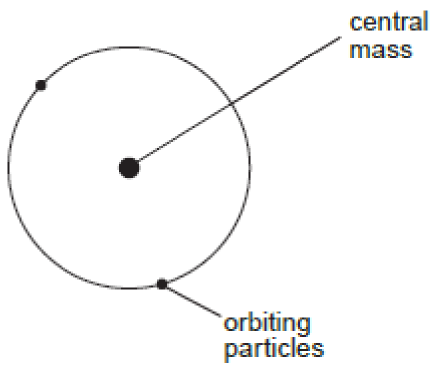
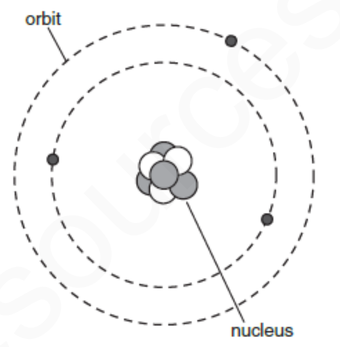
# THE ATOM

**Structure of an atom:**

- We cannot predict when an individual nucleus will decay.
- We cannot exactly predict how many nuclei will decay in a given time.




STRUCTURE OF AN ATOM

**Central mass:**

- The atom consists of a central mass which is made of protons and neutrons.
- The protons are positively charged and the neutrons are neutral.

**Orbiting particles:**

- The orbiting particles are called as electrons.
- They are negatively charged.

**Nuclear force:**

Protons and neutrons are bound together tightly in the nucleus by the strong nuclear force.

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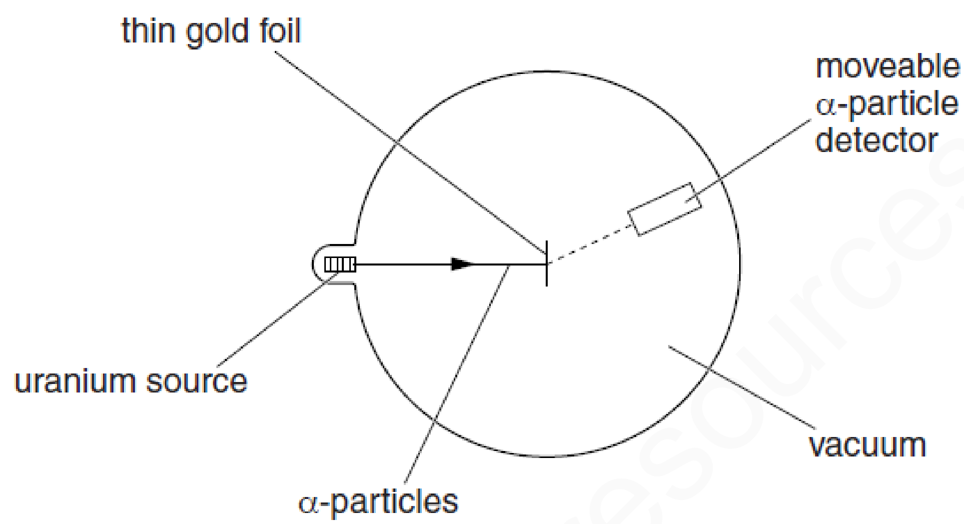
## The $\alpha$ particle scattering experiment:-Evidence for nuclear atoms

A very thin sheet of gold was placed in the path of alpha particles. A moveable detector was placed in different positions and observations were recorded.




**Observations:**

- A large number of alpha particles passed through the sheet with little or no deflection from their original path
- A very small number of alpha particles were reflected back towards the source.
- The direction of motion of the alpha particle changes when it comes close to the nucleus of a gold atom. This is because of repulsion between them as , both the alpha particle and gold nucleus are positively charged.

**The conclusions of the experiment:**

- The nucleus is very small or most of the atom is empty( as most of the particles passed through the sheet.)
- The nucleus is positively charged ( or it has all the positive charge of the atom).
- Nucleus is heavy . It has most of the mass of the atom.

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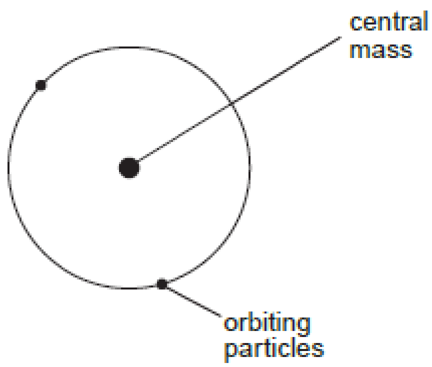
**Formation of ions:**

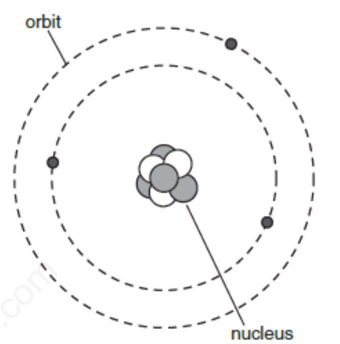
Many atoms form positive ions by losing electrons and form negative ions by gaining electrons

# THE NUCLEUS

**Structure of an atom:**

- We cannot predict when an individual nucleus will decay.
- We cannot exactly predict how many nuclei will decay in a given time.




**Representation of the atomic nucleus :**

- Atomic nucleus can be represented by $^{A}X_{Z}$.
- The chemical symbol is X.
- A= atomic mass number ( nucleon number) =number of protons+ number of neutrons
- Z=atomic number= number of protons

**Central mass:**

- The atom consists of a central mass which is made of protons and neutrons.
- The protons are positively charged and the neutrons are neutral.

**Orbiting particles:**

- The orbiting particles are called as electrons.
- They are negatively charged.

**Nuclear force:**

Protons and neutrons are bound together tightly in the nucleus by the strong nuclear force.

**Atom is electrically neutral:**

The number of positive charges is equal to the number of negative charges .So the atom as a whole is electrically neutral.

**Nuclide:**

There are more than 100 different elements and each element has a different type of a nucleus. Each different type of a nucleus is called as a nuclide or sometimes nuclear species.

**Electrostatic attraction:**

Electrostatic attraction exists between the positively charged protons and the negatively charged electrons.

**Calculation of number of protons, neutrons and electrons:**

For a neutral atom:

Proton number+ Neutron number =Nucleon number

How many protons , neutrons and electrons are there in a neutral atom of :

- $^{212}Po_{84}$:

  Protons= z= 84

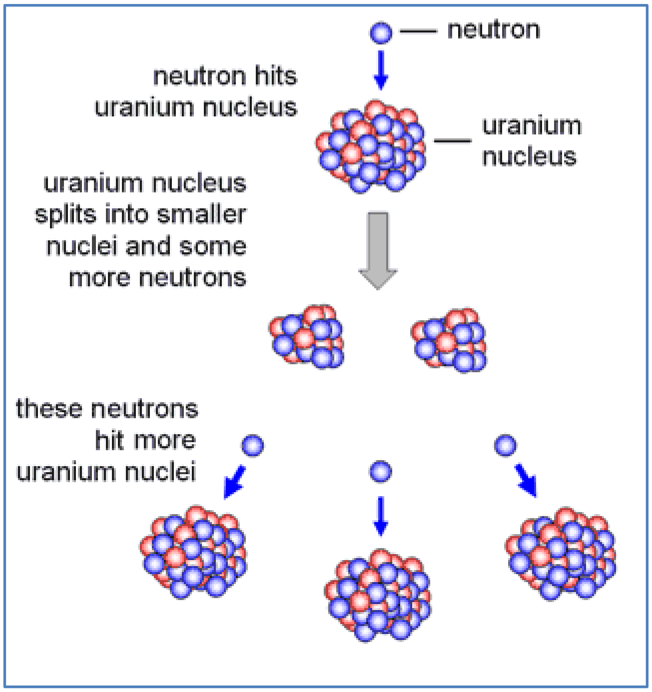
  Neutrons: Since $A=p+n=212 \Rightarrow 212=84+n \Rightarrow n=212-84=128$

  Electrons: Since the atom is neutral, the number of protons= number of electrons=84

**Charge and mass of protons, neutrons and electrons:**

| Particle | Charge/C | Relative charge | Mass/kg | Relative mass |
|---|---|---|---|---|
| Proton | $1.6 \times 10^{-19}$ | +1 | $1.67 \times 10^{-27}$ | 1 |
| Neutron | 0 | 0 | $1.67 \times 10^{-27}$ | 1 |
| Electron | $-1.6 \times 10^{-19}$ | -1 | $9.11 \times 10^{-31}$ | $\frac{1}{1836}$ |

## Nuclear fission and nuclear fusion:




**Nuclear fission-Meaning:** The process of splitting a nucleus is called nuclear fission.

**Where does nuclear fission happen?**

Nuclear power reactors.

**Use of fission:** For the generation of power.

**Isotopes used for fission:**

Common isotopes: uranium-235 and plutonium-239 because their atoms have relatively large nuclei that are easy to split, especially when hit by neutrons.

**The fission process:**

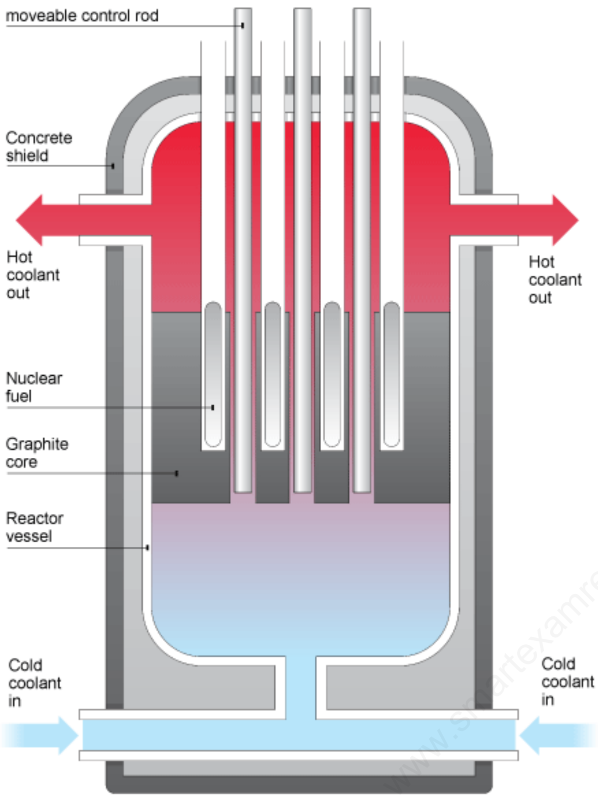
When a uranium-235 or plutonium-239 nucleus is hit by a neutron, the following happens:

- The nucleus splits into two smaller nuclei – daughter nuclei, which are radioactive
- Two or three more neutrons are released
- Some energy is released

The additional neutrons released may also hit other uranium or plutonium nuclei and cause them to split. Even more neutrons are then released, which in turn can split more nuclei. This is called a chain reaction.

## Stopping the chain reaction:

The nuclear reactor is designed to allow a controlled chain reaction to take place. Each time a uranium nucleus splits up it releases energy and three neutrons. If all the neutrons are allowed to be absorbed by other uranium nuclei the chain reaction will spiral out of control causing an explosion. To control the energy released in the reactor moveable control rods are placed between the fuel rods. These control rods are made of boron which absorbs some of the neutrons so fewer neutrons are available to split uranium nuclei. The control rods are raised to increase and lowered to decrease the number of free neutrons.

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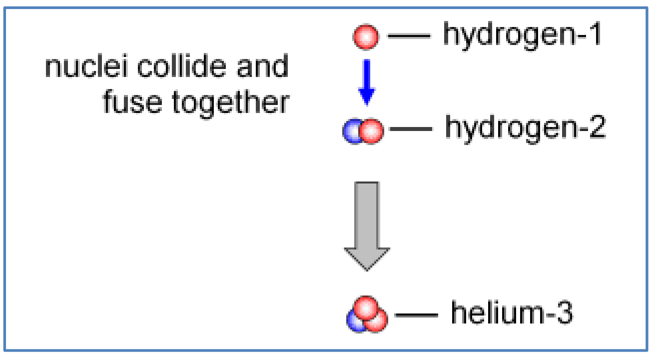
## Nuclear fusion:

**Meaning:** Nuclear fusion involves two atomic nuclei joining to make a large nucleus. Energy is released when this happens. Nuclear fusion can also be used as a source of energy.

**Fusion in nature:** The Sun and other stars use nuclear fusion to release energy. Hydrogen nuclei join to form helium nuclei.

as a source of energy.

**Fusion in nature:** As a source of energy




Nuclear fusion involves a deuterium and a tritium nucleus colliding and being forced together. Both nuclei are positively charged and therefore will repel each other. This is known as electrostatic repulsion. The nuclei have to get very close in order to collide, which is approximately a million millionth of a millimetre. If the nuclei are moving very fast then they can overcome the electrostatic repulsion. The hotter a molecule is, the faster it will move and the more likely it is to collide. For a nuclear fusion reactor to work, the temperature and pressure would each have to be very high. These extremely high temperatures and pressures are very difficult to reproduce and are very expensive. As a result, fusion as an energy source is a long way off.

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**APPLICATION BASED QUESTIONS:**

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In a laboratory experiment, the isotope uranium-238 is used as a source of α-particles.

**(a)** State

**(i)** one feature of uranium-238 nuclei that is the same for the nuclei of other uranium isotopes,

.......................................................................................................................... [1]

**(ii)** one feature of uranium-238 nuclei that is different for the nuclei of other uranium isotopes.

.......................................................................................................................... [1]

**(b)** Fig. 9.1 shows the α-particles from the uranium source being directed at a very thin gold foil, in a vacuum.

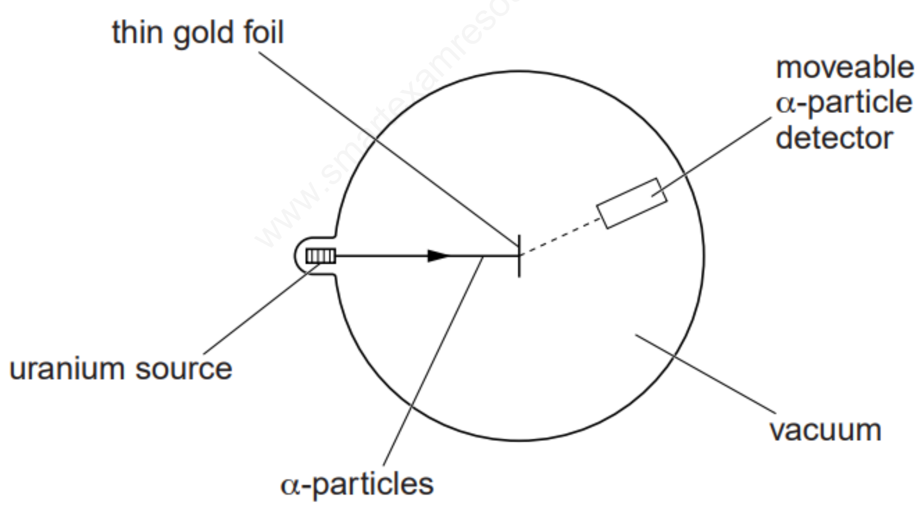


**Fig. 9.1**

To investigate the scattering of α-particles, a detector is moved to different positions around the very thin gold foil and measurements are recorded.

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............................................................................................................................................ [4]

[Total: 6]

**MARKSCHEME:**

(a) (i) same number of / 92 protons (in nucleus) (IGNORE electrons) B1
(ii) different number of neutrons B1
(b) most α-particles travel straight (through the foil) M1
nucleus small / atom mostly empty space A1
small number deflected (through large angles) M1
most of mass in nucleus ACCEPT nucleus positive/charged A1 [6]



An isotope of strontium is represented in nuclide notation as $^{90}_{38}Sr$. **M/J/14-P31**

For a neutral atom of this isotope, state

**(i)** the proton number, ...............

**(ii)** the nucleon number, ...............

**(iii)** the number of neutrons, ...............

**(iv)** the number of electrons. ...............

[

**MARKSCHEME:**

**(i)** 38

**(ii)** 90

**(iii)** 52

**(iv)** 38 B3

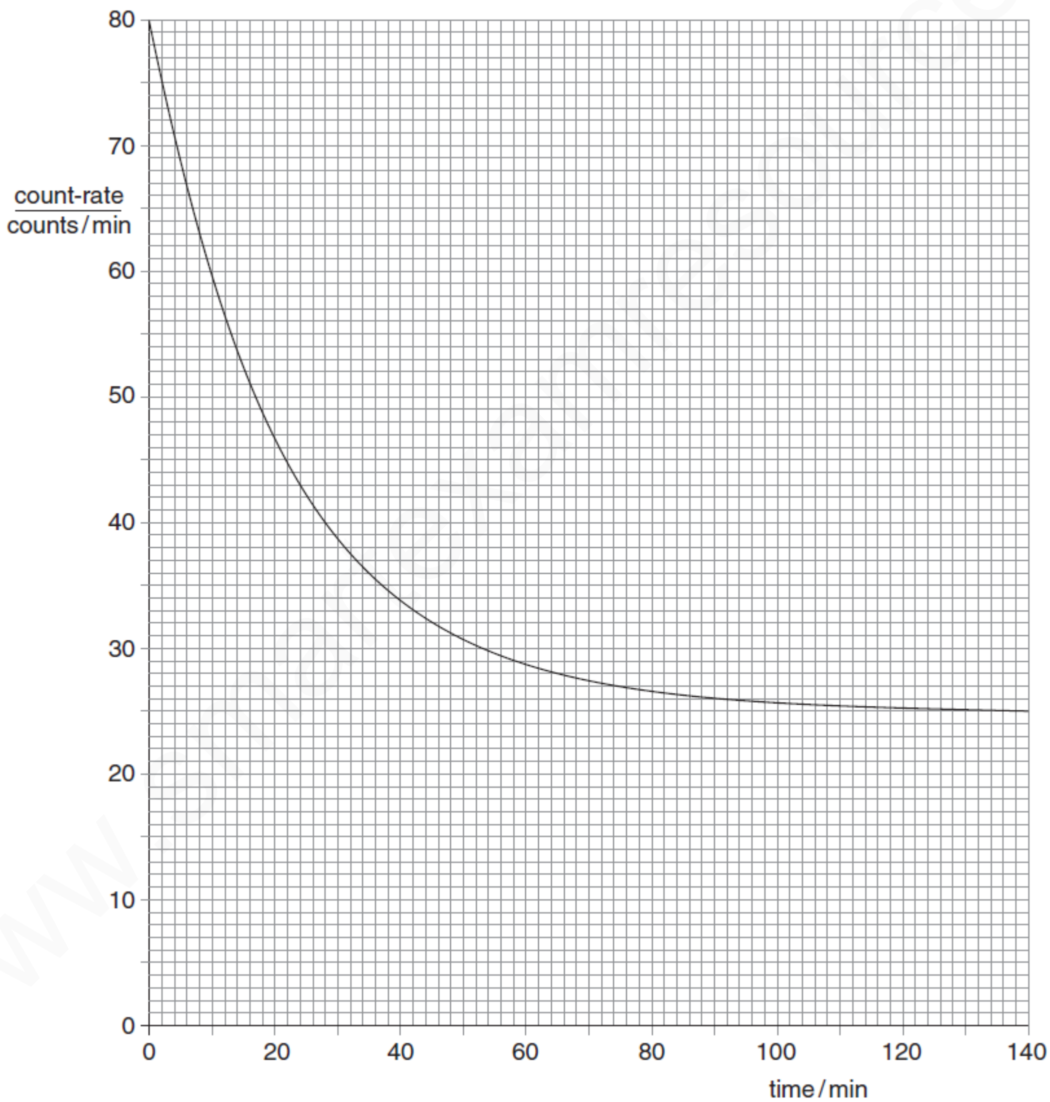
# Detection of radioactivity

**Background radiations:** These are the ionising radiations or radioactive emissions that are always present in the surroundings.

**Graphical question on background radiation:**

Q12 **(b)** In a certain laboratory, the background radiation level is 25 counts/minute.

Fig. 12.1 is a graph of the count-rate measured by a detector placed a short distance from a radioactive source in the laboratory.




The sources of background radiation include: radon gas in the air, rocks and buildings, food and drink and cosmic rays

**(i)** At zero time, the measured count-rate of the source and background together is 80 counts/minute.

Calculate the count-rate due to the source alone.

count-rate due to source = ................. counts/min [2]

**(ii)** After one half-life has elapsed, what is the count-rate

**1.** due to the source alone,

count-rate due to source = ................ counts/min

**2.** measured by the detector?

count-rate measured by detector = ....................... counts/min

[2]

**(iii)** Use the graph to find the half-life of the source.

half-life of source = ....................... min [1]

**(iv)** Why does the graph **not** drop below the 25 counts/minute line?

..........................................................................................................................

.......................................................................................................................... [1]

**(v)** On Fig. 12.1, sketch the curve that might be obtained for a source with a shorter half-life. [2]

| | | | |
|---|---|---|---|
| **(b)** | **(i)** | 80 – 25 | **C1** |
| | | 55 cao | **A1** |
| | **(ii)** | 1. 27.5 ecf | **B1** |
| | | 2. 52.5 ecf | **B1** |
| | **(iii)** | 15 ± 1 ecf | **B1** |
| | **(iv)** | background remains, even when source has decayed | **B1** |
| | **(v)** | curve to the left of existing one | **B1** |
| | | flattening out at 25 count/min | **B1** |

## Detection of $\alpha, \beta$ and $\gamma$ radiations

**12** Two radioactive sources are used by a teacher. One source emits only alpha particles and the other source emits only beta particles.

**(a)** Suggest how the sources can be identified.

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..........................................................................................................................[2]

**(b)** The teacher also has a source that emits gamma rays.

State **two** ways in which gamma rays are different from alpha particles.

1. ..........................................................................................................................

2. ..........................................................................................................................

[2]

**(c)** State an effect of ionising radiation on living things.

..........................................................................................................................[1]

[Total: 5]

| | |
|---|---|
| 12(a) | idea of paper between source and detector **OR** measuring range (in air) **OR** pass through an electric or magnetic field<br>alpha stopped by paper **OR** larger range in air for beta **OR** identify deflection when in field |
| 12(b) | **any two from:**<br>gamma travel at the speed of light<br>gamma rays have no charge<br>gamma rays have no mass<br>gamma is a wave **OR** part of the electromagnetic spectrum<br>gamma less ionising<br>greater penetration<br>not deflected by electric or magnetic fields |
| 12(c) | damages cells / tissues / DNA **OR** causes (cell) mutations **OR** radiation sickness |

## Sources of background radiation:

Rocks, cosmic radiation, radon, radiation from space, radiation from sun and nuclear waste.

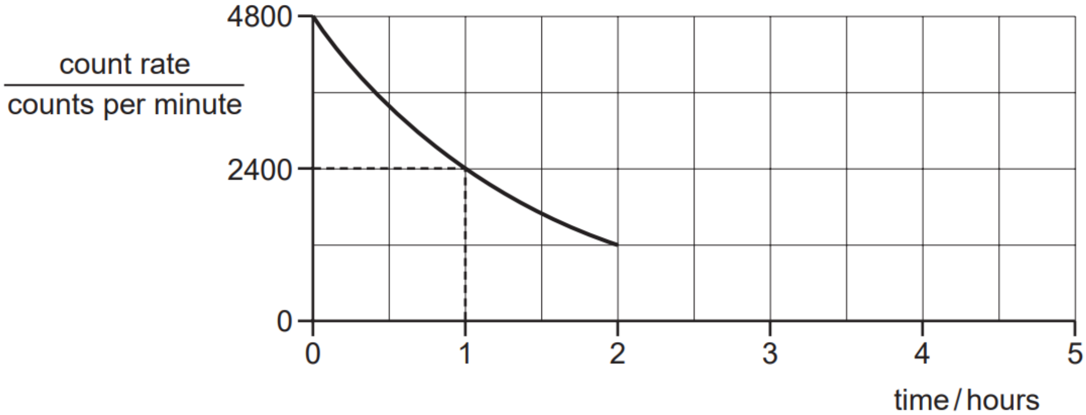
Ionising nuclear radiation can be measured using a detector connected to aa counter

Count rate is measured in counts/s or counts/min

Corrected count rate can be detected by measuring the background radiation

**BOARD QUESTION:**
**0625/13/M/J/13 -Q-40-ANS-C**

**40** The graph shows how the count rate on a detector due to a radioactive source changes with time.




What is the count rate at 5.0 hours?

**A** 960 counts per minute

**B** 600 counts per minute

**C** 150 counts per minute

**D** 0 counts per minute

# Radioactive decay

**DEFINITION OF RADIOACTIVITY**

**It is a change in an unstable nucleus that can result in the emission of α particles or β- particles and /or γ-radiation.**

**KEY-POINTS:**

- **These changes are spontaneous and random.**
- **The isotopes of an element may be radioactive due to an excess of neutrons in the nucleus and/or the nucleus being too heavy.**
- **During α-decay or β-decay, the nucleus changes to that of a different element**
- **The effect of α-decay, β-decay and γ-emissions on the nucleus are an increase in stability and a reduction in the number of excess neutrons.**
- **The following change in the nucleus occurs during β-emission.**
  **neutron → proton + electron**

## DECAY EQUATIONS:

### Products of nuclear decay:

A radioactive substance emits one or more of the three types of radiations: namely alpha , beta and gamma decay along with the release of energy.

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### Alpha decay (α):

- When an alpha particle is emitted from a nucleus the nucleus loses two protons and two neutrons.
- This means the atomic mass number decreases by 4 and the atomic number decreases by 2.
- A new element is formed that is two places lower in the Periodic Table than the original element.

**(b)** A nucleus of radon-220 decays to an isotope of polonium (Po) by emitting an alpha particle.

Complete the nuclide equation for the decay of radon-220.

$$^{220}_{86}\text{Rn} \rightarrow \, ^{4}_{2}\alpha + \, ^{216}_{84}\text{Po}$$

[3]

Note : the sum of the numbers in the LHS = RHS

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### Beta decay($\beta^-$):

- In Beta (β-) decay, a neutron changes into a proton plus an electron. The proton stays in the nucleus.
- The electron leaves the atom with high energy, and we call it a beta particle.

When a beta particle is emitted from the nucleus; the nucleus has one more proton and one less neutron.(A neutron changes to a proton)

This means the atomic mass number remains unchanged and the atomic number increases by 1.

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## EXAMPLE OF BETA DECAY

**11** The radioactive isotope bismuth-210 ($^{210}_{83}Bi$) decays by β-particle emission to an isotope of polonium (Po).

**(a)** Complete the nuclide equation that represents this decay.

$$^{210}_{83}Bi \rightarrow \, ^{210}_{84}Po + \, ^{0}_{-1}\beta$$

[3]

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## GAMMA DECAY (γ):

- After a nucleus undergoes alpha or beta decay, it is often left in an excited state with excess energy.
- An atomic nucleus loses energy by emitting a gamma ray.

# Half life

## Definition:

Half-life is the time taken for:

- The number of nuclei of the radioactive isotope in a sample to halve
  or
- The count rate from a sample containing the radioactive isotope to fall to half its starting level
- or
  The time taken for the activity /count rate or the mass to decrease to half its original value. [1m]

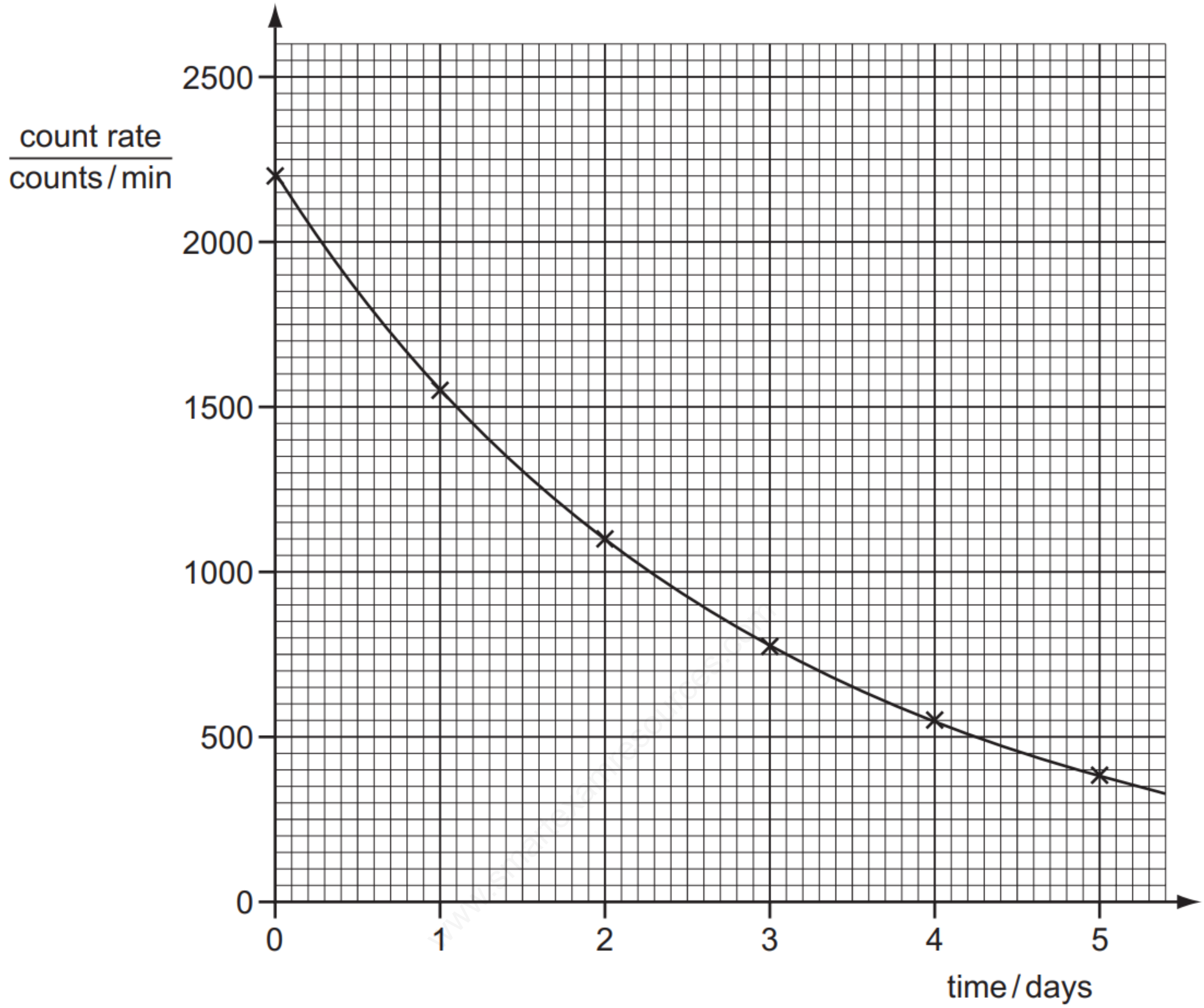
## APPLICATION BASED QUESTIONS

MCQ'S:

1. A powder contains 400mg of a radioactive material that emits α-particles. The half-life of the material is 5 days. What mass of that material remains after 10 days?
   A 0 mg B 40mg C 100mg D 200mg
   Ans: C

2. A radioactive element has a half-life of 70s. The number of emissions per second, N, of a sample of the element is measured at a certain time.
   What was the number of emissions per second 70s earlier?
   A 0 B N/ 2 C N D 2N
   Ans: D

3.The graph shows the decay curve for one particular radioactive nuclide.




What is the half-life of this nuclide?

A 1.0 day B 1.5 days C 2.0 days D 2.5 days

Ans: C

4.The count rate from a radioactive isotope is recorded every hour. The count rate is corrected for background radiation.

The table shows the readings.

| time / hours | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| corrected count rate / counts / s | 800 | 620 | 480 | 370 | 290 | 220 |

What estimate of the half-life of the isotope can be obtained from the readings in the table?

A between 1 and 2 hours

B between 2 and 3 hours

C between 3 and 4 hours

D between 4 and 5 hours

Ans: B

## Half life calculation

## Decay curves:

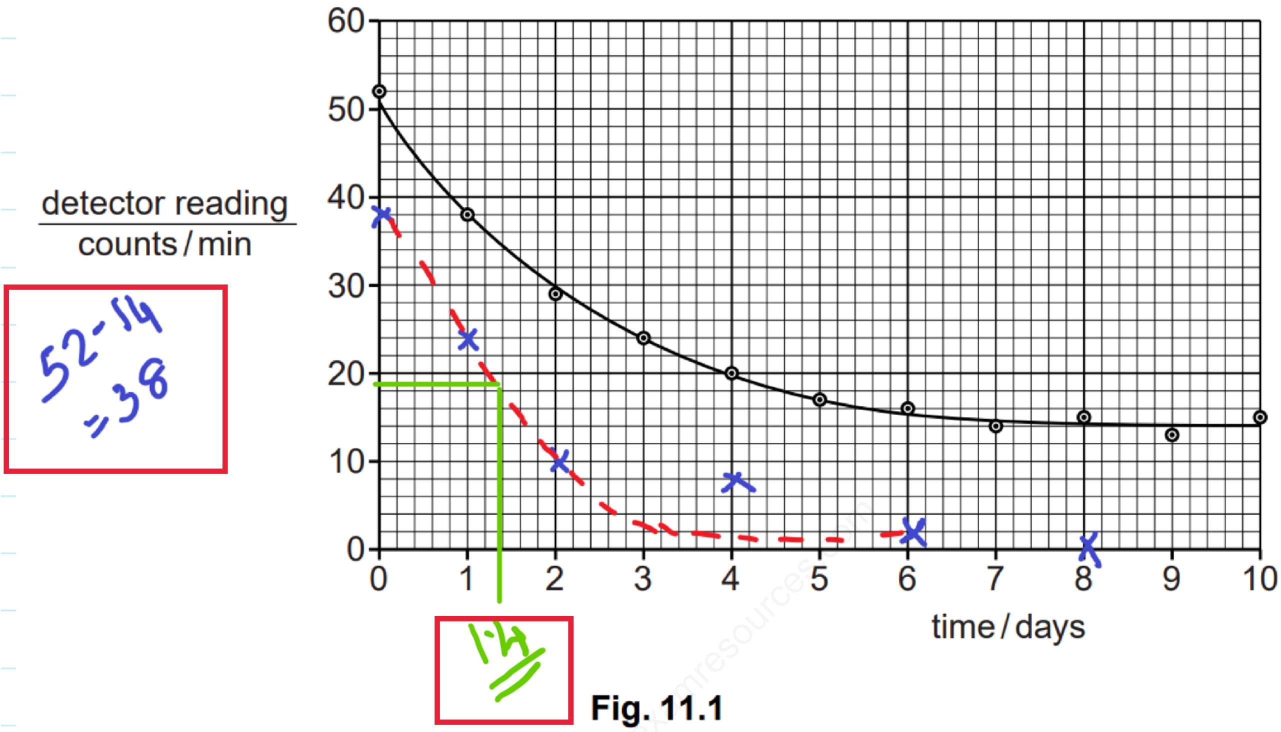



**Fig. 11.1**

**(a)** After 6 days the count rate hardly decreases and, in fact, increases a little at times. Explain these observations.

*The increase in the counts is due to background radiation.*
*If after 6 days the counts have hardly decresed then ; either all the sample has decayed already or the rate of decay is very small.*

Using the graph we may determine the half life of the sample in the following way

14 counts are due to background radiation.
So initial 52 counts included 14 background counts.
Hence actual counts due to radioactive source=52-14=38
After 6 hours counts became alomost 0.
Redrawing a new graph considering 14 counts as background, we get the half life as 1.4 days

------------------------------------------------------------

## Graph (ii)

(c) The graph in Fig. 11.1 shows part of the decay curve of a radioactive nuclide. The count rate is plotted against time.

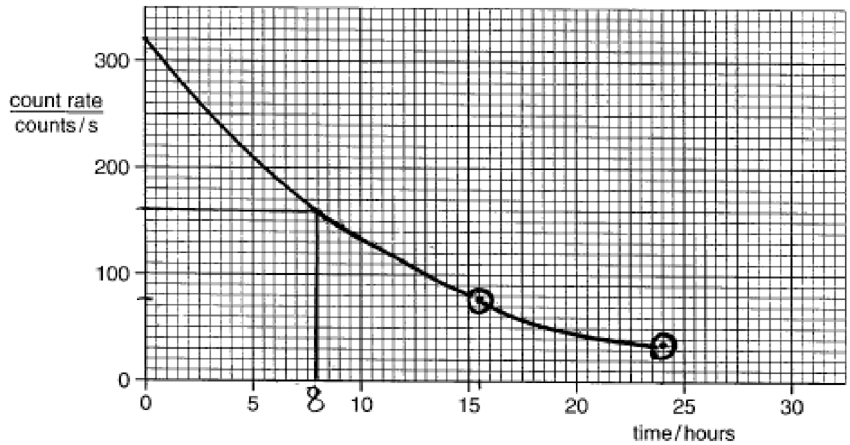



**Fig. 11.1**

(i) Use the graph to find the half-life of this nuclide.

*8 hrs*

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**Sums:**

(c) A detector of radiation is placed near a sample of radon-220 and gives a reading of 720 counts / s. The half-life of radon-220 is 55 s.

Calculate the reading after 220 s. Ignore background radiation.

Note 220 s= 55 x 4.
This means it covers 4 half lives.

Hence:
220/55 = 4 half lives
=45 counts

Hint: 720/2=360
360/2=180
180/2=90 and
90/2=45

reading = 45 counts [2]

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**(iii)** The half-life of bismuth-210 is 5.0 days.
A sample of bismuth-210 is brought close to the detector and in one minute, the reading displayed is 487. The equipment is left in the same place for exactly 10 days.

Predict the reading in a one-minute period at the end of this time.

Average counts per minute=(24+22+25+25+21+20+24)/7=23.

Half life is 5 days.
So after 5 days, the sample will reduce to its half
In another 5 days , that is after total 10 days and at the end of this time, the nuclei will be (487/4=121+(23)=144nuclei will be left.

reading = ........144........[3]

**The type of radiation emitted and the half-life of that isotope determines which isotope is used for applications ,**

**Examples:**

**(a) household fire (smoke) alarms**
**(b) irradiating food to kill bacteria**
**(c) sterilisation of equipment using gamma rays**
**(d) The thicknesses of materials such as metal or paper is controlled using beta radiations.**

**Method:**

**An emitter is placed on one side of a sheet and a detector on the other.If the thickness of the sheet remains constant the activity does not change.If the thickness, increases , the activity decreases .This can trigger the rollers to squeeze less hard to maintain the correct thickness and vice-versa.**

**A beta source is used because beta radiation can penetrate paper or thin aluminium, but the amount of penetrating will vary sufficiently as thickness changes.**

**(e)Gamma rays are used to diagnose and treat cancer**

**Treating cancer:**

**Gamma rays have high penetrating power and hence are known to kill living cells, They are used to kill cancer cells without the need for surgery through a process called as "Radiotherapy"This method is successful because once the cancer cells are damaged by radiations, they are unable to repair themselves like healthy cells .Radiation therapy is a type of cancer treatment that uses high doses of radiation to kill cancer cells and shrink tumors.**

**Detecting cancer:**

**A radioactive tracer is injected into the patient's arm by a physician. The cancer cells have a high metabolic rate and hence these cells accumulate more of the tracer than normal cells and so emit more gamma rays as it decays. A gamma camera can detect this and records a high-resolution image of the tumor.**

A technician sets up a radiation detector in a university laboratory, for use in some experiments.
Even before the radioactive source for the experiments is brought into the laboratory, the detector
registers a small count rate due to background radiation.

(a) Suggest one source of this background radiation.

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...........................................................................
...........................................................................[1]

(b) The radioactive source emits γ-rays. It is placed on the laboratory bench close to the detector.

(i) State what γ-rays are.

...........................................................................
...........................................................................
...........................................................................
...........................................................................[2]

(ii) A lead sheet of thickness 10 mm is positioned between the detector and the radioactive
source.

State and explain what happens to the count rate on the detector.

...........................................................................
...........................................................................
...........................................................................
...........................................................................[2]

**MARKSCHEME:**

(a) any one specific source of background radiation
e.g. rocks, ground, building materials, radon, radiation from space, Sun, cosmic rays, nuclear waste B1
(b) (i) electromagnetic radiation OR photons B1
(very) high frequency OR (very) short wavelength or high energy B1
(ii) (count rate) decreases B1
(count rate decreases but) not completely absorbed (by lead) OR only some γ-rays detected B1

In a research laboratory, a radioactive sample is placed close to a radiation detector. The graph in Fig. 11.1 shows the decay of the sample.

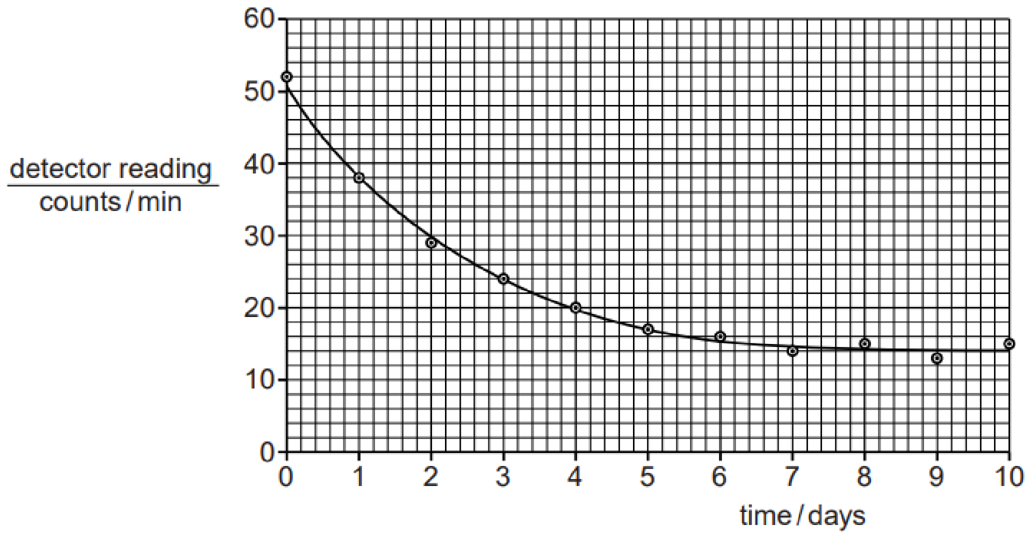


**Fig. 11.1**

**(a)** After 6 days the count rate hardly decreases and, in fact, increases a little at times. Explain these observations.

..........................................................................................................................................

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.................................................................................................................................... [2]

**(b)** Use the graph to determine the half-life of the sample. Explain your working carefully.

half-life = ................................................ [4]

**(c)** Another radioactive sample is a strong emitter of α-particles and γ-rays. A junior researcher suggests that a sufficient safety precaution, when working with this sample, would be to hold the sample with long forceps. Explain why this suggestion, although helpful, may be insufficient.

..........................................................................................................................................

..........................................................................................................................................

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.................................................................................................................................... [2]

[Total: 8]

**MARKSCHEME:**

**(a) any mention background B1**
**background/radiation varies randomly o.w.t.t.e. OR rate of decay very small OR**
**sample nearly all decayed B1 [2]**
**(b) correctly deducts correct background (13 – 15 /s) B1**
**takes 2 detector readings, one twice the other B1**
**correct working, with/without background subtraction, i.e. use of graph B1**
**half life = 1.2 – 1.8 days OR follows from working B1 [4]**
**(c) α (very) short range in air OR will not reach researcher**
**NOT will not penetrate skin B1**
**γ long range/very penetrating/heavy shielding needed OR will reach researcher B1 [2]**
**[Total: 8]**

Thorium-232 has a half-life of $1.4 \times 10^{10}$ years.

At a particular instant, the activity of a sample of thorium-232 is 120 Bq.

**(i)** Calculate the time taken for the activity of this sample to fall to 15 Bq.

time taken ..........................................................[1]

**(ii)** Explain why, when the activity has become 15 Bq, much of the sample will no longer be thorium-232.

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................[1]

**(iii)** The sample of thorium-232 is used in an experiment in a laboratory.

Explain why its activity may be regarded as constant.

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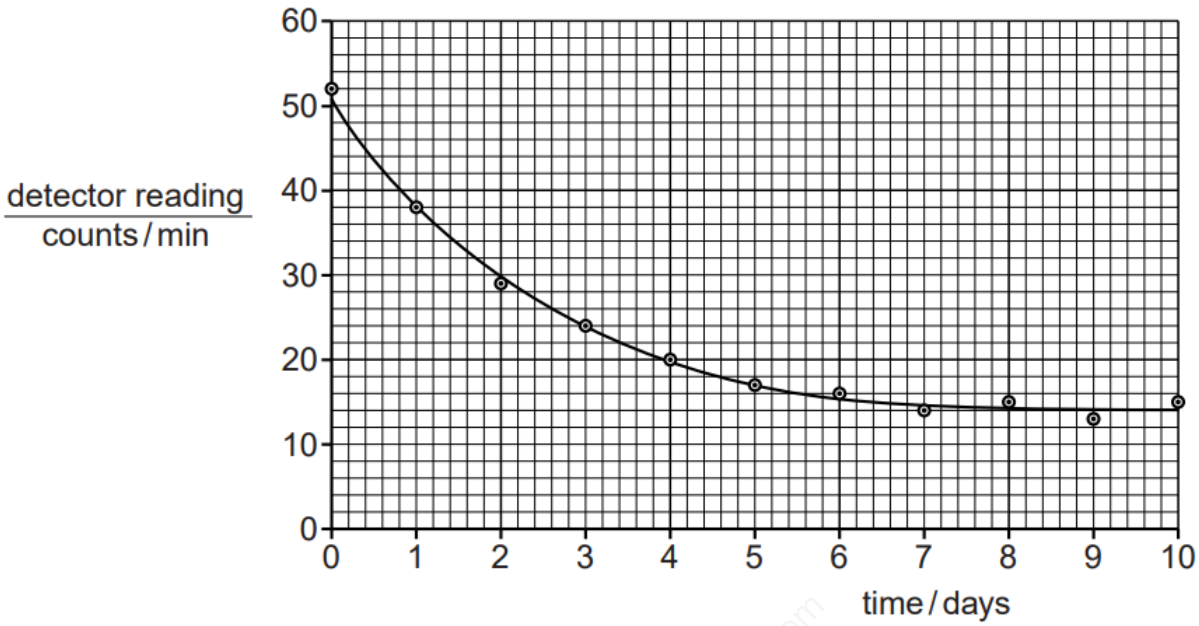
..........................................................................................................................[1]



## MARKSCHEME:

(b) (i) $4.2 \times 10^{10}$ years B1
(ii) idea of decay OR changes proton/neutron/nucleon number OR change into another nuclide/isotope/element/type of atom OR emits α/β particle (ignore γ / radiation) B1

In a research laboratory, a radioactive sample is placed close to a radiation detector. The graph in Fig. 11.1 shows the decay of the sample.

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..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.......................................................................................................................................... [2]

**(b)** Use the graph to determine the half-life of the sample. Explain your working carefully.

half-life = .................................................. [4]

**MARKSCHEME:**

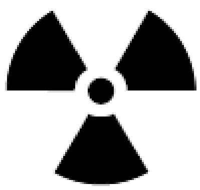
**(a) any mention background B1**
**background/radiation varies randomly o.w.t.t.e. OR rate of decay very small OR sample nearly all decayed B1 [2]**
**(b) correctly deducts correct background (13 – 15 /s) B1**
**takes 2 detector readings, one twice the other B1**
**correct working, with/without background subtraction, i.e. use of graph B1**
**half life = 1.2 – 1.8 days OR follows from working B1 [4]**

# Safety precautions

## Effects of ionising radiations on living things:

- They may kill or change the nature of living cells [mutation]
- The effects can be severe and cause immediate effects.
- One long term effect of exposure to ionising radiation is cancer.
- Mutations can cause damage to body cells as well as reproductive cells,

Symbol to warn of radioactive hazard:



## Radioactive materials-Safe ways to:

### Handle and Use

- wearing protective clothing
- keeping as far away as is practicable - for example, by using tongs
- keeping your exposure time as short as possible, and
- keeping radioactive materials in lead-lined containers, labelled with the appropriate hazard symbol.

### Store:

- Radioactive substances should be stored in lead containers.

### Safety precautions for all ionising radiations

- Reducing exposure time
- Increasing distance between the source and the living tissue.
- using sheilding to absorb radiation
- Cause people to move away

**APPLICATION BASED QUESTIONS:**
**MCQ:**

**0625/11/O/N/11-Q38-B**

**38** A scientist needs to use a source of γ-rays as safely as possible.

Which action will **not** reduce the amount of radiation that reaches the scientist?

**A** keeping the distance between the source and the scientist as large as possible

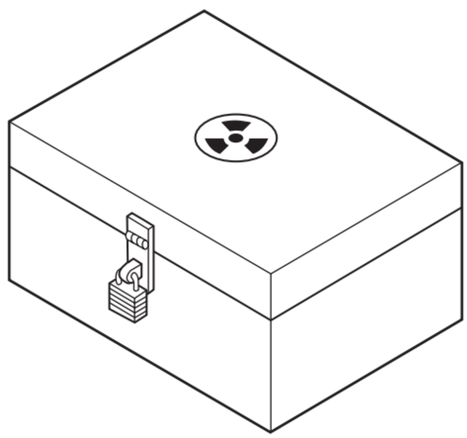
**B** keeping the temperature of the source as low as possible

**C** keeping the time for which the scientist uses the source as small as possible

**D** placing a lead screen between the scientist and the source

**0625/12/M/J/14 -Q38-ANS:B**

**39** The diagram shows a box used for storing radioactive sources.



Which material is best for lining the box to prevent the escape of most radioactive emissions?

**A** aluminium

**B** copper

**C** lead

**D** steel