C23

RADIOACTIVITY

CIE IGCSE PHYSICS for board 0625 and 0972
(For exam 2025+)

EXAM PAPERS PRACTICE

CHAPTER OUTLINE

23.1 Introduction

23.2 Radioactive decay

23.3 Activity and Half life

23.4 Using radioisotopes

23.5 Safety precautions on using radioactive materials

EXAM PAPERS PRACTICE

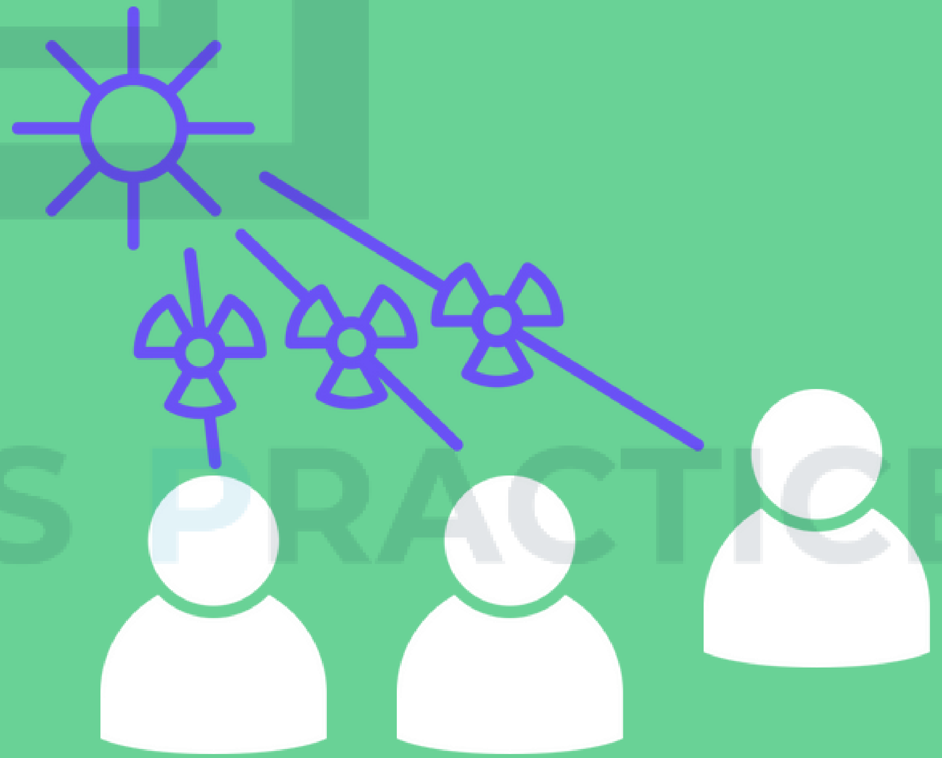
Radioactive Substance

A SUBSTANCE THAT DECAYS BY EMITTING RADIATION FROM ITS ATOMIC NUCLEI IS RADIOACTIVE.

CONTAMINATION

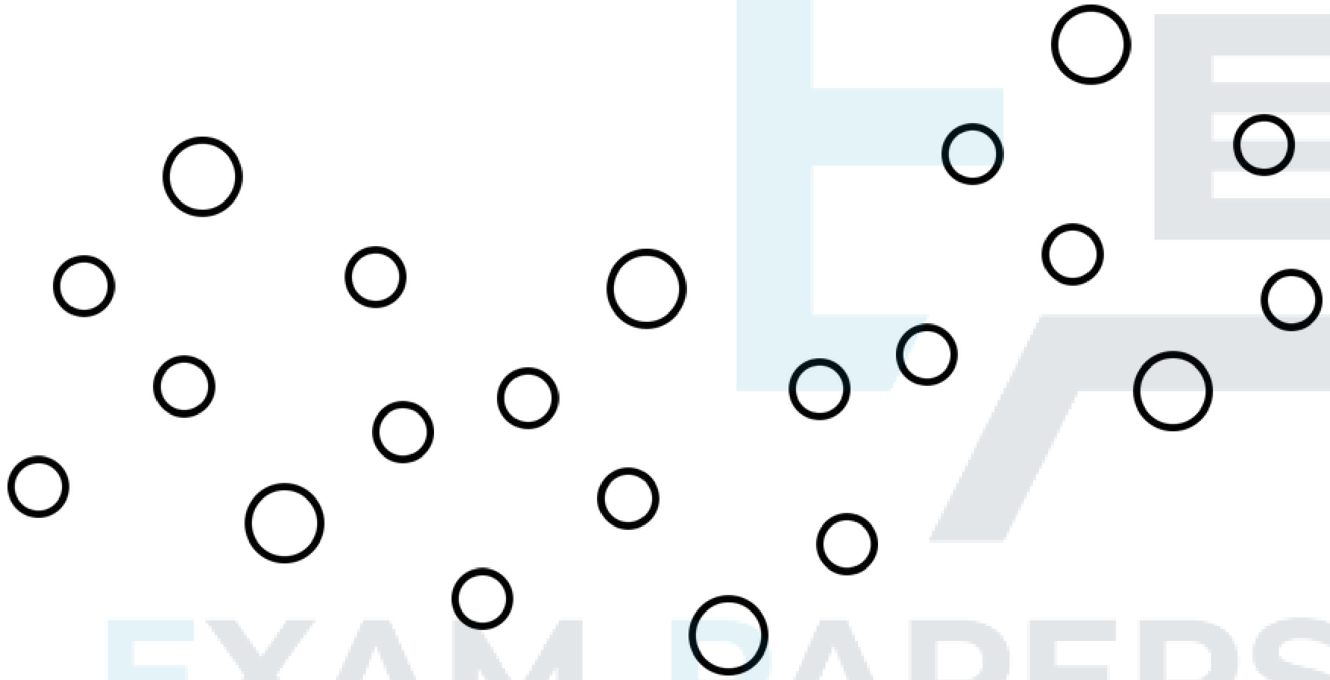
If a radioactive substance enters our bodies, its emitted radiation can cause harm, resulting in contamination.

IRRADIATION



Exposure to radiation or radioactive substances can also irradiate our bodies, leading to exposure to radiation doses.

23.1 NATURAL RADIATION SOURCE



1

The air contains a radioactive gas called radon, which originates from radioactive uranium rocks underground and seeps up to the Earth's surface.

2

Radioactive substances are present in the ground. When we use materials sourced from the ground for construction, such as building houses, we are exposed to radiation from these substances.

23.1

INTRODUCTION

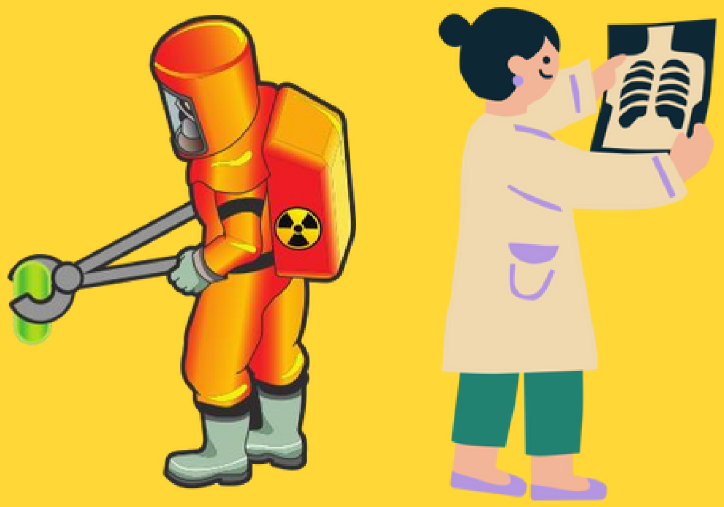
3

Radiation also reaches us from space in the form of cosmic rays.

Most radiation from artificial sources comes from medical sources.

X rays

Gamma rays for destroying cancer cells



Professionals such as medical radiographers and staff at nuclear power stations work directly with radiation as part of their duties.

Radiation can be measured using a Geiger counter. The Geiger counter records the rate at which radiation is detected. This rate is known as the count rate and is typically measured in counts per second (count/s) or counts per minute (count/min).

23.2

RADIOACTIVE DECAY

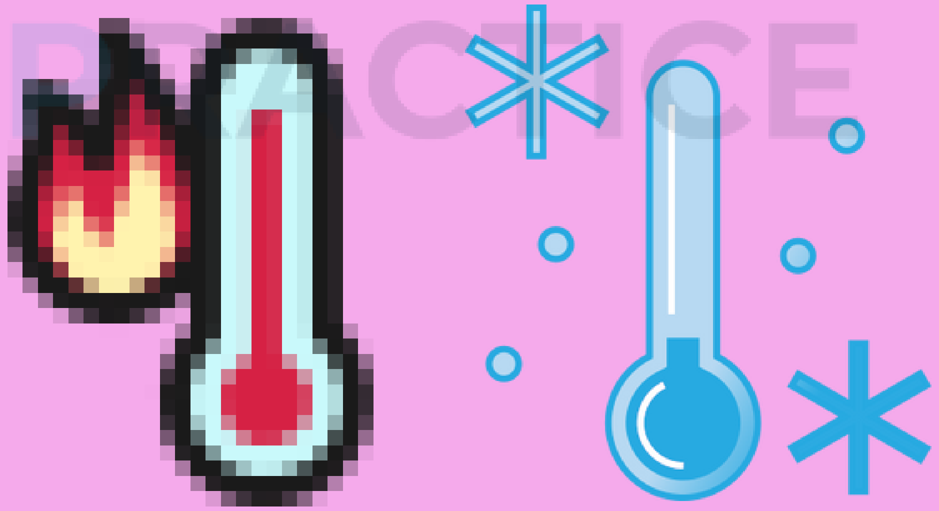
EXAM PAPERS PRACTICE

The process in which an unstable nucleus gives out radiation to become more stable.

Nucleus becomes unstable when they:

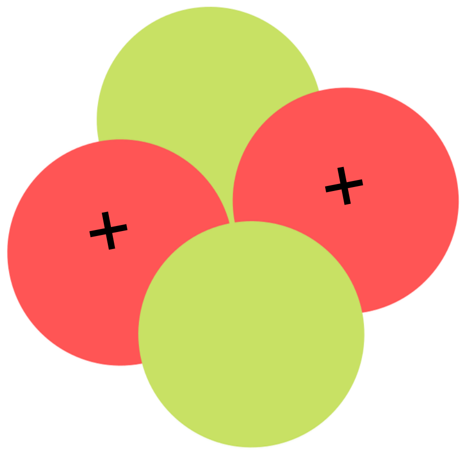
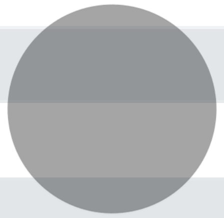
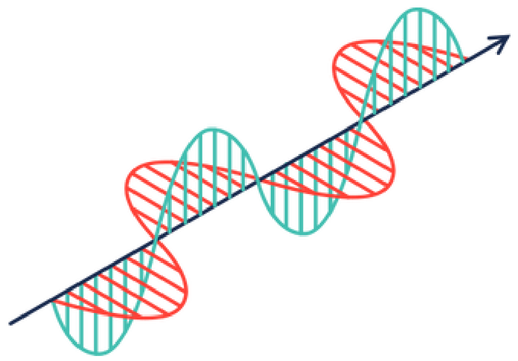
- Contains too many protons
- Contains too many electrons

Radioactive decay is a random process, and the direction in which radiation is emitted is also random.

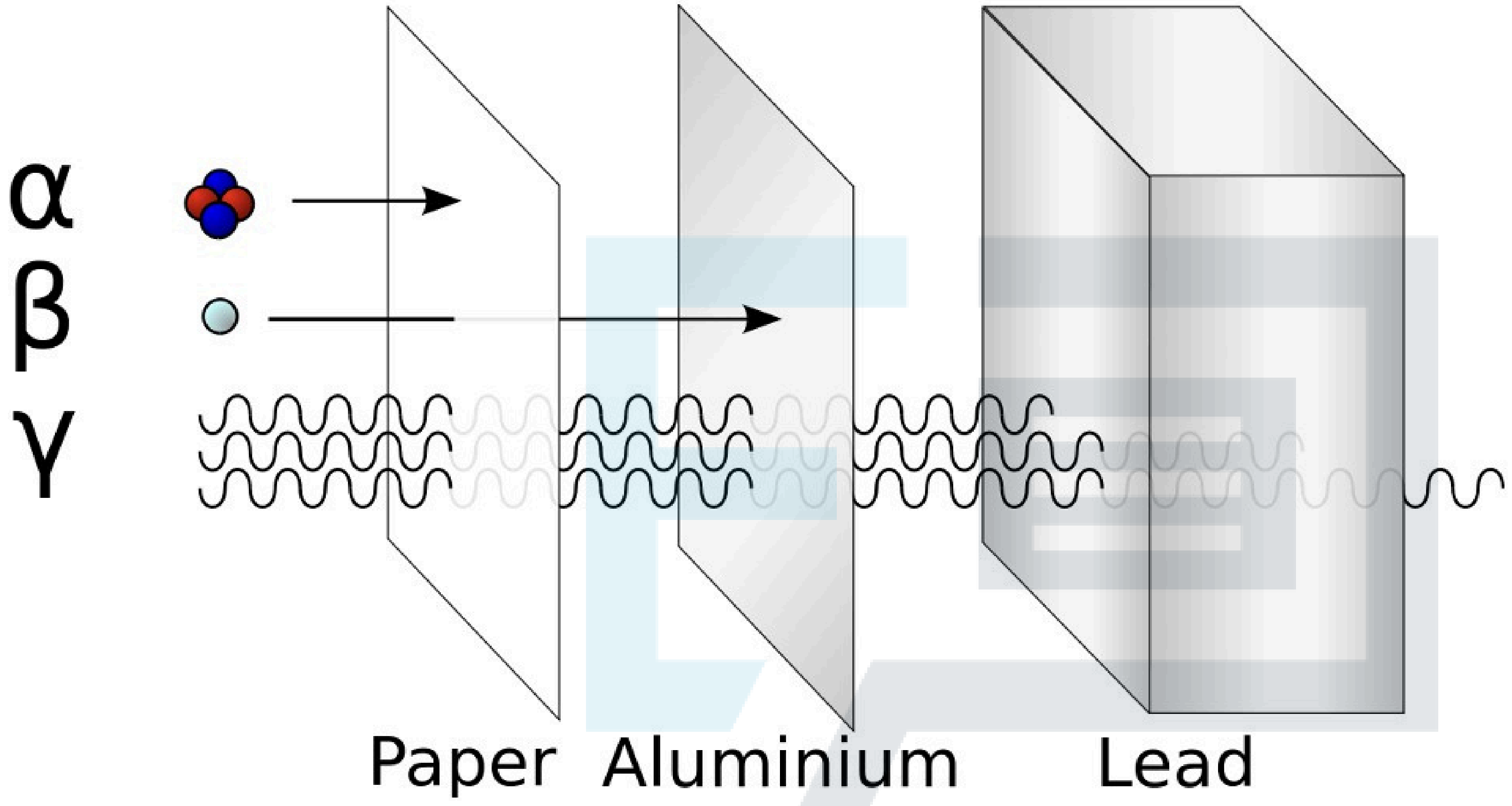


Radioactive decay is not influenced by external factors such as temperature.

THREE TYPES OF RADIATION

NAME	ALPHA PARTICLE	BETA PARTICLE	GAMMA RAYS
How does it look like?	 	 Beta Particle. It is an electron from inside the nucleus.	 It is a form of electromagnetic radiation with a very short wavelength and high frequency.
Symbol	α	β	γ
Made of	2 protons + 2 neutrons	An electron	Electromagnetic radiation
Charge	Positive	Negative	Neutral

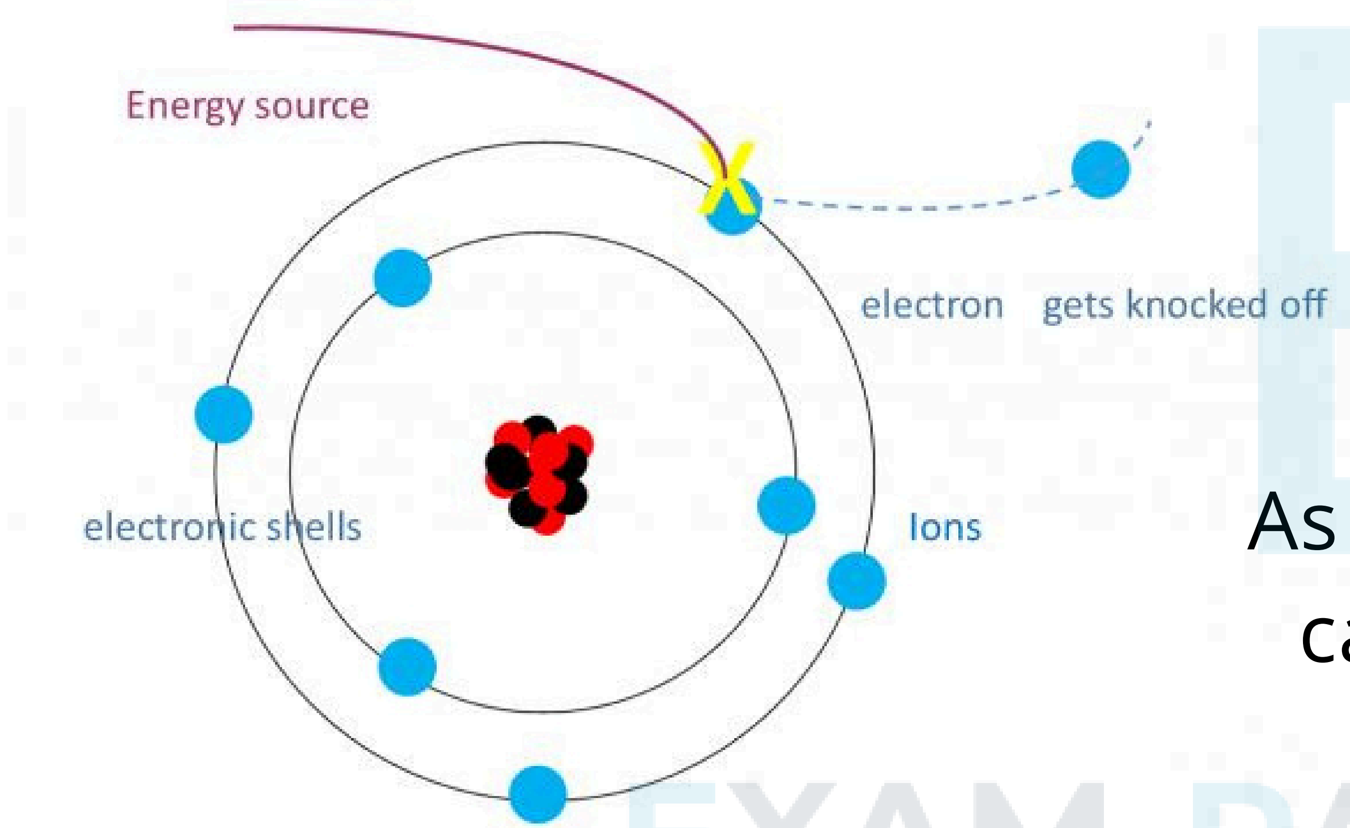
An atom of a radioactive substance can emit an α-particle, a β-particle, or a γ-ray as part of its decay process. When an atom of a radioactive substance decays by emitting an α-particle or a β-particle, it transforms into an atom of another element because the number of protons in the nucleus changes during the decay process.

<table>
<tr><th>NAME</th><th>ALPHA PARTICLE</th><th>BETA PARTICLE</th><th>GAMMA RAYS</th></tr>
<tr><td rowspan="2">Penetrating Power</td><td colspan="3">

Radiation can pass through solid materials. Different radiation can penetrate different thicknesses of materials.</td></tr>
<tr><td>•Alpha particles are easily absorbedand can be stopped by a thin sheet of paper.
•Alpha particles cannot penetrate the outer layer of human skin.</td><td>•Beta particles can travel relatively easily throughair or paper.
•They can be absorbedby a few millimeters of metal, such as aluminum.</td><td>• Gamma radiation is the most penetratingtype of radiation.
• It requires several centimeters of dense materials like lead, or several meters of concrete, to effectively absorb most gamma radiation.</td></tr>
</table>

NAME		ALPHA PARTICLE	BETA PARTICLE	GAMMA RAYS
Ionisation	Speed	3 x 107 m/s	2.9 x 10 8 m/s	3×10^8 m/s
	Mass	Mass of proton x 4	$\frac{\text{Mass of proton}}{1840}$	0
	Charge	+2	-1	0
	Description	• Slowest moving • Has the largest charge • May knock an electron from the air molecule, so it becomes charged. It then loses a little of its energy • α radiation is highly ionising, making it easily absorbed and the least penetrating.	• Less ionizing compared to alpha. ○ Less charge ○ Move faster, this means that it is more likely to travel straight past an air molecule without interacting with it • They can travel further in air without getting absorbed	• It is uncharged and moves fastest of all • Least readily absorbed in air • ~~Least ionizing~~ • γ-radiation is the least strongly ionizing, so it is the least easily absorbed and the most penetrating.

NAME	ALPHA DECAY	BETA DECAY
Radioactive Decay Equation	1. Thedecayofaradioactivenucleusby emitting an α-particle involves the emission of two protons and two neutrons. 2. Duringα-decay,theprotonnumber (atomic number) of the nucleus decreases by 2, and the nucleon number (mass number) decreases by 4. $${}^{241}_{94}Am \rightarrow {}^{237}_{92}U + {}^{4}_{2}He + \text{energy}$$ • This equation represents the decay of americium-241, the isotope used in smoke detectors. • Americium-241 emits an alpha particle (which is essentially a helium nucleus). • The proton number (atomic number) and nucleon number (mass number) must be conserved before and after the decay.	1. Thedecayofaradioactivenucleusby the emission of a β-particle. $${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \text{energy}$$ • This is the decay that is used in radiocarbon dating. • A carbon-14 nucleus decays to become a nitrogen-14 nucleus. • But where does the extra proton and electron come from? A single neutron split into a proton and an electron. $${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

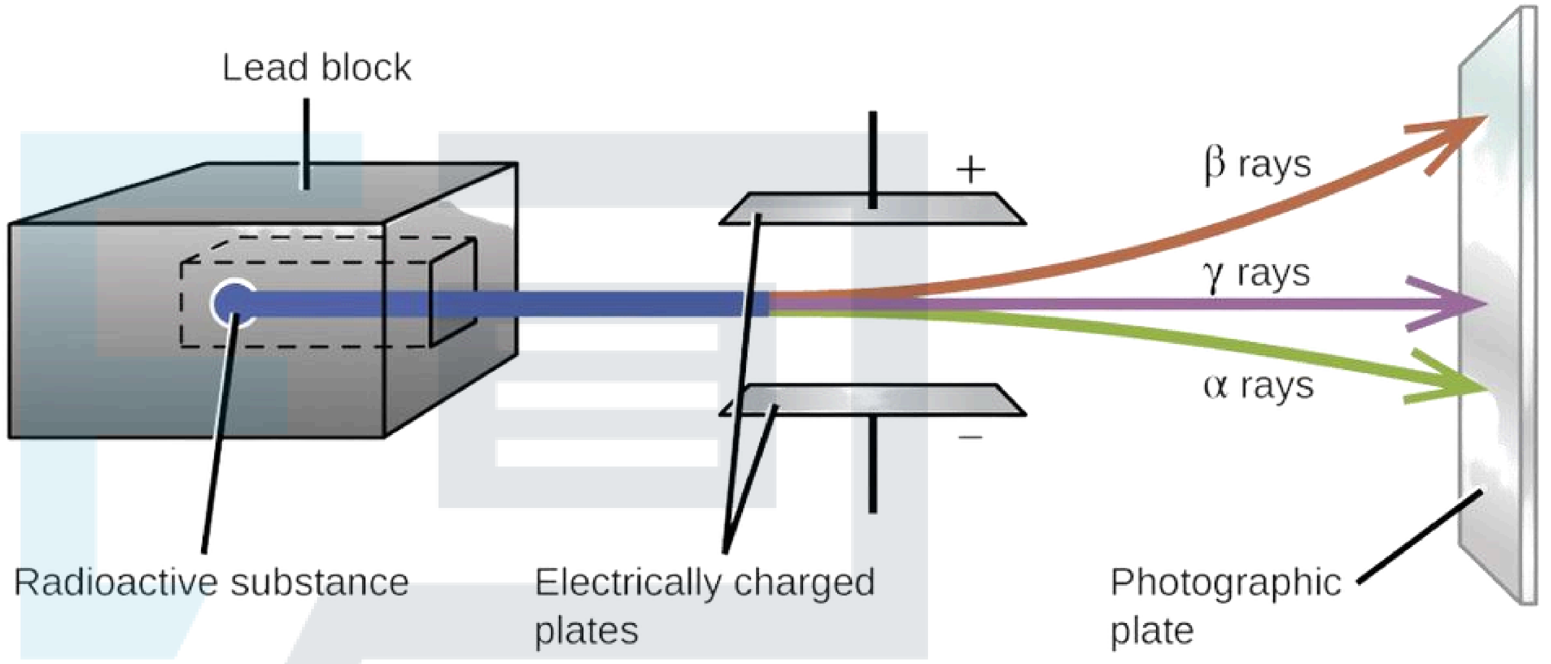


Radiation may knock electrons out of atoms. This means ions are formed. This is the process of ionization.

As radiation emitted by the nuclei of radioactive substances causes the ionization of the materials that absorb it, it is often known as ionizing nuclear radiation.

23.2 RADIOACTIVE DECAY

Experiment 1: We can tell the difference between the three types of radiation by looking at how they behave in an electric field.

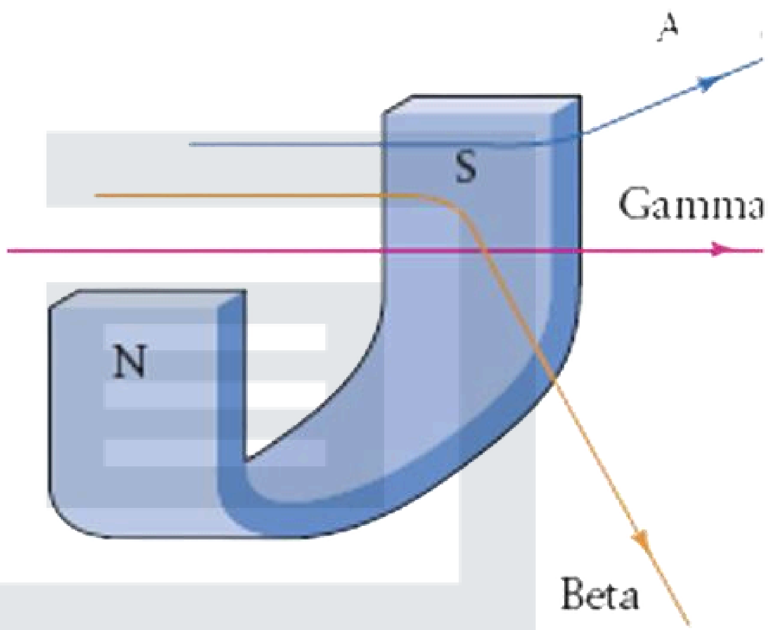


- Alpha (α) particles, which are positively charged, are attracted towards a negatively charged plate.
- Beta (β) particles, being negatively charged, are attracted towards a positively charged plate.
- Beta particles are more deflectable compared to alpha particles due to their lighter mass.
- Gamma (γ) rays remain undeflected as they are uncharged.

23.2

RADIOACTIVE DECAY

Experiment 2: We can tell the difference between the three types of radiation by looking at how they behave in a magnetic field.



- Alpha (α) particles and beta (β) particles carry electric charges, thus constituting an electric current when they move.
- Due to their opposite charges, they experience forces in opposite directions when in a magnetic field.
- The direction of deflection of these particles can be determined using Fleming's left-hand rule.

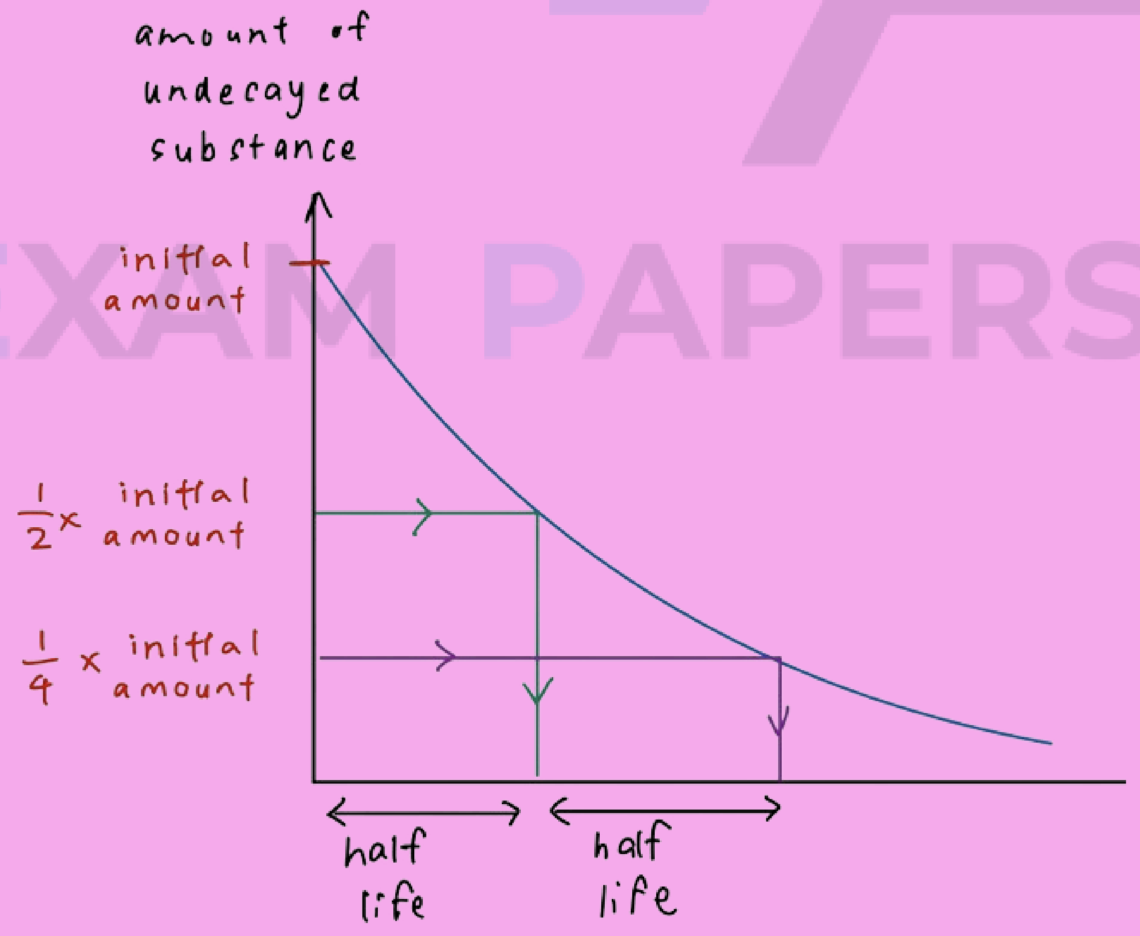
ACTIVITY AND HALF LIFE

EXAM PAPERS PRACTICE

Activity: The rate at which a radioactive source's nuclei decay.

Over time, the activity of a source decreases because as unstable nuclei decay and become stable, there are fewer remaining unstable nuclei, resulting in fewer decays per second.

Decay graph:

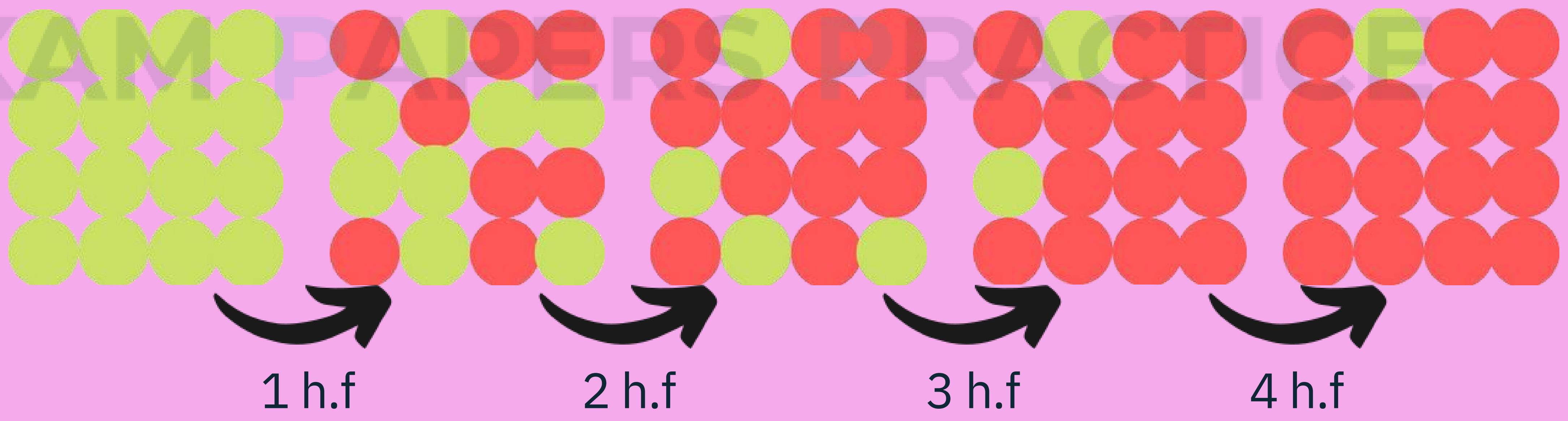


- The graph illustrates that the radioactive substance decreases rapidly initially, followed by a slower decline over time.
- As the graph shows a gradual tapering off, it becomes challenging to predict when the last atoms will decay precisely.
- Different radioactive substances decay at varying rates.

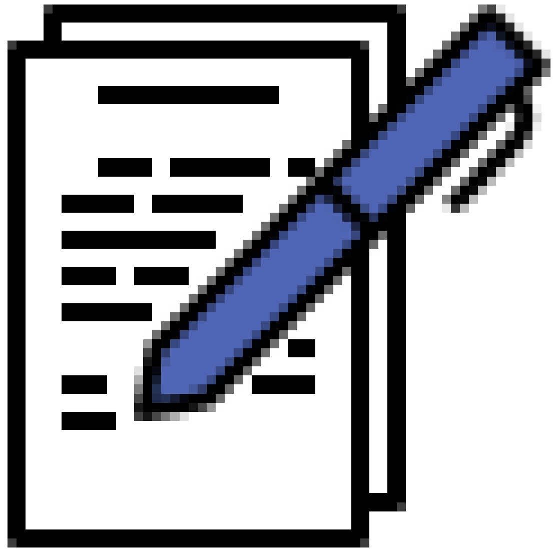
ACTIVITY AND HALF LIFE

The half-life of a radioactive isotope is defined as the average time taken for half of the atoms in a sample to decay, or alternatively, the time it takes for the activity or count rate of the sample to halve.

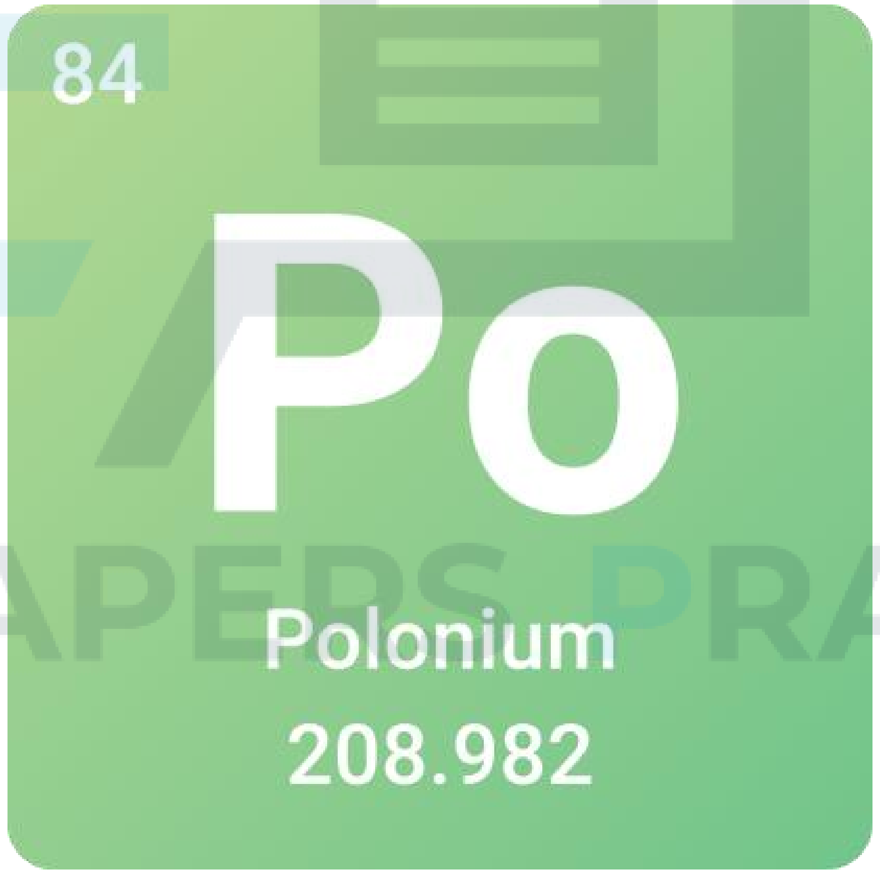
- After one half-life, half of the atoms in a radioactive sample have decayed.
- However, this does not mean that all of the atoms will have decayed after two half-lives.
- The idea of a half life is more like this:



WORKED EXAMPLE



Polonium-210 has a half-life of 138 days. The count rate of a sample is 552 count/s. How long will it take for the count rate to drop to 35 count/s?



SOLUTION

Polonium-210 has a half-life of 138 days. The count rate of a sample is 552 count/s. How long will it take for the count rate to drop to 35 count/s?

$$552 \xrightarrow{\text{138 days}} 276 \xrightarrow{\text{138 days}} 138 \xrightarrow{\text{138 days}} 69 \xrightarrow{\text{138 days}} 34.5$$

Answer: 138 x 4 = 552 days

EXAM PAPERS PRACTICE

1. The count rate recorded by a Geiger counter typically includes both the background radioactivity and the count rate from the radioactive source. In many cases, the background count is minimal compared to the activity of the source.
2. If the background count is being considered, it should be subtracted from the Geiger counter measurements.

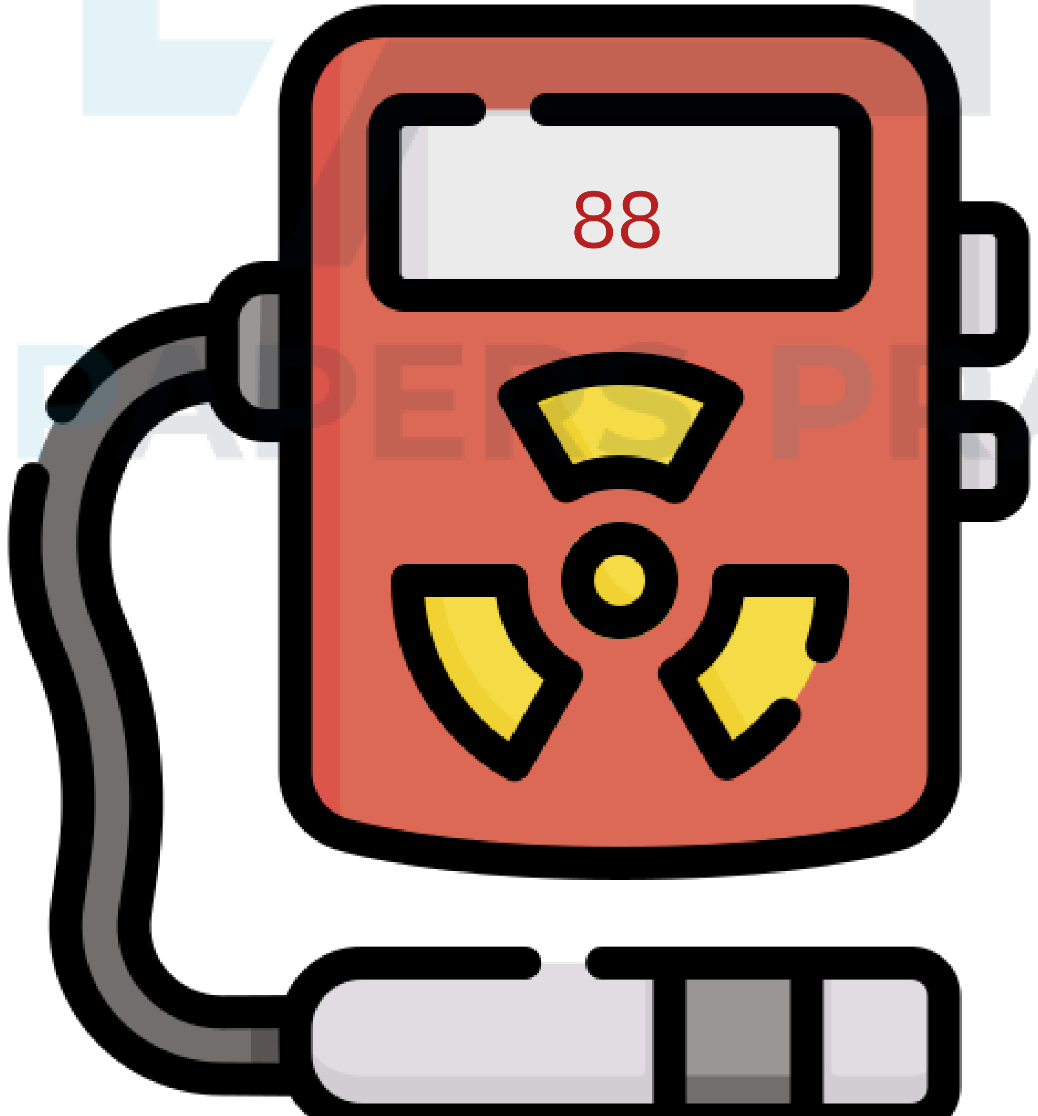
> corrected count rate =
> measured count rate – background count rate

PAST YEAR QUESTION

EXAM PAPERS PRACTICE

The count rate of a radioactive material is measured using a detector. The reading on the detector is 88 counts per second. The background count rate is 40 counts/second.

The half-life of the radioactive substance is 12 hours. What is the reading on the detector after 24 hours?



SOLUTION

The count rate of a radioactive material is measured using a detector. The reading on the detector is 88 counts per second. The background count rate is 40 counts/second.

The half-life of the radioactive substance is 12 hours. What is the reading on the detector after 24 hours?

Step 1: Find corrected count rate

88 -40 = 48 counts / seconds

Step 2: Find the readings on the detector after 24 hours

$$48 \xrightarrow{\text{12 hours}} 24 \xrightarrow{\text{12 hours}} 12$$

Answer: (12+ 40) 52 counts / second

EXAM PAPERS PRACTICE

Smoke detectors

The radioactive material in a smoke detector is Americium-241, which emits α-radiation and has a half-life of 430 years. This means that the detector's count rate for this substance will remain fairly consistent over the duration of its use.

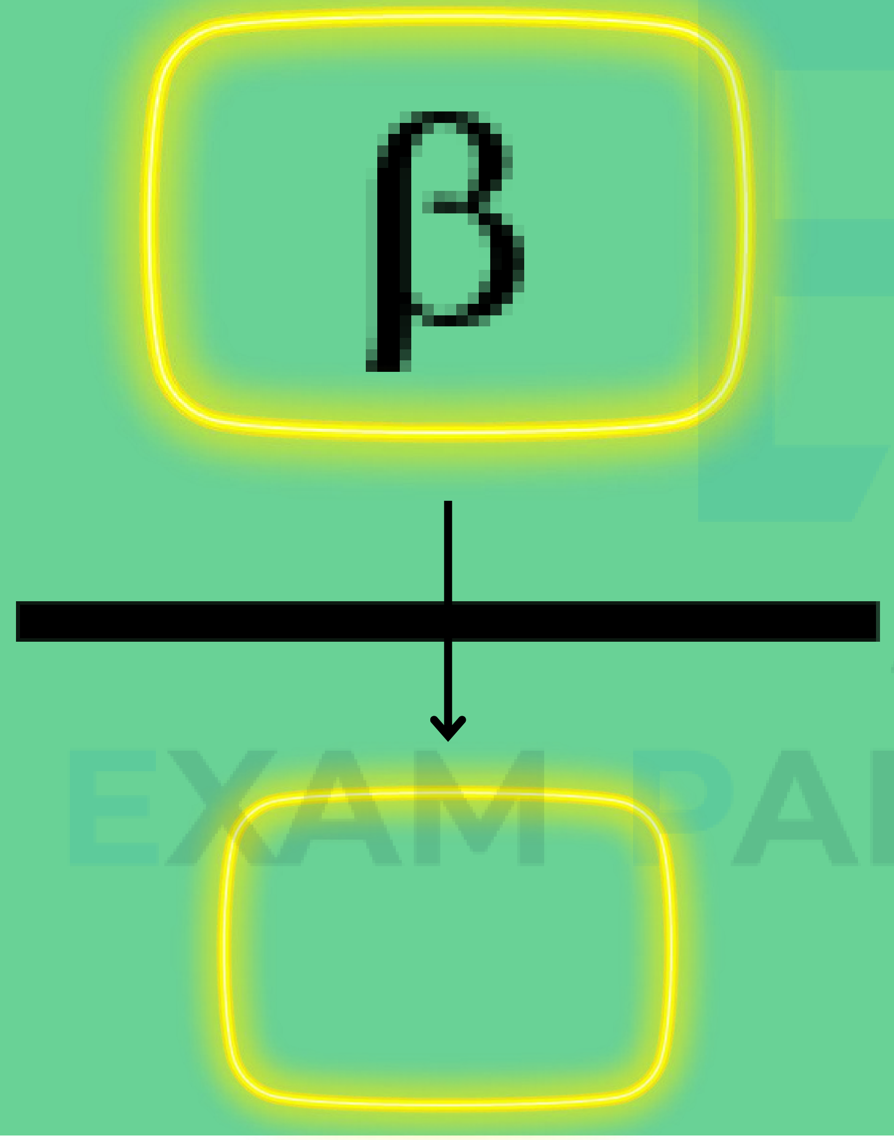
How it works

A smoke detector works by using a small amount of radioactive material (usually americium-241) that emits alpha particles. When smoke enters, it interrupts the alpha particles' path, causing a drop in electrical conductivity in the detector, triggering an alarm to alert of potential fire.

EXAM PAPERS PRACTICE

Thickness measurement

In industry, β-radiation is often used in to measure thickness.



How it works

Beta radiation is used to measure paper thickness by emitting beta particles through a radioactive source towards the paper. A detector on the opposite side measures the intensity of beta particles that pass through. Thicker paper absorbs more beta particles, resulting in a lower detected intensity, providing a measurement of paper thickness.

Out of the three types of radiation, β-radiation is the most suitable.α-particle would be absorbed entirely by the paper, γ -ray and would hardly be affected, because it is the most penetrating.

Cancer treatment

How it works

Gamma rays in cancer treatment, often emitted from a radioactive source like cobalt-60 or produced by linear accelerators, target and destroy cancerous cells. These high-energy rays penetrate deeply into the body, damaging DNA within cancer cells to inhibit their growth and ultimately lead to cell death, helping to shrink tumours and manage cancer.

EXAM PAPERS PRACTICE

Food irradiation

How it works

Gamma rays in food irradiation are generated from a radioactive source such as cobalt-60 or cesium-137. These rays penetrate food products, disrupting the DNA of bacteria, insects, and other pathogens, which reduces spoilage and extends shelf life. The process does not make food radioactive but enhances safety by reducing harmful microorganisms and pests.

EXAM PAPERS PRACTICE

Sterilization

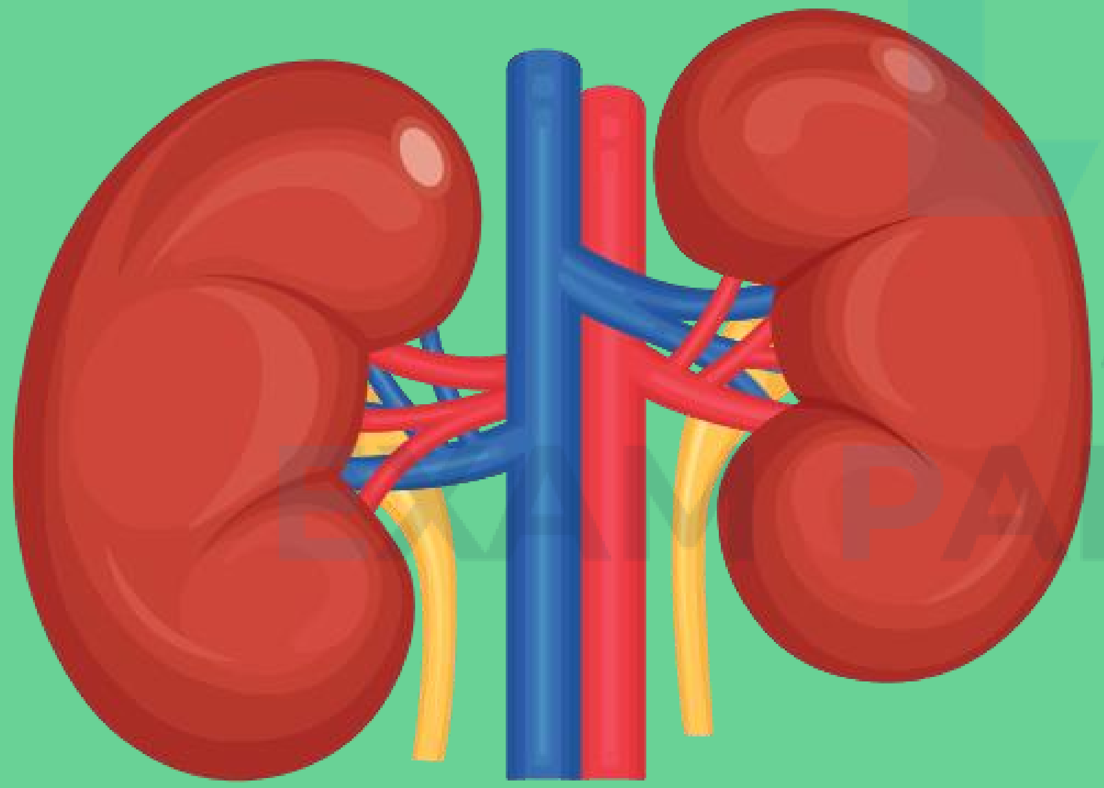
How it works

Gamma rays ensure sterilization of medical equipment by penetrating packaging and material to destroy microorganisms' DNA. Using a gamma radiation source, such as cobalt-60, items are exposed to controlled doses that eliminate bacteria, viruses, and spores. This method ensures high effectiveness without heat or chemical residues, crucial for medical safety.

EXAM PAPERS PRACTICE

Medicine

Some diseases can be diagnosed using γ-radiation. A radioactive chemical is injected into the patient, and a scanner tracks its movement.



Eg. Identify kidney blockage

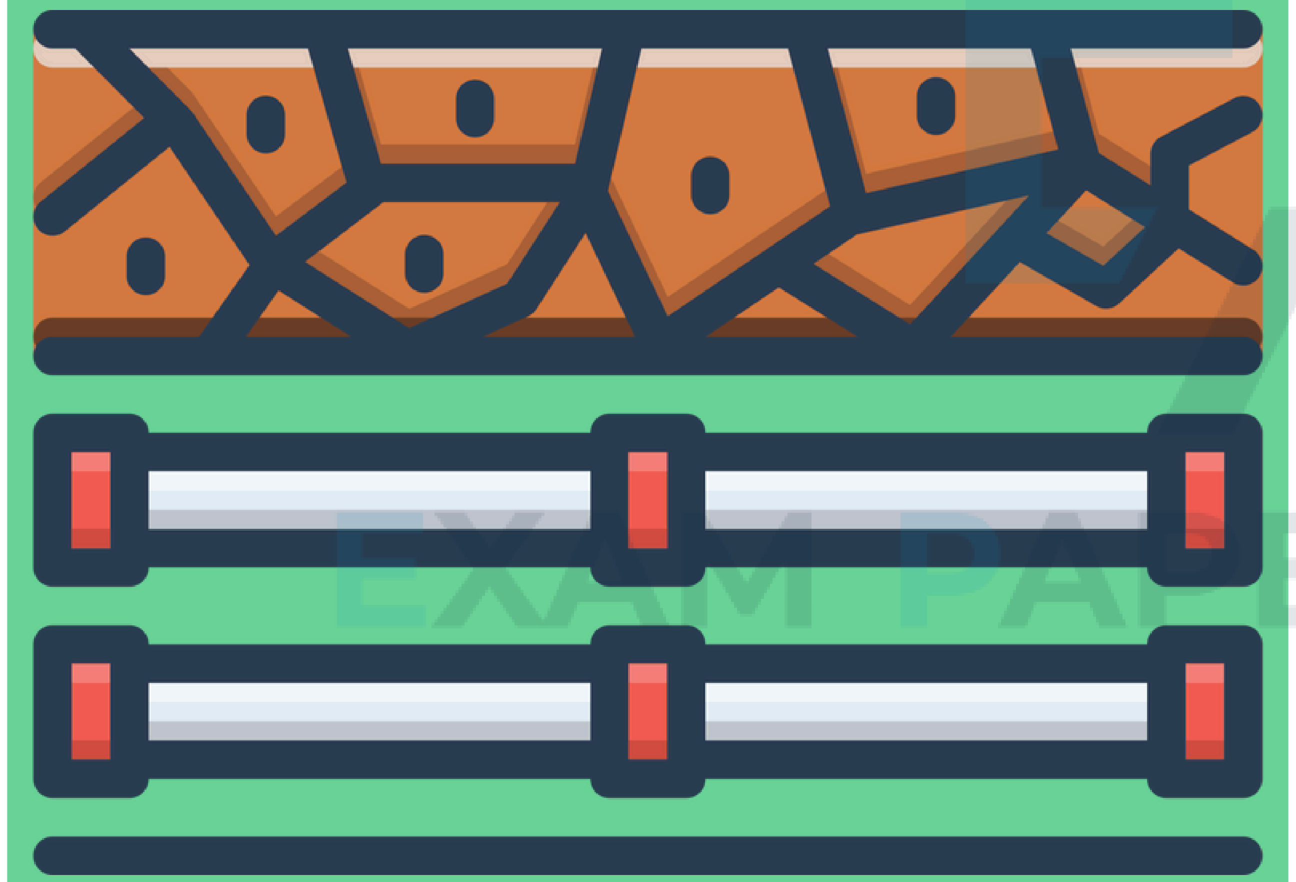
T

To detect kidney blockage, technetium-99, a radioactive tracer, is injected into the bloodstream. If there's a blockage in the kidney, the tracer won't pass through, signaling the presence of a blockage. Technetium-99 has a short half-life, ensuring safety during this diagnostic procedure.

EXAM PAPERS PRACTICE

Engineering

Engineers may want to trace underground water flow.



How it works

To prevent toxic water from a new waste dump from contaminating the local water supply, engineers employ a method where water containing a radioactive substance is injected into a deep hole under high pressure. The movement of this water through underground fissures is then monitored using a γ-detector at ground level. This approach enables engineers to monitor water flow and pinpoint potential pathways that might lead to contamination of the local water supply.

EXAM PAPERS PRACTICE

Radiocarbon dating

Radiocarbon dating is a method used to determine the age of organic materials by measuring the decay of the radioactive isotope carbon-14.

There are two ways to measure the amount of carbon-14 present in an object:

1. Use a detector, such as a Geiger counter, to measure the level of activity in the sample.
2. By counting the number of carbon-14 atoms using a mass spectrometer

How it works

Carbon exists in all living organisms, and upon their death, the carbon-14 within their bodies starts to undergo decay. As time passes, the quantity of carbon-14 in the organism diminishes. By understanding carbon-14's half-life (5700 years), scientists can gauge the remaining amount of carbon-14 in the organism and approximate its age when it was alive. This method is widely applied in archaeology and other disciplines to determine the age of various materials and artifacts.

Two challenges with radiocarbon dating are variations in the amount of carbon-14 present in the atmosphere in the past and the additional carbon-14 introduced into the atmosphere from nuclear weapons testing during the 1950s and 1960s.

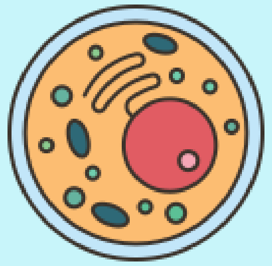
23.5

SAFETY PRECAUTIONS ON USING RADIOACTIVE MATERIALS

Any element comes in several forms or isotopes.
Unstable isotopes are known as radioisotopes.

There are 3 ways radiation can damage living cells.

KILLING A CELL

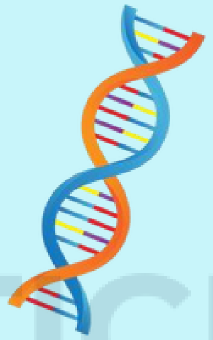


When someone experiences radiation burns, a high dose of radiation causes extensive ionization within cells, potentially resulting in cell death. This damage occurs when cells are exposed to significant radiation levels, leading to the development of radiation burns.

CAUSE CANCER

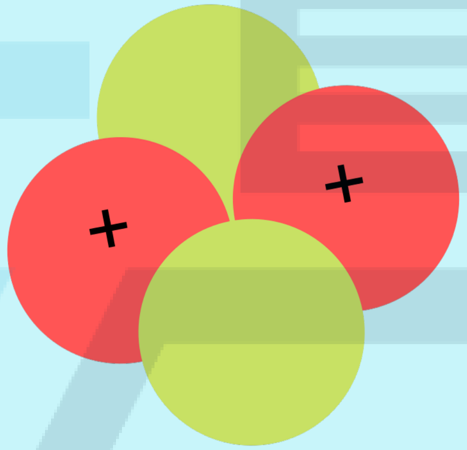
Damage to the DNA within the cell nucleus can disrupt the cell's regulatory mechanisms. This disruption may lead to uncontrolled cell division, potentially resulting in the formation of a tumor.

GENETIC MUTATIONS



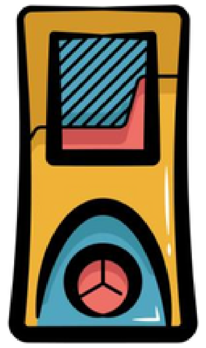
If a gamete is affected by radiation and its DNA is damaged, this damage can potentially be passed on to future generations. This may result in genetic mutations that could cause developmental issues in a fertilized egg or lead to the birth of a baby with a genetic disorder.

ALPHA PARTICLES



Alpha particles pose the least external harm due to their low penetration capability, typically being stopped by the outer layer of dead skin. However, if an alpha-emitting source enters the body, it can cause significant damage because of its high ionisation potential. Inhaling radon and thoron gases can lead to internal radiation exposure in the lungs, potentially resulting in lung cancer.

23.5 SAFETY PRECAUTIONS ON USING RADIOACTIVE MATERIALS

Safety precaution	Explanation
Workers in contaminated areas wear protective suits 	Radiation can be absorbed by protective suits, and the choice of materials varies based on the type of radiation. For gamma rays, suits lined with lead are commonly used to provide effective shielding.
Radioactive hazard labels 	These warning signs inform individuals about the potential hazard, allowing them to maintain a safe distance and limit their exposure time to the source.
Photographic film dosimeter badges 	These devices are employed to monitor the amount of radiation exposure a person receives. When a safe limit is reached, workers may need to be relocated to different areas to minimize further exposure.

23.5 SAFETY PRECAUTIONS ON USING RADIOACTIVE MATERIALS

Safety precaution	Explanation
Record keeping 	Schools must document the duration of use and personnel responsible for radioactive sources to prevent excessive exposure.
Remote operating of scanners 	The scanner operator usually operates the scanner from a remote location, which increases the distance between them and the radiation source. Additionally, they may be shielded by a screen or barrier that absorbs some of the radiation, further minimizing exposure.
Storage boxes for sources	Radioactive sources should be stored safely, often within lead containers to absorb the majority of radiation emitted.

A student carried out an experiment to find the half-life of a radioactive substance.
Their results are shown in the table below.

time (seconds)	count-rate from source (counts per second)
0	300
20	200
40	150
60	100
80	75

What is the half-life of this substance?

A 20 seconds.

B 40 seconds

C 60 seconds

D 80 seconds

A student carried out an experiment to find the half-life of a radioactive substance.
Their results are shown in the table below.

time (seconds)	count-rate from source (counts per second)
0	300
20	200
40	150
60	100
80	75

What is the half-life of this substance?

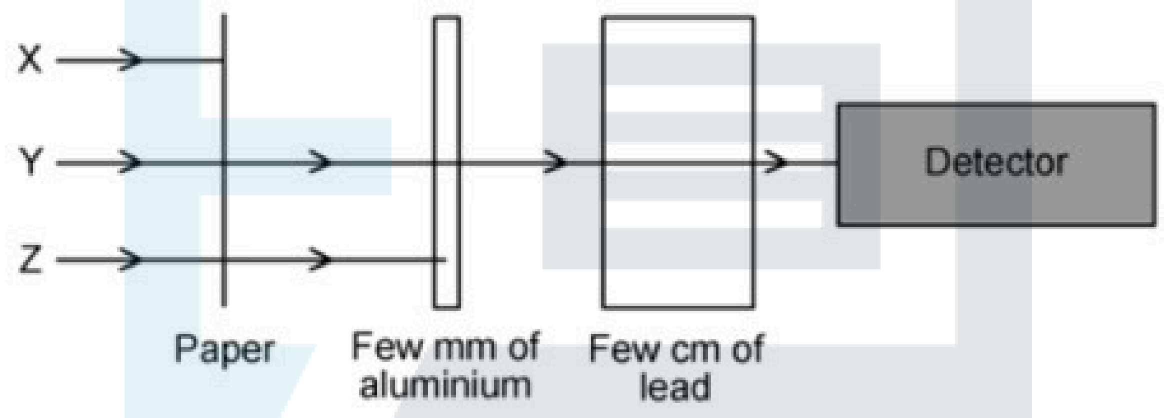
A 20 seconds.

B 40 seconds

C 60 seconds

D 80 seconds

A student has three radioactive sources **X**, **Y** and **Z**. They devised the following experiment to determine what type of radiation each source is emitting.

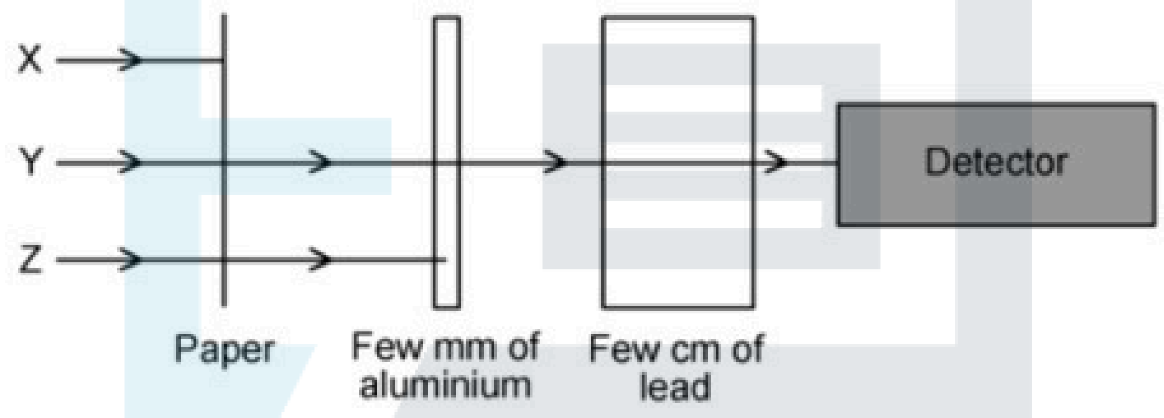


The student found that the radiation from **X** was stopped by a sheet of paper, **Y** was partially stopped by a few cm of lead and **Z** was stopped by a few mm of aluminium.

Which of the following correctly identifies each type of radiation

	X	Y	Z
A	α-particle	β-particle	γ-ray
B	α-particle	γ-ray	β-particle
C	γ-ray	β-particle	α-particle
D	β-particle	γ-ray	α-particle

A student has three radioactive sources **X**, **Y** and **Z**. They devised the following experiment to determine what type of radiation each source is emitting.



The student found that the radiation from **X** was stopped by a sheet of paper, **Y** was partially stopped by a few cm of lead and **Z** was stopped by a few mm of aluminium.

Which of the following correctly identifies each type of radiation

	X	Y	Z
A	α-particle	β-particle	γ-ray
B	α-particle	γ-ray	β-particle
C	γ-ray	β-particle	α-particle
D	β-particle	γ-ray	α-particle

Which statement is **not** a method used to minimise the risk caused by working with radioactive sources.

A Store the sources in lead-lined boxes.

B Minimise the amount of time spent handling the sources.

C Keep the source cold.

D Keep the source as far away as possible, for example, using a pair of tongs.

Which statement is **not** a method used to minimise the risk caused by working with radioactive sources.

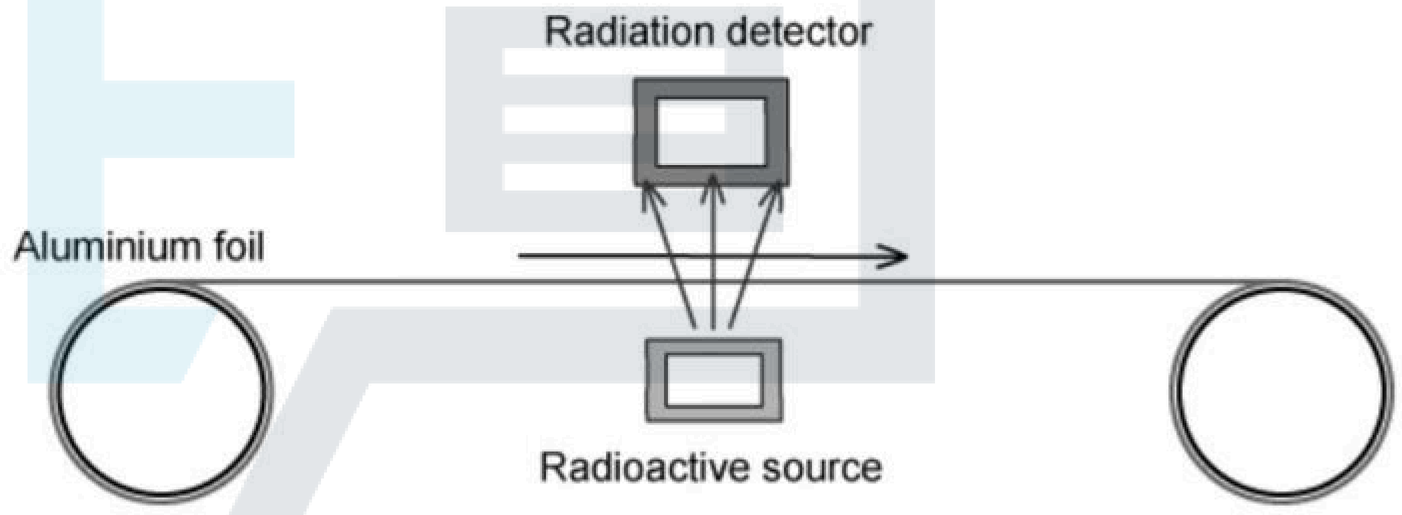
A Store the sources in lead-lined boxes.

B Minimise the amount of time spent handling the sources.

C Keep the source cold.

D Keep the source as far away as possible, for example, using a pair of tongs.

Radioactive sources are often used in industry as part of manufacturing processes. The diagram below shows radiation being used to measure the thickness of a sheet of aluminium foil. The detector feeds back to the rollers to adjust the thickness.



What type of radiation would be the most suitable for this purpose?

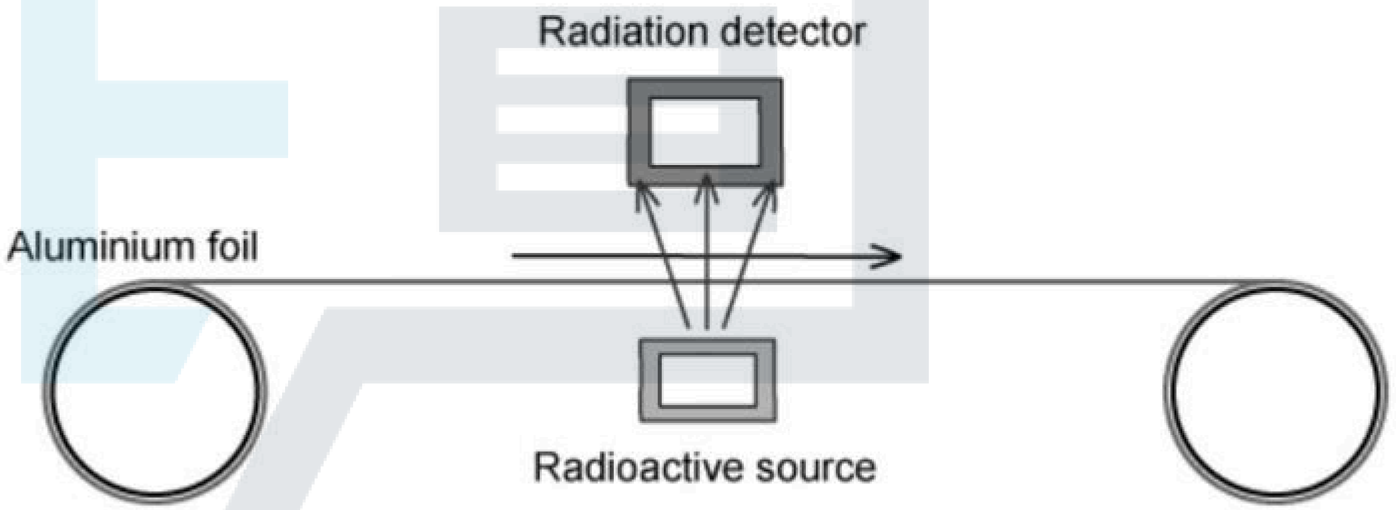
A α-particles

B β-particles

C γ-rays

D All of the above.

Radioactive sources are often used in industry as part of manufacturing processes. The diagram below shows radiation being used to measure the thickness of a sheet of aluminium foil. The detector feeds back to the rollers to adjust the thickness.



What type of radiation would be the most suitable for this purpose?

A α-particles

B β-particles

C γ-rays

D All of the above.

An nucleus of Uranium (${}^{238}_{92}U$) is unstable and decays by emitting an α-particle.

Which equation correctly describes this process?

A ${}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{90}Th$

B ${}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{90}U$

C ${}^{238}_{92}U + {}^{4}_{2}\alpha \rightarrow {}^{234}_{90}Th$

D ${}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{88}Ra$

An nucleus of Uranium (${}^{238}_{92}U$) is unstable and decays by emitting an **α**-particle.

Which equation correctly describes this process?

A $\;{}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{90}Th$

B $\;{}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{90}U$

C $\;{}^{238}_{92}U + {}^{4}_{2}\alpha \rightarrow {}^{234}_{90}Th$

D $\;{}^{238}_{92}U \rightarrow {}^{4}_{2}\alpha + {}^{234}_{88}Ra$

A radioactive substance has a half-life of 4 days.

It is currently emitting 8000 β-particles per minute.

How many β-particles will it emit per minute after 12 days?

A 4000

B 2000

C 1000

D 667

A radioactive substance has a half-life of 4 days.

It is currently emitting 8000 β-particles per minute.

How many β-particles will it emit per minute after 12 days?

A 4000

B 2000

C 1000

D 667