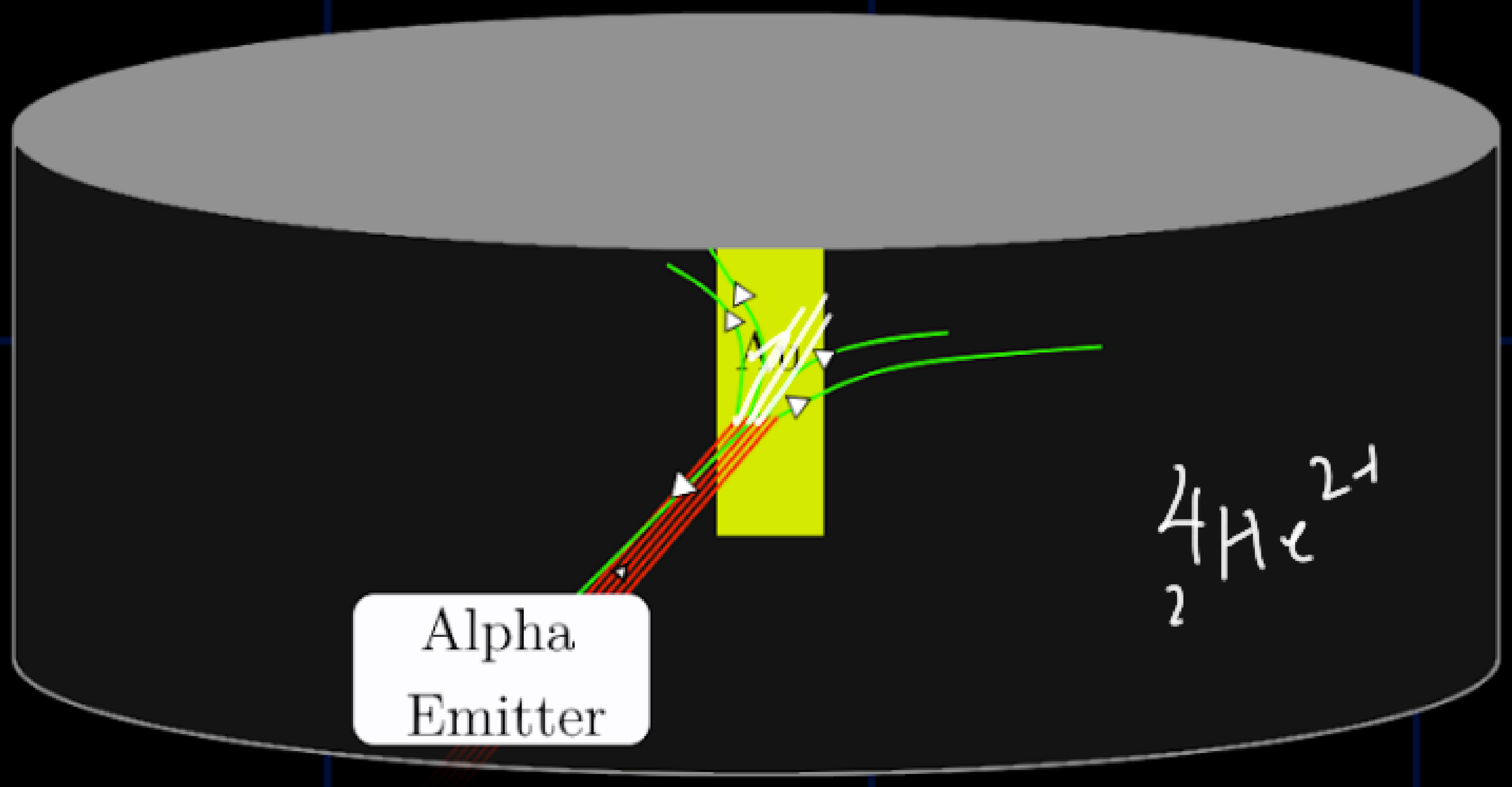
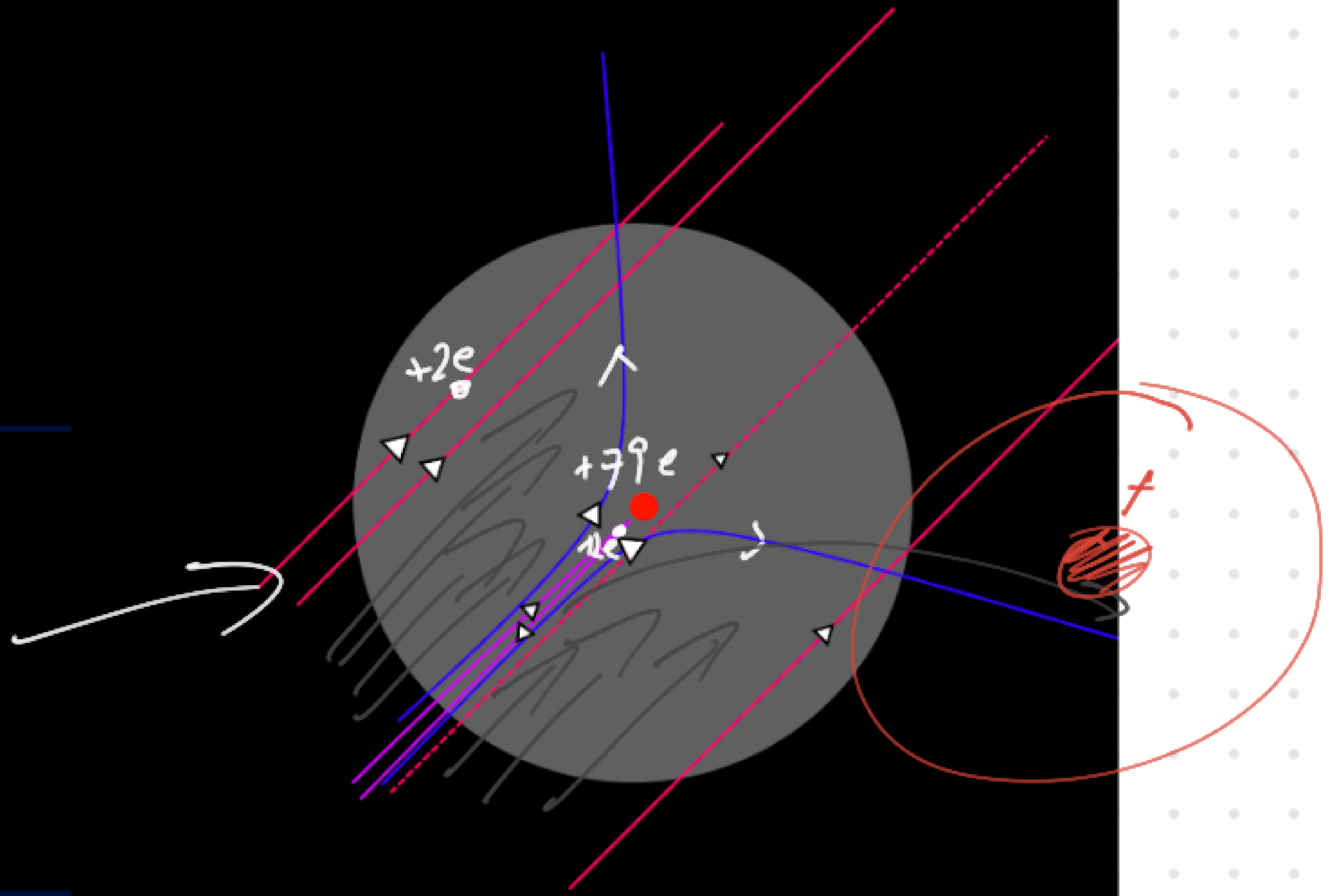
What is inside an atom?? (Rutherford Experiment)

Rutherford Experiment





① An atom is mostly empty space

② The charge of an atom is concentrated at ~~its~~ its centre (i.e, in the nucleus)

Types of Radioactive decay

The universe tends to stability

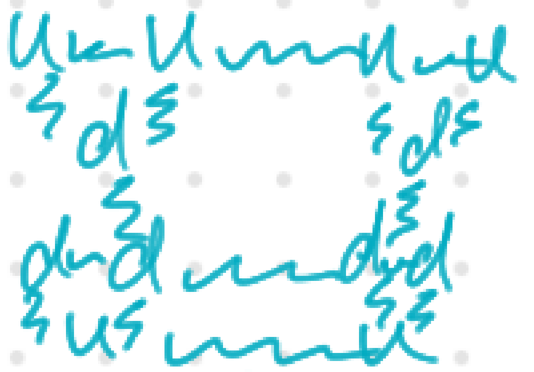
Alpha

→ no. of proton

$Z : -2$

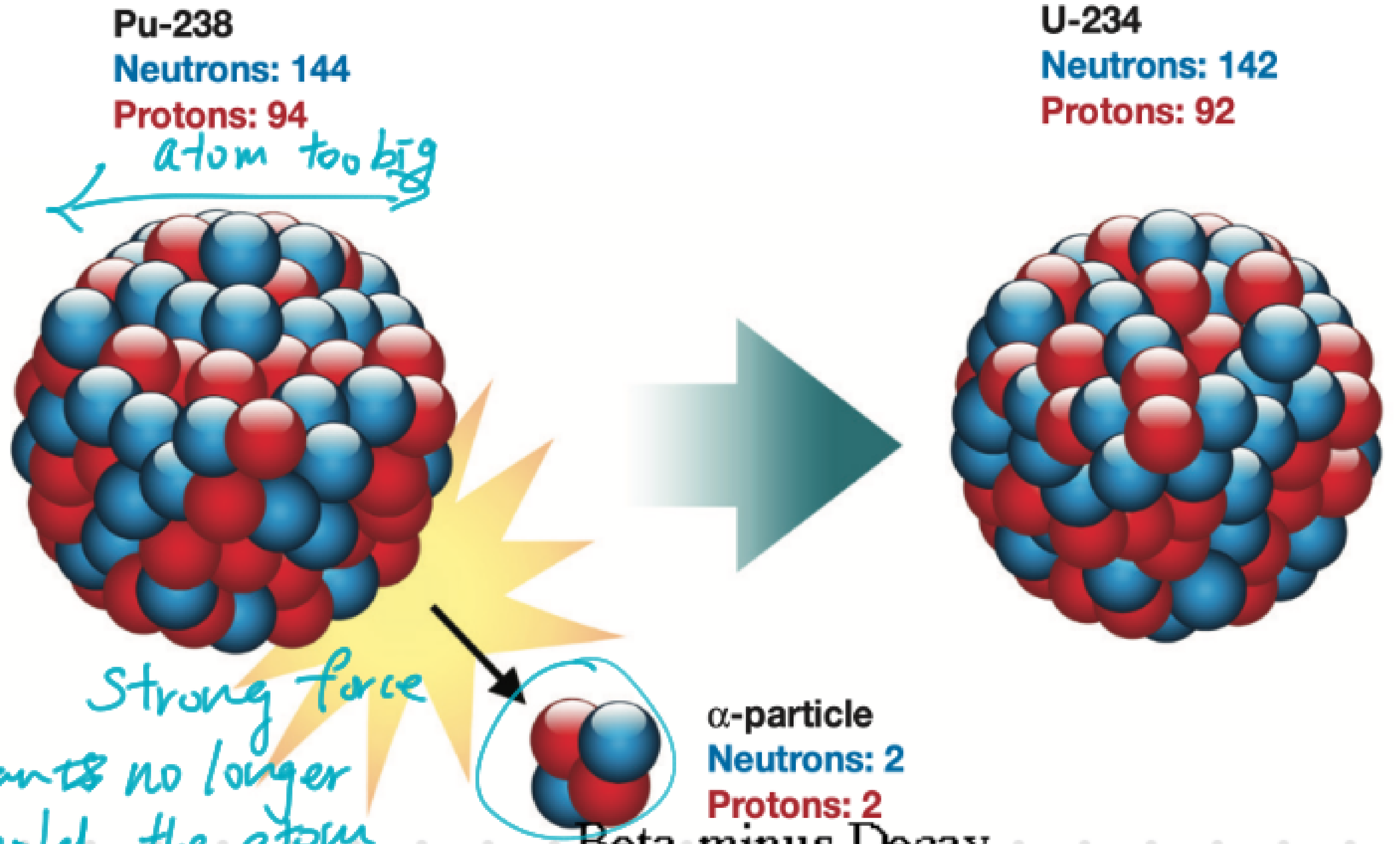
$N : -4$

atomic mass



Strong force :
Distance : 10^{-15} m

Magnitude = 100x EM force



atom too big

Strong force can't no longer hold the atom together

Beta

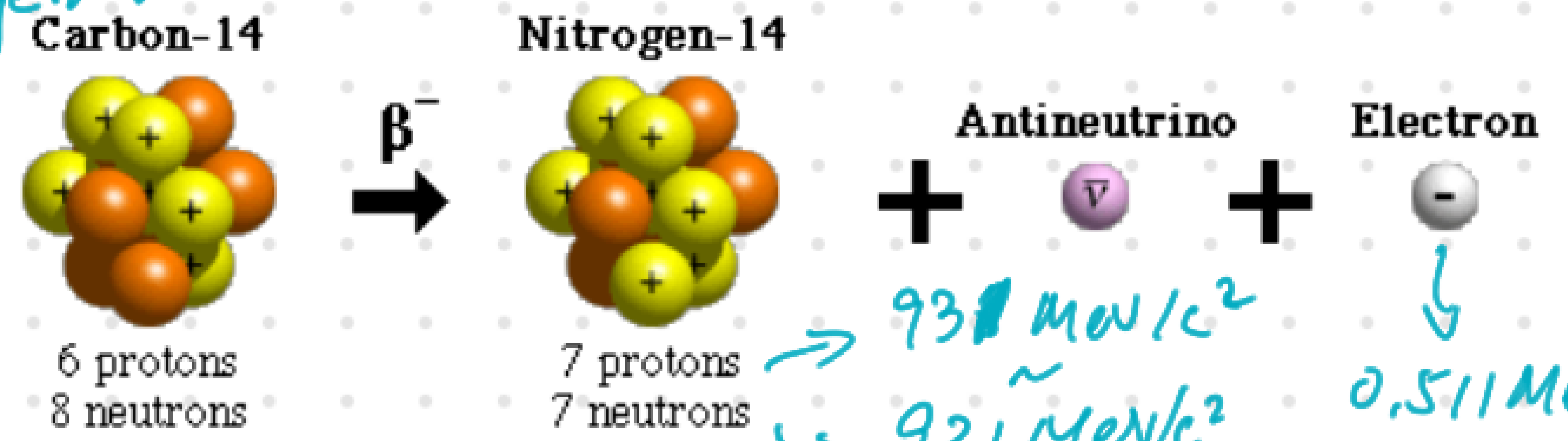
Beta Minus (More common)

emit : e^- and $\bar{\nu}$ (antineutrino)

Neutron → Proton (in nucleus) + e^- (emitted) + $\bar{\nu}$

β^- : Z : +1
Proton : +1
neutron : −1
Mass : 0

Beta-minus Decay



→ 931 MeV/c^2
→ 931 MeV/c^2

0.511 MeV/c^2

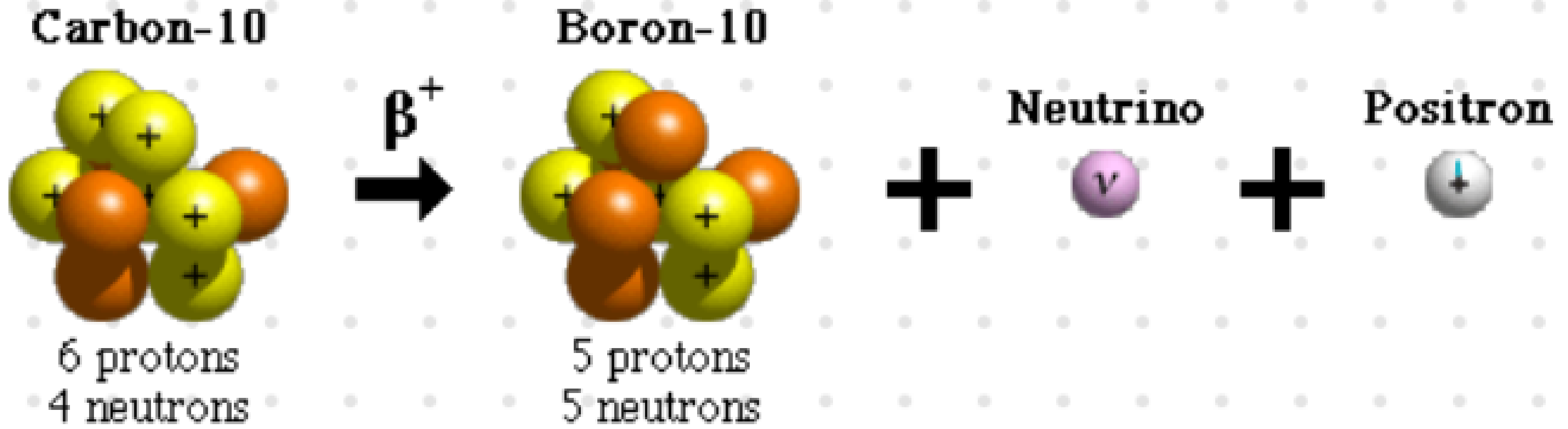
Beta Plus (less common)

emit : e^+ and ν (neutrino)

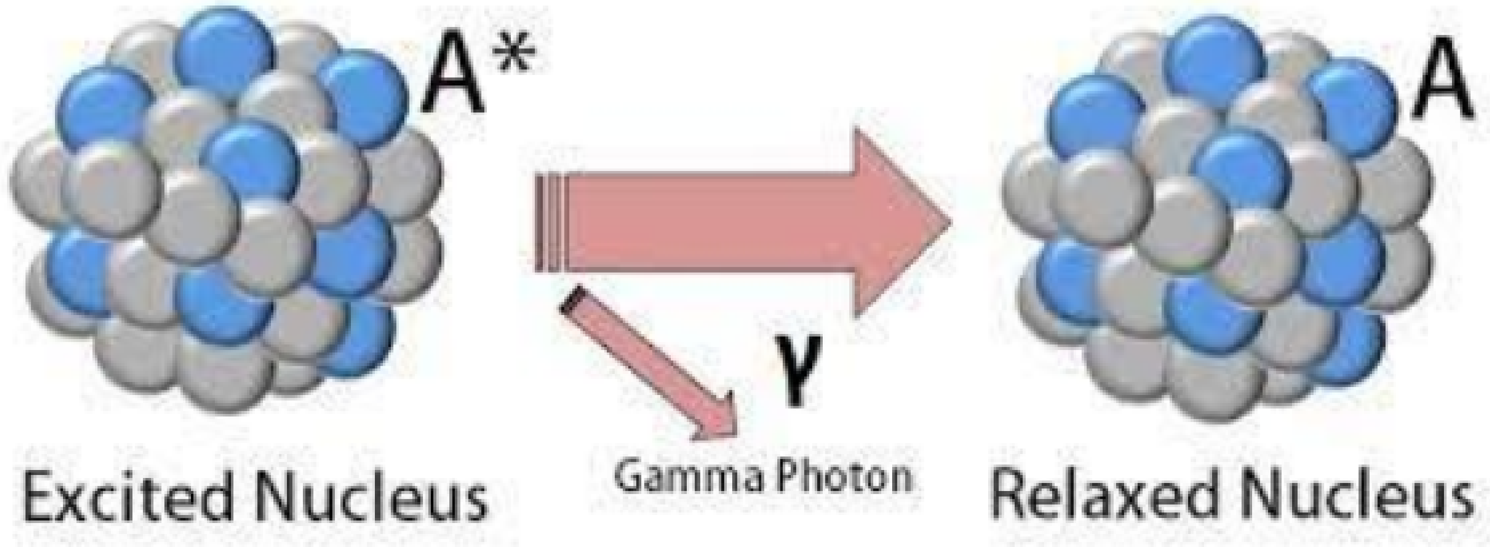
Proton → Neutron (in nucleus) + e^+ (emitted) + ν

β^+ : Z : −1
P : −1
n : +1
Mass : 0

Beta-plus Decay



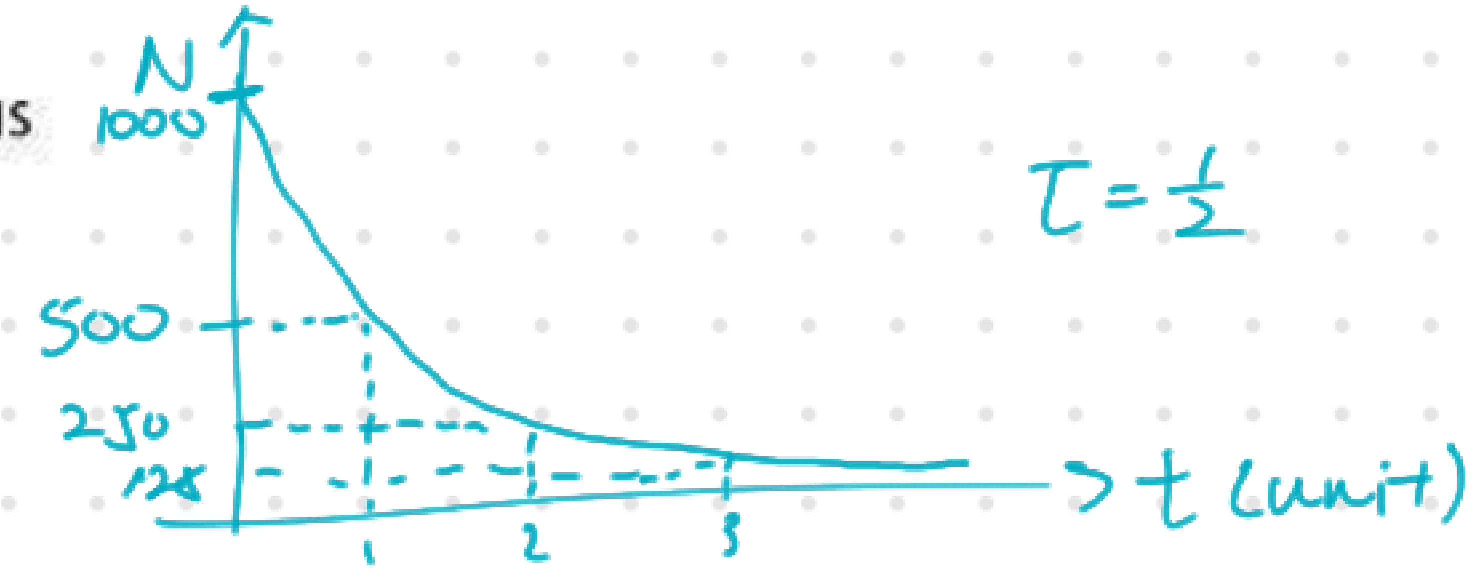
Gamma γ



(Excess energy)

Emits: γ ray

Z: 0 p: 0 n: 0



$T = \frac{1}{2}$

Depends on your isotope.

1s 240s 1yr

T (half life)

→ Time taken for $\frac{1}{2}$ of radionucliedes in a sample to decay

→ Time taken for the activity of a radioactive sample to decrease by $\frac{1}{2}$ of its original

	Alpha decay (α)	Beta decay (β)	Gamma decay (γ)
Particle emitted	α — $^{4}_{2}He^{2+}$	β^+ — e^+ and ν β^- — e^- and $\bar{\nu}$	γ ray (EM Wave)
Range	~5cm Paper	~1m	Infinite
Blocked by	Paper α →	5mm Aluminium sheet β^+/β^- → paper → 5mm Al	25mm lead block (doesn't perfectly eliminate) Pb
Penetrating power (how well it can go through solids)	Weakest H^+	Between α and γ	Strongest
Ionising power	Strongest	Between α and γ	Weakest

Nuclear radius

$$\underbrace{R}_{\text{Radius of nucleus}} = \underbrace{R_0}_{\text{constant}} \cdot \underbrace{A}_{\text{No of nucleons}}^{1/3} \qquad R_0 \approx 1.4 \cdot 10^{-15}\,m$$

Here the nucleus is approximated as a sphere

The formula was found experimentally
see electron diffraction.

33. The radius of a nucleus of the iron nuclide $^{56}_{27}Fe$ is 4.35×10^{-15} m.

What is the radius of a nucleus of the uranium nuclide $^{238}_{92}U$?

- **A** 2.69×10^{-15} m
- **B** 2.89×10^{-15} m
- **C** 6.55×10^{-15} m
- **D** 7.05×10^{-15} m

Density of an atom with nucleon no. A.

$$m = Au$$

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi (R_0^3 A)$$

$$\rho = \frac{m}{V} = \frac{3u}{4\pi R_0^3}$$

Q2.

Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

The rock sample contains uranium. The radioactive decay of uranium allows it to be used to determine the time since the rock was formed on the Earth.

(i) The uranium isotope $^{238}_{92}U$ becomes the lead isotope $^{206}_{82}Pb$ through a series of radioactive decays.

Calculate the number of α particles and the number of β particles emitted for one nucleus of $^{238}_{92}U$ to decay to become a nucleus of $^{206}_{82}Pb$.

(2)

$\frac{238-206}{4} = \alpha \quad \alpha = 8$

$92 - 2\alpha + \beta = 82$

$\beta = 6$

Number of α particles = 8

8a 6b

Number of β particles = ...

(ii) The half-life of $^{238}_{92}U$ is 4.47×10^9 years. $T_{1/2}$

The half-lives of the other stages in the decay to $^{206}_{82}Pb$ are relatively so short that they can be ignored.

There was no lead in the rock when it formed, so all the $^{206}_{82}Pb$ in the sample is a product of $^{238}_{92}U$ decay. In the sample, for every 103 uranium nuclei present at the start, 50 are now lead nuclei.

Show that the age of the sample is about 4×10^9 years.

(3)

$T_{1/2} = \frac{\ln 2}{k}$

$N = N_0 e^{-kt}$

$N = N_0 \left(\frac{1}{2}\right)^{t/T_{1/2}}$

$53 = 103 \left(\frac{1}{2}\right)^{\frac{t}{T}}$

$\frac{t}{T} = 0.959$

$t = 4.28 \cdot 10^9$ yr

(Total for question = 5 marks)

$N(t) = N_0 e^{-kt}$

仅存在的 Nucleon

原有 nucleon

$N_0 \left(e^{\ln 2}\right)^{-\frac{t}{T_{1/2}}}$

$\frac{-kt}{\ln 2}$

$= N_0 (2)^{-\frac{t}{T_{1/2}}}$

$= N_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}}$

$\frac{N}{N_0} = e^{-kt}$

$\frac{1}{2} = e^{-kT_{1/2}}$

$-\ln 2 = -kT_{1/2}$

$T_{1/2} = \frac{\ln 2}{k}$

Nuclear Fission & fusion

Need a lot of energy

Fusion : Small atoms joining together to form a larger atom

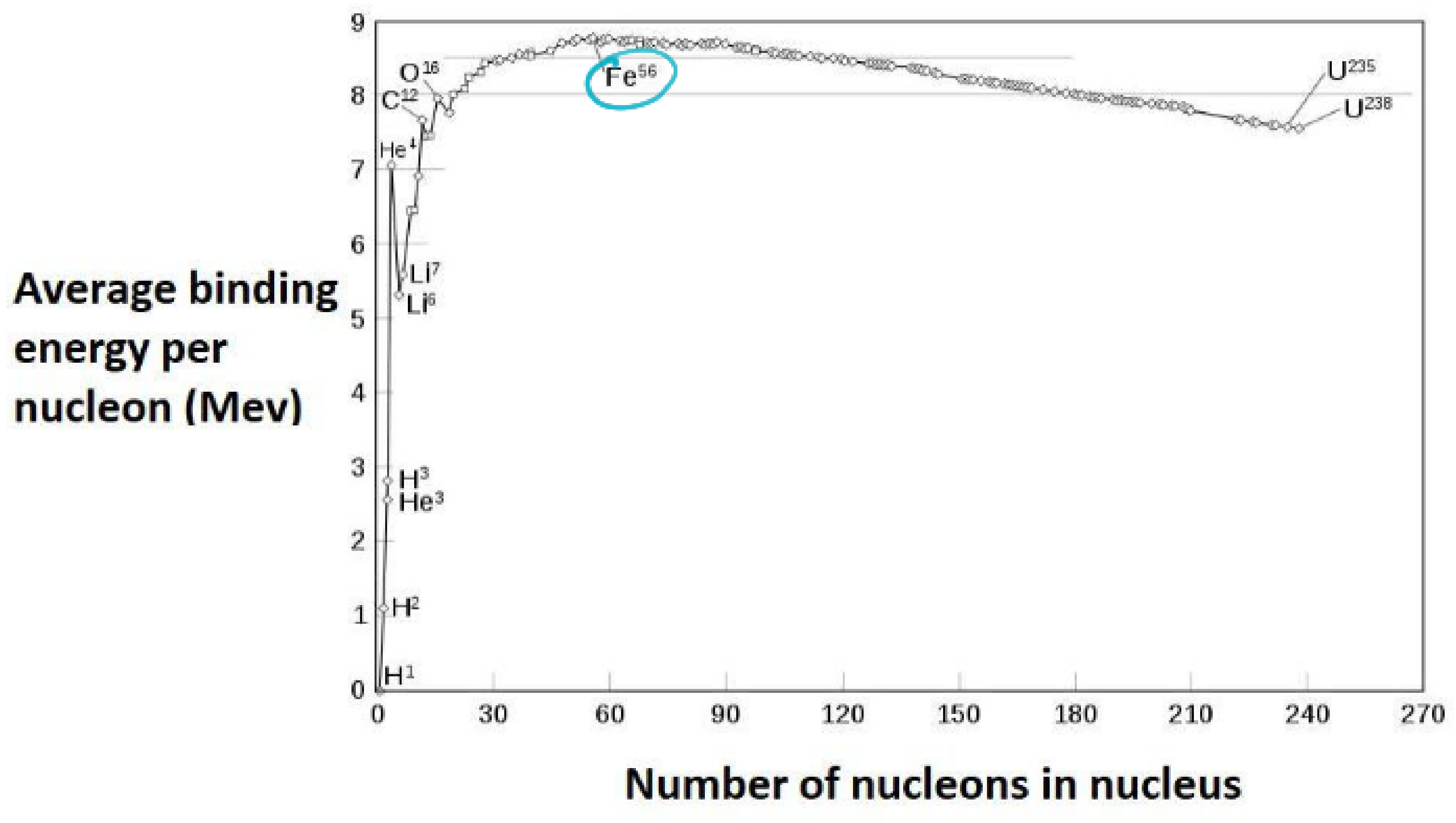
$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

Fission : Large atom split apart by into smaller atoms by a neutron

$$^{1}_{0}n + ^{235}_{92}U \rightarrow 3\,^{1}_{0}n + ^{89}_{36}Kr + ^{144}_{56}Ba$$

Products have higher E_B

↳ Energy released in fission and the resulting nuclides are more stable

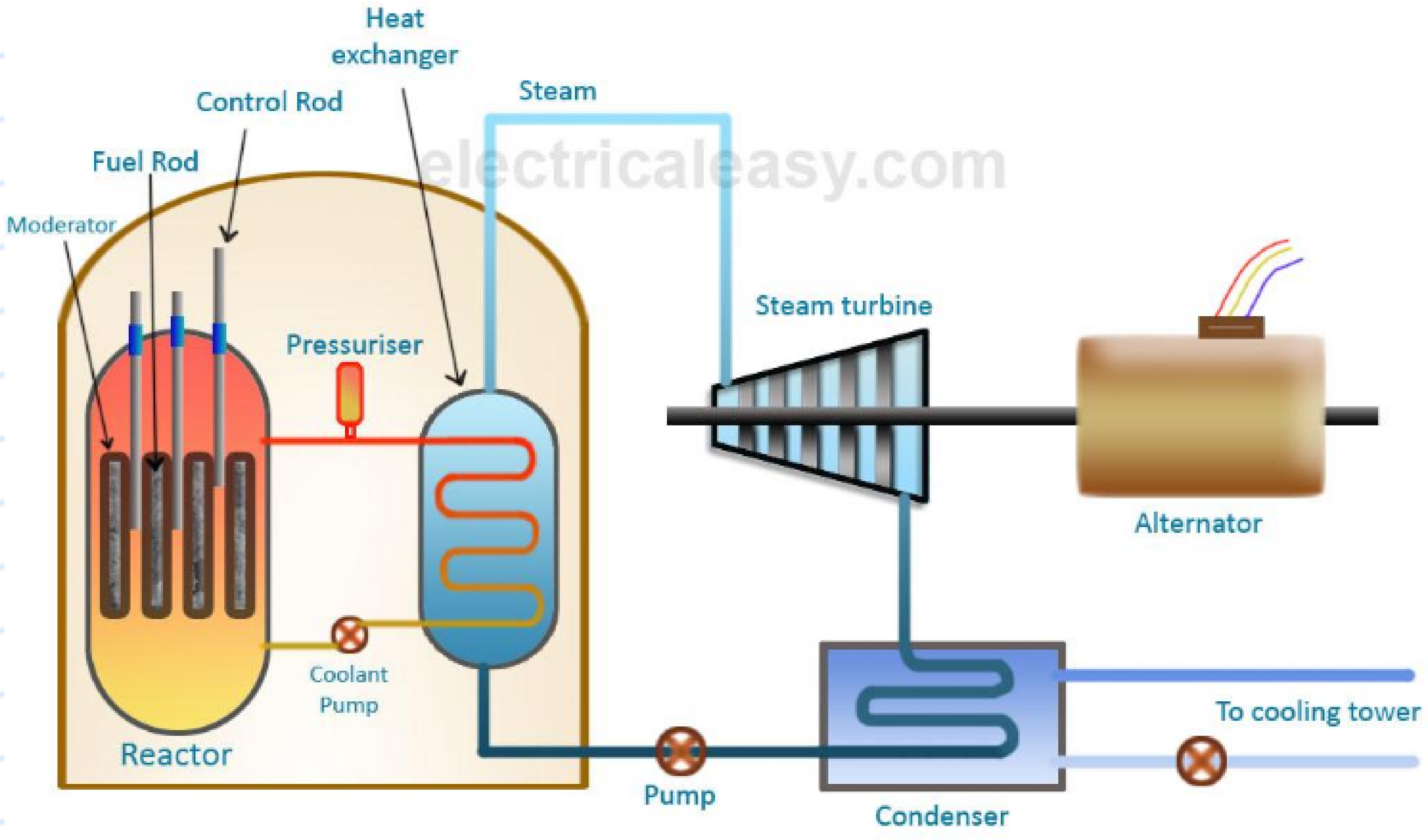


Nuclear reactor

Fuel Rod :

Moderator :

Control Rod :



(b) Muons with a speed of 0.99c travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

$$\frac{15000}{0.99c} = 50.5\ \mu s$$

$$\approx 51\ \mu s$$

(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.
half-life of muon = 2.2 μs

$\frac{N}{N_0}$

(4)

$$N = N_0 (e)^{-kt}$$

$$k = \frac{\ln 2}{T_{1/2}}$$

$$\frac{N}{N_0} = e^{-\ln(2) \cdot \frac{51 \cdot 10^{-6}}{2.2 \cdot 10^{-6}}}$$

$$= 1.05 \cdot 10^{-7}$$

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

$v_\mu = 0.99c$ (comparable to c)

2

Relativistic effects would occur, so the observed lifetime of muons for the observer on Earth is longer.

Qualitative :

$v \to c$

(1) Time slows down for you

(2) You appear shorter to other observers.

(3) $KE \neq \frac{1}{2}mv^2$ $\quad KE = \left(\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right)mc^2$

$$\gamma = \frac{1}{\sqrt{1-0.99^2}} \approx 7.08$$

$$\Delta t_{earth} = 1.55 \cdot 10^{-5}\ s$$

(Total for question = 6 marks)

Q11.

The photograph shows a vase made of uranium glass. Uranium glass is radioactive.

Uranium glass usually contains a maximum of 2% uranium. Uranium glass made in the early part of the 20th century can contain up to 25% uranium.

A student carried out an investigation to determine the percentage of uranium in the glass.

The student measured the count rate by placing a Geiger Muller (GM) tube against the vase at a single position. This value was used to calculate the decay rate for the whole vase.

(i) Show that the decay constant for uranium is about $5 \times 10^{-18}\ s^{-1}$

half-life of uranium = 1.41×10^{17} s

(2)

$k = \frac{\ln 2}{\tau} = \frac{\ln 2}{1.41 \cdot 10^{17}}$

$k = 4.92 \cdot 10^{-18}\ s^{-1}$

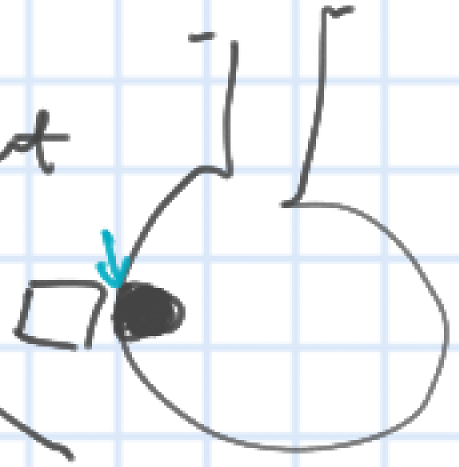
(ii) Calculate the percentage of uranium, by mass, in the glass.

area of GM tube window = $6.36 \times 10^{-5}\ m^2$ → $2,27 \cdot 10^{18}$
surface area of vase = $0.0177\ m^2$
background count rate = 525 counts in 10 minutes 300
count rate when GM tube next to vase = 3623 counts in 5 minutes ↳ A
mass of vase = 149 g
mass of uranium atom = 238 u
↳ $1u = 1,67 \cdot 10^{-27}$ kg

(6)

$A = kN$

Assume A is the same throughout 5 min



$A = \frac{3623}{300} - \frac{525}{600} = 11.2$ Bq

$N = \frac{A}{k} = 2.27 \cdot 10^{18}$ atoms

Assume U is uniformly distributed throughout the vase

$N_{tot} = 2.27 \cdot 10^{18} \cdot \frac{0.0177}{6.36 \cdot 10^{-5}}$

$= 6.32 \cdot 10^{20}$ U atom

$m = 0.2499$ g

$\% = \frac{0.2499}{149} = 0.17\%$

(iii) The uranium decays by emitting alpha particles.

Criticise the method used to determine the percentage of uranium in the vase.

α has very weak penetrating power, some α particles may be absorbed by the glass,

Calculated % by mass is lower than actual.

10. Given: mass of proton = 1.0073 u
mass of α particle = 4.0015 u
mass of ${}^{14}_{7}N$ nucleus = 13.9993 u
mass of ${}^{17}_{8}O$ nucleus = 16.9947 u

When a stationary ${}^{14}_{7}N$ nucleus is bombarded by an α particle, the following nuclear reaction can be triggered with products ${}^{17}_{8}O$ and X fly off:

$$\alpha + {}^{14}_{7}N \longrightarrow {}^{17}_{8}O + X$$

${}^{1}_{1}H$ / proton

(a) What is X? (1 mark)

${}^{1}_{1}H$ / proton

*(b) Based on energy consideration, estimate the minimum kinetic energy, in MeV, of the α particle required for such a nuclear reaction to occur. (2 marks)

$1\ u = 931\ MeV$

$\Delta m = (16.9947 + 1.0073) - (4.0015 + 13.9993)$

$= +1.2 \cdot 10^{-3}\ u$

KE $\Rightarrow$ Rest mass E.

Min KE $\Rightarrow$ 1.12 MeV

$\hookrightarrow$ To overcome mass deficit

(c) However, when conservation of momentum is also taken into account, the α particle must possess a kinetic energy greater than that found in (b) to bring about such a reaction. Explain. (2 marks)

$\sum p_i \neq 0$ $\quad \alpha \xrightarrow{v_0} {}^{14}_{7}N$ $\quad v \ll c$.

$\sum p_f = \sum p_i$ $\quad {}^{17}_{8}O \quad p$

$|v| \neq 0$ $\quad$ KE $\neq 0$

${}^{17}_{8}O\ p \xrightarrow{v'}$

$$v' = v_{cm} = \frac{m_\alpha v_0}{m_\alpha + m_N}$$

$$KE = \frac{1}{2}(m_O + m_p) v_{cm}^2$$

19. **Figure 1** shows a sealed radioactive source used in schools and colleges.

Figure 1

(a) State **two** safety procedures to reduce risk when using this type of source.

1. Wear lead lined suit to absorb most radiation

2. Do not point the source directly at anyone.

3. Use tongs / handling tool when handling the source

4. Remove source from lab after expt

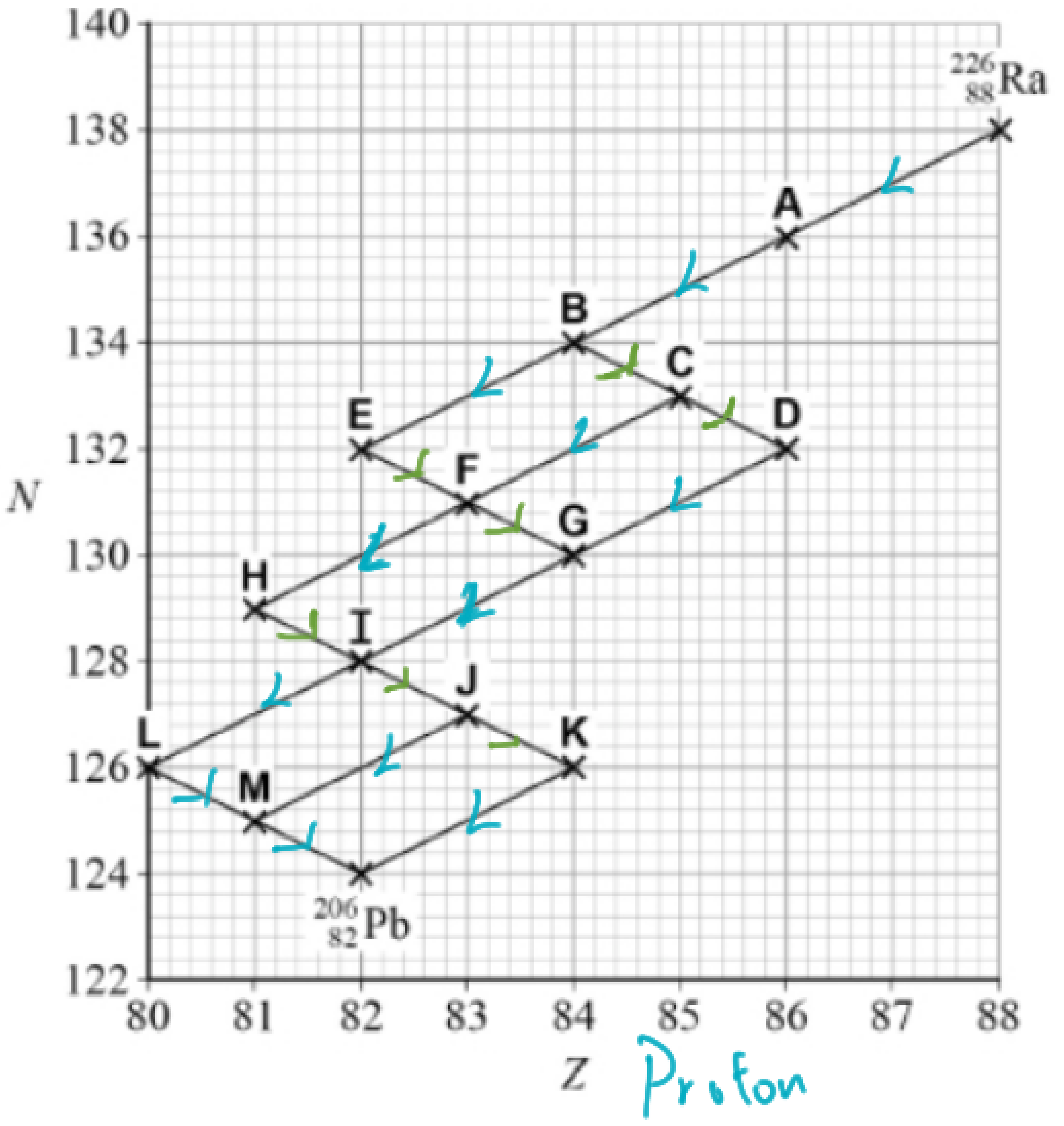
(b) A sealed source contains radium-226 ($^{226}_{88}Ra$).

$^{226}_{88}Ra$ decays by emitting α and β^- particles to produce $^{206}_{82}Pb$ which is stable.

Figure 2 is a graph of neutron number N against proton number Z, showing the different ways that $^{226}_{88}Ra$ can decay into $^{206}_{82}Pb$.

Points **A** to **M** represent all the unstable nuclei that may be formed as $^{226}_{88}Ra$ decays into $^{206}_{82}Pb$.

Figure 2



α: $-2P$
$-2N$
β^-: $-1N$
$+1P$

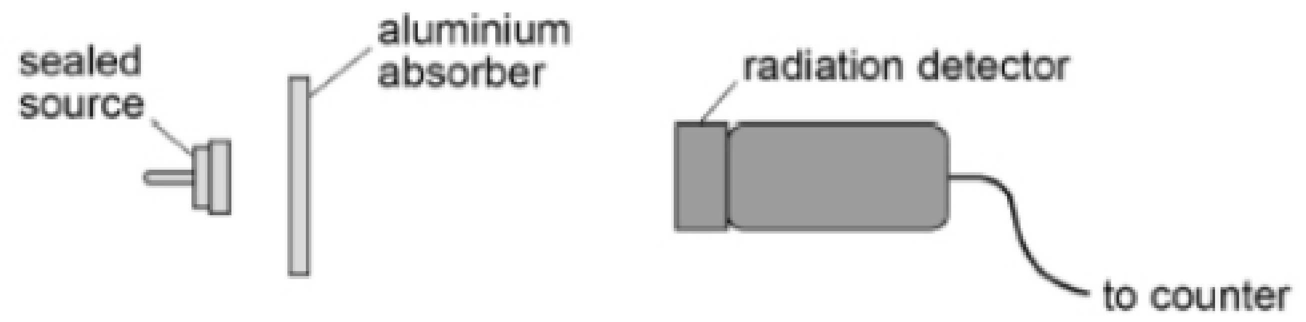
Determine the number of routes by which **B** can change into **K**.

5

(1)

(e) **Figure 3** shows an aluminium absorber placed between the sealed source and a radiation detector. This is to make sure that only γ radiation from the source reaches the detector.

Figure 3



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PhysicsAndMath

The sealed source emits:

- α particles with energy E_k between 3.8 MeV and 7.8 MeV
- β^- particles with energy E_k between zero and 5.5 MeV.

Figure 4 shows how the range of β^- particles in aluminium depends on E_k.

Deduce the minimum thickness of the aluminium absorber that should be used in the experiment.

____

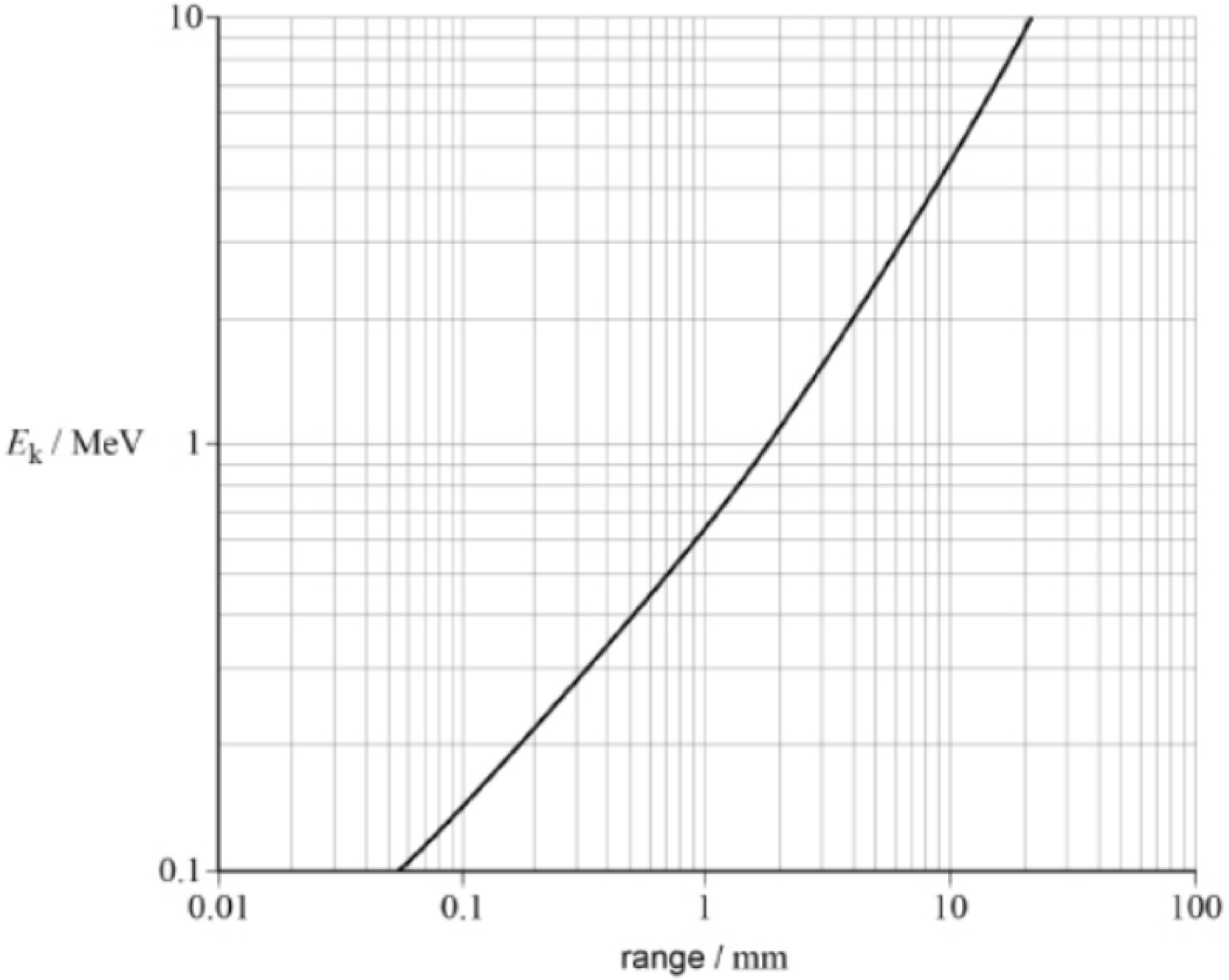
____

____

minimum thickness = ____________________ mm

Figure 4 shows how the range of β^- particles in aluminium depends on E_k.

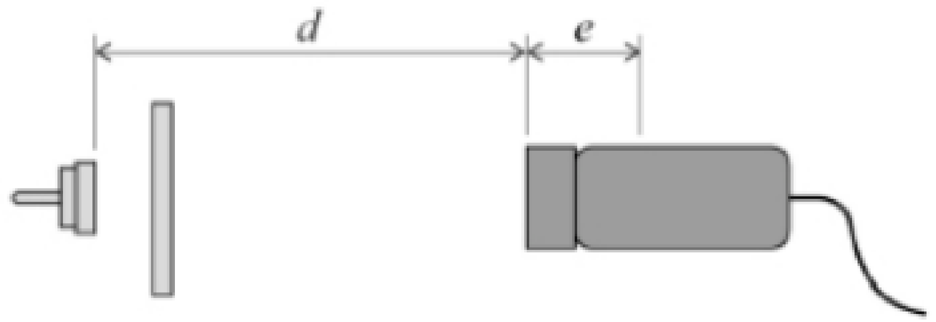
Figure 4



(f) Ionisation takes place inside the detector. The effective distance travelled by γ radiation from the source is $(d + e)$.

The distance e, shown in **Figure 5**, cannot be measured directly.

Figure 5



From the inverse-square law for γ radiation, it can be shown that

$$(d + e) = \sqrt{\frac{k}{A}}$$

where A is the count rate, corrected for background radiation
k is a constant.

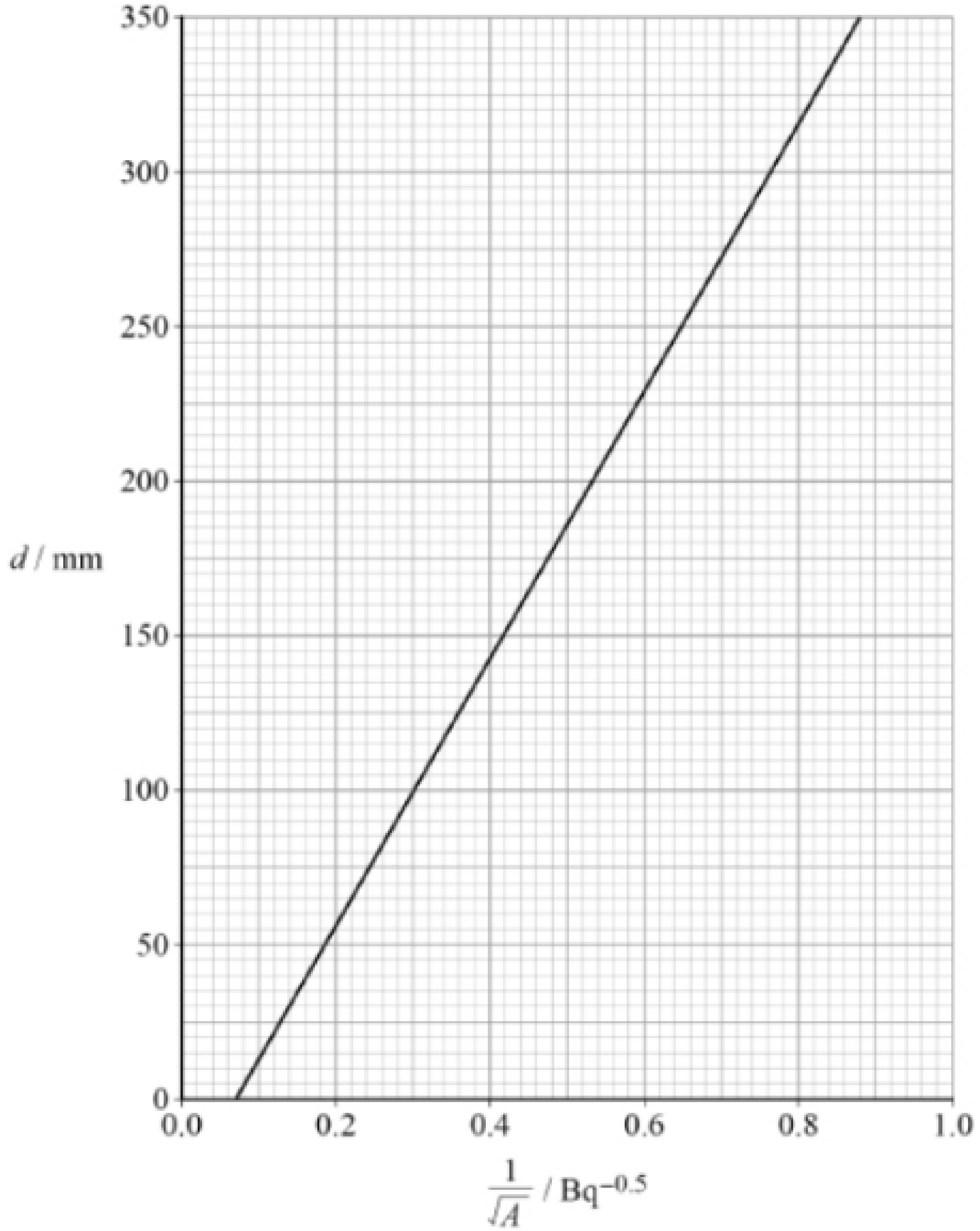
The student plots the graph of d against $\frac{1}{\sqrt{A}}$ shown in **Figure 6**.

Deduce k using **Figure 6**.
Explain your reasoning.
Give a suitable unit for your result.

k = ____________________ unit _______

(5)

Figure 6



(g) Determine e using **Figure 6**.

e = ____________________ mm

(c) Identify which of the nuclei **A** to **M** are common to all the possible ways that $^{226}_{88}\mathrm{Ra}$ decays into $^{206}_{82}\mathrm{Pb}$.

A B I

(3)

(d) The sealed source emits γ radiation in addition to α and β^- particles.
A student uses the sealed source to investigate the inverse-square law for γ radiation.
The student begins by making measurements to find the count rate A_b for the background radiation.

State and explain procedures

- to eliminate systematic error in the measurements used to find A_b
- to reduce the percentage uncertainty in A_b.

+0.1 +0.2

$10\ ms^{-1}$

100m ~~10.1~~ 10.1s

Theo: 10s

$\downarrow$

% err ≈ 1%

sys error

1. Remove all radioactive sources from the room
2. Check that the counter has no zero error

+0.1 +0.2

10m

Theo: 1s actual: 1.1s

% err: 10%

% error

3. Measure the background count rate for a prolonged time

(b) (i) The radius of a gold-197 nucleus $^{197}_{79}\mathrm{Au}$ is 6.87×10^{-15} m.

Show that the density of this nucleus is about 2.4×10^{17} kg m^{-3}.

(2)

(ii) Using the data from part (b)(i) calculate the radius of an aluminium-27 nucleus, $^{27}_{13}\mathrm{Al}$.

answer = ... m

(2)

(c) Nuclear radii have been investigated using α particles in Rutherford scattering experiments and by using electrons in diffraction experiments.

Make comparisons between these two methods of estimating the radius of a nucleus.

Detail of any apparatus used is not required.

For each method your answer should contain:

- the principles on which each experiment is based including a reference to an appropriate equation
- an explanation of what may limit the accuracy of each method
- a discussion of the advantages and disadvantages of each method.

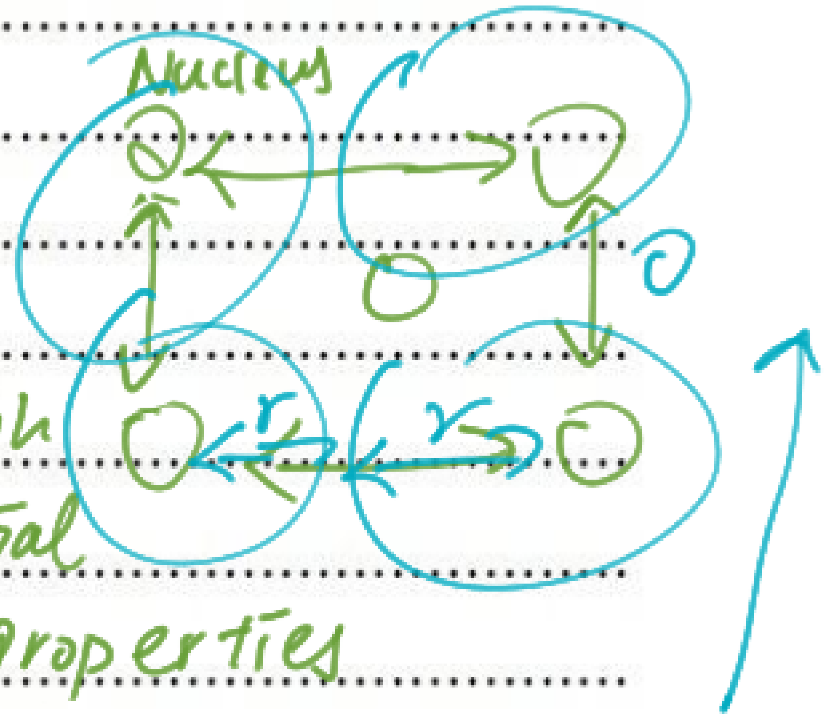
The quality of your written communication will be assessed in your answer.

Rutherford

→ Measure proportion of α particles scattered with a large angle

→ α ~~large~~ will scatter at a large when ~~KE~~ it is close to nucleus due to high electrostatic repulsion force (r small)

→ The measured ratio can be further used to calculate nuclear radius



Electron diffraction

A beam of electron with high KE is directed at the material

Electron have wave like properties

$$\lambda = \frac{h}{p} = \frac{h}{mv} \sim 1.8 \cdot 10^{-11} \text{ m}$$

$$\frac{1}{2} m_e v_e^2 = eV_0$$

$$v_e = \sqrt{\frac{2eV_0}{m_e}} \sim 4 \cdot 10^7$$

• Thin film is needed to prevent multiple scattering

• Diffraction occurs since λ is comparable to diameter of atom

• Electron Scattering

→ Measure first order diffraction minima

$$\Delta y = \frac{1.22\lambda}{D}$$ ← diameter

$$a \sin\theta = \frac{0.61\lambda}{R}$$

Accuracy

Rutherford

↳ only measure least distance of approach instead of nuclear radius

↳ Overestimate

Electron diffraction

e^- must have sufficient KE to undergo significant diffraction

Adv + Disadv

- Hard to determine 1st order minima in diffraction pattern as there are other scattering events superimposing on it.

$$T_{1/2} = 5.4\text{ yr}$$

$$A = A_0\left(\tfrac{1}{2}\right)^{\frac{t}{T_{1/2}}}$$

$$\frac{1}{8} = \left(\tfrac{1}{2}\right)^{\frac{t}{T_{1/2}}}$$

$$\frac{t}{T_{1/2}} = 3$$

$$t = 16.2\text{ yr.}$$

$$N = N_0\left(e^{-\lambda t}\right)$$

$$\lambda N = \lambda N_0\left(e^{-\lambda t}\right)$$

$$\cancel{A/t}\ A = A_0\left(e^{-\lambda t}\right)$$

↳ $\left(\tfrac{1}{2}\right)^{\frac{t}{T_{1/2}}}$

$$\cancel{\lambda}\ T_{1/2} = \frac{\ln 2}{\lambda}$$

$$\lambda = 0.128$$

$\tau = 5.4$