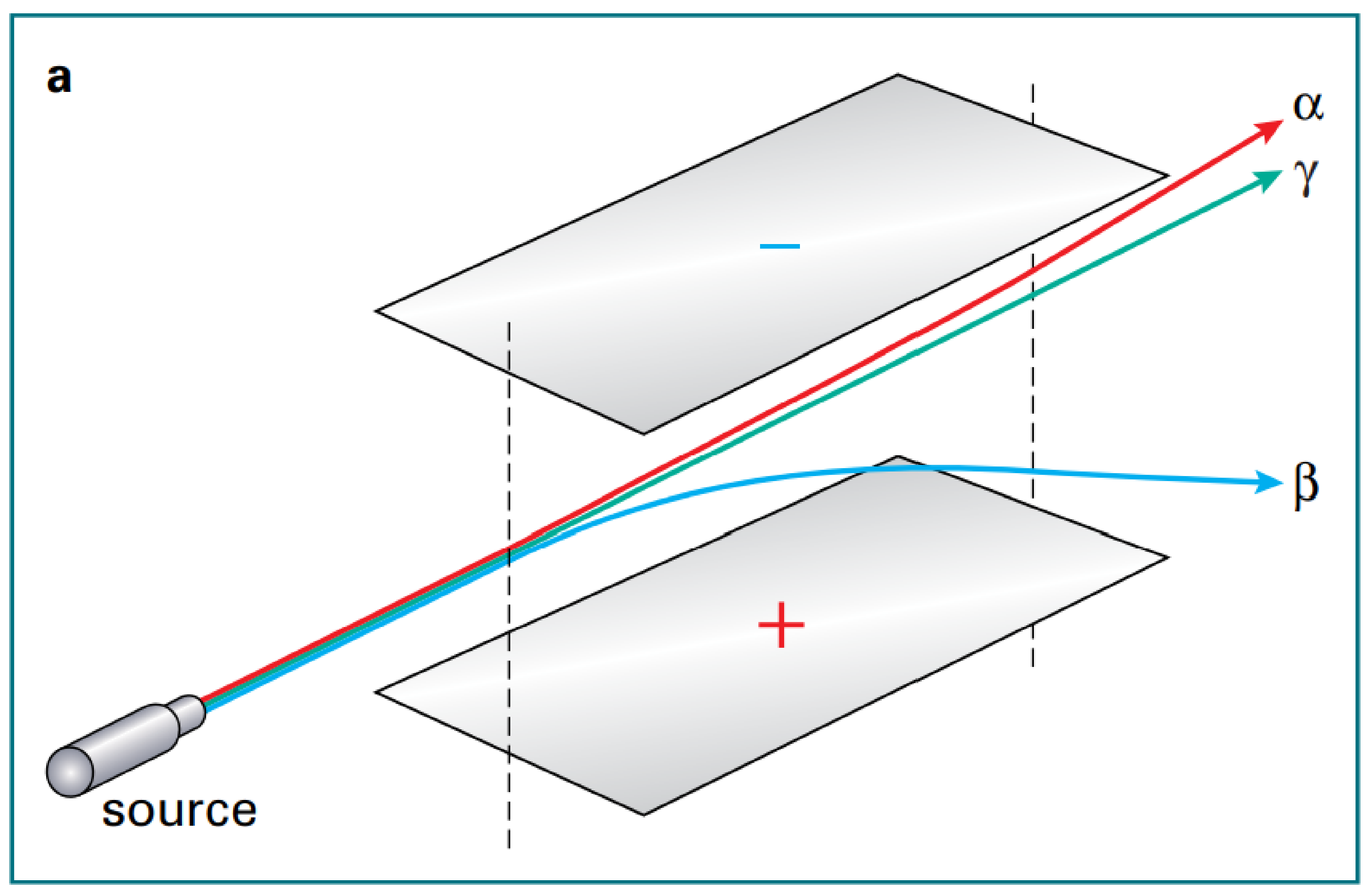
Deflecting radiation

Alpha and beta particles are deflected in opposite directions when they pass through an **electric field**, because they have opposite charges.

Alpha particles are attracted towards a negatively charged plate, while **beta particles** are attracted towards a positively charged plate.

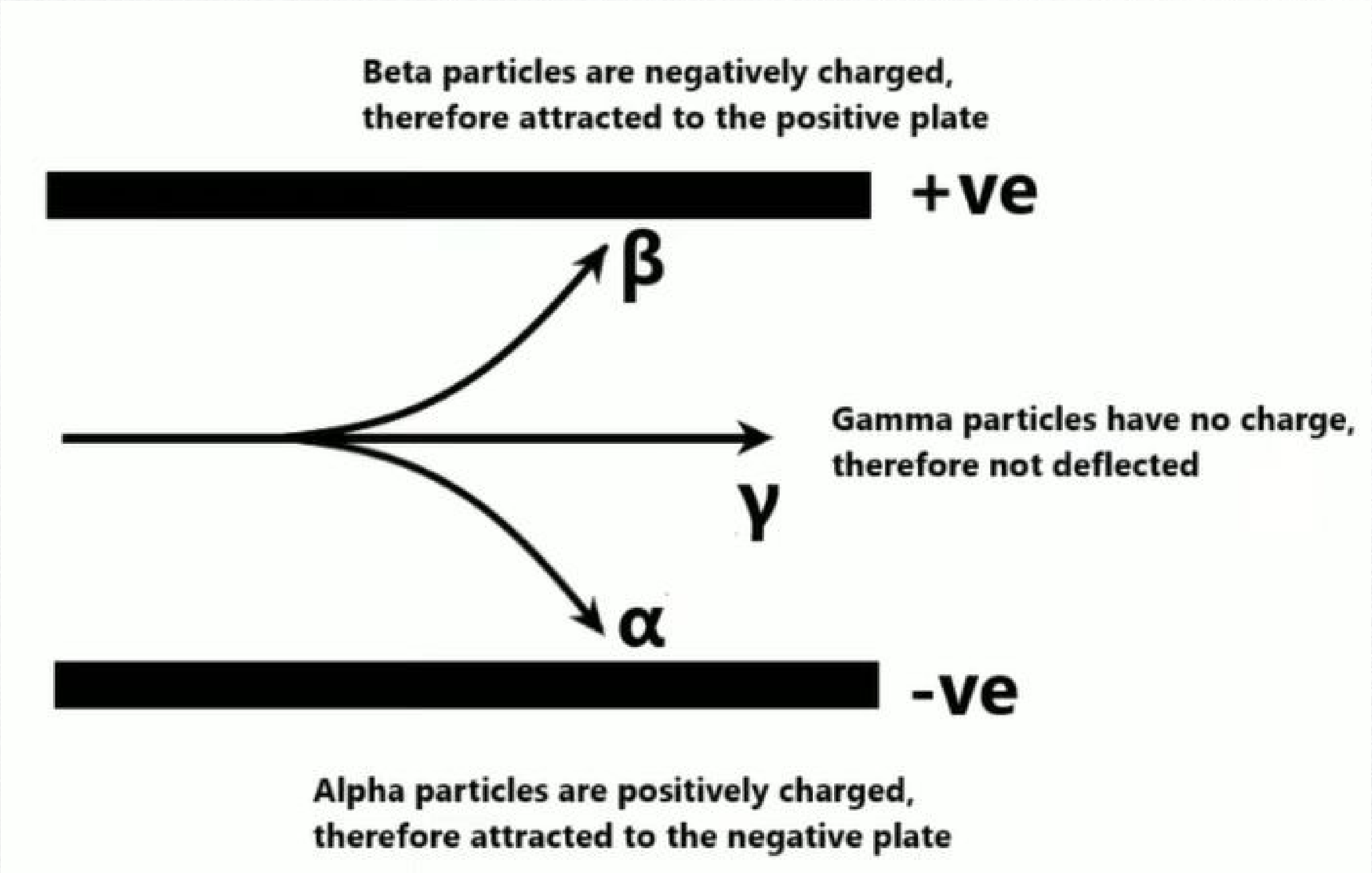
Gamma rays are not deflected because they are uncharged.

Deflecting radiation



Alpha and beta radiations are deflected in opposite directions: a) in an electric field

Effect of electric fields

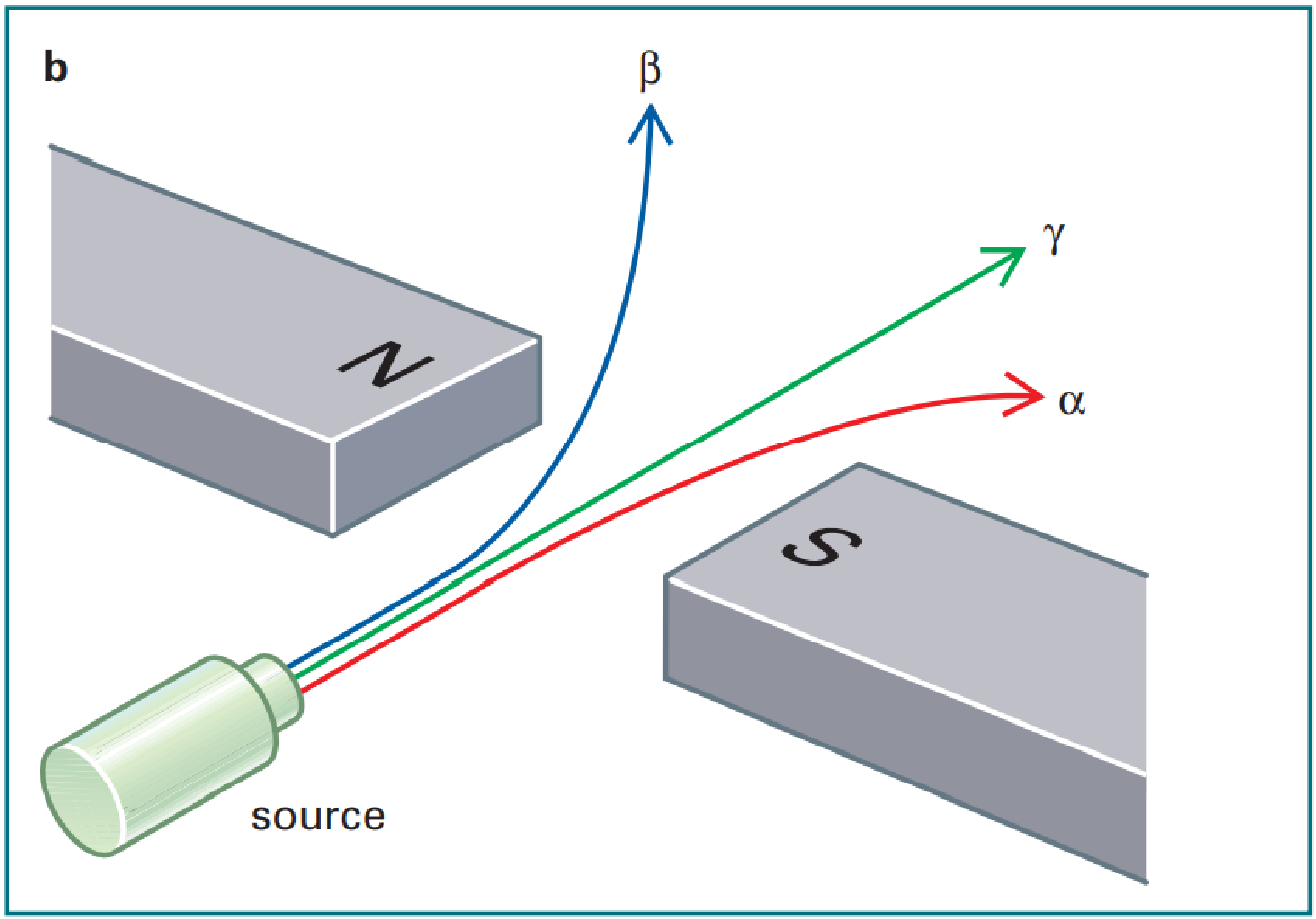


Deflecting radiation

Alpha and beta particles are charged, so, when they move, they constitute an electric current. Because of their opposite signs, the forces on them in a **magnetic field** are in opposite directions.

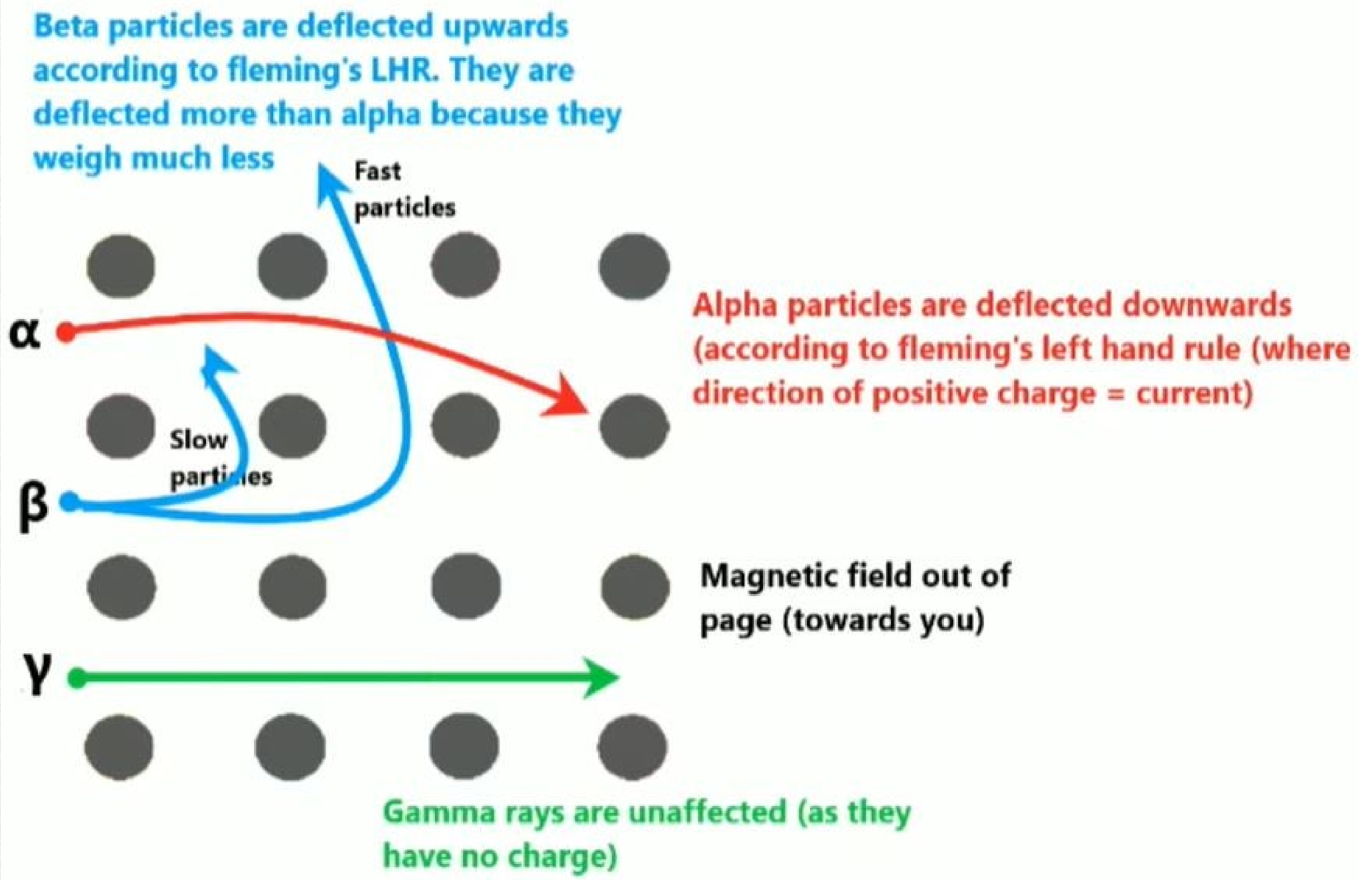
The direction in which the particles are deflected can be predicted using **Fleming's left-hand rule**. As in an electric field, gamma rays are not deflected because they are uncharged.

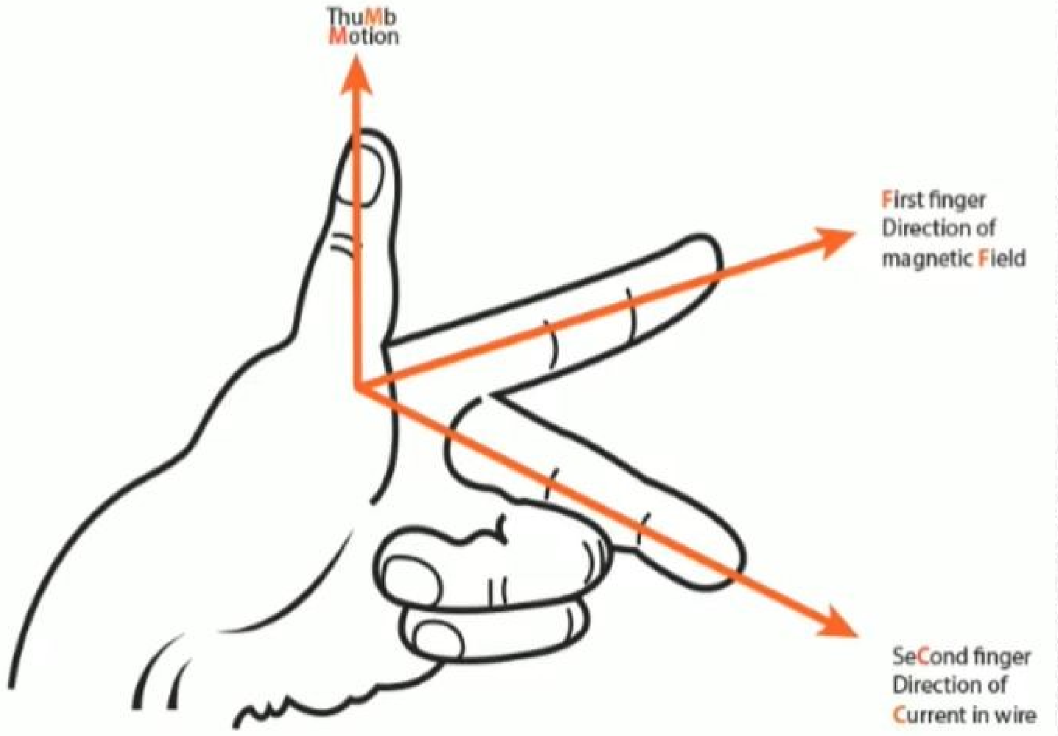
Deflecting radiation



Alpha and beta radiations are deflected in opposite directions: b) in a magnetic field.

Effect of magnetic fields



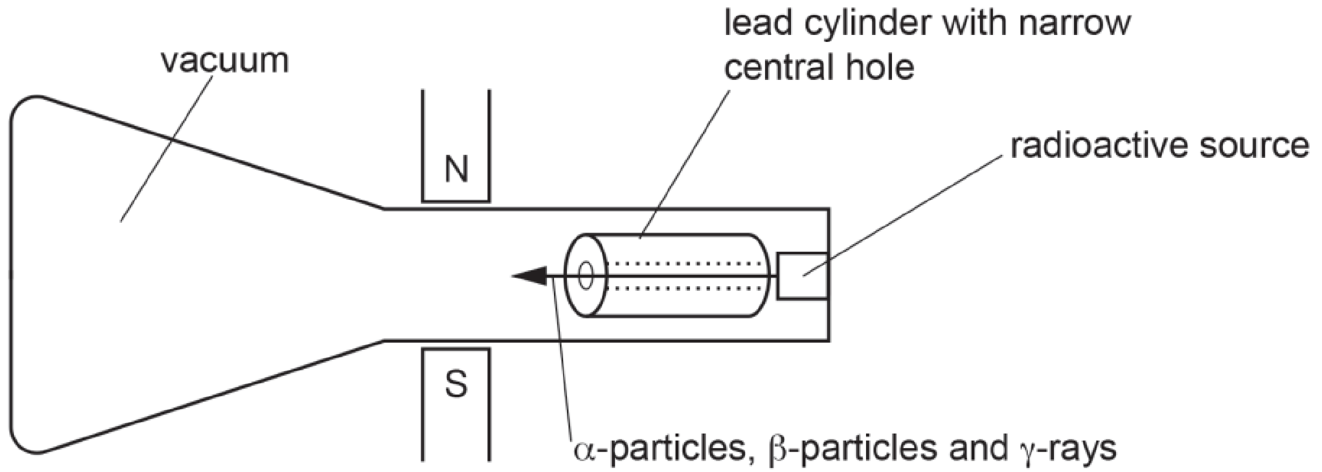


THANK YOU

Radioactivity

Review

The diagram shows a vacuum tube with a radioactive source. The radioactive source emits α-particles, β-particles and γ-rays. There is a very strong magnetic field between the N pole and the S pole of the magnet.



Describe the path of the β-particles as they pass through the magnetic field. Explain your answer.

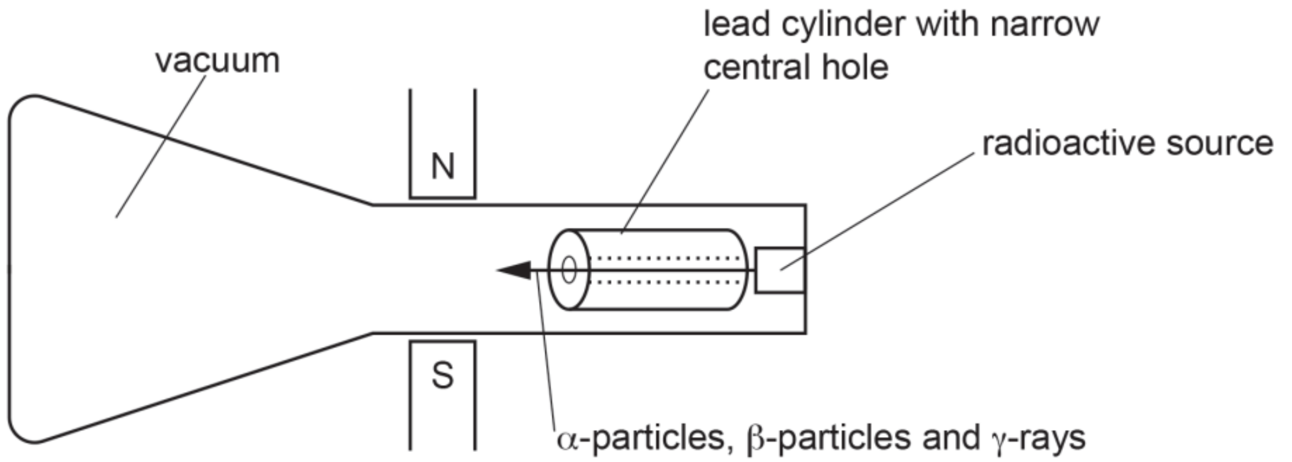
....

.... [2]

[Total: 2]

Review

The diagram shows a vacuum tube with a radioactive source. The radioactive source emits α-particles, β-particles and γ-rays. There is a very strong magnetic field between the N pole and the S pole of the magnet.



Describe the path of the β-particles as they pass through the magnetic field. Explain your answer.

....

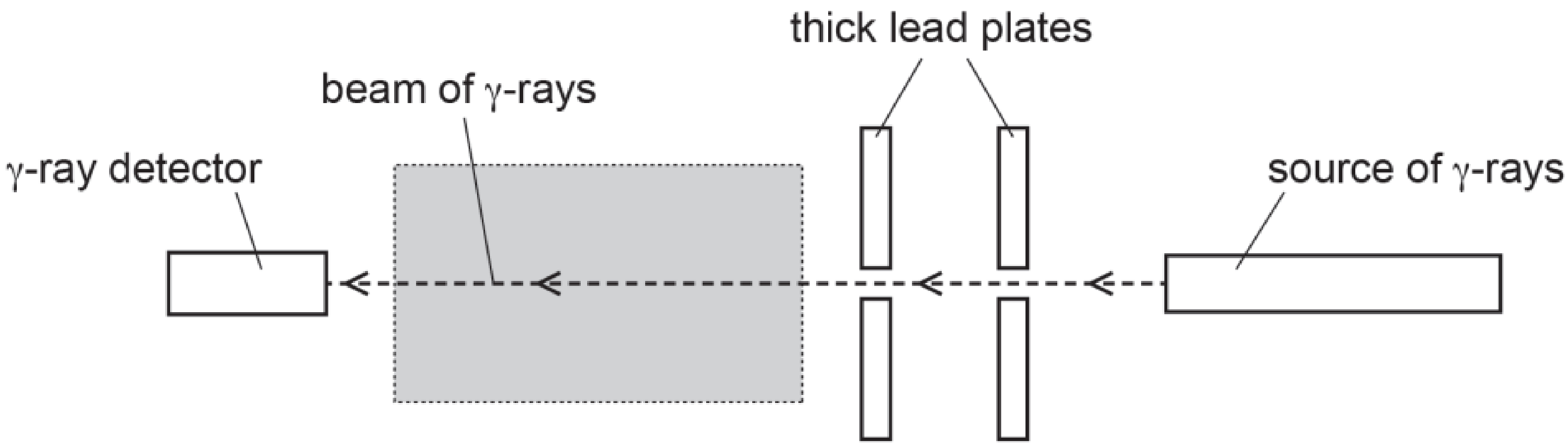
.... [2]

[Total: 2]

The path of beta particle should be into page / away from viewer. By using the left-hand rule, the current direction of beta-particle is to the right, while the direction of magnetic field is downwards.

Review

The diagram shows equipment that is used to investigate the effect of a magnetic field on the path of a beam of γ-rays.



A radioactive source emits γ-rays. The γ-rays pass through two small holes in thick lead plates. Then the γ-rays pass through the shaded region and into the detector.

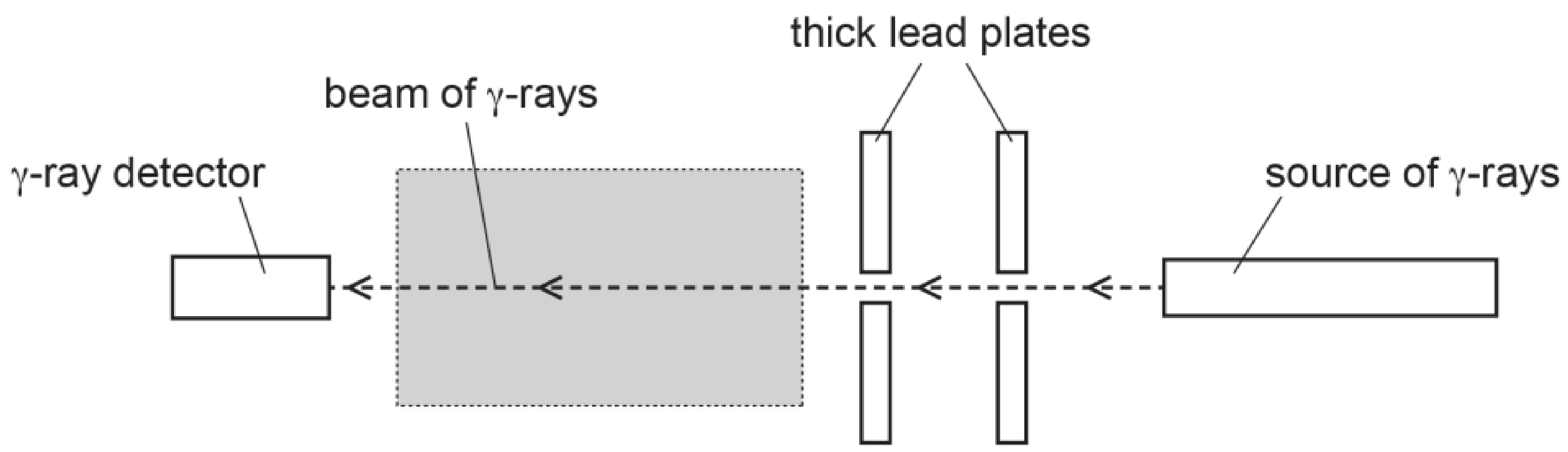
(a) Suggest the purpose of the two lead plates.

....

.... [1]

Review

The diagram shows equipment that is used to investigate the effect of a magnetic field on the path of a beam of γ-rays.



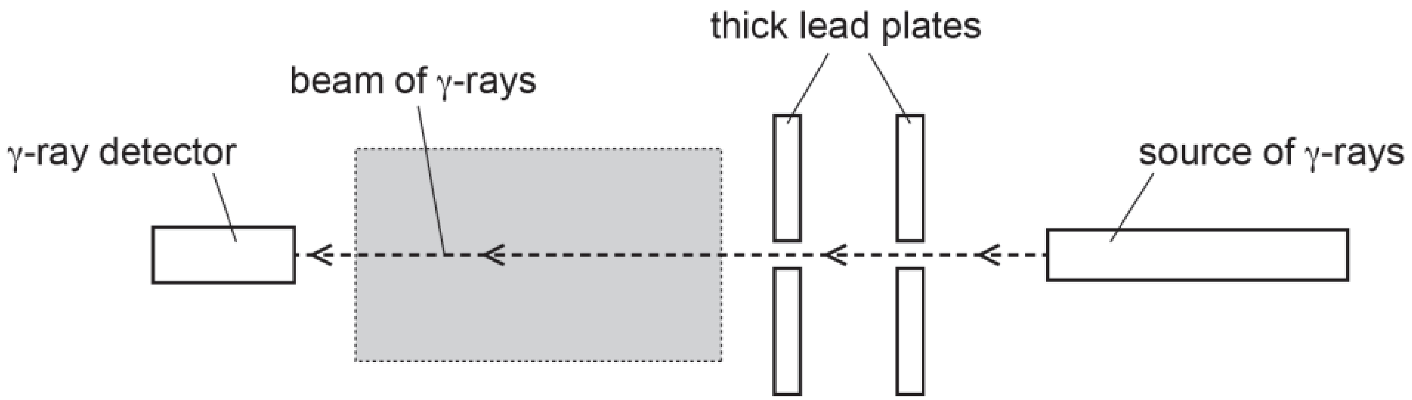
A radioactive source emits γ-rays. The γ-rays pass through two small holes in thick lead plates. Then the γ-rays pass through the shaded region and into the detector.

(a) Suggest the purpose of the two lead plates.

Produces a narrow beam of γ-rays OR absorb γ-rays that are not on the path shown [1]

Review

The diagram shows equipment that is used to investigate the effect of a magnetic field on the path of a beam of γ-rays.



(b) A magnetic field, directed into the page, is set up in the shaded region.

State and explain what happens to the reading of the detector.

....

....

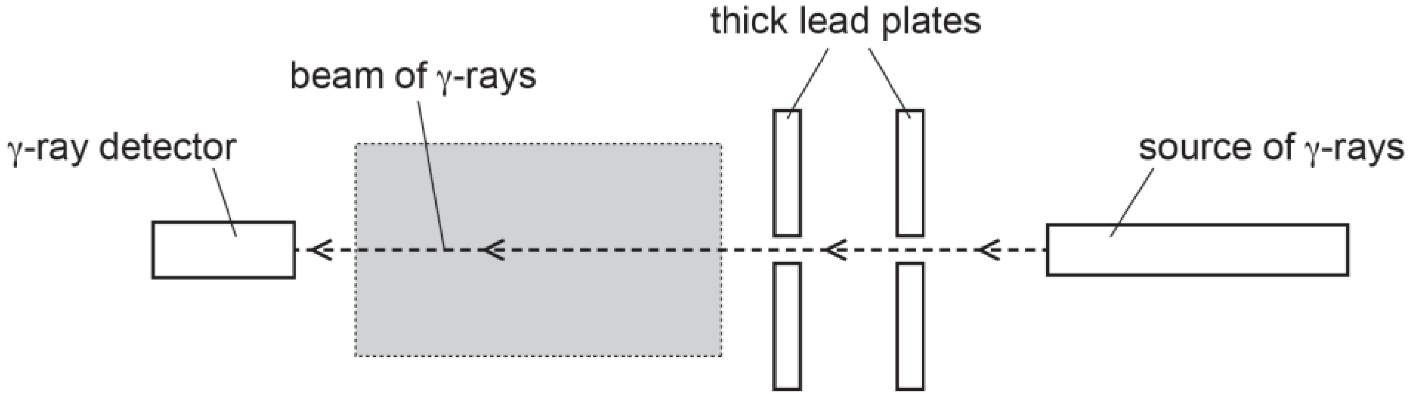
....

.... [3]

[Total: 4]

Review

The diagram shows equipment that is used to investigate the effect of a magnetic field on the path of a beam of γ-rays.



(b) A magnetic field, directed into the page, is set up in the shaded region.

State and explain what happens to the reading of the detector.

no change OR γ-rays not deflected

γ-rays are electromagnetic radiation/unchanged

γ-rays do not deflected by magnetic field

[3]

[Total: 4]

Review

A beam that consists of both α-particles and β-particles is passed through a region of space where there is a magnetic field perpendicular to the direction of the beam.

State **two** ways in which the deflection of the α-particles differs from that of the β-particles.

1. ....

2. .... [2]

[Total: 2]

Review

A beam that consists of both α-particles and β-particles is passed through a region of space where there is a magnetic field perpendicular to the direction of the beam.

State **two** ways in which the deflection of the α-particles differs from that of the β-particles.

1. Opposite direction

2. One is deflected more than the other. [2]

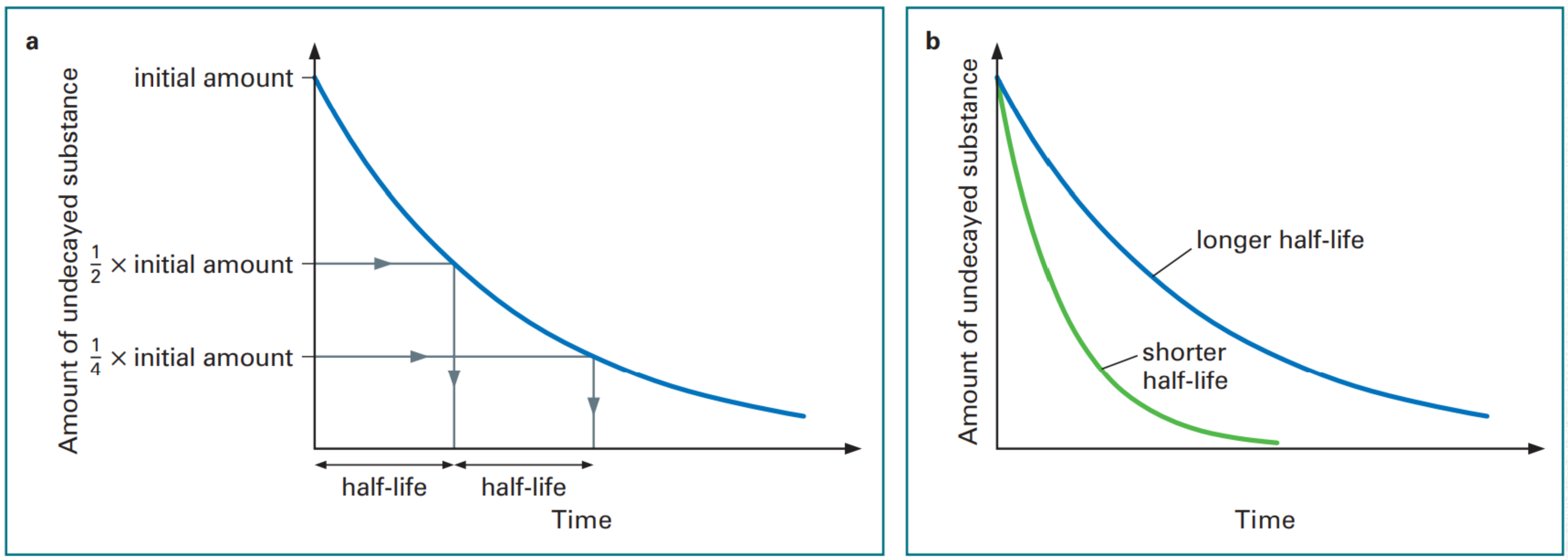
[Total: 2]

Half-life

- The radioactivity of a sample always decreases over time
  - ✓ Each time a decay happens (i.e. an alpha or beta particle or gamma ray is given out), it means one more radioactive nucleus has disappeared.
  - ✓ As the unstable nuclei disappear, the **activity** (the number of decays in a given time) will **decrease**.
  - ✓ **The older sample becomes, the less radiation it will emit**.

- The amount of a radioactive substance decreases rapidly at first, and then more and more slowly.

Half-life


a
initial amount
$\frac{1}{2}$ × initial amount
$\frac{1}{4}$ × initial amount
Amount of undecayed substance
half-life
half-life
Time
b
Amount of undecayed substance
longer half-life
shorter half-life
Time

Half-life

In fact, because the graph (please refer to the previous page) tails off more and more slowly, we cannot say when the last atoms will decay.

Because we cannot say when the substance will have entirely decayed, we have to think of another way of describing the **rate of decay**.

- How quickly the activity drops off varies a lot.
- The problem with trying to measure this is that **the activity never reaches zero**

Half-life

Half-life:

The time taken for half of the radioactive atoms now present to decay.

The time taken for the activity (or counter rate) to fall by half.

- A short half-life means the activity falls quickly, because lots of the nuclei decay quickly.
- A long half-life means the activity falls more slowly because most of the nuclei don't decay for a long time.
- For any particular isotope, the half-life is always the same.

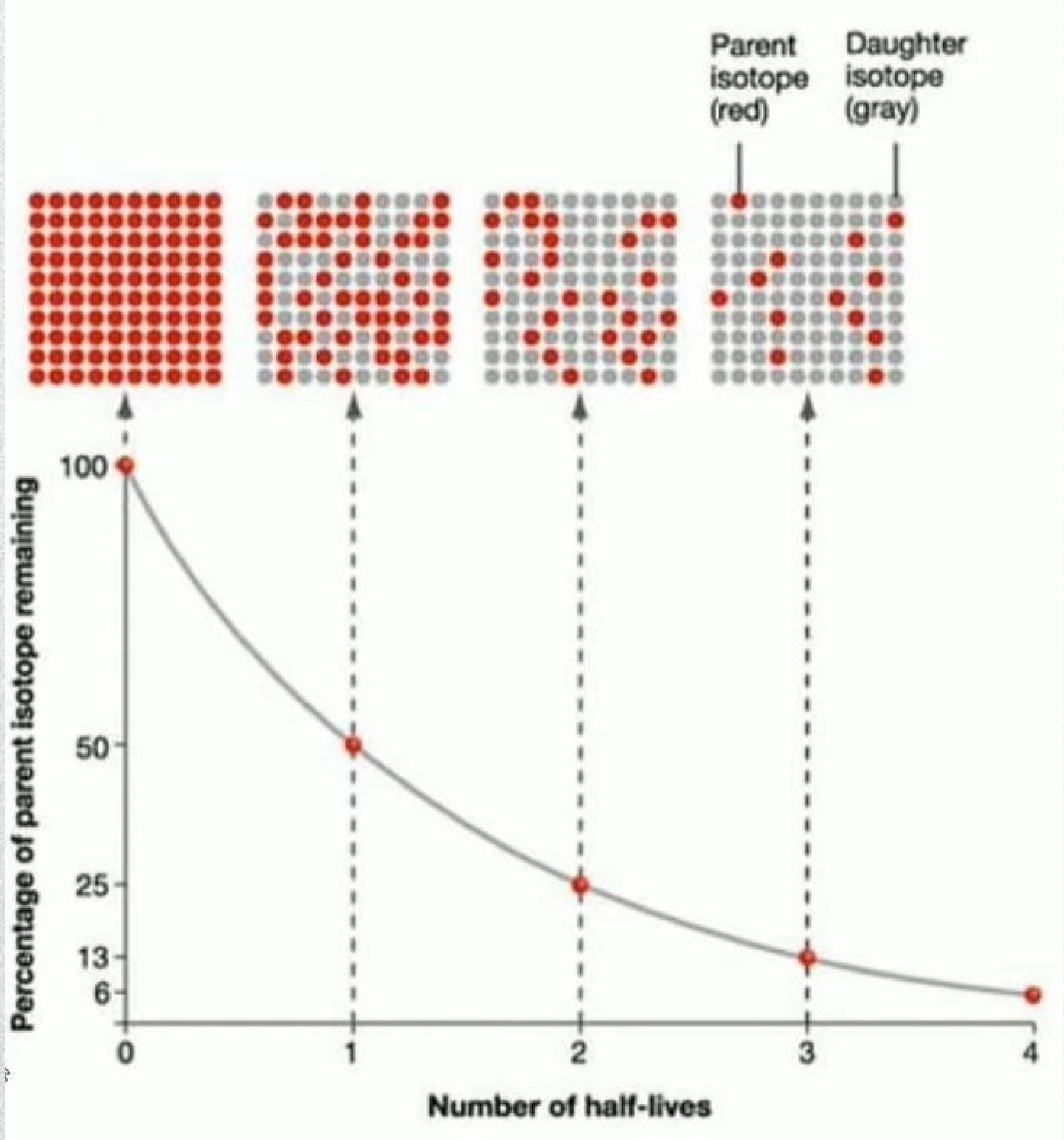
Half-life

- Usually, we cannot measure the numbers of atoms in a sample. Instead, we measure the **counter rate (the amount of radioactivity)** using a Geiger counter or some other detector.

- We might also determine **the activity of a sample**. and is measured in **becquerels (Bq)**.
  - ✓ **Radioactivity** is measured in **becquerels (Bq)**.
  - ✓ **1Bq = 1 decay per second.** This is the number of atoms that decay each second. As number of unstable nuclei decreases, the number of emitted particles become reduced, too.

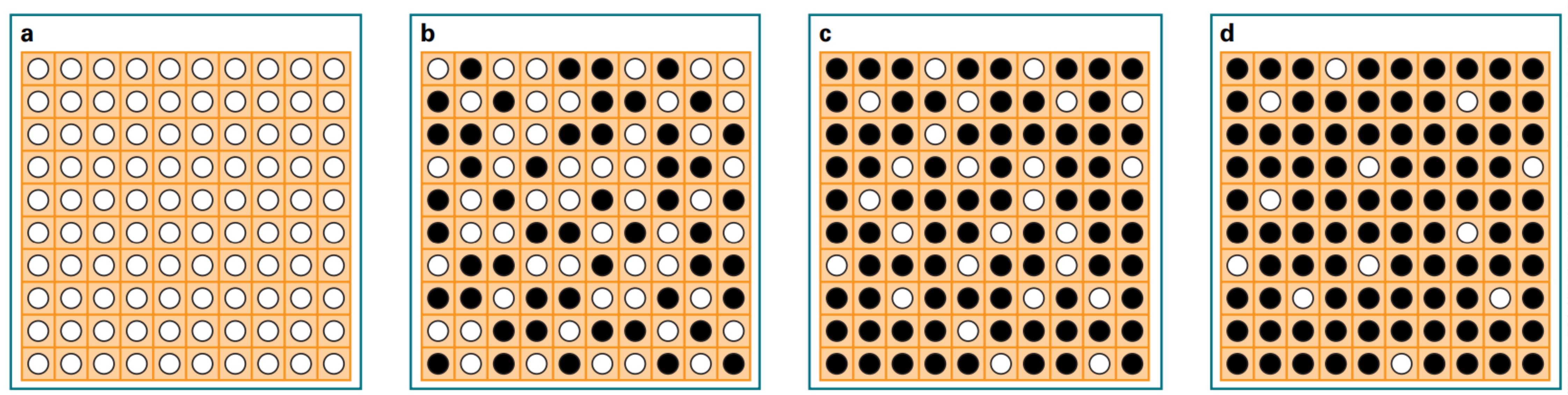
The **counter rate** and **activity** both decrease following the same pattern as the number of undecayed atoms.

Half-life



Parent isotope (red)
Daughter isotope (gray)
100
50
25
13
6
Percentage of parent isotope remaining
0
1
2
3
4
Number of half-lives

Half-life



Radioactive decay of individual atoms is random. Half of the atoms decay during each half-life, but we have no way of predicting which individual atoms decay.

Study Question

Study question #1:

The activity of a radioactive isotope is 640 Bq. 2 hours later, it has fallen to 40 Bq. Find the half-life of the sample. Remember: 1 Bq = 1 decay per second.

Study Question

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Example: The activity of a radioactive isotope is 640 Bq. Two hours later it has fallen to 40 Bq. Find the half-life of the sample.

Radioactivity is measured in becquerels (Bq).
1 Bq is 1 decay per second.

To answer, go through it in short simple steps like this:

INITIAL count:		after ONE half-life:		after TWO half-lives:		after THREE half-lives:		after FOUR half-lives:
640	$(\div 2)\rightarrow$	320	$(\div 2)\rightarrow$	160	$(\div 2)\rightarrow$	80	$(\div 2)\rightarrow$	40

Notice the careful step-by-step method, which tells us it takes four half-lives for the activity to fall from 640 to 40. So two hours represents four half-lives, so the half-life is 30 minutes.

Study Question

Study question #2:

A sample of radioactive element X has an activity of 240 Bq. If the half-life of X is 3 years, what will its activity be after 12 years?

Study Question

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A sample of radioactive element X has an activity of 240 Bq. If the half-life of X is 3 years, what will its activity be after 12 years?

Method 1:

Step 1: Calculate the number of half-lives in 12 years.

12 years / 3 years = 4 half-lives

Hence we want to know the activity of the sample after 4 half-lives.

Step 2: Calculate the activity after 1, 2, 3 and 4

initial activity = 240 Bq

activity after 1 half-life = 120 Bq

activity after 2 half-lives = 60 Bq

activity after 3 half-lives = 30 Bq

activity after 4 half-lives = 15 Bq

So the activity of the sample has fallen to 15 Bq after 12 years.

Study Question

Study question #2:

A sample of radioactive element X has an activity of 240 Bq. If the half-life of X is 3 years, what will its activity be after 12 years?

Method: 2

We have found that 12 years is 4 half-lives, so we need to divide the initial activity by 2^4, which is 16, giving: 240Bq / 16 = 15 Bq

So the activity is 15 Bq after 12 years, as before.

Half-life

Study question #3:

The initial activity of a sample is 40 Bq. Calculate the count-rate after three half-lives.

Half-life

Study question #3:

The initial activity of a sample is 40 Bq. Calculate the count-rate after three half-lives.

After one half-life the activity will be 40/2 = 20 Bq.
After the second: 20/2 = 10 Bq
After a third: 10/2 = 5

(Alternatively, $\frac{40}{2^3} = 5$ *)*

Half-life

Study question #4:

A sample of a radioactive isotope has a half-life of 40 seconds.

a) The initial activity of the sample is 8000 Bq. Calculate the activity after 2 minutes.
b) Calculate the number of whole minutes it would take for the activity to fall below 200 Bq from its initial activity.

Half-life

Study question #4:

A sample of a radioactive isotope has a half-life of 40 seconds.

a) The initial activity of the sample is 8000 Bq. Calculate the activity after 2 minutes.

$$2\ min. = 2\ \times 60\ s = 120\ s$$

$$\frac{120}{40} = 3\ half - lives$$

$$\frac{8000Bq}{2} = 4000\ Bq$$

$$\frac{4000Bq}{2} = 2000\ Bq$$

$$\frac{2000Bq}{2} = 1000\ Bq$$

Half-life

Study question #4:

A sample of a radioactive isotope has a half-life of 40 seconds.
b) The initial activity of the sample is 8000 Bq. Calculate the activity after 2 minutes.

ii) Calculate the number of whole minutes it would take for the activity to fall below 200 Bq from its initial activity.

$$\frac{2000Bq}{2} = 1000\ Bq\ (from\ last\ question)$$

$$\frac{1000Bq}{2} = 500\ Bq$$

$$\frac{500Bq}{2} = 250\ Bq$$

$$\frac{250Bq}{2} = 125\ Bq$$

$$2\min + 40s\ \times 3 = 240\ s$$

$$\frac{240}{60} = 4\ mins$$

Half-life

Study question #5:

Which of the following statements about half life are true?

1. Two samples of the same size but of different isotopes would have the same half-life.
2. Two samples of the same size but of different isotopes would have different half-lives.
3. Two samples of the same isotope of different sizes would have the same half-life.
4. Two samples of the same isotope of different sizes would have different half-lives.

Half-life

Study question #5:

Which of the following statements about half life are true?

1. Two samples of the same size but of different isotopes would have the same half-life.
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3. Two samples of the same isotope of different sizes would have the same half-life.
4. Two samples of the same isotope of different sizes would have different half-lives.

Half-life

Study question #6:

A sample of a radioactive isotope emits particles at a rate of 240 per minute.

After 48 hours the rate of emission has decreased to 15 per minute.

What is the half-life of the radioactive material?

A 4.0 hours **B** 8.0 hours **C** 12 hours **D** 16 hours

[1]

Half-life

Study question #6:

A sample of a radioactive isotope emits particles at a rate of 240 per minute.

After 48 hours the rate of emission has decreased to 15 per minute.

What is the half-life of the radioactive material? ***C*** $\frac{240}{2^4}$=15 $\frac{48}{4} = 12$

A 4.0 hours **B** 8.0 hours **C** 12 hours **D** 16 hours

[1]

Half-life

Study question #7:

With no radioactive sample present, a scientist records a background radiation count of 40 counts / minute.

The scientist brings a radioactive sample close to the detector. The count rate increases to 200 counts / minute.

After 24 days the count rate is 50 counts / minute.

Calculate the half-life of the radioactive sample.

half-life = ... [4]

[Total: 4]

Half-life

Study question #7:

With no radioactive sample present, a scientist records a background radiation count of 40 counts / minute.

The scientist brings a radioactive sample close to the detector. The count rate increases to 200 counts / minute.

After 24 days the count rate is 50 counts / minute.

Calculate the half-life of the radioactive sample.

$$200 - 40 = 160\ counts/min$$
$$50 - 40 = 10\ counts/min$$

$$\frac{160}{2} = 80 \qquad \frac{20}{2} = 10$$

$$\frac{80}{2} = 40 \qquad 4\ half - life$$

$$\frac{40}{2} = 20 \qquad \frac{24}{4} = 6\ days$$

half-life = $6\ days$ [4]

[Total: 4]

Half-life

Study question #8:

The isotope radon-220 is radioactive.

The half-life of radon-220 is 56 s.

A sample of this isotope contains 7.2×10^6 atoms.

Predict the number of α-particles that the radon-220 in the sample emits in the next 168 s.

number of α-particles emitted = ... [3]

[Total: 3]

Half-life

Study question #8:

The isotope radon-220 is radioactive.

The half-life of radon-220 is 56 s.

A sample of this isotope contains 7.2×10^6 atoms.

Predict the number of α-particles that the radon-220 in the sample emits in the next 168 s.

$\frac{168}{56}$=3 half-life

$$7.2 * 10^6 - 9 * 10^5 = 6.3 * 10^6 \text{ emited}$$

$$\frac{7.2 * 10^6}{2^3} = 9 * 10^5 \; atoms\ remain$$

number of α-particles emitted = $6.3 * 10^6$ [3]

[Total: 3]

Half-life

Study question #9:

Thorium-234 ($^{234}_{90}Th$) is radioactive. It decays by β-emission to form an isotope of protactinium (Pa).

(a) A pure sample of thorium-234 emits β-particles at a count rate of 2480 counts/second. The half-life of thorium-234 is 24 days.

Calculate the count rate for the emission of β-particles from the thorium in the sample after 72 days have passed.

count rate .... [3]

Half-life

Study question #9:

Thorium-234 ($^{234}_{90}Th$) is radioactive. It decays by β-emission to form an isotope of protactinium (Pa).

(a) A pure sample of thorium-234 emits β-particles at a count rate of 2480 counts/second. The half-life of thorium-234 is 24 days.

Calculate the count rate for the emission of β-particles from the thorium in the sample after 72 days have passed.

$$\frac{72}{24} = 3\ half\ life$$

$$\frac{2480}{2^3} = 310$$

count rate ....310............ [3]

Half-life

Study question #10:

Thorium-234 ($^{234}_{90}Th$) is radioactive. It decays by β-emission to form an isotope of protactinium (Pa).

(b) The isotope of protactinium produced by the decay of Thorium-234 is also radioactive. It decays by β-emission and has a half-life of 70 seconds.

State and explain how this would affect the **observed** count rate for the sample in **(a)** after 72 days.

....

....

....

.... [3]

[Total: 6]

Half-life

Study question #10:

Thorium-234 ($^{234}_{90}Th$) is radioactive. It decays by β-emission to form an isotope of protactinium (Pa).

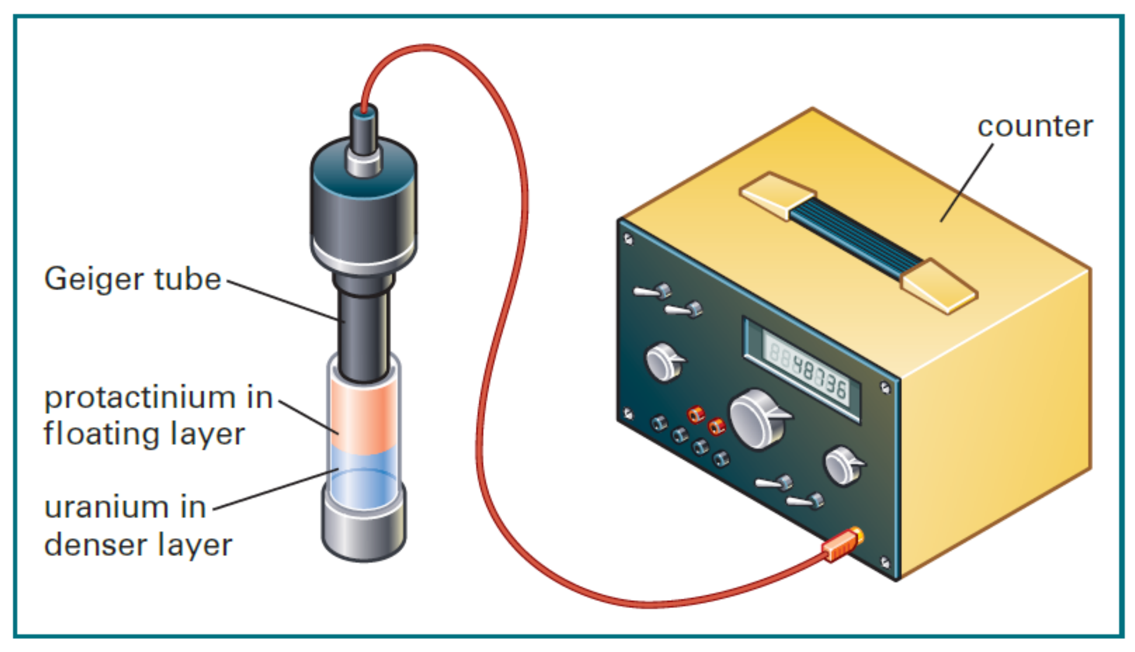
(b) The isotope of protactinium produced by the decay of Thorium-234 is also radioactive. It decays by β-emission and has a half-life of 70 seconds.

State and explain how this would affect the **observed** count rate for the sample in **(a)** after 72 days.

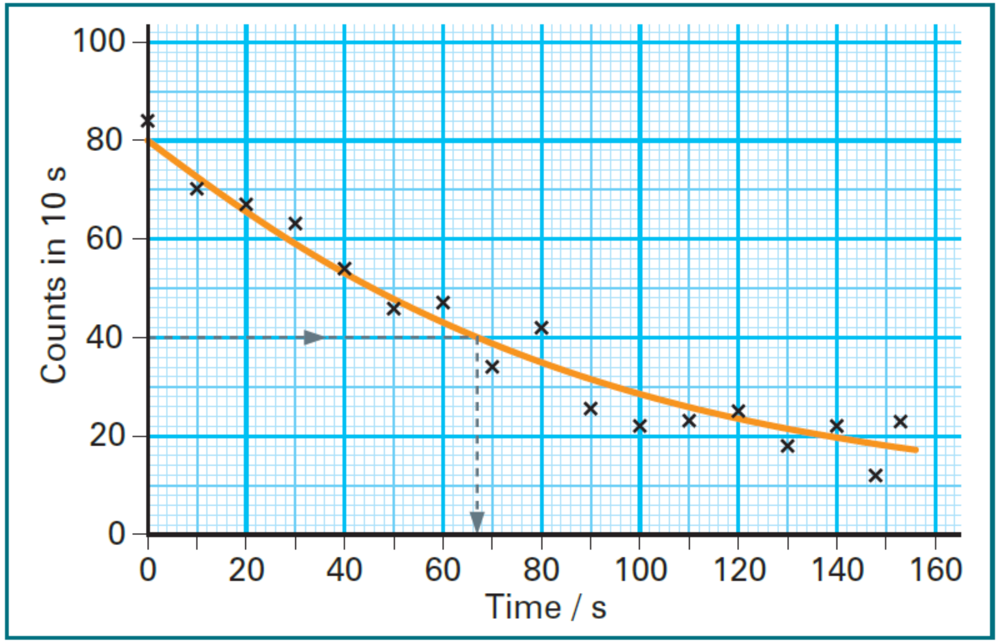
count rate larger (than 310 3 counts / second) ; protactinium is also emitting (β-)particles ; product of protactinium decay also radioactive; protactinium is highly radioactive ; half-life of protactinium is much shorter (than half-life of thorium) [3]

[Total: 6]

Measuring a half-life



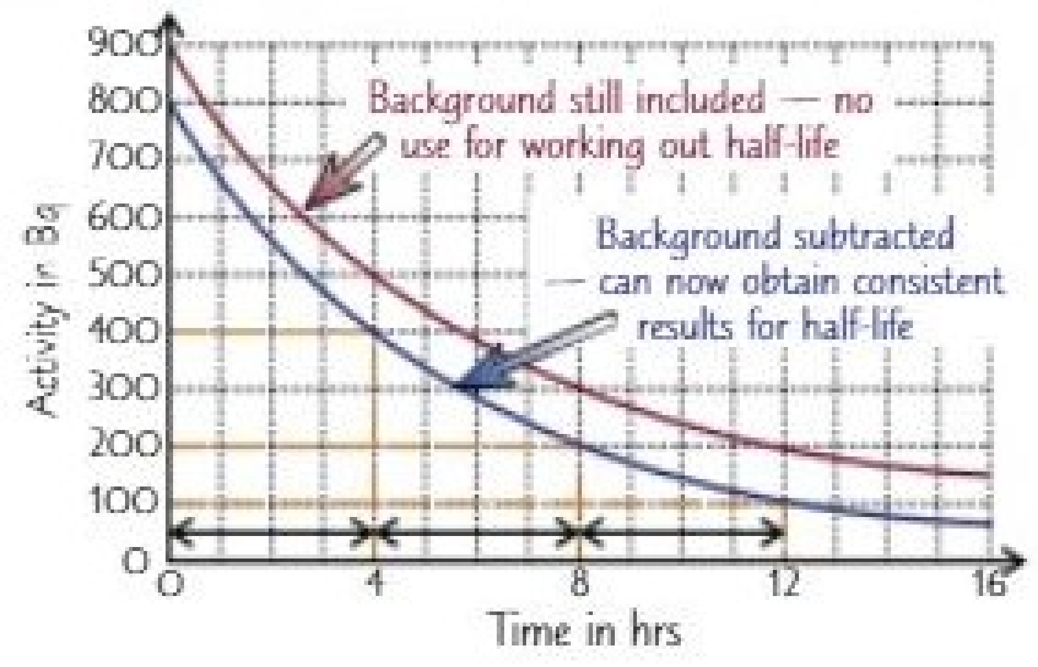
A practical arrangement for measuring the half-life of the radioactive decay of protactinium-234.

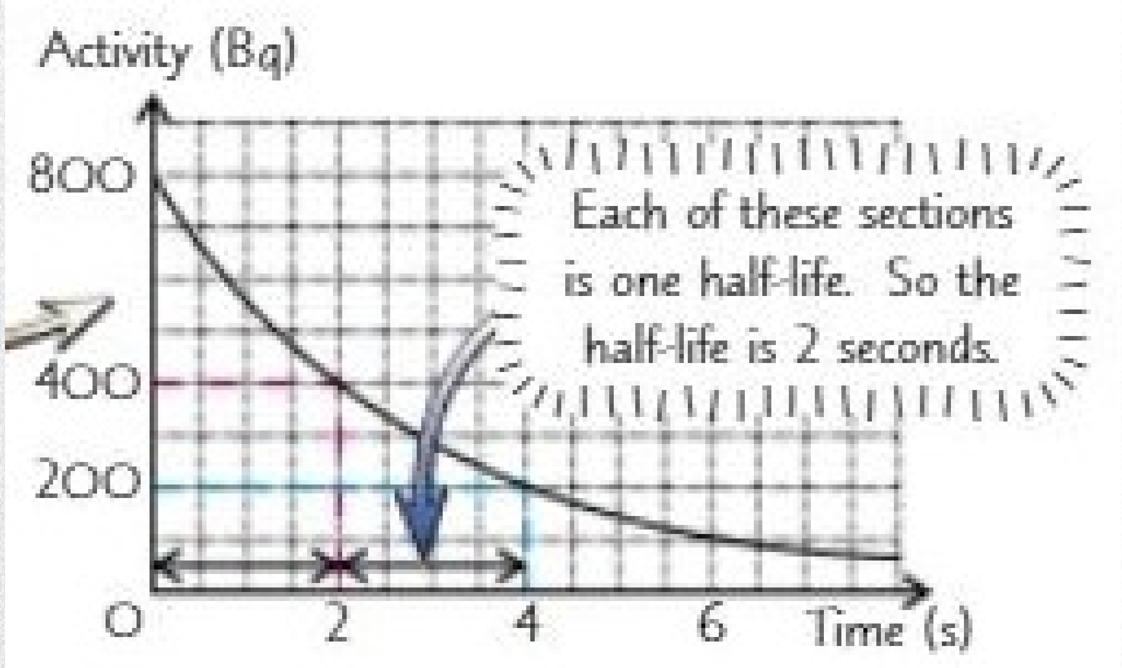


The half-life of the radioactive decay of protactinium-234 is 67 s.

Half-life

***Measuring** the half-life of a sample using a graph:*





THANK YOU

Radioactivity

1 Radioactivity all around
2 The microscopic picture
3 Radioactive decay
4 **Using radioisotopes**

Uses of nuclear radiation

Any element comes in several forms or isotopes.

Some may be stable, but others are unstable – in other words, they are radioactive. For example, carbon has two stable isotopes ($^{12}_{6}C$ and $^{13}_{6}C$), but $^{14}_{6}C$ is an unstable isotope.

Unstable (radioactive) isotopes are known as **radioisotopes**.

Uses of nuclear radiation

Effects of radioisotopes on cells

Safe handling of radioisotopes requires an understanding of how radiation affects cells. There are 3 ways in which **radiation can damage living cells**.

- An intense dose of radiation causes a lot of ionisation in a cell, which can **kill the cell**. This is what happens when someone suffers radiation burns. The cells affected simply die, as if they had been burned. If the sufferer is lucky and receives suitable treatment, the tissue may regrow.
- If the DNA in the cell nucleus is damaged, the mechanisms that control the cell may break down. The cell may divide uncontrollably and a **tumour** forms. This is how radiation can **cause cancer**.
- If the affected cell is a gamete (a sperm or egg cell), the damaged DNA of its genes may be passed on to future generations. This is how radiation can **produce genetic mutations**. Occasionally, a mutation can be beneficial to the off spring, but more usually it is harmful. A fertilised egg cell may not develop at all, or the baby may have some form of **genetic disorder**.

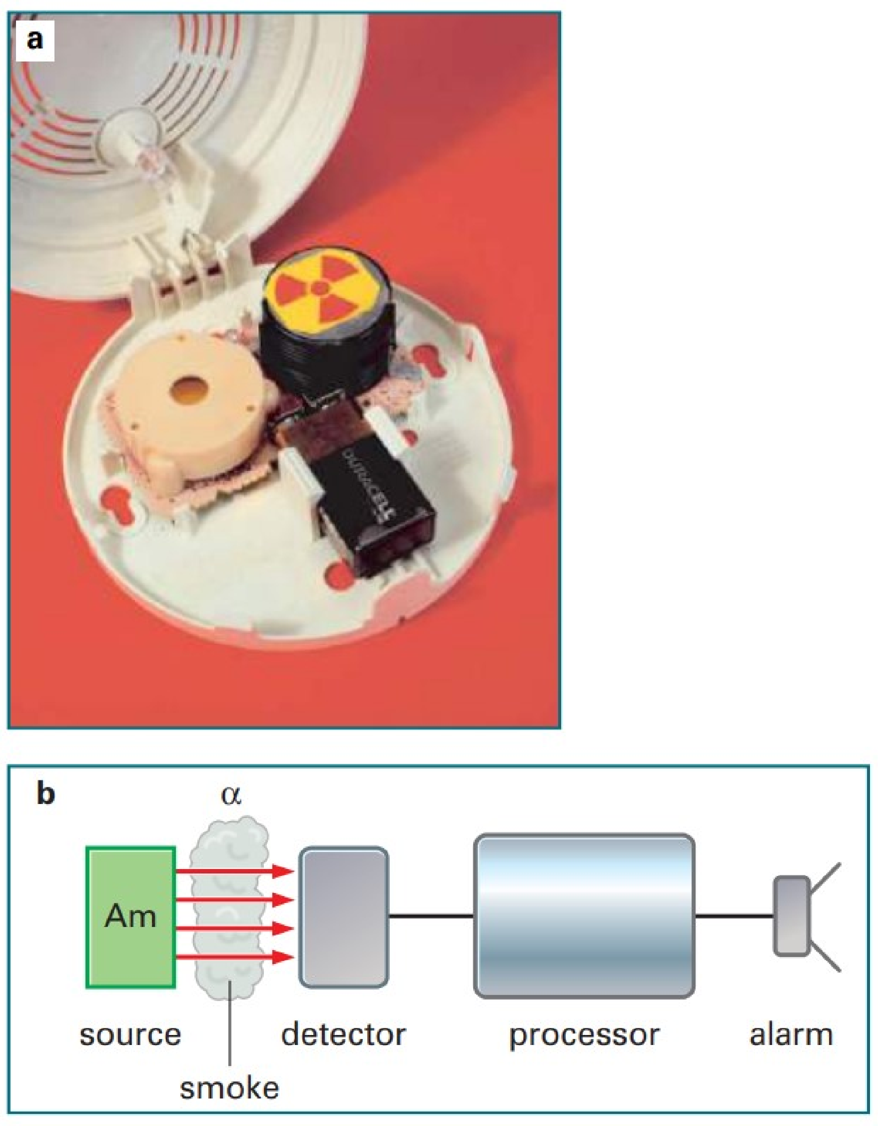
Uses of nuclear radiation

Effects of radioisotopes on cells

We are least likely to be harmed by alpha radiation coming from a source outside our bodies. This is because the radiation is entirely absorbed by the layer of dead skin cells on the outside of our bodies (and by our clothes).

However, if an alpha source gets inside us, it can be very damaging, because its radiation is highly ionising. That is why radon and thoron gases are so dangerous. We breathe them into our lungs, where they irradiate us from the inside. The result may be lung cancer.

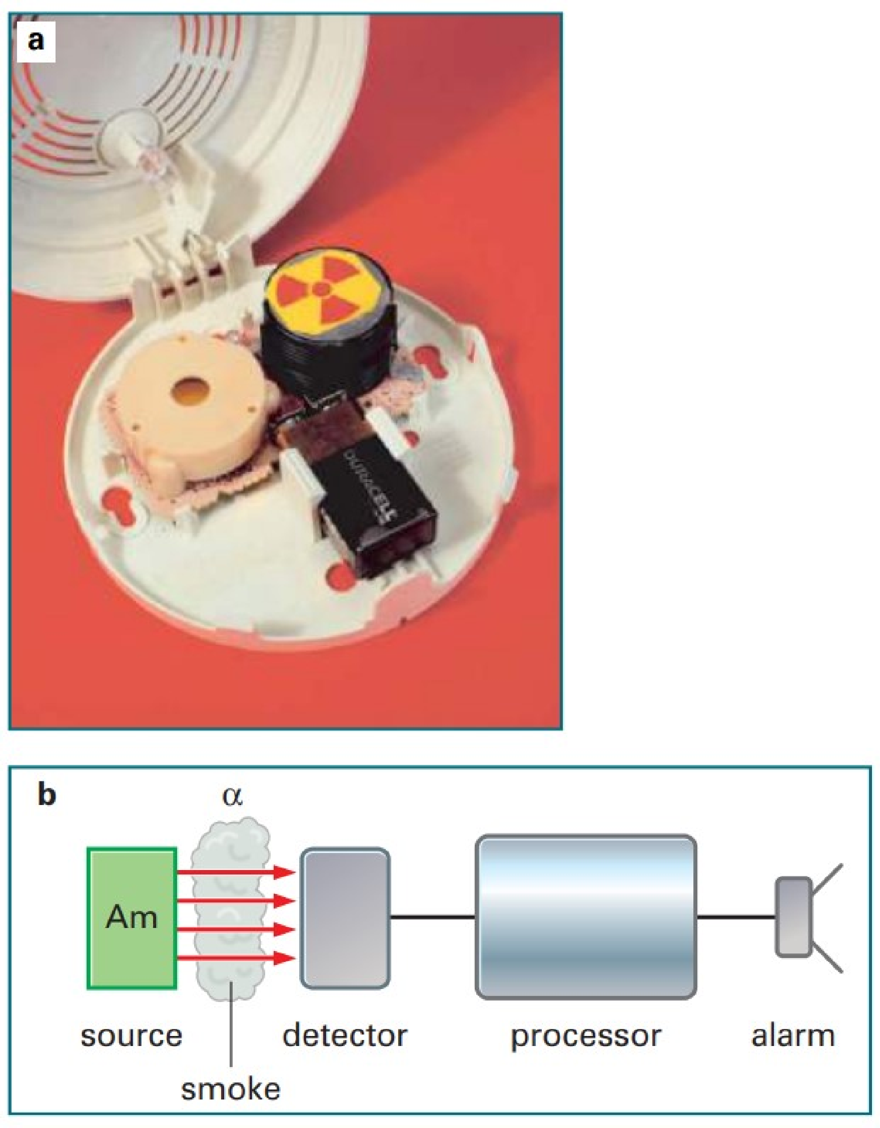
Uses related to penetrating power



Smoke detectors

These are often found in domestic kitchens, and in public buildings such as offices and hotels. If you open a smoke detector to replace the battery, you may see a yellow and black radiation hazard warning sign**. The radioactive material used is americium-241, a source of alpha radiation**.

Uses related to penetrating power



Smoke detectors

Radiation from the source falls on a detector. Since **alpha radiation is charged, a small current flows in the detector**. The output from the processing circuit is OFF, so the alarm is silent.

When smoke enters the gap between the source and the detector, it **absorbs the alpha radiation**. Now **no current flows** in the detector, and the processing circuit switches ON, sounding the alarm.

In this application, a source of alpha radiation is chosen because alpha radiation is easily absorbed by the smoke particles.

Uses related to penetrating power

Americium is a radioactive isotope.

Ionisation smoke detectors contain americium and two small electrodes with a small voltage between them. The air between the electrodes is ionised by α-particles so that there is a small electric current between the electrodes.

Suggest and explain the effect of smoke on the current between the electrodes in the smoke detector.

suggestion: ....

....

explanation: ....

.... [1]

[Total: 1]

Uses related to penetrating power

Americium is a radioactive isotope.

Ionisation smoke detectors contain americium and two small electrodes with a small voltage between them. The air between the electrodes is ionised by α-particles so that there is a small electric current between the electrodes.

Suggest and explain the effect of smoke on the current between the electrodes in the smoke detector.

suggestion: current cannot be formed (is stopped)

....

explanation: Alpha particles are absorbed by smoke

.... [1]

[Total: 1]

Uses related to penetrating power

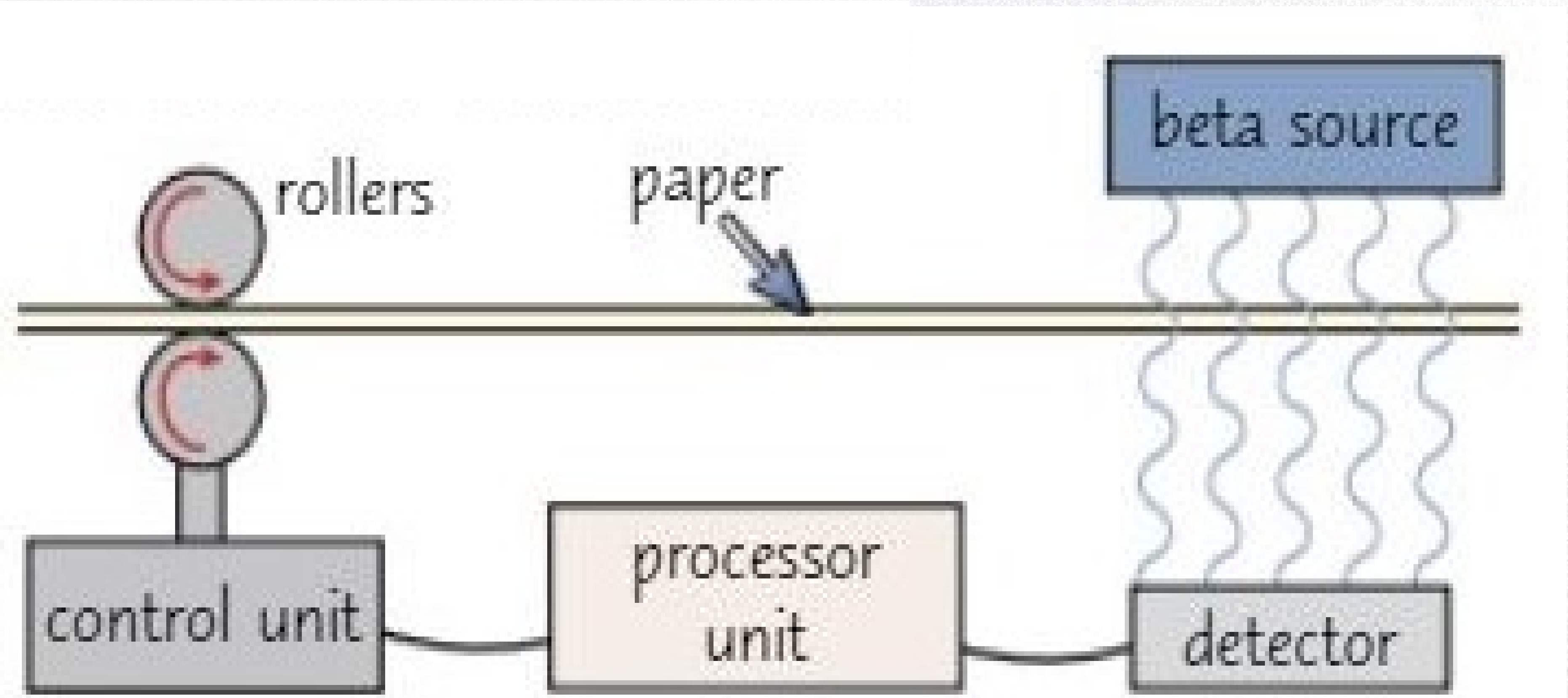
Thickness measurements

In industry, **beta radiation** is often used in measuring thickness. Manufacturers of paper need to be sure that their product is of **a uniform thickness**.

To do this, beta radiation is directed through the paper as it comes off the production line. A detector measures the amount of radiation getting through. If the paper is too thick, the radiation level will be low and an automatic control system adjusts the thickness. The same technique is used in the manufacture of plastic sheeting.

Beta radiation is used in this application because **alpha radiation would be entirely absorbed by the paper or plastic**. **Gamma radiation would hardly be affected, because it is the most penetrating.**

Uses of nuclear radiation



Uses related to penetrating power

Medical diagnosis

The diagnosis of some diseases may be carried out using **a source of gamma radiation**. The patient is injected with a radioactive chemical that targets the problem area (it may accumulate in bone, for example). Then a camera detects the radiation coming from the chemical and gives an image of the tissue under investigation.

Fault detection

Fault detection in manufactured goods sometimes makes use of **gamma rays**. In some **pipework**, **photographic film** is strapped to the outside of the pipe, and the radioactive source is placed on the inside. When the film is developed, it looks like an X-ray picture, and shows any faults in the welding.

Uses related to cell damage

Radiation therapy

The patient is receiving **radiation treatment as part of a cure for cancer**.
A source of gamma rays (or X-rays) is directed at the tumour that is to be destroyed. The source moves around the patient, always aiming at the tumour. In this way, other tissues receive only a small dose of radiation. **Radiation therapy** is often combined with **chemotherapy**, using chemical drugs to target and **kill the cancerous cells**.

Food irradiation

This is a way of **preserving food**. Food often decays because of the action of **microbes**. These can be killed using intense **gamma rays**. Because these organisms are single-celled, any cell damage kills the entire organism. Different countries permit different foods to be irradiated. The sterile food that results has been used on space missions (where long life is important) and for some hospital patients whose resistance to infection by microbes may be low.

Uses related to cell damage

Sterilisation

Sterilisation of medical products works in the same way as food irradiation. Syringes, scalpels and other instruments are sealed in plastic bags and then exposed to **gamma radiation**. Any microbes present are killed, so that, when the packaging is opened, the item can be guaranteed to be sterile. The same technique is used to sterilise sanitary towels and tampons.

Uses related to detectability

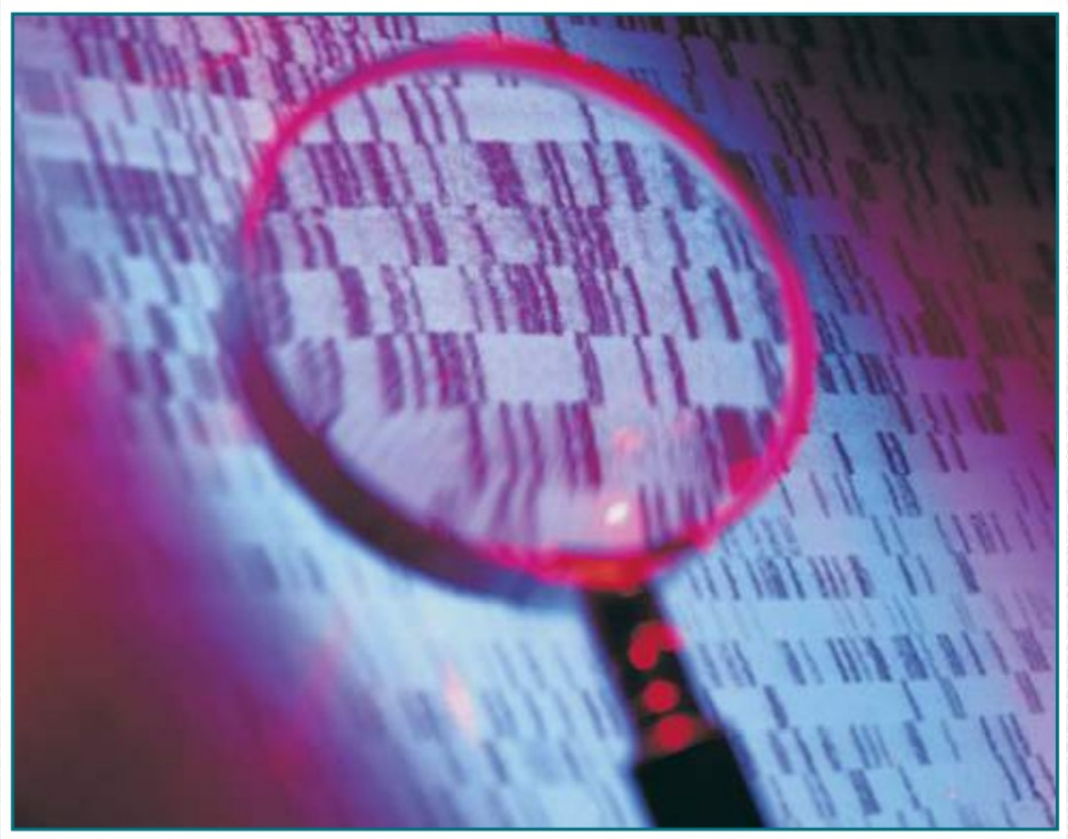
Radioactive tracing

Every time you hear a Geiger counter click, it has detected the radioactive decay of a single atom. This means that we can **use radiation to detect tiny quantities of substances**, far smaller than can be detected by chemical means. Such techniques are often known as radioactive tracing.

Radioactive labelling and genetic fingerprinting

Biochemists use **radioactively labelled chemicals** to monitor chemical reactions. The chemicals bond to particular parts of the molecules of interest, so that they can be tracked throughout a complicated sequence of reactions. The same technique is used to show up the pattern of a genetic fingerprint.

Uses related to detectability



A DNA (genetic) fingerprint appears as a series of bands. Each band comes from a fragment of DNA labelled with a radioactive chemical. The bands (and thus particular DNA fragments) show up on a photographic film.

Uses related to radioactive decay

Half-life and radiocarbon dating:
Because **radioactive substances decay at a rate** that we can determine, we can use them to discover how old objects and materials are. The best-known example of this is **radiocarbon dating**.

Most carbon is ${}^{12}_{6}C$ which is not radioactive. A tiny fraction is radioactive carbon-14 ${}^{14}_{6}C$, with a half-life of 5370 years (It emits beta radiation).

When a living organism dies, the carbon-14 in its body decays. *As time passes, the amount remaining decreases. If we can measure the amount remaining, we can work out when the organism was alive.*

There are two ways to measure the amount of carbon-14 present in an object:
- by measuring the **activity** of the sample using a detector such as a **Geiger counter**
- by **counting the number of carbon-14 atoms** using a **mass spectrometer**.

Uses related to radioactive decay

Half-life and radiocarbon dating: Other radioactive dating techniques

Geologists use a radioactive dating technique to find **the age of some rocks**. Many rocks contain a radioactive isotope, potassium-40, which decays by **beta emission** to a stable isotope of argon. Argon is a gas, and it is trapped in the rock as the potassium decays.

Here is how the dating system works. The rocks of interest form from molten material (for example, in a volcano). There is no argon in the molten rock because it can bubble out. After the rock solidifies, the amount of trapped argon gradually increases as the potassium decays. Geologists take a sample and measure the relative amounts of argon and potassium. The greater the proportion of argon, the older the rock must be.

Study questions

1. Explain why sources of alpha radiation cannot used to measure the thickness of aluminum.

Study questions

1. Explain why sources of alpha radiation cannot used to measure the thickness of aluminum.

Alpha radiation does not penetrate aluminum, so the reading on a detector wouldn't change as the thickness of the aluminum changes.

Study questions

2. Explain the difference between contamination and irradiation.

3. Give three safety measures that should be followed to avoid the risk of radiation.

Study questions

2. Explain the difference between contamination and irradiation.

Irradiation is when an object is exposed to radiation from a source. Contamination is when the source itself gets onto the object.

3. Give three safety measures that should be followed to avoid the risk of radiation.

- *handle sources with tongs*
- *use a robotic arm to handle sources*
- *stand behind a protective / lead shield*
- *in a different room/ keep sources in lead-lined boxes*

THANK YOU