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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Nuclear physics (3.8)

A Level Physics (7408) · Section 3.8

76 questions · 305 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

76 questions · 305 marks · 8 sub-topics



SUB-TOPIC 3.8.1.1

RUTHERFORD SCATTERING

Sub-topic 3.8.1.1 · 7 questions · 16 marks · lowest tariff first



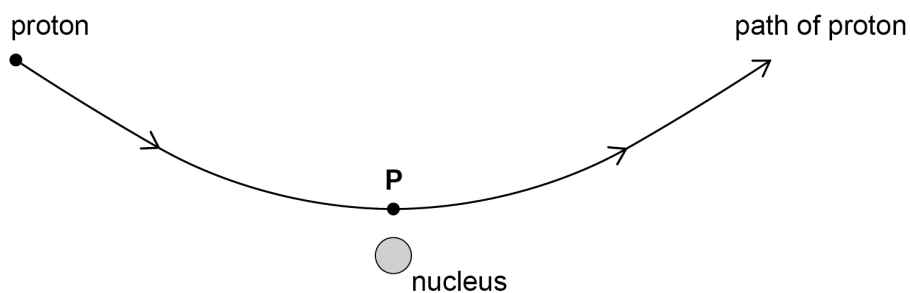
2 6

The Rutherford scattering experiment led to

[1 mark]**A** the discovery of the electron.☐**B** the quark model of hadrons.☐**C** the discovery of the nucleus.☐**D** evidence for wave-particle duality.☐

2 6

The diagram shows the path of a proton being deflected by the nucleus of an atom. Point **P** is the position of the proton when it is closest to the nucleus.



What is **not** true about the proton along its path at **P**?

[1 mark]

- A** Its rate of change of momentum is at a minimum. ☐
- B** Its kinetic energy is at a minimum. ☐
- C** Its potential energy is at a maximum. ☐
- D** Its acceleration is at a maximum. ☐

2 5

What was deduced or observed in the Rutherford scattering experiment?

[1 mark]**A** All gold atoms are not alike.☐**B** Alpha particles are helium nuclei.☐**C** Some particles were deflected through angles greater than 90° .☐**D** The motion of most alpha particles was reversed.☐

1 9

An alpha particle is moving towards a stationary gold nucleus. The alpha particle has a kinetic energy of 9.0×10^{-13} J when it is a large distance from the gold nucleus. The gold nucleus contains 79 protons.

What is the closest possible distance of approach of the alpha particle to the gold nucleus?
[1 mark]

A 2.5×10^{-16} m ☐

B 2.0×10^{-14} m ☐

C 4.0×10^{-14} m ☐

D 2.0×10^{-7} m ☐



2 6

Alpha particle scattering can be demonstrated using a thin gold foil.

Which statement about this demonstration is **not** true?

[1 mark]

- A** The foil is thin enough to assume that alpha particles are deflected only once. ☐
- B** Nuclei are more massive than alpha particles which allows the alpha particles to be deflected by more than 90° . ☐
- C** The number of alpha particles deflected backwards is greater than the number that pass straight through the foil. ☐
- D** Deflections of alpha particles by electrons in the foil are much smaller than deflections due to nuclei. ☐



2 9

What can be deduced about the radius r of a nucleus of gold from the scattering of alpha particles by gold nuclei?

[1 mark]

A $r < 10^{-14}$ m

☐

B $r < 10^{-15}$ m

☐

C $r \approx 10^{-15}$ m

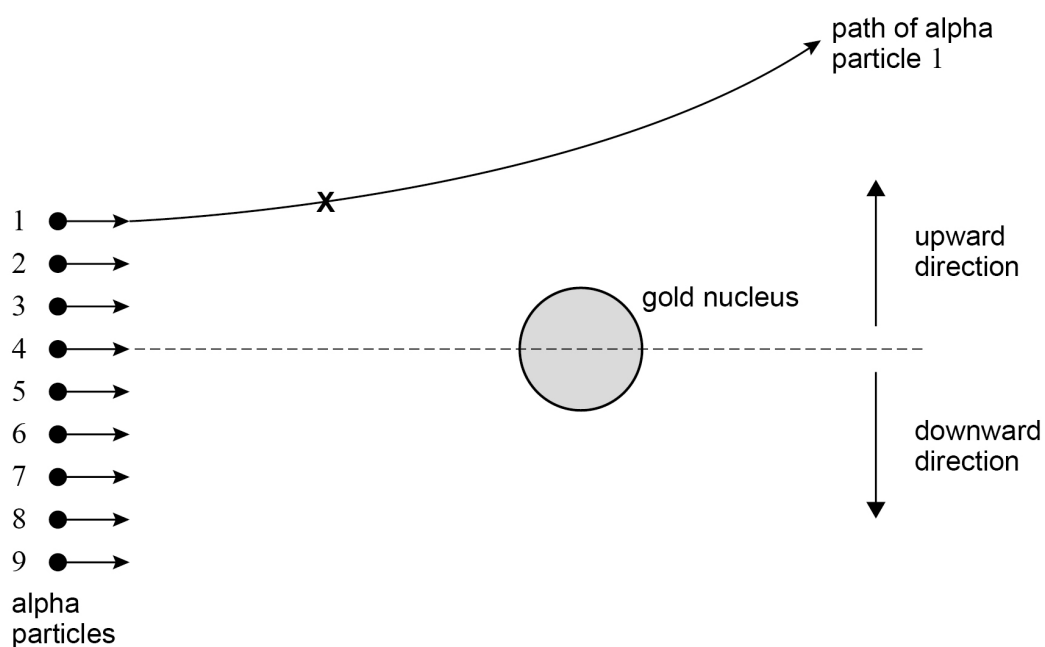
☐

D $r \approx 10^{-16}$ m

☐

0 5

Figure 11 shows alpha particles all travelling in the same direction at the same speed. The alpha particles are scattered by a gold ($^{197}_{79}\text{Au}$) nucleus. The path of alpha particle **1** is shown.

Figure 11

0 5 . 1

State the fundamental force involved when alpha particle **1** is scattered by the nucleus in **Figure 11**.

[1 mark]

0 5 . 2

Draw an arrow at position **X** on **Figure 11** to show the direction of the rate of change in momentum of alpha particle **1**

[1 mark]

0 5 . 3

Suggest **one** of the alpha particles in **Figure 11** which may be deflected downwards with a scattering angle of 90°

Justify your answer.

[2 marks]

alpha particle number = _____

0 5 . 4

Alpha particle **4** comes to rest at a distance of $5.5 \times 10^{-14} \text{ m}$ from the centre of the $^{197}_{79}\text{Au}$ nucleus.

Calculate the speed of alpha particle **4** when it is at a large distance from the nucleus. Ignore relativistic effects.

mass of alpha particle = $6.8 \times 10^{-27} \text{ kg}$

[3 marks]

speed = _____ m s^{-1}

Question 5 continues on the next page



0 5 . 5 The nuclear radius of $^{197}_{79}\text{Au}$ is $6.98 \times 10^{-15} \text{ m}$.

Calculate the nuclear radius of $^{107}_{47}\text{Ag}$.

[2 marks]

radius = _____ m

0 5 . 6 All nuclei have approximately the same density.

State **one** conclusion about the nucleons in a nucleus that can be deduced from this fact.

[1 mark]



SUB-TOPIC 3.8.1.2

ALPHA, BETA AND GAMMA RADIATION

Sub-topic 3.8.1.2 · 8 questions · 53 marks · lowest tariff first



2 7

A Geiger counter is placed near a radioactive source and different materials are placed between the source and the Geiger counter.

The results of the tests are shown in the table.

Material	Count rate of Geiger counter / s ⁻¹
None	1000
Paper	1000
Aluminium foil	250
Thick steel	50

What is the radiation emitted by the source?

[1 mark]

A α only

☐

B α and γ

☐

C α and β

☐

D β and γ

☐

1 8

When a small radioactive source is placed in a cloud chamber, straight tracks about 4 cm long are observed. The same source is placed 10 cm from a Geiger tube and a count rate is detected. When a sheet of aluminium 5 mm thick is placed between the source and the Geiger tube the count rate falls to the background count rate.

Which types of radiation are emitted by the source?

[1 mark]

A α , β and γ

☐

B β and γ

☐

C α and γ

☐

D α and β

☐

3	0
---	---

Which is **not** true for gamma radiation?

[1 mark]

A It is more penetrating than alpha or beta radiation of the same energy through the same material.

☐

B Its intensity is inversely proportional to the square of the distance from its source.

☐

C It is emitted with discrete frequencies.

☐

D When it is absorbed it makes the absorber radioactive.

☐

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235

2 5

A radiation meter is placed at a distance d from a source of gamma radiation. The corrected count rate is 800 counts per second.

When the radiation meter is moved a further 10 cm from the source the corrected count rate is 600 counts per second.

What is d ?

[1 mark]

A 8.7 cm ☐

B 13 cm ☐

C 30 cm ☐

D 64 cm ☐

0 5 . 1

Suggest, with a reason, which type of radiation is likely to be the most appropriate for the sterilisation of metallic surgical instruments.

[1 mark]

0 5 . 2

Explain why the public need not worry that irradiated surgical instruments become radioactive once sterilised.

[1 mark]

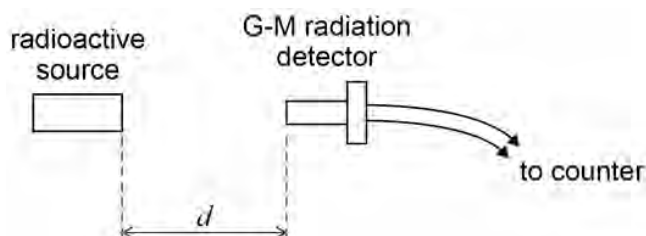
Question 5 continues on the next page



0 5 . 3

A student detects the counts from a radioactive source using a G-M radiation detector as shown in **Figure 10**.

Figure 10



The student measures the count rate for three different distances d . **Table 1** shows the count rate, in counts per minute, corrected for background for each of these distances.

Table 1

d/m	Corrected count rate / counts per minute			
0.20	9013			
0.50	1395			
1.00	242			

Explain, with the aid of suitable calculations, why the data in **Table 1** are **not** consistent with an inverse-square law. You may use the blank columns for your working.

[2 marks]

0 5 . 4

State **two** possible reasons why the results do **not** follow the expected inverse-square law.

[2 marks]

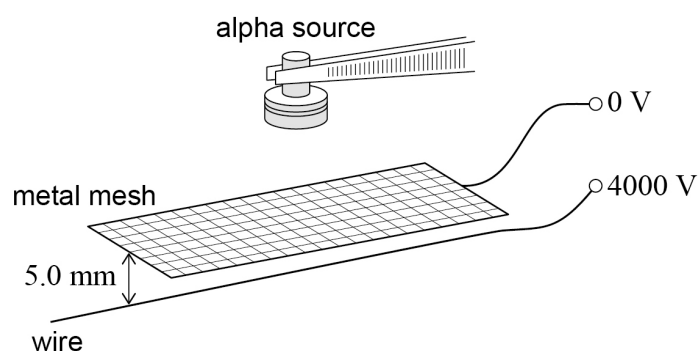
Reason 1 _____

Reason 2 _____

0	4
---	---

Figure 4 shows a spark detector used to detect alpha particles.

Figure 4



The detector consists of a metal mesh placed 5.0 mm above a wire.
A potential difference of 4000 V is applied between the mesh and the wire.

Molecules in the air between the mesh and the wire are ionised by an alpha particle and a spark is produced.

Figure 5 shows equipotentials between the mesh and the wire.

Figure 5

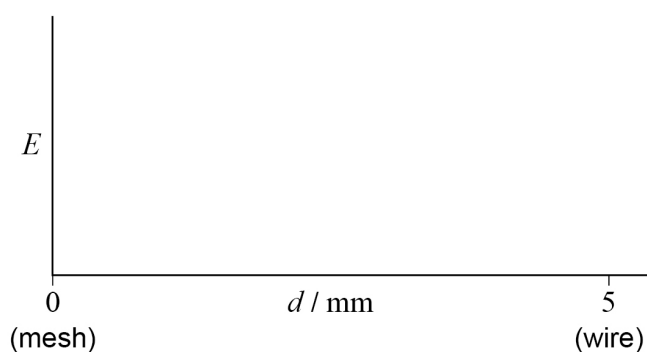
0 4 . 1

Figure 5 shows a dashed line between the mesh and the wire.

Sketch on **Figure 6** a graph to show how the magnitude E of the electric field strength varies with the distance d from the mesh along this dashed line.
No values are required on the E axis.

[2 marks]

Figure 6



An alpha particle passes through the mesh.
The alpha particle ionises an argon atom at **P** on **Figure 5**, releasing one electron.
The electron and the argon ion have no kinetic energy at **P**.
The electron then travels to the wire and the argon ion travels to the mesh.

0 4 . 2

Calculate the ratio $\frac{\text{speed of electron when it reaches the wire}}{\text{speed of argon ion when it reaches the mesh}}$.

Assume that the air has no effect on the motion of the electron or on the motion of the argon ion.

$$\text{mass of argon ion} = 6.64 \times 10^{-26} \text{ kg}$$

[2 marks]

ratio = _____

Question 4 continues on the next page



0 4 . 3

In practice, the air **does** affect the motion of the electron and the motion of the argon ion.

Suggest how the presence of air between the mesh and the wire changes the ratio in Question **04.2**.

No numerical detail is required.

[1 mark]

0 4 . 4

The alpha source in **Figure 4** is moved to different heights h above the mesh.

Figure 7 shows how the number of sparks N produced in 10 minutes varies with h . No sparks are produced when the source is not present.

Figure 7

Student **A** suggests that the spark rate obeys an inverse-square law.
Student **B** suggests that the spark rate decreases exponentially with h .

Determine whether either student is correct.

[3 marks]

0 1

Figure 1 shows apparatus used to investigate the inverse-square law for gamma radiation.

Figure 1

A sealed source that emits gamma radiation is held in a socket attached to clamp **B**. The vertical distance between the open end of the source and the bench is 138 mm. A radiation detector, positioned vertically above the source, is attached to clamp **T**.

A student is told **not** to move the stands closer together.

0 1 . 1

Describe a procedure for the student to find the value of d , the vertical distance between the open end of the source and the radiation detector.

In your answer, annotate **Figure 1** to show how a set-square can be used in this procedure.

[2 marks]

Question 1 continues on the next page

0 1 . 2

Before the source was brought into the room, a background count C_b was recorded.

$$C_b = 630 \text{ counts in 15 minutes}$$

With the source and detector in the positions shown in **Figure 1**, $d = 530 \text{ mm}$.

Separate counts C_1 , C_2 and C_3 are recorded.

$$C_1 = 90 \text{ counts in 100 s}$$

$$C_2 = 117 \text{ counts in 100 s}$$

$$C_3 = 102 \text{ counts in 100 s}$$

R_C is the mean count rate corrected for background radiation.

Show that when $d = 530 \text{ mm}$, R_C is about 0.3 s^{-1} .

[2 marks]



- 0 1 . 3** The apparatus is adjusted so that $d = 380$ mm.
Counts are made that show $R_C = 0.76 \text{ s}^{-1}$.

The student predicts that:

$$R_C = \frac{k}{d^2}$$

where k is a constant.

Explain whether the values of R_C in Questions **01.2** and **01.3** support the student's prediction.

[2 marks]

- 0 1 . 4** Describe a safe procedure to reduce d . Give a reason for your procedure.

[2 marks]

Question 1 continues on the next page

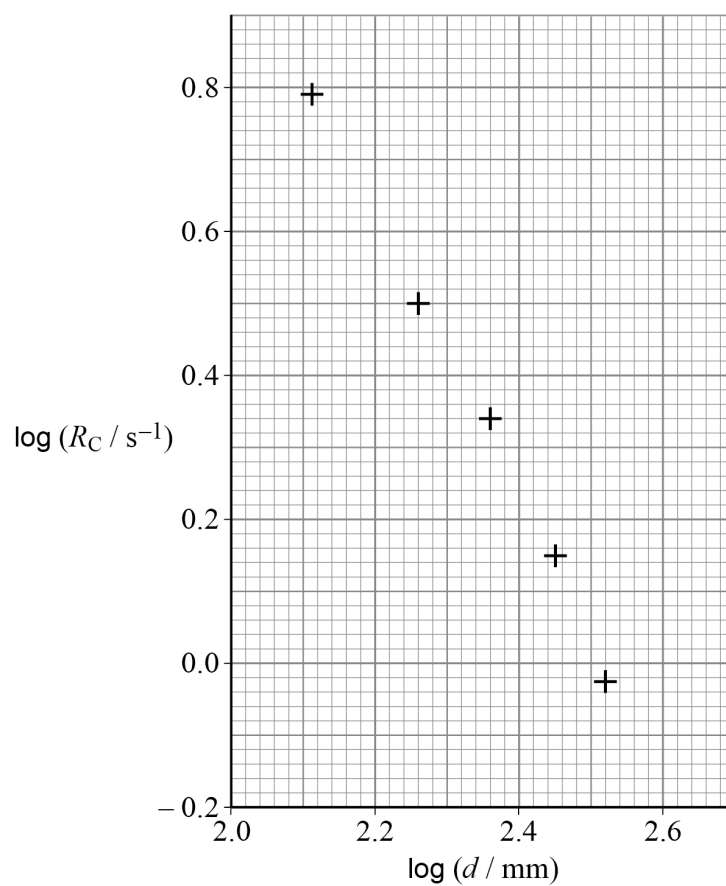


The student determines R_C for further values of d .

The values of d change by the same amount Δd between each measurement.

Figure 2 shows these data.

Figure 2



0 1 . 5 Determine Δd .

[2 marks]

$\Delta d =$ _____ mm

0 1 . 6Explain how the student could confirm whether **Figure 2** supports the prediction:

$$R_C = \frac{k}{d^2}$$

No calculation is required.

[3 marks]

Question 1 continues on the next page

When a gamma photon is detected by the detector, another photon cannot be detected for a time t_d called the dead time.

It can be shown that:

$$t_d = \frac{R_2 - R_1}{R_1 \times R_2}$$

where R_1 is the measured count rate

R_2 is the count rate when R_1 is corrected for dead time error.

0 1 . 7

The distance between the source and the detector is adjusted so that d is very small and R_1 is 100 s^{-1} .

On average, two of the gamma photons that enter the detector every second are not detected.

Calculate t_d for this detector.

[1 mark]

$t_d =$ _____ s

0 1 . 8

A student says that if 100 gamma photons enter a detector in one second and t_d is 0.01 s, all the photons should be detected.

Explain, with reference to the nature of radioactive decay, why this idea is **not** correct.
[2 marks]



0	1
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Figure 1 shows a sealed radioactive source used in schools and colleges.

Figure 1



0	1	.	1
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State **two** safety procedures to reduce risk when using this type of source.

[2 marks]

Safety procedure 1 _____

Safety procedure 2 _____

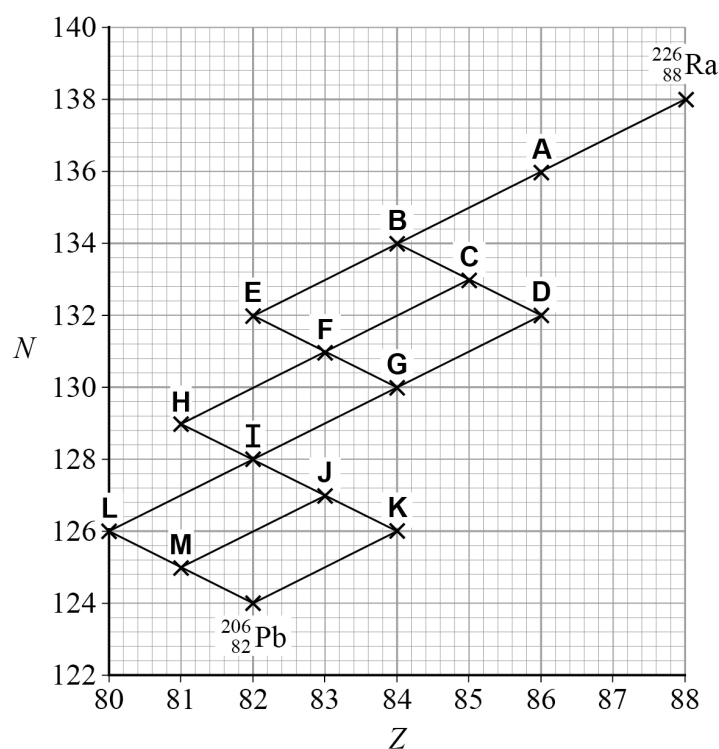
0 1 2 A sealed source contains radium-226 ($^{226}_{88}\text{Ra}$).

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

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

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

Figure 2



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

[1 mark]

0 1 3 Identify which of the nuclei **A** to **M** are common to all the possible ways that $^{226}_{88}\text{Ra}$ decays into $^{206}_{82}\text{Pb}$.

[3 marks]

Question 1 continues on the next page

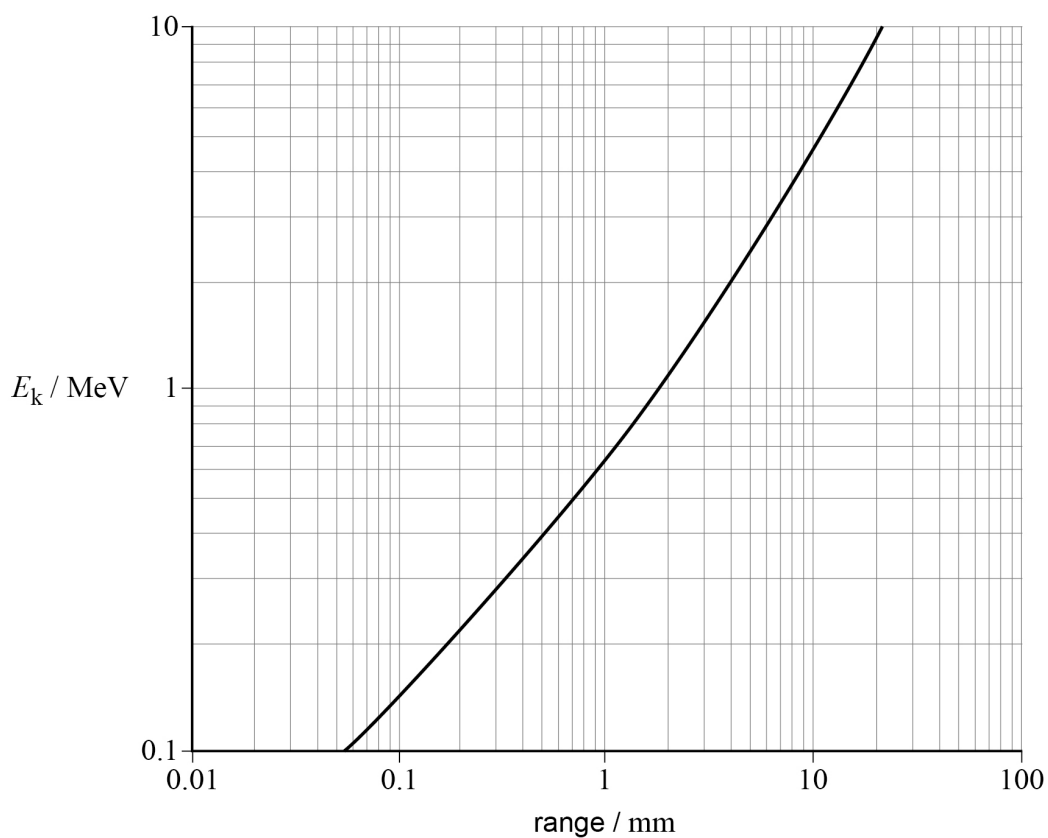


The sealed source emits:

- 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 .

Figure 4



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

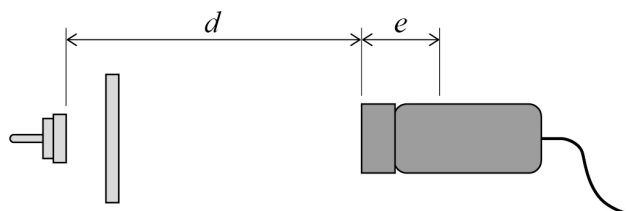
[3 marks]

minimum thickness = _____ mm

Question 1 continues on the next page

- 0 1 . 6** 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.

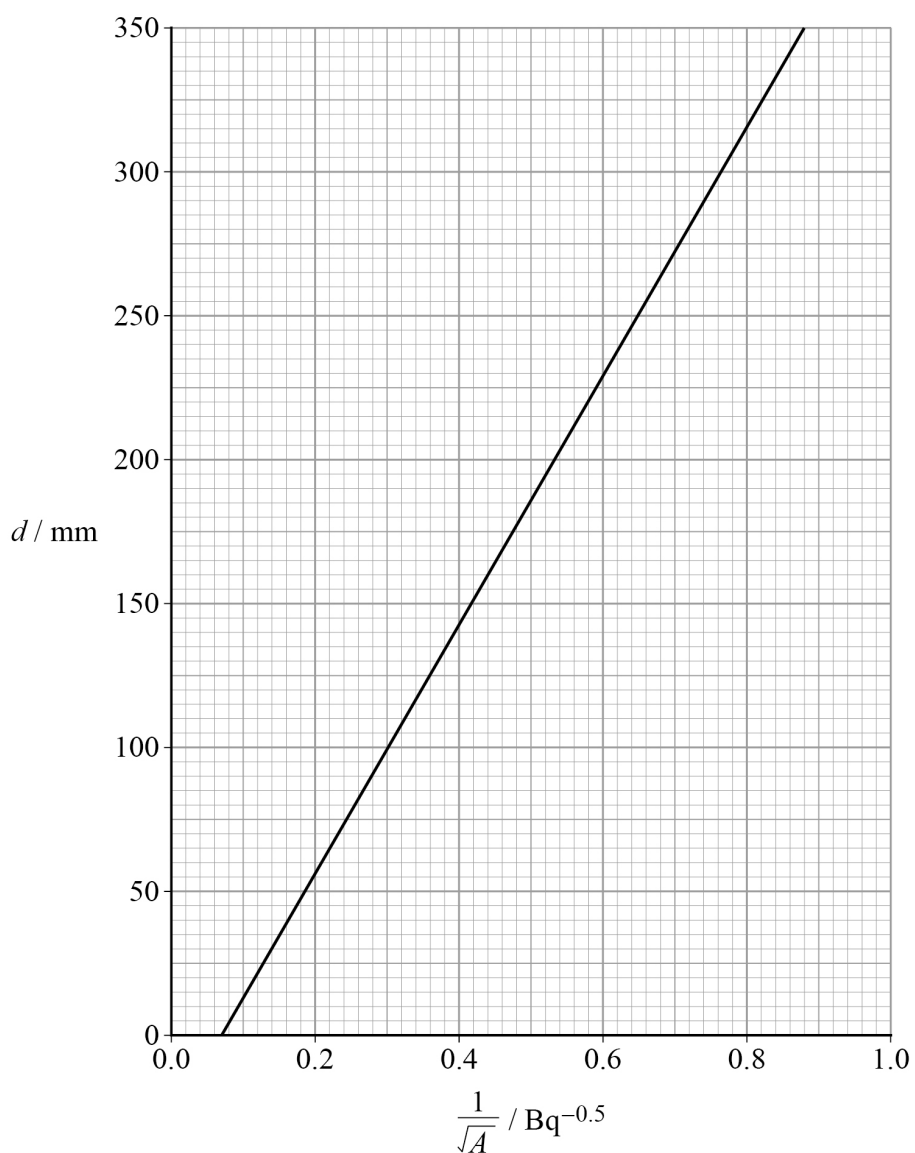
The student plots the graph of d against $\frac{1}{\sqrt{A}}$ shown in **Figure 6**.

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

[5 marks]

$k =$ _____ unit _____

Figure 6



0 1 . 7 Determine e using **Figure 6**.

[2 marks]

$e =$ _____ mm

SUB-TOPIC 3.8.1.3

RADIOACTIVE DECAY AND HALF-LIFE

Sub-topic 3.8.1.3 · 13 questions · 41 marks · lowest tariff first



2 8

Nobelium-259 has a half-life of 3500 s.

What is the decay constant of nobelium-259?

[1 mark]

A $8.7 \times 10^{-5} \text{ s}^{-1}$

☐

B $2.0 \times 10^{-4} \text{ s}^{-1}$

☐

C $1.7 \times 10^{-2} \text{ s}^{-1}$

☐

D $1.2 \times 10^{-2} \text{ s}^{-1}$

☐

2	9
---	---

A pure sample of nuclide **X** containing N nuclei has an activity A .
The half-life of **X** is 6000 years.

A pure sample of nuclide **Y** containing $3N$ nuclei has an activity $6A$.

What is the half-life of nuclide **Y**?

[1 mark]

A 1000 years

☐

B 3000 years

☐

C 12 000 years

☐

D 18 000 years

☐

3 0

Cobalt-60 has a half-life of 5.27 years.

What is the total activity of 1.0 g of cobalt-60?

[1 mark]

A 4.2×10^{13} Bq

☐

B 2.2×10^{14} Bq

☐

C 2.5×10^{15} Bq

☐

D 1.3×10^{21} Bq

☐

2 9

The number of parent nuclei in a sample of a radioactive element is N at time t .

The radioactive element has a half-life $t_{\frac{1}{2}}$

The rate of decay is proportional to

[1 mark]**A** N ☐**B** t ☐**C** $\frac{1}{t}$ ☐**D** $t_{\frac{1}{2}}$ ☐

2 **8**

X and **Y** are two radioactive nuclides. **X** has a half-life of 3.0 minutes and **Y** has a half-life of 9.0 minutes.

Two freshly prepared samples of **X** and **Y** start decaying at the same time.
After 18 minutes the number of radioactive nuclei in both samples is the same.
The sample of **Y** initially contained N radioactive nuclei.

What was the initial number of radioactive nuclei in the sample of **X**?

[1 mark]**A** $4N$ ☐**B** $16N$ ☐**C** $32N$ ☐**D** $64N$ ☐

2 7

A sample of radioactive material consists of 200 g of nuclide **P** and 100 g of nuclide **Q**.

Nuclide **P** has a half-life of 2 days and nuclide **Q** has a half-life of 4 days.

What is the total mass of nuclides **P** and **Q** after 12 days?

[1 mark]**A** 3.1 g☐**B** 12.5 g☐**C** 15.6 g☐**D** 18.8 g☐

2 8

A nuclide has a half-life of 10 ms.

The decay constant for this nuclide lies between

[1 mark]

A 1 s^{-1} and 10 s^{-1} .

☐

B 10 s^{-1} and 10^2 s^{-1} .

☐

C 10^2 s^{-1} and 10^3 s^{-1} .

☐

D 10^3 s^{-1} and 10^6 s^{-1} .

☐

2 8

The random nature of radioactive decay means that it is never possible to predict

[1 mark]**A** when a particular nucleus will decay.☐**B** whether a β^- particle or a β^+ particle is emitted.☐**C** the approximate time taken for the activity to decrease to a specified value.☐**D** the approximate thickness of an absorber needed to reduce the count rate to a specified value.☐

3 0

Tritium is a radioactive nuclide used in 'Exit' signs.
When a sign was manufactured the activity of the tritium in it was 37 MBq.
After 10 years the tritium in the sign has an activity of 21 MBq.

What will the activity be 15 years after it was manufactured?

[1 mark]

A 12 MBq ☐

B 13 MBq ☐

C 16 MBq ☐

D 17 MBq ☐

3 0

100% correct



3 2

A rock sample is found to contain the stable isotope lead-207. When it was formed, the rock contained uranium-235 but did not contain any lead-207.

Uranium-235 decays by a series of steps into lead-207. The half-life of uranium-235 is 0.71 billion years. The half-lives of the nuclides in the intermediate steps are negligible.

The sample of rock now contains one atom of lead-207 for every four atoms of uranium-235.

How long ago was the rock formed?

[1 mark]

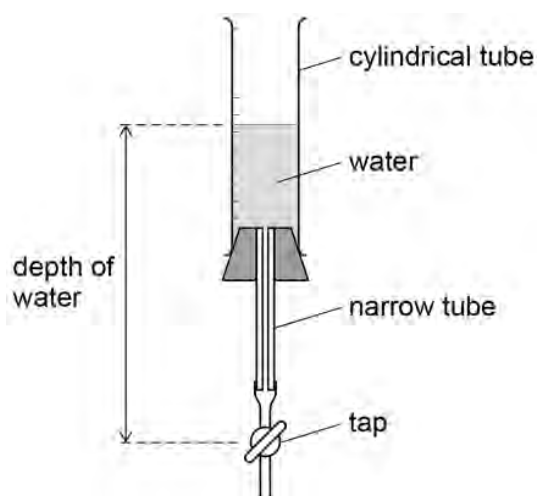
- A** 0.23 billion years ☐
- B** 0.31 billion years ☐
- C** 1.4 billion years ☐
- D** 2.0 billion years ☐

END OF QUESTIONS

0	6
---	---

Figure 11 shows how radioactive decay of one nuclide can be modelled by draining water through a tap from a cylindrical tube.

Figure 11



The water flow-rate is proportional to the pressure of the water. The pressure of the water is proportional to the depth of the water. Therefore the rate at which the depth decreases is proportional to the depth of the water.

Before the tap is opened the depth is 16.0 cm

The tap is opened and the depth is measured at regular intervals. These data are plotted on the graph in **Figure 12**.

Figure 12

0 6 . 1 Determine the predicted depth of water when the time is 57 s

[1 mark]

depth = _____ cm

0 6 . 2 Suggest how the apparatus in **Figure 11** may be changed to represent a radioactive sample of the same nuclide with a greater number of nuclei.

[1 mark]

0 6 . 3 Suggest how the apparatus in **Figure 11** may be changed to represent a radioactive sample of a nuclide with a smaller decay constant.

[1 mark]

0 6 . 4 The age of the Moon has been estimated from rock samples containing rubidium (Rb) and strontium (Sr), brought back from Moon landings.
 $^{87}_{37}\text{Rb}$ decays to $^{87}_{38}\text{Sr}$ with a radioactive decay constant of $1.42 \times 10^{-11} \text{ year}^{-1}$

Calculate, in years, the half-life of $^{87}_{37}\text{Rb}$.

[1 mark]

half-life = _____ years

Question 6 continues on the next page



0 6 . 5 A sample of Moon rock contains 1.23 mg of $^{87}_{37}\text{Rb}$.

Calculate the mass, in g, of $^{87}_{37}\text{Rb}$ that the rock sample contained when it was formed 4.47×10^9 years ago.

Give your answer to an appropriate number of significant figures.

[3 marks]

mass = _____ g

0 6 . 6 Calculate the activity of a sample of $^{87}_{37}\text{Rb}$ of mass 1.23 mg

Give an appropriate unit for your answer.

[3 marks]

activity = _____ unit _____



07

A team of students uses 900 dice, each with n sides, to model the decay of a radioactive material. Each dice represents a single undecayed nucleus. A throw of the dice represents a constant time interval.

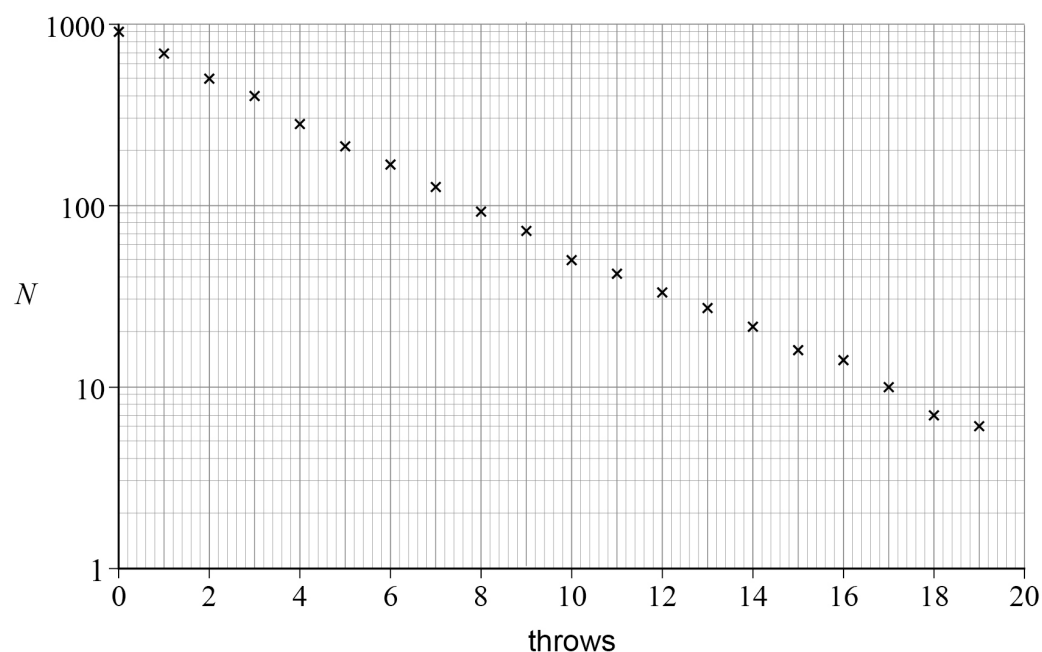
When the dice are thrown, those that show a 1 represent decayed nuclei and are removed.

The students count the number N of 'undecayed' dice that remain.

The procedure is repeated using the undecayed dice.

Figure 10 shows the students' data.

Figure 10



07.1

Explain why N has been plotted on a logarithmic scale in **Figure 10**.

[1 mark]

Question 7 continues on the next page



07.2

In this experiment, a decay constant λ can be defined that models the radioactive decay constant.

Determine λ .

Go on to use your value for λ to show that $n = 4$ for the dice used in this experiment.

[5 marks]

$\lambda =$ _____ throw^{-1}

07.3

A typical radioactive source used in schools has an activity of 100 kBq.
A radioactive source used in a hospital has an activity of 370 GBq.

State **one** safety measure when using a radioactive source in a school laboratory.
Go on to discuss how this safety measure needs to be adapted for safe use of the hospital radioactive source.

[2 marks]

07.4 X-rays are a form of ionising radiation.

A person has check-ups with a dentist every six months.

The dentist only takes X-ray images when the person has reported a problem.

Suggest why.

[2 marks]

END OF SECTION A

Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 3

A radioisotope thermoelectric generator (RTG) uses radioactive decay to generate electrical energy.

A vehicle that is used to examine the surface of Mars includes an RTG that initially contains 3.23×10^{24} atoms of plutonium-238 (${}^{238}_{94}\text{Pu}$).

0 3**. 1**

Determine the initial mass of plutonium-238 in the RTG.

[2 marks]

initial mass = _____ kg



03.2

The plutonium-238 undergoes alpha decay.

The energy released by this decay is converted into electrical energy with an efficiency of 4.58%.

The power provided by the RTG decreases over time as the plutonium-238 decays.

The vehicle requires a minimum electrical power of 29.6 W to operate.

Calculate the initial activity of the plutonium-238.

Go on to determine, in Earth years, the time for which the RTG can provide sufficient power for the vehicle to operate.

$$\text{decay constant of plutonium-238} = 2.51 \times 10^{-10} \text{ s}^{-1}$$

$$\text{energy of alpha particle emitted by plutonium-238} = 8.94 \times 10^{-13} \text{ J}$$

[5 marks]

initial activity = _____ Bq

time = _____ Earth years

Question 3 continues on the next page



0 3 . 3

The vehicle has a battery-powered laser that is used to vaporise small samples of ice. On Mars, ice changes directly from solid to vapour at a temperature of $0\text{ }^{\circ}\text{C}$. The ice does not form a liquid.

The energy required to vaporise 1.0 g of solid ice directly into water vapour is the same as the total energy required to melt 1.0 g of ice and then to vaporise the melted ice.

The laser produces an output power of 1.0 kW for a maximum time of 3.0 s before its battery needs to be recharged.

The laser heats the ice from an initial temperature of $-25\text{ }^{\circ}\text{C}$ to a temperature of $0.0\text{ }^{\circ}\text{C}$. The laser then transfers energy to vaporise the ice at $0.0\text{ }^{\circ}\text{C}$.

Determine whether the laser is able to vaporise 1.0 g of the ice that is initially at $-25\text{ }^{\circ}\text{C}$ before the battery needs to be recharged.

specific heat capacity of ice $= 2.1\text{ kJ kg}^{-1}\text{ K}^{-1}$

specific latent heat of fusion of ice $= 334\text{ kJ kg}^{-1}$

specific latent heat of vaporisation $= 2500\text{ kJ kg}^{-1}$

[4 marks]

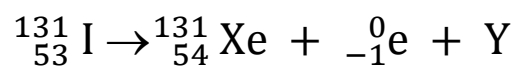
SUB-TOPIC 3.8.1.4

NUCLEAR INSTABILITY

Sub-topic 3.8.1.4 · 11 questions · 58 marks · lowest tariff first



- 1 2** An iodine nucleus decays into a nucleus of Xe-131, a beta-minus particle and particle Y.



Which is a property of particle Y?

[1 mark]

- A** It has a lepton number of +1
- B** It is an antiparticle
- C** It is negatively charged
- D** It experiences the strong interaction

☐☐☐☐

1 0

The radioactive nuclide ${}_{90}^{232}\text{Th}$ decays by one α emission followed by two β^- emissions.

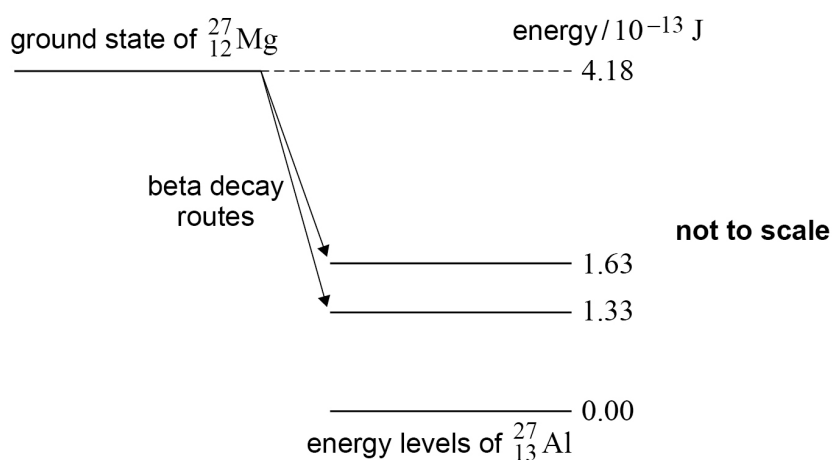
Which nuclide is formed as a result of these decays?

[1 mark]**A** ${}_{92}^{238}\text{U}$ ☐**B** ${}_{90}^{230}\text{Th}$ ☐**C** ${}_{90}^{228}\text{Th}$ ☐**D** ${}_{88}^{228}\text{Rn}$ ☐

3 1

$^{27}_{12}\text{Mg}$ can decay by beta minus emission to one of two possible excited states of $^{27}_{13}\text{Al}$.

Both excited states decay by the emission of a gamma photon directly to the ground state.



The diagram shows the energy levels and two routes for the beta decay.

One route results in the emission of a gamma photon with a higher frequency than the other photon.

What is the maximum possible kinetic energy for the beta particle emitted in this route?

[1 mark]

A 1.33×10^{-13} J

☐

B 1.63×10^{-13} J

☐

C 2.55×10^{-13} J

☐

D 2.85×10^{-13} J

☐

END OF QUESTIONS



2 9

Which provides evidence for the existence of energy levels in nuclei?

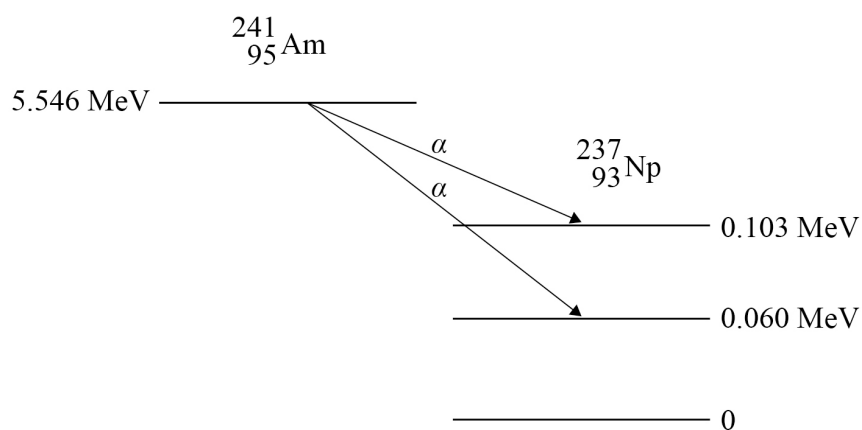
[1 mark]**A** the Rutherford alpha particle scattering experiment☐**B** the existence of X-ray line spectra☐**C** the existence of gamma radiation☐**D** electron diffraction by crystals☐

2 6

$^{241}_{95}\text{Am}$ decays to one of two excited states of $^{237}_{93}\text{Np}$ by emitting an alpha particle.

The excited $^{237}_{93}\text{Np}$ nucleus then decays with the emission of a gamma photon.

The diagram shows the energy levels involved in the decay of $^{241}_{95}\text{Am}$.



What is the energy of the emitted gamma photon that has the shortest wavelength?

[1 mark]

A 5.546 MeV ☐

B 5.486 MeV ☐

C 0.103 MeV ☐

D 0.043 MeV ☐

0	1
---	---

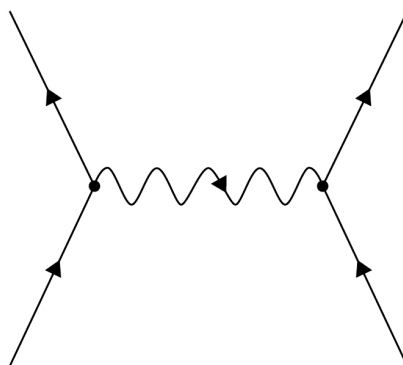
This question is about an isotope of titanium that **only** decays by electron capture.

0	1	.	1
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Complete **Figure 1** to show the quark change that occurs during electron capture. Label the incoming and outgoing particles and the exchange particle.

[3 marks]

Figure 1



0	1	.	2
---	---	---	---

In some circumstances, a nucleus of this isotope can exist with **no** orbiting electrons.

Explain why a neutral atom of this isotope is less stable than a nucleus that has no orbiting electrons.

[1 mark]

0	1	.	3
---	---	---	---

A nucleus of this isotope of titanium has a proton number of 22 and a specific charge of $4.8 \times 10^7 \text{ C kg}^{-1}$.

Determine the number of neutrons in this nucleus.

[2 marks]

number of neutrons = _____



0 1 · 1 Two isotopes of iodine are $^{125}_{53}\text{I}$ and $^{131}_{53}\text{I}$.

Determine, for these two isotopes, the difference between the constituents of the nuclei.

[1 mark]

0 1 · 2 A $^{131}_{53}\text{I}$ nuclide undergoes beta (β^-) decay to form a xenon nuclide.

State the nucleon number of the xenon nuclide.

[1 mark]

0 1 · 3 A $^{125}_{53}\text{I}$ nuclide decays by electron capture to form a tellurium nuclide.

State **two** differences between the constituents of the iodine nucleus and the tellurium nucleus it decays into.

[2 marks]

0 1 · 4 Internal conversion is a process in which a nucleus in an excited state can release its excess energy. In internal conversion all of the excess energy is transferred from the nucleus to an orbital electron through the electromagnetic force. This orbital electron is ejected from the atom.

The tellurium nucleus formed in question **01.3** is in an excited state and can undergo internal conversion.

Discuss **three** differences between internal conversion and beta (β^-) decay.

[3 marks]

1

2

3



0 2

Carbon-14 decays into nitrogen-14 with the release of a beta (β^-) particle and an antineutrino ($\bar{\nu}_e$).

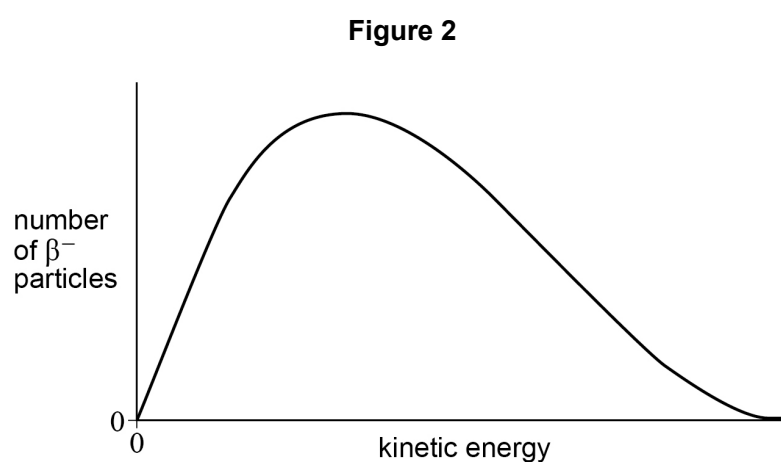
0 2 . 1

State the change of quark character in β^- decay.

[1 mark]

0 2 . 2

Figure 2 shows the distribution of kinetic energies of β^- particles from the decay of carbon-14.

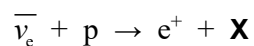


Explain how **Figure 2** supports the existence of the antineutrino.

[2 marks]

Question 2 continues on the next page

The existence of the antineutrino was confirmed by experiments in which antineutrinos interact with protons. The equation for this interaction is:



0 2 3 Identify particle **X**.

[1 mark]

0 2 4 The positron released in this interaction is annihilated when it encounters an electron. A pair of gamma photons is then produced. Particle **X** can be absorbed by a nucleus. This produces another gamma ray. **Table 1** contains data for three gamma photons detected during an antineutrino–proton interaction experiment.

Table 1

Gamma photon	Photon energy / J
G1	5.0×10^{-14}
G2	6.6×10^{-14}
G3	1.0×10^{-13}

Deduce which of the three gamma photons could have been produced by positron annihilation.

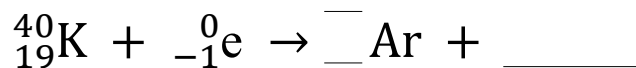
[3 marks]

0 1

An isotope of potassium ${}^{40}_{19}\text{K}$ is used to date rocks. The isotope decays into an isotope of argon (Ar) mainly by electron capture.

0 1 . 1

The decay is represented by this equation:



Complete the equation to show the decay by filling in the gaps.

[2 marks]**0 1 . 2**

Explain which fundamental interaction is responsible for the decay in question **01.1**.

[2 marks]

0 1 . 3

One decay mechanism for the decay of ${}^{40}_{19}\text{K}$ results in the argon nucleus having an excess energy of 1.46 MeV. It loses this energy by emitting a single gamma photon.

Calculate the wavelength of the photon released by the argon nucleus.

[3 marks]

wavelength = _____ m

0 1 . 4

The potassium isotope can also decay by a second decay process to form a calcium-40 nuclide (${}^{40}_{20}\text{Ca}$).

Suggest how the emissions from a nucleus of decaying potassium can be used to confirm which decay process is occurring.

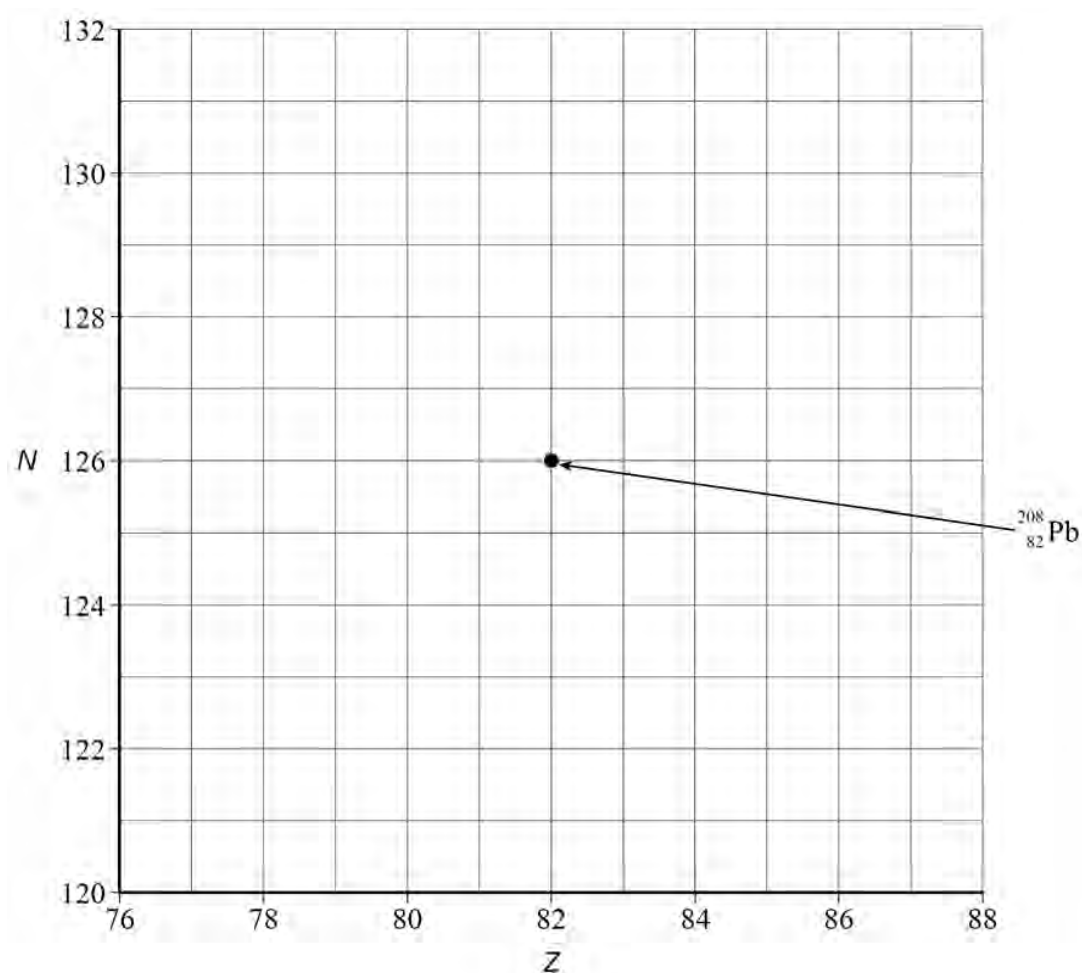
[3 marks]

0 7

A nucleus of polonium Po may decay to the stable isotope of lead $^{208}_{82}\text{Pb}$ through a chain of emissions following the sequence $\alpha \beta^- \beta^- \alpha$.

Figure 13 shows the position of the isotope $^{208}_{82}\text{Pb}$ on a grid of neutron number N against proton number Z .

Figure 13



0 7 . 1

Draw **four** arrows on **Figure 13** to show the sequence of changes to N and Z that occur as the polonium nucleus is transformed into $^{208}_{82}\text{Pb}$.

[2 marks]

Question 7 continues on the next page



0 7 . 4

The thallium nucleus is formed in an excited state. Electromagnetic radiation is emitted from the thallium atom following its formation.

Explain the origin and location of **two** sources of this radiation.

[2 marks]

Source 1 _____

Source 2 _____

0 7 . 5

Other nuclides also emit electromagnetic radiation.

Explain why the metastable form of the isotope of technetium $^{99}_{43}\text{Tc}$ is a radioactive source suitable for use in medical diagnosis.

[2 marks]

END OF SECTION A

Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each answer completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

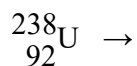
0	1
---	---

Two stable isotopes of helium are ${}^4_2\text{He}$ and ${}^3_2\text{He}$.

0	1	.	1
---	---	---	---

An atom of ${}^4_2\text{He}$ is produced in a rock that contains uranium. It is produced following the radioactive decay of a ${}^{238}_{92}\text{U}$ atom. The decay also creates an atom of thorium (Th).

Write an equation for the decay of ${}^{238}_{92}\text{U}$.

[2 marks]

0	1	.	2
---	---	---	---

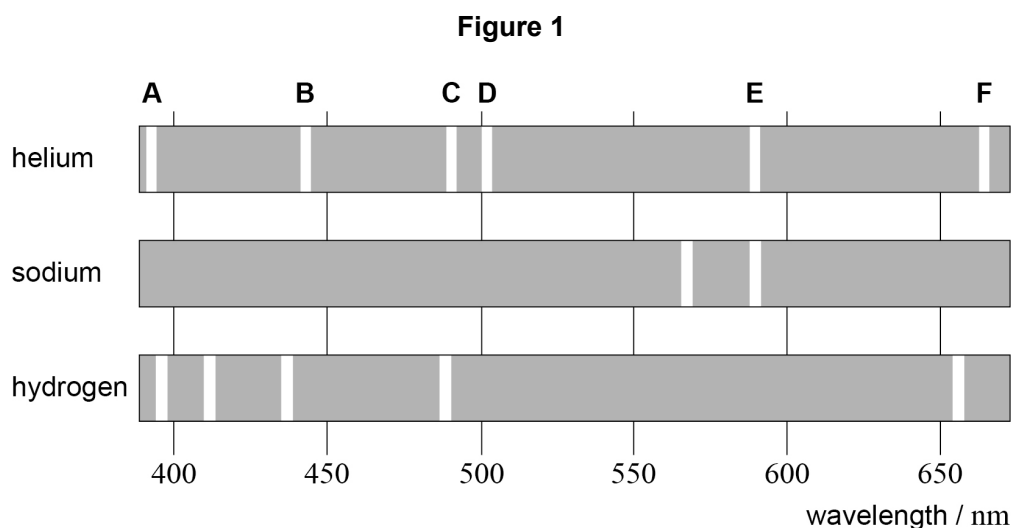
A ${}^3_2\text{He}$ nucleus can be produced by the decay of a tritium nucleus ${}^3_1\text{H}$.

State and explain which exchange particle is responsible for this decay.

[2 marks]

Helium was discovered by analysing the light in the **absorption** spectrum of the Sun.

Figure 1 shows the positions of the brightest lines, labelled **A** to **F**, in the **emission** spectrum of helium. The brightest lines in the emission spectra of sodium and hydrogen are also shown.



0 1 . 3 Before helium was identified, some scientists suggested that the lines of the helium spectrum seen in the absorption spectrum of the Sun were due to the presence of sodium and hydrogen.

Discuss, with reference to the lines **A** to **F** in **Figure 1**, the evidence for and against this suggestion.

[2 marks]

Question 1 continues on the next page

0	1	.	4
---	---	---	---

Calculate, in eV, the change in energy level responsible for the spectral line labelled **E** in **Figure 1**.

[3 marks]

change in energy level = _____ eV

0	1	.	5
---	---	---	---

Explain, with reference to the processes within an atom, the difference between an emission spectrum and an absorption spectrum.

[3 marks]



SUB-TOPIC 3.8.1.5

NUCLEAR RADIUS

Sub-topic 3.8.1.5 · 4 questions · 21 marks · lowest tariff first



3**1**

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

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

[1 mark]

A $2.69 \times 10^{-15} \text{ m}$

☐

B $2.89 \times 10^{-15} \text{ m}$

☐

C $6.55 \times 10^{-15} \text{ m}$

☐

D $7.05 \times 10^{-15} \text{ m}$

☐

2 0

The nuclear radius of an element with nucleon number x is r .

What is the nuclear radius of an element with nucleon number y ?

[1 mark]

A $r\left(\frac{x}{y}\right)^3$ ☐

B $r\left(\frac{y}{x}\right)^3$ ☐

C $r\left(\frac{x}{y}\right)^{\frac{1}{3}}$ ☐

D $r\left(\frac{y}{x}\right)^{\frac{1}{3}}$ ☐

0 1

Information about the radius of a nucleus can be deduced from the closest approach of alpha particles and from electron diffraction.

0 1**. 1**

Alpha particles, each with a kinetic energy of 5.59 MeV, are fired at a thin foil made of gold ($^{197}_{79}\text{Au}$) atoms.

Some of the alpha particles are scattered through an angle of 180° .

Estimate the radius of a $^{197}_{79}\text{Au}$ nucleus from this information.

[3 marks]

radius of nucleus = _____ m

0 1**. 2**

Explain why your answer to Question **01.1** is an estimate.

[2 marks]

0 1 . 3

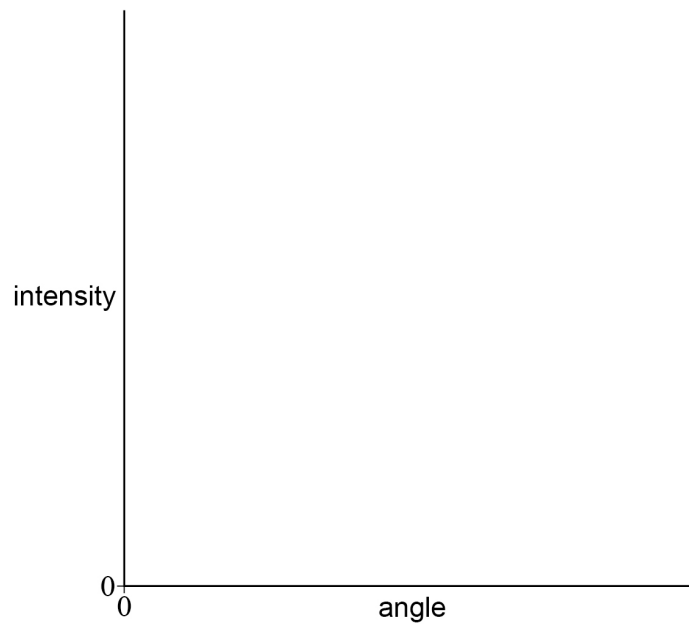
Electron diffraction gives a more precise value for the radius of the nucleus.

Sketch, on **Figure 1**, a graph of intensity against angle for electron diffraction by a nucleus.

Go on to state the feature of this graph that is used to determine the radius of the nucleus.

[2 marks]

Figure 1



Question 1 continues on the next page

0 1 . 4

Results from electron-diffraction experiments lead to the equation:

$$R = R_0 A^{\frac{1}{3}}$$

Show that the equation provides evidence for the constant density of nuclear material.

[2 marks]



1

1



0 6 . 1

Nuclear radii can be estimated using either alpha particles or high-energy electrons.

State **two** advantages of using high-energy electrons rather than alpha particles for this estimate.

[2 marks]

1 _____

2 _____

Question 6 continues on the next page

0 6 . 2

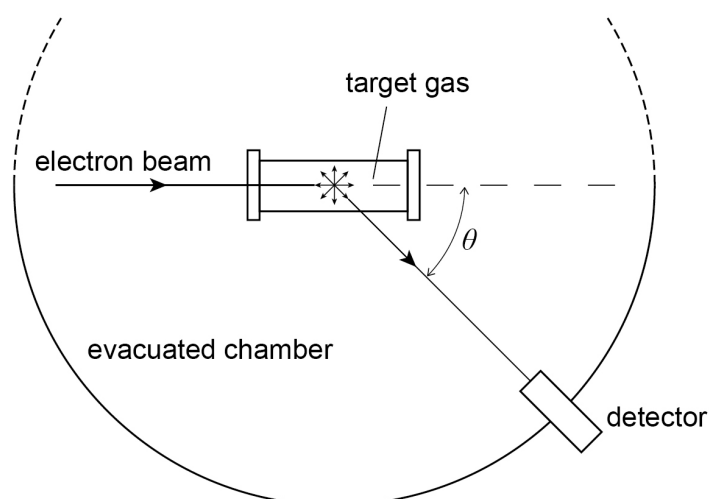
Figure 11 shows a beam of electrons, each with the same high energy, incident on a target gas.

The electrons are diffracted by the nuclei in the gas.

The intensities of these diffracted electrons are measured at various angles θ .

The data are used to determine the nuclear radius R of the atoms in the gas.

Figure 11



Sketch on **Figure 12** a graph showing how the electron intensity varies with θ .

[2 marks]

Figure 12



06.3

The radius R of a nucleus is related to its nucleon number by $R = R_0 A^{\frac{1}{3}}$.

Show that this equation is consistent with the idea that all nuclei have the same density.

[2 marks]

06.4

The equation $R = R_0 A^{\frac{1}{3}}$ is derived from experimental data.

Suggest **one** reason why the constant density of nuclear material derived from this equation is only approximate.

[1 mark]

06.5

The measured radius R of $^{35}_{17}\text{Cl}$ is $4.02 \times 10^{-15} \text{ m}$.

Calculate an estimate of

- the constant R_0
- the density of nuclear material.

[3 marks]

$R_0 =$ _____ m density = _____ kg m^{-3}



SUB-TOPIC 3.8.1.6

MASS AND ENERGY

Sub-topic 3.8.1.6 · 12 questions · 40 marks · lowest tariff first



3 2

Uranium-236 undergoes nuclear fission to produce barium-144, krypton-89 and three free neutrons.

What is the energy released in this process?

Nuclide	Binding energy per nucleon / MeV
$^{236}_{92}\text{U}$	7.5
$^{144}_{56}\text{Ba}$	8.3
$^{89}_{36}\text{Kr}$	8.6

[1 mark]

- A** 84 MeV
- B** 106 MeV
- C** 191 MeV
- D** 3730 MeV

☐☐☐☐

END OF QUESTIONS



3 1

During a single fission event of uranium-235 in a nuclear reactor the total mass lost is 0.23 u. The reactor is 25% efficient.

How many events per second are required to generate 900 MW of power?

[1 mark]

A 1.1×10^{14}

☐

B 6.6×10^{18}

☐

C 1.1×10^{20}

☐

D 4.4×10^{20}

☐

3 0 The table shows the masses of three particles.

Particle	Mass / u
proton	1.00728
neutron	1.00867
nucleus of lithium ${}^7_3\text{Li}$	7.01436

What is the mass difference of a ${}^7_3\text{Li}$ nucleus?

[1 mark]

A 4.99841 u ☐

B 0.04216 u ☐

C 0.04147 u ☐

D 0.04077 u ☐

3 0

In the core of a nuclear reactor, the mass of fuel decreases at a rate of $9.0 \times 10^{-6} \text{ kg hour}^{-1}$ due to nuclear reactions.

What is the maximum power output of the reactor?

[1 mark]**A** $2.3 \times 10^8 \text{ W}$ ☐**B** $1.4 \times 10^{11} \text{ W}$ ☐**C** $8.1 \times 10^{11} \text{ W}$ ☐**D** $2.9 \times 10^{15} \text{ W}$ ☐**3 0**

27

27



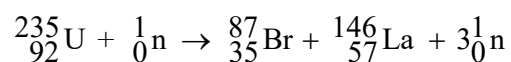
3 **1**

The mass of fuel in a nuclear reactor decreases at a rate of 4.0×10^{-6} kg per hour.

What is the rate at which energy is transferred due to nuclear fission?

[1 mark]**A** 4.0×10^7 W☐**B** 1.0×10^8 W☐**C** 6.0×10^8 W☐**D** 3.6×10^{10} W☐

1 8 The equation represents a typical fission reaction.



Which statement about this reaction is **not** true?

[1 mark]

A ${}_{57}^{146}\text{La}$ has the greatest binding energy per nucleon of the three nuclides. ☐

B The mass of ${}_{92}^{235}\text{U}$ is greater than the sum of the masses of ${}_{35}^{87}\text{Br}$ and ${}_{57}^{146}\text{La}$. ☐

C The binding energy of the neutrons released in the reaction is zero. ☐

D The binding energy of ${}_{92}^{235}\text{U}$ is greater than the binding energy of ${}_{57}^{146}\text{La}$. ☐



2 8 Polonium-210 decays into lead-206 by emitting an alpha particle.

mass of nucleus of polonium-210 = 209.983 u

mass of nucleus of lead-206 = 205.975 u

mass of alpha particle = 4.003 u

Assume that the recoil speed of the lead nucleus is negligible.

What is the kinetic energy of the emitted alpha particle?

[1 mark]

A 5.0 meV

☐

B 4.0 MeV

☐

C 4.7 MeV

☐

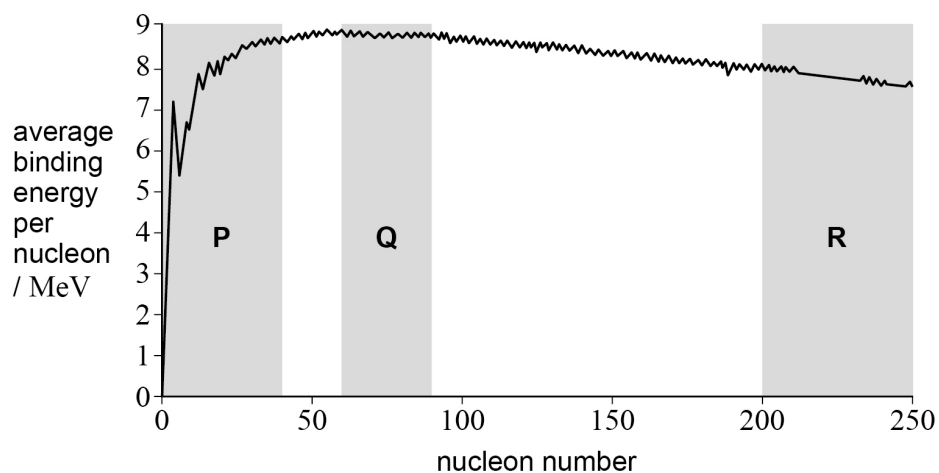
D 3.7 GeV

☐

3 1

The plot of average binding energy per nucleon is shown.

P, **Q** and **R** indicate regions of the plot.



In which region or regions labelled on the plot do nuclei undergo fission to release energy?
[1 mark]

- A** **P** only ☐
- B** **P** and **R** ☐
- C** **Q** and **R** ☐
- D** **R** only ☐

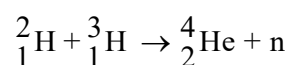
END OF QUESTIONS



0 4

The deuterium–tritium (D–T) reaction is a nuclear reaction between two isotopes of hydrogen.

The D–T reaction is



The energy from this reaction is transferred to the kinetic energy of the helium nucleus and the kinetic energy of the neutron.

Assume that the kinetic energies of the hydrogen nuclei are zero just before the reaction occurs.

0 4 . 1

Show that the kinetic energy of the neutron represents approximately 80% of the total energy transferred.

[2 marks]**0 4 . 2**

The combined kinetic energy of the helium nucleus and the neutron is $2.82 \times 10^{-12} \text{ J}$.

Calculate the initial speed of the neutron.

[2 marks]

initial speed = _____ m s^{-1}



0	5	.	1
---	---	---	---

Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\text{Co}$.

nuclear mass of $^{59}_{27}\text{Co} = 58.93320 \text{ u}$

[3 marks]

binding energy = _____ MeV

Question 5 continues on the next page



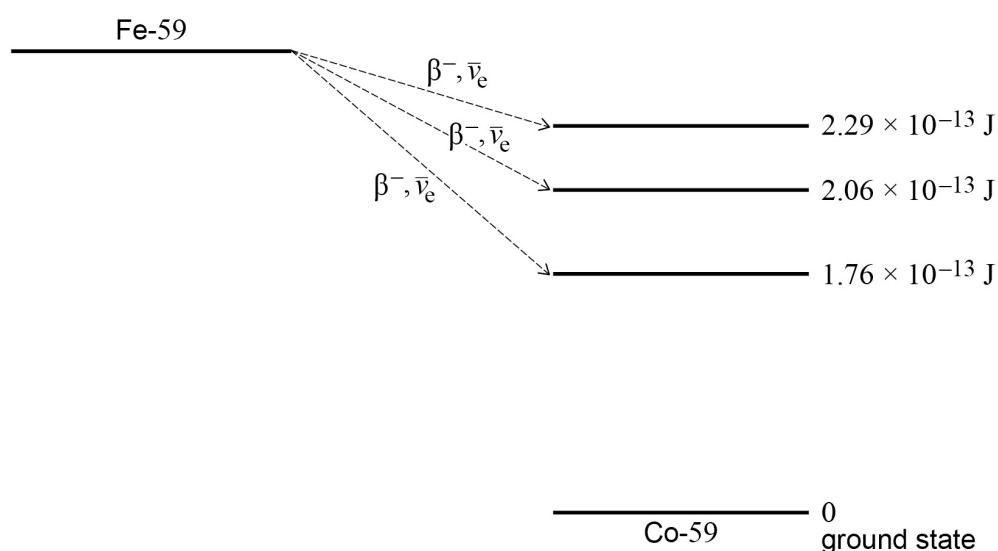
0 5 . 2

A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ -radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown in **Figure 5**. The energies of the excited states are shown relative to the ground state.

Figure 5



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

[2 marks]

maximum kinetic energy = _____ MeV



0	5
---	---

 ·

3

Following the production of excited states of $^{59}_{27}\text{Co}$, γ -radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

[1 mark]

maximum number = _____

0	5
---	---

 ·

4

Calculate the longest wavelength of the emitted γ -radiation.

[3 marks]

longest wavelength = _____ m



0 6 . 1

Explain, in terms of binding energy, why energy can be released when two nuclei undergo nuclear fusion.

[2 marks]

0 6 . 2

During the collapse of a supermassive star, helium-3 and oxygen-17 fuse to release energy. The equation for this reaction is

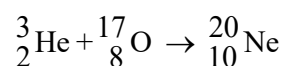


Table 2 gives data for these nuclei.

Table 2

Nucleus	Mass / u
${}^3_2\text{He}$	3.01603
${}^{17}_8\text{O}$	16.99913
${}^{20}_{10}\text{Ne}$	19.99244

Calculate, in J, the energy released when this reaction occurs.

[2 marks]

energy released = _____ J



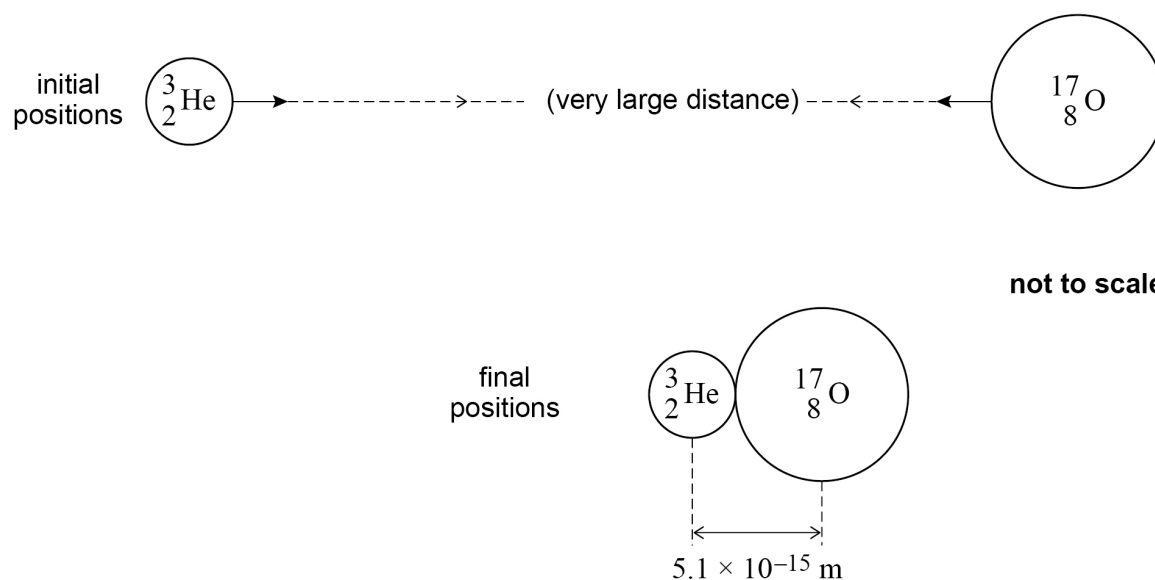
0 6 . 3

One model of nuclear fusion suggests that fusion happens when nuclei touch.

Initially the helium nucleus and oxygen nucleus are separated so that the force between them is negligible. They move towards each other until they fuse. Fusion occurs when their centres are separated by a distance of $5.1 \times 10^{-15} \text{ m}$.

Figure 10 shows the initial positions and final positions of the nuclei.

Figure 10



Calculate the total change in electrostatic potential energy between the initial positions and final positions of the nuclei.

[2 marks]

change in electrostatic potential energy = _____ J

Question 6 continues on the next page

0	6	.	4
---	---	---	---

${}^3_2\text{He}$ can undergo fusion reactions with either ${}^{34}_{16}\text{S}$ or ${}^{17}_8\text{O}$ at the same temperature in a star.

The nucleus has properties that depend on its proton number and its nucleon number. These properties affect the fusion reaction.

Discuss, for this star, how these properties affect the rate of fusion of ${}^{34}_{16}\text{S}$ with ${}^3_2\text{He}$ compared to the rate of fusion of ${}^{17}_8\text{O}$ with ${}^3_2\text{He}$.

[3 marks]

END OF SECTION A



Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 6

Fission and fusion are two processes that can result in the transfer of binding energy from nuclei.

0 6**. 1**

State what is meant by the binding energy of a nucleus.

[2 marks]

0 6**. 2**

Calculate, in MeV, the binding energy for a nucleus of iron ${}^{56}_{26}\text{Fe}$.

$$\text{mass of } {}^{56}_{26}\text{Fe nucleus} = 9.288 \times 10^{-26} \text{ kg}$$

[3 marks]

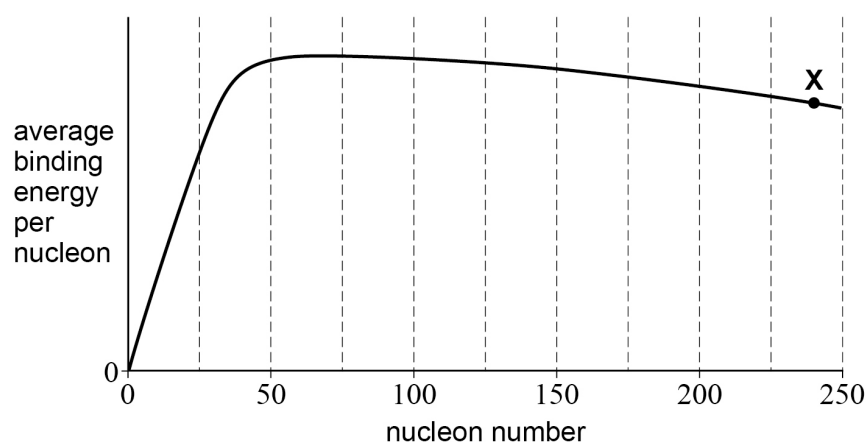
binding energy = _____ MeV

Question 6 continues on the next page



Figure 10 shows a graph of average binding energy per nucleon against nucleon number for common nuclides.

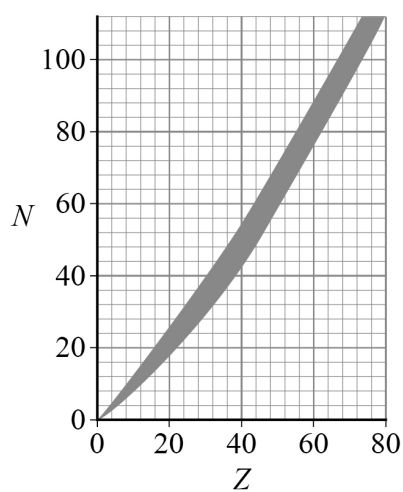
Figure 10



0 6 . 3 The nuclide labelled **X** in **Figure 10** undergoes fission.

Annotate **Figure 10** with F_1 and F_2 to show **one** possible pair of nuclides resulting from the fission of **X**.

[2 marks]

0 6 . 4**Figure 11** shows a graph of N against Z for stable nuclides.**Figure 11**

Deduce the likely initial mode of decay of F_1 and F_2 .
Refer to **Figure 11** in your answer.

[3 marks]

END OF SECTION A

Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



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Do **not** use additional sheets for this working.



SUB-TOPIC 3.8.1.7

INDUCED FISSION AND THERMAL REACTORS

Sub-topic 3.8.1.7 · 12 questions · 50 marks · lowest tariff first



3 2 Which of the following substances can be used as a moderator in a nuclear reactor?

[1 mark]

A Boron

☐

B Concrete

☐

C Uranium-238

☐

D Water

☐

END OF QUESTIONS



3 1

What effect are the control rods intended to have on the average kinetic energy and number of fission neutrons in a thermal nuclear reactor?

[1 mark]

	Average kinetic energy of fission neutrons	Number of fission neutrons	
A	unchanged	unchanged	☐
B	reduced	unchanged	☐
C	unchanged	reduced	☐
D	increased	reduced	☐

END OF QUESTIONS

2 9

What is the main purpose of a moderator in a thermal nuclear reactor?

[1 mark]

- A** to shield the surroundings from ionising radiations ☐
- B** to decrease the number of fission chain reactions ☐
- C** to decrease neutron speeds ☐
- D** to prevent the core from overheating ☐

3 1

In a thermal reactor, induced fission occurs when a $^{235}_{92}\text{U}$ nucleus captures a neutron.

Which statement is true?

[1 mark]

A The moderator absorbs excess neutrons.

☐

B A large number of neutrons should be produced per fission to sustain the reaction.

☐

C Slow neutrons are required for this induced fission.

☐

D The control rods slow down neutrons.

☐

END OF QUESTIONS



2 5

After radioactive waste is removed from a cooling pond, it is often stored in underground caves.

This is to protect workers from the effects of

A alpha particles from nuclides with a large decay constant.

☐

B alpha particles from nuclides with a small decay constant.

☐

C gamma radiation from nuclides with a large decay constant.

☐

D gamma radiation from nuclides with a small decay constant.

☐

2 9Which is **not** a use of water in the nuclear industry?**[1 mark]****A** to absorb neutrons released from fission☐**B** to cool a nuclear reactor☐**C** to shield radiation produced by nuclear waste☐**D** to slow neutrons to thermal speeds☐

3 0

The purpose of a moderator in a thermal nuclear reactor is to:

[1 mark]**A** absorb neutrons to reduce the reaction rate.☐**B** add neutrons to start the chain reaction.☐**C** remove heat from the reactor.☐**D** slow neutrons to thermal speeds.☐

0 4 . 1

One purpose of the coolant in a thermal nuclear reactor is to maintain a safe working temperature within the core.

State the other purpose.

[1 mark]

0 4 . 2

State **two** properties that engineers consider when choosing a liquid to use as a coolant in a thermal nuclear reactor.

[2 marks]

1

2

0 4 . 3

Explain how the power output of a thermal nuclear reactor is decreased.

[2 marks]

0 6

A thermal nuclear reactor uses enriched uranium as its fuel.
This is fuel in which the ratio of U-235 to U-238 has been artificially increased from that found in naturally-occurring ore.

0 6 . 1

Describe what happens when neutrons interact with U-235 and U-238 nuclei in a thermal nuclear reactor.

[3 marks]

0 6 . 2

The amounts of U-235 and U-238 in the ore decrease due to radioactive decay at different rates.

A sample of uranium ore today contains 993 g of U-238

The mass of U-238 in this sample was greater 2.00×10^9 years ago.

Show that the mass of U-238 in this sample at that time was about 1.4 kg.

$$\text{decay constant of U-238} = 1.54 \times 10^{-10} \text{ year}^{-1}$$

[2 marks]

Question 6 continues on the next page



06.3

A thermal nuclear reactor requires a minimum of 3.0% of its uranium mass to be U-235

The ratio of U-235 to U-238 in the ore has changed over time.

2.00×10^9 years ago, the sample in Question **06.2** contained 52 g of U-235

Deduce whether the sample had a high enough U-235 content to be used in a reactor 2.00×10^9 years ago.

[1 mark]

END OF SECTION A**Section B**

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD 

WRONG METHODS    

If you want to change your answer you must cross out your original answer as shown. 

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You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 7 . 1 Carbon is used as the moderator in some thermal nuclear reactors.

Identify **one** other material commonly used as a moderator.

[1 mark]

0 7 . 2 State **two** benefits of slowing down the neutrons released during fission.

[2 marks]

1 _____

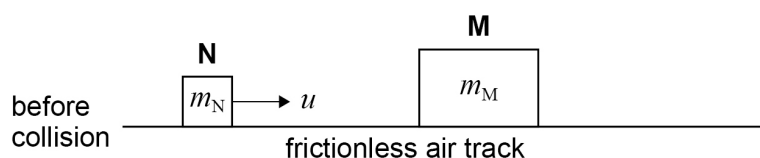
2 _____

0 7 . 3 The collision of a neutron with the nucleus of a moderator atom is modelled using two gliders on a horizontal frictionless air track.

In **Figures 13** and **14** the glider **N** of mass m_N represents the neutron and the glider **M** of mass m_M represents the moderator nucleus.

Figure 13 shows glider **N** travelling with initial speed u towards the stationary glider **M**.

Figure 13

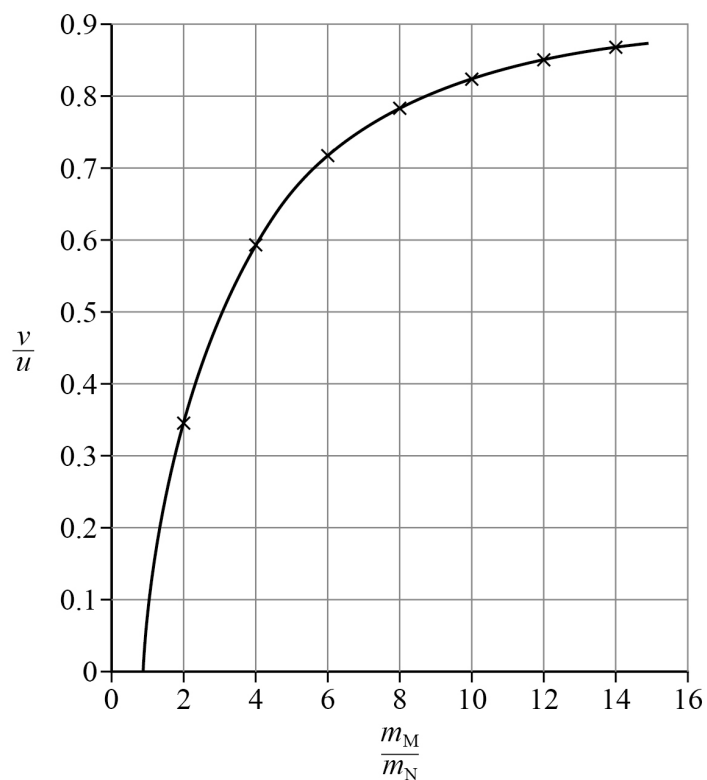


The gliders collide. **N** rebounds with speed v as shown in **Figure 14**.

Figure 14

Figure 15 shows the variation of the ratio $\frac{v}{u}$ with the ratio $\frac{m_M}{m_N}$.

Figure 15



Show that when $\frac{m_M}{m_N}$ is 12, **N** loses about 30% of its initial kinetic energy in the collision.

[2 marks]

Question 7 continues on the next page

07.4

In a reactor, the speed of a fast-moving neutron is reduced by a series of y random collisions with carbon-12 nuclei.

The final kinetic energy E_f of the neutron is

$$E_f = E_0 e^{-by}$$

where E_0 is the initial kinetic energy of the neutron and $b = 0.73$

A thermal neutron has kinetic energy equivalent to that of the average particle of an ideal gas with a temperature of 350 K.

One neutron has an initial kinetic energy of 1.0 MeV.

Calculate the minimum value of y required so that this neutron becomes a thermal neutron.

[3 marks] $y =$ _____

07.5

Explain, with reference to **Figure 15**, why elements with a small nucleon number are preferred as moderator materials.

[2 marks]

END OF SECTION A

Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked. Do **not** use additional sheets for this working.

0	4
---	---

The core of a thermal nuclear reactor contains a number of components that are exposed to moving neutrons.

0	4	.	1
---	---	---	---

State what happens to a neutron that is incident on the moderator.

[1 mark]

0	4	.	2
---	---	---	---

State what happens to a neutron that is incident on a control rod.

[1 mark]

0	4	.	3
---	---	---	---

A slow-moving neutron is in collision with a nucleus of an atom of the fuel which causes fission.

Describe what happens in the process.

[3 marks]



0 6

A thermal nuclear reactor uses a moderator to lower the kinetic energy of fast-moving neutrons.

0 6 · 1

Explain why the kinetic energy of neutrons must be reduced in a thermal nuclear reactor.

[1 mark]

0 6 · 2

As a result of a collision with an atom of a particular moderator, a neutron loses 63% of its kinetic energy.

A neutron has an initial kinetic energy of 2.0 MeV.

Calculate the kinetic energy of the neutron after five collisions.

[2 marks]

kinetic energy = _____ eV

Question 6 continues on the next page

0 6 · 3

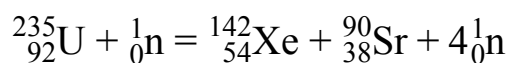
The kinetic energy of a neutron in a thermal nuclear reactor is reduced from about 2 MeV to about 1 eV.

Explain why the number of collisions needed to do this depends on the nucleon number of the moderator atoms.

[2 marks]

0 6 . 4

One fission process which can occur in a thermal nuclear reactor is represented by the equation



Calculate in MeV the energy released in this fission process.

$$\text{mass of } {}_{92}^{235}\text{U} = 235.044 \text{ u}$$

$$\text{mass of } {}_{54}^{142}\text{Xe} = 141.930 \text{ u}$$

$$\text{mass of } {}_{38}^{90}\text{Sr} = 89.908 \text{ u}$$

$$\text{mass of } {}_0^1\text{n} = 1.0087 \text{ u}$$

[3 marks]

energy released = _____ MeV

Question 6 continues on the next page



0 6 5 Many magazine and newspaper articles focus on the risks of using nuclear power.

State **three benefits** of using nuclear power.

[3 marks]

1 _____

2 _____

3 _____

END OF SECTION A

Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

SUB-TOPIC 3.8.S

SYNOPTIC AND CROSS-TOPIC QUESTIONS

Sub-topic 3.8.S · 9 questions · 26 marks · lowest tariff first



0 9

An electron collides with an isolated atom and raises an orbiting electron to a higher energy level.

Which statement is correct?

[1 mark]

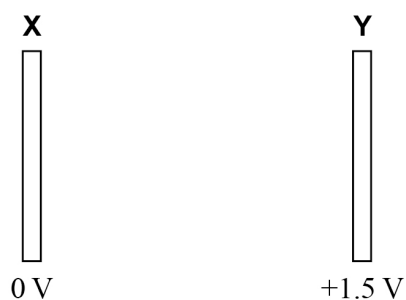
- A** The colliding electron is captured by the nucleus of the atom. ☐
- B** A photon is emitted when the electron rises to the higher energy level. ☐
- C** An electron is emitted when the excited electron returns to the ground state. ☐
- D** Energy is transferred from the colliding electron to the orbiting electron. ☐

1 2 3 4 5 6 7 8 9 10 11 12

1 2 3 4 5 6 7 8 9 10 11 12

2 2

Charged plates **X** and **Y** have a potential difference 1.5 V between them.



Which particle gains 3.0 eV of kinetic energy when moving from **Y** to **X**?

[1 mark]

A proton

☐

B positron

☐

C electron

☐

D alpha particle

☐

1 2

An electron collides with an isolated atom and raises an atomic electron to a higher energy level.

Which statement is correct?

[1 mark]

- A** The colliding electron is captured by the nucleus of the atom.
- B** A photon is emitted when the electron rises to the higher energy level.
- C** An electron is emitted when the excited electron returns to the ground state.
- D** The colliding electron transfers energy to the atomic electron.

☐☐☐☐

09

Which can lead to a value for the absolute zero of temperature?

[1 mark]**A** Boyle's law☐**B** Brownian motion☐**C** Charles's law☐**D** Rutherford scattering☐

2 1

A beam consists of ionised atoms of two isotopes of an element. When the beam enters a uniform magnetic field, the ions move in circular paths. The ions have the same charge and travel at the same speed when they enter the magnetic field.

Which statement is true?

[1 mark]

- A** The force acting on an ion is different for each isotope. ☐
- B** The radius of the path followed by an ion is different for each isotope. ☐
- C** The kinetic energy of an ion increases for both isotopes. ☐
- D** The acceleration of an ion is the same for both isotopes. ☐

1 0 In β^- decay:

[1 mark]

A energy is conserved.

☐

B an up quark changes into a down quark.

☐

C the interaction occurs outside the nucleus of an atom.

☐

D momentum is not conserved.

☐

2 7 An alpha particle has a speed of $4.5 \times 10^5 \text{ m s}^{-1}$.

What is the de Broglie wavelength of the alpha particle?

[1 mark]

A $2.2 \times 10^{-13} \text{ m}$ ☐

B $4.4 \times 10^{-13} \text{ m}$ ☐

C $8.8 \times 10^{-13} \text{ m}$ ☐

D $3.9 \times 10^{-12} \text{ m}$ ☐

- 0 1 . 1** Determine whether the following reaction is a possible decay for the neutral pion π^0 .

$$\pi^0 \rightarrow e^- + \mu^+ + \bar{\nu}_e$$

[2 marks]

- 0 1 . 2** State the **two** possible quark configurations of a π^0 .

[1 mark]

1

2

- 0 1 . 3** A student suggests that the kaon K^0 and the anti-kaon $\bar{K}^0$ are the same particle.

Discuss whether this suggestion is correct.

[2 marks]

- 0 1 . 4** The nucleus is held together by a force. It was predicted that a particle exists that is responsible for this force. The particle itself must experience this force.

The particle would have a rest energy between that of an electron and half that of a nucleon.

Discuss whether a kaon, a muon and a pion **each** have the properties of the predicted particle.

Information about these three particles is in the Data and Formulae Booklet.

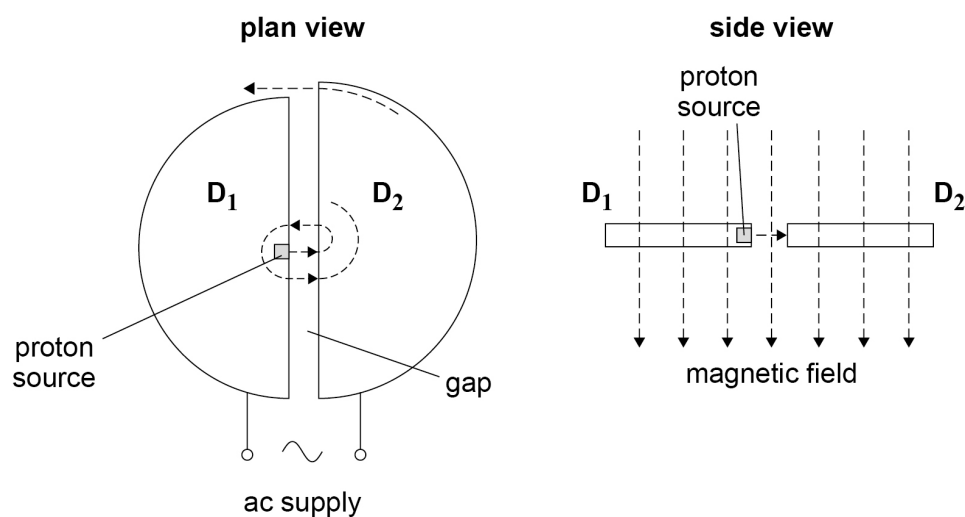
[4 marks]



0 5

Figure 9 shows a cyclotron. A proton is released from rest and is accelerated each time it reaches the gap between two horizontal 'dees' D_1 and D_2 . Between these accelerations the proton moves at constant speed. A vertical magnetic field of flux density B acts over the dees so that the proton follows a semicircular path in each dee.

The dees are connected to an alternating potential difference (pd). This pd is adjusted so that the proton is always accelerated by the peak electric field as it crosses the gap between the dees.

Figure 9

0 5 . 1

Explain why the proton travels in a semicircular path in a dee.

[2 marks]

Question 5 continues on the next page

0 5 . 2

The peak pd of the alternating supply is 10.0 kV. The proton leaves the cyclotron with kinetic energy of 14 MeV.

Determine the number of times the proton moves across the gap before it leaves the cyclotron.

[1 mark]

number of times = _____

The radius of the outermost semicircular path of the proton is R and the proton leaves with a maximum kinetic energy E_k .

0 5 . 3

Show that E_k is given by

$$E_k = \frac{e^2 B^2 R^2}{2m_p}$$

[3 marks]

0 5 . 4

A hospital decides to purchase a cyclotron in order to manufacture its own radioactive isotopes using high-speed protons.

The required minimum kinetic energy of the emerging protons is 11 MeV.

The cost of a cyclotron is approximately proportional to $E_k^{1.5}$.

The cost of a 10 MeV cyclotron is about £2.3 million.

Table 1 gives information for three cyclotrons **X**, **Y** and **Z**.

Table 1

Cyclotron	B / T	R / m
X	1.3	0.38
Y	1.1	0.50
Z	0.5	0.60

Deduce which cyclotron **X**, **Y** or **Z** will satisfy the energy requirement for the lowest cost.

Go on to determine the approximate cost of this cyclotron.

[4 marks]

cyclotron = _____

cost = _____



MARK SCHEMES

official mark schemes



C



26	A	Its rate of change of momentum is at a minimum.
----	---	---



25

C (AO1)

Some particles were deflected through angles greater than 90° .

19	C	$4.0 \times 10^{-14} \text{ m}$
10	1	10



26

C

The number of alpha particles deflected backwards is greater than the number that pass straight through the foil.



29

A

$$r < 10^{-14} \text{ m}$$



05.1	Electromagnetic ✓	Reject electrostatic as it is not one of the fundamental forces.	1	AO1.1a
05.2	Arrow drawn at X in a direction radially away from the centre of the gold nucleus ✓		1	AO1.1b
05.3	Answer number 5 or 6 plus one consistent justification ✓ One more consistent justification ✓ List of justifications: Cannot be 1, 2, or 3 as these α's deflect up Or must be 5 to 9 as these all α's deflect down. Cannot be 4 as this would backscatter or is scattered at 180° Cannot be 7, 8 or 9 as the deflection would be too small Or must be 2, 3, 5, 6 as these have a greater deflection than α_1.	First mark must come with at least one justification. The second mark is possible to obtain with two consistent justifications even if the first mark is missed. E.g. if an answer 7 is given then quoting the first two justifications gains a mark.	2	AO1.1b AO3.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	(Using of potential energy = $\frac{Qq}{4\pi\epsilon_0 r}$) Substituting the values of the two charges multiplied together into an equation $(2 \times 1.6 \times 10^{-19})(79 \times 1.6 \times 10^{-19}) \checkmark_1$ $PE = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.9 \times 10^{-12} \times 5.5 \times 10^{-14}}$ or 6.58×10^{-13} (J) $\checkmark_2$ (loss of KE = $\frac{1}{2}mv^2$ = gain in PE) $\left(v = \left(\frac{2 \times 6.58 \times 10^{-13}}{6.8 \times 10^{-27}} \right)^{1/2} \right)$ $v = 1.4 \times 10^7$ (m s⁻¹) $\checkmark_3$	$\checkmark_2$ The substitution may be inferred at the next stage of the calculation that uses $KE = \frac{1}{2}mv^2 = PE$	3	AO1.1b AO2.1h ×2 M2 ×2

05.5	Using by substitution or rearrangement $R = r_0 A^{1/3}$ ✓ $R_{\text{Ag}} = 5.7 \times 10^{-15} \text{ (m)}$ ✓	$\left(R_{\text{Ag}} = R_{\text{Au}} \times \left(\frac{A_{\text{Au}}}{A_{\text{Ag}}} \right)^{1/3} \right)$ $\left(R_{\text{Ag}} = 6.98 \times 10^{-15} \times \left(\frac{107}{197} \right)^{1/3} \right)$ The use of the equation must involve both nuclei.	2	AO1.1b ×2 M2 ×2
05.6	Nucleons are incompressible / Nucleons have a constant separation / Neutrons and protons have similar masses / Neutrons and protons have similar volumes ✓	A mark can be given for 'nucleons touch' but it must be implied that this is with all 12 neighbours'.	1	AO3.1a
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
----------	---------	--------------------------------	------	----



D



D



30

D (AO1)

When it is absorbed it makes the absorber radioactive.



25

D

64 cm

AO2



05.1	sides of the instruments. OR γ radiation is penetrating so instruments can be sterilised without removing the packaging. ✓ OWTTE	It is not sufficient to just state 'gamma'. The <u>mark is based on the reason</u> for the choice.	1	AO3
05.2	To become radioactive the nucleus has to be affected which (ionising) radiation does not do OR (Ionising) radiation <u>only</u> affects the outer electrons and not the nucleus. OR The energy of the radiation is insufficient to induce radioactivity. (For this mark high energy is not the same as highly ionizing) OR (ionising) radiation does not affect the nucleus ✓ owtte		1	AO2

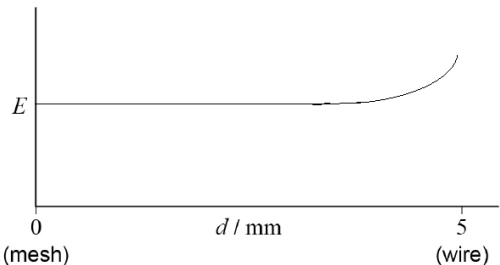
05.3	(Conclusion using the inverse square law $I = k/d^2$) Make the point that $I \times d^2$ should be constant if the inverse square law is operating. ✓ owtte Show calculations using data from <u>3 rows</u>. The column may be completed in the following ways. ✓ <table><tr><th>Corrected count rate count s⁻¹</th><th>$I \times d^2$ Using I as count rate</th><th></th><th>$I \times d^2$ Using $I \propto$ count in 1.0 minute</th></tr><tr><td>150</td><td>6.00</td><td>Or</td><td>361</td></tr><tr><td>23.3</td><td>5.83</td><td></td><td>349</td></tr><tr><td>4.03</td><td>4.03</td><td></td><td>242</td></tr></table>	Corrected count rate count s ⁻¹	$I \times d^2$ Using I as count rate		$I \times d^2$ Using $I \propto$ count in 1.0 minute	150	6.00	Or	361	23.3	5.83		349	4.03	4.03		242	Accept 2 sig figs and 1 sig fig in the case of the 4 and 6 in the second column shown here. The mark is mainly based on the technique used. The written answer must be enough to indicate a conclusion. This mark can be gained even if there is a slip in the table. The conclusion mark can be gained even if the second mark is lost because only two data points are taken. Look out for different approaches. Eg.use the CCR at one distance to predict the CCR at other distances if the inverse function is followed. Eg CCR might be in order 9013,1440 and 360.	2	AO1
Corrected count rate count s ⁻¹	$I \times d^2$ Using I as count rate		$I \times d^2$ Using $I \propto$ count in 1.0 minute																	
150	6.00	Or	361																	
23.3	5.83		349																	
4.03	4.03		242																	
05.4	Mark given for any of these ideas (max 2) The random nature of the radiation count (although small in this case) Dead-time in the G-M detector d is not the real distance between source and detector or source is not a point source The source may not be a pure gamma emitter. (Gamma and beta is acceptable but not gamma and alpha together) A reference to short half-life provided that an explanation of how this has an effect on separate measurements eg activity	No credit for unexplained bland statements such as 'because of systematic errors' or 'more data needs to be taken to be certain' etc. Note: reference to background count does not gain a mark because the corrected count-rate is supplied in the question.	2	2 AO1																

	Assumes no absorption between source and detector(although small in this case) ✓✓			
Total			6	



Question	Answers	Additional Comments/Guidance	Mark	ID details
		(The depth halves in 19s. With the graph being exponential the depth will halve every 19s.		



04.1	Horizontal line above zero for > half the distance ✓ (then) curves upwards ✓	 Marks are independent.	2	AO2 ×2
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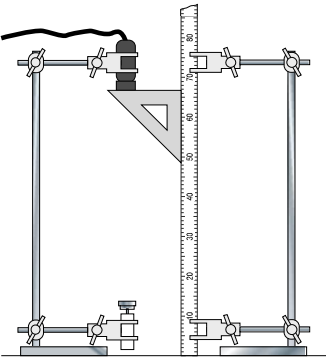
Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	statement that (kinetic) energy is the same OR correct substitution of data into equation/ratio ✓ ratio $\left(= \sqrt{\frac{6.64 \times 10^{-26}}{9.11 \times 10^{-31}}} \right) = 270$ ✓	Some factors (e.g. $\frac{1}{2}$) that cancel may be absent.	2	AO3 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Due to collisions argon loses more energy / speed / momentum (than electron) OR Electron is less ionising (than argon) / Argon is more ionising (than electron) so ratio is larger. ✓	Mark is for the explanation Do not allow explanations that suggests the particles have different distances to travel. Do not allow references to air resistance. Accept idea that “argon has higher probability of collision (than electron)” Accept reverse arguments	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Evidence of suitable test for student A suggestion involving 2+ data points ✓₁ Evidence of suitable test for student B suggestion involving 2+ sets of data ✓₂ Both tests performed AND rejects both suggestions ✓₃	✓₁ test inverse square: e.g. $Nh^2 = \text{constant}$ ✓₂ test exponential: e.g. N should decrease by half in equal intervals of h OR test $N = k e^{-h}$: show that $N e^h$ is not constant Accept log/ln interpretations of the test. ✓₃ Expect to see for student A $10 \times 1.0^2 = 10$ and $4 \times 1.34^2 = 7.18$ or similar Expect to see for student B $N = 10$ to $N = 5$ changes h by 0.25 and $N = 5$ to $N = 2.5$ changes h by 0.31 or similar reject both students' suggestions with reasons eg Nh^2 is not constant and N does not fall by the same fraction in equal intervals of h Allow answer accepting B if a reference to experimental error is made and the difference is small.	3	AO3 ×3
Total			8	

Question	Answers	Additional comments/Guidelines	Mark	AO



01.1	finds d by reading position of (lower end of) detector; subtracts 138 mm or wtte ₁✓ annotates Figure 1 to show suitable use of a recognisable set-square ₂✓	for ₁✓ allow 'reads / measures height of detector' / 'distance from detector to bench'; reject 'measures height of clamp T' if 'subtracts 138' is not seen; allow 'subtract distance from source to bench' / 'between source and bench' / 'height of source from ground' / 'position of top / open end / mouth of source'; allow 'measures height of the detector and the source and finds difference'; condone 'reversed' subtraction for ₂✓ expect a <u>triangular</u> 90° set-square in contact with a vertical edge of the ruler, top edge aligned with open end of the detector, eg 	2	AO2-1g
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		condone use of recognisable T-square in contact with vertical edge etc		
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	background count rate correct $_1✓$	for $_1✓$ accept any of: background count rate = $0.7(0) / \frac{630}{900} (s^{-1})$ OR background count in 100 s = 70 OR background count in 300 s = 210	1	AO1-1b
	working leading to correct R_C $_2✓$	for $_2✓$ [cao] ≥ 2 sf $R_C = 0.33 (s^{-1})$ reject $R_C = 0.30$ if their uncorrected count has been rounded to 1.0	1	AO2-1h

Question	Answers	Additional comments/Guidelines	Mark	AO																																
01.3	attempts two calculations that would lead to a conclusion₁✓ a reasoned judgement that the evidence does not support the prediction₂✓ <table><tr><td>d / mm</td><td>380</td><td>530</td><td>$\Delta\%$</td></tr><tr><td>R_C / s^{-1}</td><td>0.76</td><td>0.33</td><td></td></tr><tr><td>$d^2 \times R_C$</td><td>$1.1(0) \times 10^5$</td><td>9.27×10^4</td><td>18%</td></tr><tr><td>$d \times \sqrt{R_C}$</td><td>331 / 330</td><td>305 / 310</td><td>8.4%</td></tr></table> <table><tr><td>d / mm</td><td>380</td><td>530</td><td>$\Delta\%$</td></tr><tr><td>R_C / s^{-1}</td><td>0.76</td><td>0.3 (1 sf)</td><td></td></tr><tr><td>$d^2 \times R_C$</td><td>$1.1(0) \times 10^5$</td><td>$8(.43) \times 10^4$</td><td>29%</td></tr><tr><td>$d \times \sqrt{R_C}$</td><td>331 / 330</td><td>$3.(0) \times 10^2$</td><td>14%</td></tr></table>	d / mm	380	530	$\Delta\%$	R_C / s^{-1}	0.76	0.33		$d^2 \times R_C$	$1.1(0) \times 10^5$	9.27×10^4	18%	$d \times \sqrt{R_C}$	331 / 330	305 / 310	8.4%	d / mm	380	530	$\Delta\%$	R_C / s^{-1}	0.76	0.3 (1 sf)		$d^2 \times R_C$	$1.1(0) \times 10^5$	$8(.43) \times 10^4$	29%	$d \times \sqrt{R_C}$	331 / 330	$3.(0) \times 10^2$	14%	for ₁✓ the result of at least one calculation of $d^2 \times R_C$ or of $d \times \sqrt{R_C}$ must be correct to 2 sf (see table) otherwise withhold both marks; allow use of d in m but reject POT error; allow 1 sf $d^2 \times R_C$ for use of $R_C = 0.3$; allow $530^2 \times$ their 01.2 result for ₂✓ two correct calculations of $d^2 \times R_C$ or of $d \times \sqrt{R_C}$, both must be correct to 2 sf OR one correct calculation of $d^2 \times R_C$ or of $d \times \sqrt{R_C}$ correct to 2 sf and an appropriate reverse-working calculation; the statement rejecting the prediction should be supported by a calculation of the percentage difference between the results of their calculations (see $\Delta\%$ in table); condone weaker 'large' / 'significant differences' (between calculation results); reject 'prediction not correct' because 'values are different' / 'not constant' / 'not close enough'	2	AO3-1a
d / mm	380	530	$\Delta\%$																																	
R_C / s^{-1}	0.76	0.33																																		
$d^2 \times R_C$	$1.1(0) \times 10^5$	9.27×10^4	18%																																	
$d \times \sqrt{R_C}$	331 / 330	305 / 310	8.4%																																	
d / mm	380	530	$\Delta\%$																																	
R_C / s^{-1}	0.76	0.3 (1 sf)																																		
$d^2 \times R_C$	$1.1(0) \times 10^5$	$8(.43) \times 10^4$	29%																																	
$d \times \sqrt{R_C}$	331 / 330	$3.(0) \times 10^2$	14%																																	

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	lower / adjust the position of the detector / clamp T ₁ ✓	for ₁ ✓ condone 'lower clamp' (this implies clamp T since B cannot be lowered further) allow 'remove source using tongs while adjusting detector / clamp T ' otherwise ₂ ✗	1	AO3-1b
	to maximise distance between the experimenter and the source or wtte OR to reduce (limit) exposure (time) of the experimenter to radiation or wtte ₂ ✓	for ₂ ✓ allow 'not going (too) close (to source)' reject 'don't touch / make contact with source' suggesting using lead shielding is neutral allow ₁₂ ✓ for 'remove source or wtte using tongs to maximise distance etc before moving B upwards' changes to the position of source / clamp B without the use of tongs loses both marks	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	determines $10^a - 10^b$ where a and b are (any) plotted values of $\log(d / \text{mm})$ ₁ ✓ use of $\Delta d = \frac{10^a - 10^b}{n}$ where n is 1, 2, 3 or 4; Δd in range 47(.0) to 53(.0) (mm) ₂ ✓	insist on a and $b \geq 2$ dp; allow read-off errors $\pm$ one square; expect $\frac{10^{2.52} - 10^{2.11}}{4} = 50(.6) \text{ (mm)}$; allow ₁₂ ✓ for $\frac{e^a - e^b}{n}$ leading to Δd correct for their values ₂ ✓ is contingent on ₁ ✓ ie there is no credit for an unsupported answer	2	AO3-1a

Question	Answers	Additional comments/Guidelines	Mark	AO
01.6	suitable analysis ₁✓ appropriate use of Figure 2 ₂✓ processing and conclusion ₃✓	for ₁✓ $\log R_C = -2 \log d + \log k$ seen; minus sign essential for ₂✓ draw best-fit line and measure gradient; allow implication that a (linear) best-fit line is drawn and the gradient is being measured, eg 'check gradient of best-fit line'; condone $m = \text{gradient}$ for ₃✓ states that the prediction is confirmed if the gradient / m is ≈ -2 OR prediction is not confirmed if the gradient is $\neq -2$ condone 'the gradient should be -2 (to confirm prediction)' (no ECF for $m = (+)2$ if denied in ₁✓ for missing – sign) allow ₁₂₃✓ prediction is not confirmed if the best-fit line is a curve reject 'prediction is confirmed if the best-fit line is straight' / 'there is a negative gradient' / 'because 'k is constant'	3	AO3-2a

Question	Answers	Additional comments/Guidelines	Mark	AO
01.7	$t_d = 1.96 \times 10^{-4} \text{ (s)}$ ✓	minimum 2 sf; accept $196 \mu\text{s}$; calculation should be $\frac{102 - 100}{102 \times 100}$ so only accept $2.0 \times 10^{-4} \text{ (s)}$ / $200 \mu\text{s}$ only if rounding up $(\frac{100 - 98}{100 \times 98})$ gives $t_d = 2.04 \times 10^{-4} \text{ (s)}$	1	AO2-1h

Question	Answers	Additional comments/Guidelines	Mark	AO
01.8	random nature of decay or wtte $_1$ ✓	for $_1$ ✓ condone 'the source emits (photons) sporadically' / 'unpredictably'; reject explanation based on exponential decay reject 'decay occurs by chance' / 'source does not emit photons at a constant rate' / 'photons decay' / 'decay is spontaneous / inconsistent'	1	AO1-1a
	idea that more than one photon may arrive per 0.01 s interval OR idea that no photon may arrive during per 0.01 s interval OR photons 'arrive randomly' / 'do not arrive at a steady rate or wtte $_2$ ✓	$_2$ ✓ is contingent on $_1$ ✓ (if no other answer given) allow $_{12}$ ✓ for: 'only counts 50 since detector still 'dead' at 0.01 s so only 'sees' odd-numbered photons'; use of formula to show $R_1 = 50$ is neutral	1	AO1-1b

Total			16
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Question	Answers	Additional comments/Guidelines	Mark	AO
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01.1	₃✓ is about shielding using a <u>named</u> absorber stand behind a <u>lead</u> absorber / screen (when source is in the open) ₄✓ is safe use of source <u>when removed</u> from castle <u>never point</u> (open end of) the source at anyone / at yourself OR do not <u>look directly</u> at / look <u>into</u> the source ₅✓ is about good practice read local <u>rules</u> (about the use of radioactive sources) / OR read / post <u>warning</u> / <u>notice</u> on the door	source sealed' for ₃✓ accept aluminium or steel for lead; use of lead apron for ₄✓ accept 'avoid <u>eyes</u>' treat as neutral: 'avoid direct contact' / 'don't touch source' / 'always point source at ground' for ₅✓ accept 'report any damage to a source' treat as neutral: 'use safety screen' / 'don't stand in front' / 'don't ingest / swallow' / 'wash hands after use' / 'wear safety glasses / goggles / gloves / lab coats' / 'use film badge' no credit for procedures that are the responsibility of the teacher / radiation protection adviser, eg 'obtained signed consent form'	AO2-1g = MAX 2
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01.2	5 ✓	correct answer only	AO3-1a = 1
01.3	A OR $^{222}_{86}\text{Rn}$ / radon 222 / Rn 222 ✓ B OR $^{218}_{84}\text{Po}$ / polonium 218 / Po 218 ✓ I OR $^{210}_{82}\text{Pb}$ / lead 210 / Pb 210 ✓	if candidates have provided more than 3 responses, each extra error / contradiction negates one correct response; if there are 3 or more errors / contradictions, award no marks answers may be given in any order accept unnamed isotope with correct A, Z eg $^{222}_{86}\text{X}$ eg while the suggestion that A, B and I are correct earns 3 the suggestion that A, B, I and J are correct earns 3 – 1 = 2	AO3-1a = 3



01.4	suitable procedures to eliminate systematic error are: remove (all radioactive) <u>source(s)</u> (from the room) OR measure A_b before the source is present / in another room OR put source in (lead) castle / (lead) container / behind a (lead) absorber ₁✓ zero / reset the <u>counter</u> AND/OR <u>stopwatch</u> (before use) OR check the <u>counter</u> AND/OR <u>stopwatch</u> has no zero error ₂✓ measure A_b on same day as experiment is carried out ₃✓ measure A_b in same room / location / area as that where experiment is to be carried out ₄✓ suitable procedure to reduce percentage uncertainty in A_b is: use long(er) (integration) time / prolonged time OR (total of) at least 100 s ₅✓	do not insist on references to systematic or random error but give no credit for explicit talk-out eg 'use a long integration time to eliminate systematic error' for ₁✓ treat as neutral: 'measure A_b with no source near' / 'check source is shielded / far away / out of range / sealed' / 'in another area' / 'point detector away from the source (or vice-versa)' / 'don't point source at counter' / 'put detector behind source' for ₂✓ treat as neutral: 'zero / reset the equipment (before use)' / 'zero the detector' for ₃✓ treat as neutral: 'measure A_b after experiment to double-check' for ₄✓ treat as neutral: / 'keep detector in the same position' / 'measure A_b in different positions' for ₅✓ accept idea of a suggested <u>total</u> time, taking account of repeats, exceeding 100 s (eg 10 repeated 10 s counts and 1 single 100 s single count amount to the same thing) treat as neutral: 'repeat and average' ignore anomalous results' / 'use room with high background count / record large reading' / 'use more than one detector'	AO2-1g = MAX 3
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01.5	use of 5.5 MeV shown by working on Figure 4 _{1✓} minimum thickness MAX 3sf that rounds to 12 mm _{2✓3✓} OR minimum thickness MAX 3sf that rounds to 11 mm / MAX 3sf that rounds to 13 mm _{23✓}	for _{1✓} use of 5.5 MeV can be inferred from Figure 4 as a (horizontal) line, a mark on the vertical axis or a mark on the curve / intersection between curve and a vertical line, above 5 MeV and below 6 MeV; a single line / mark between 5 and 6 MeV with no subsequent working can score _{1✓} any line does not have to be ruled or perfectly parallel to the grid line; allow a cross or a small blob as the mark on the curve; do not insist on seeing a vertical line if more than one line is drawn / mark is made then mark as per scheme if a clear decision has been made about which read-off has been used to provide the result for the thickness; allow only one thickness given as final answer _{2✓3✓} OR _{23✓} can be earned without any working on the grid / other intermediate working	AO3-1a = 1 AO3-1b = 2
	OR use of 7.8 MeV shown by working on Figure 4 AND minimum thickness is 16, 17 or 18 mm _{123✓}	for _{123✓} use of 7.8 MeV can be inferred from Figure 4 as a line, mark on axis / curve etc above 7 MeV and below 8 MeV; accept MAX 3 sf result that rounds to 16, 17 or 18 mm	



01.6	$d = \sqrt{k} \times \frac{1}{\sqrt{A}} - e$ OR $d = \sqrt{k} \times \sqrt{\frac{1}{A}} - e$ OR $d = \sqrt{\frac{k}{A}} - e$ seen ₁✓ states $\sqrt{k}$ = gradient OR k = gradient² ₂✓ gradient from Δd divided by $\Delta \frac{1}{\sqrt{A}}$ with $\Delta \frac{1}{\sqrt{A}} \geq 0.5$ ₃✓ k minimum 2 sf in range $1.7(0) \times 10^5$ to $1.9(5) \times 10^5$ ₄✓ unit for k = mm² Bq or mm² s⁻¹ ₅✓	for ₁✓ d must be the subject; allow obvious slips, eg D for d for ₂✓ allow $\sqrt{k} = m$ if $y = mx + c$ is quoted so inference that $\sqrt{k}$ = gradient is clear; this mark is for explaining the step and not for performing the calculation for ₃✓ the mark is for the process, not the result; evidence of acceptable steps on grid with plausible result are enough; no credit if false origin missed allow working subsumed into calculation of k for ₄✓ gradient based on d in mm (expected = 433 mm Bq^{0.5}) POT 10⁵ required	AO2-1d = 2 AO2-1h = 1 AO3-1b = 2
	for statement that k = gradient mark as follows: for $d = k \times \frac{1}{\sqrt{A}} - e$ AND k = gradient ₁₂✓ = 1 MAX; award ₃✓ as above ₄₅✓ = 1MAX ecf for the following: k in range 410 to 450 or 2 sf 4.1 to 4.5×10^2 mm Bq^{0.5} or mm s^{-0.5} OR k in range 0.41(0) to 0.45(0) m Bq^{0.5} or m s^{-0.5} OR k in range 41.(0) to 45(.0) cm Bq^{0.5} or cm s^{-0.5}	for ₅✓ the unit given for k must be consistent with the POT of the result for k / gradient² order not important Bq mm² is acceptable; do not accept incorrect symbol, eg bq for Bq otherwise: if for ₄✓ gradient based on d in m (expected ≈ 0.43 m Bq^{0.5}) k in range 0.17(0) to 0.19(5) then for ₅✓ m² Bq or m² s⁻¹ if for ₄✓ gradient based on d in cm (expected ≈ 43 cm Bq^{0.5}) k in range $1.7(0) \times 10^3$ to $1.9(5) \times 10^3$ then for ₅✓ cm² Bq or cm² s⁻¹	

01.7	second mark ($_2\checkmark$) is contingent on award of first ($_1\checkmark$) an unsupported answer or an answer obtained by scale drawing or by extrapolation off the grid score zero attempts to find e by <u>calculation</u> by any valid method using gradient or k with all data correctly substituted in their expression; allow use of y for d, x for $\frac{1}{\sqrt{A}}$, m for $\sqrt{k}$ and c for e; attempts to solve for e $_1\checkmark$ ≥ 2 sf result in range $\geq 28(.0)$ and $\leq 32(.0)$ (mm) $_2\checkmark$	for $_1\checkmark$ use of $y = mx + c$ with recognisable data correctly substituted, eg $e = \text{their gradient} \times \frac{1}{\sqrt{A}} - d$ with substitution of their gradient and values of values of d and $\frac{1}{\sqrt{A}}$ from a point on the line from Figure 6 OR $e = \sqrt{k} \times \frac{1}{\sqrt{A}} - d$ with substitution of their k etc OR $(-)e = \text{gradient} \times \text{horizontal intercept}$, with substitution of their gradient and horizontal intercept ignore POT errors in their gradient / their k; allow mixed units and read-off errors of 1 small square for $_2\checkmark$ answer in range only (no ecf from 01.6) allow negative answer	AO2-1d = 1 AO3-1b = 1
Total			19

Question	Answers	Additional Comments/Guidelines	Mark
	general procedure - collect water for a measured time; divide measured / calculated volume by time to determine rate ₁✓	static volume should be measured after timing , eg reject 'measure time to fill cylinder' or ₁ ✓ = 0 accept 'find V for different t, plot V against t, gradient = Q' but not if by continuous flow method	AO2-1g = 1
	names 2 suitable instruments ₂ ✓	for time use <u>stopwatch</u> or <u>stopclock</u> ; treat as neutral: 'timer' or 'light gate / data logger' for volume use <u>measuring cylinder</u> / graduated beaker; treat as neutral: 'measuring beaker' / 'burette' OR for mass use <u>balance</u> ; use of $V = \frac{m}{\rho}$ (any subject) condone 'volume of 1 g is 1 cm ³ '; reject 'weigh'/'weighed'	AO2-1g = 1

B



B



A



A



28	B	$16N$
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27

C (AO2)

15.6 g



28

B (AO2)

 10 s^{-1} and 10^2 s^{-1} .

28	A	when a particular nucleus will decay.
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30	C	16 MBq
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32

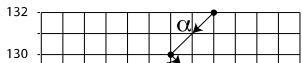
A

0.23 billion years



06.1	2.0 cm ✓ (allow 1.96 to 2.00 cm) (answer alone gains mark and ignore number of sig.figs)	$57/19 = 3$ so the halving occurs 3 times. 16 cm → 8 cm → 4 cm → 2 cm	1	AO3 1a
06.2	use more water/greater depth/greater volume (in the existing cylinder) (this should give the same half-life) ✓	Assume the word water is present in the answer if there is no reference to it. Eg 'greater depth' is taken as 'greater depth of water'.	1	AO3 1b
06.3	closing the tap more Or using a more viscous fluid (density is not the same as viscosity) Or using a wider cylinder Or use a smaller diameter capillary/narrow tube ✓	To decrease the decay constant the depth decrease rate should be reduced ie the cylinder should take longer to empty) Changes to the tube need to be specific. Also tube needs to be identified	1	AO2 1f
06.4	(Using $T_{1/2} = \ln 2 / \lambda = 0.693 / 1.42 \times 10^{-11}$) $T_{1/2} = 4.9(4.88) \times 10^{10}$ (year) ✓		1	AO1 1b

06.5	(Use of $N = N_0 e^{-\lambda t}$ mass is proportional to number so $m = m_0 e^{-\lambda t}$ $m_0 = m e^{+\lambda t}$) $\lambda t = 1.42 \times 10^{-11} \times 4.47 \times 10^9$ or 0.0635 ✓ $(m_0 = 1.23 \times 10^{-3} e^{1.42 \times 10^{-11} \times 4.47 \times 10^9})$ $m_0 = 1.31 \times 10^{-3}$ (g) ✓ (allow and look out for unit being modified to mg) mark for 3 sig figs but must be attached to a final answer for mass with some attempt at a relevant exponential calculation ✓	May calculate $N = 8.51(2) \times 10^{18}$ and N_0 9.07×10^{18} but marks will be the same	3	AO2 1f
06.6	$(N = \text{mass}/87u = 1.23 \times 10^{-6} / (87 \times 1.661 \times 10^{-27})$ $N = 8.5(1) \times 10^{18}$ ✓ (this does not have to be calculated out for the mark) $(\lambda = 1.42 \times 10^{-11} / (365 \times 24 \times 60 \times 60) = 4.50 \times 10^{-19})$ $(A = \lambda N = 4.50 \times 10^{-19} \times 8.51 \times 10^{18})$ $A = 3.8(4)$ ✓ (this calculation must use in seconds) Bq, B/becquerel, counts s^{-1} or s^{-1} ✓	In first mark is obtainable from calculating number of moles and then multiplying by Avogadro's number. $\{n = 1.23 \times 10^{-6} / 87 = 1.41 \times 10^{-5}$ $N = 1.41 \times 10^{-5} \times 6.02 \times 10^{23}\}$ A power of 10 error will count as an AE and will allow an error carried forward. Answer must follow working showing correct process as correct answer can come from incorrect working	3	AO1 1a AO2 1f
Total			10	

Question	Answers	Additional Comments/Guidance	Mark	ID details
	First mark for either both α's or both β^-'s arrows shown correctly ie α arrow moving down 2 and left 2 or β^- arrow moving down 1 and right 1 ✓ (must be sequential) Second mark for fully correct ✓ 	The first mark is independent of the start position. The question asks for arrows, so a series of positions marked does not gain marks. One mark can be awarded if all the lines with arrows are included but in wrong direction with		



Question	Answers	Additional comments/Guidelines	Mark	AO																
07.3	Suitable precaution ✓ Valid assessment of suitability based on the increased activity of the medical source ✓	Example answers <table><tr><th>Mp1</th><th>Mp2</th></tr><tr><td>Keep distance of at least 2 m / keep a long distance</td><td>distance does reduce intensity / inverse square law but 2 m not enough / not be in the room</td></tr><tr><td>Condone don't point at people</td><td>Not being in the room</td></tr><tr><td>Put warning sign on the door</td><td>Install permanent warning signs</td></tr><tr><td>Store in lead-lined box</td><td>increase thickness of lead (condone concrete for mp2)</td></tr><tr><td>Put away when not using it</td><td>Exclude unnecessary people</td></tr><tr><td>Handle with long tongs / forceps / tweezers</td><td>need to keep larger distance so use eg robot arms or remote handling Do NOT allow longer tongs</td></tr><tr><td>Using a small portable lead screen while source is in use</td><td>need a larger / thicker screen</td></tr></table> Ignore references to wearing gloves	Mp1	Mp2	Keep distance of at least 2 m / keep a long distance	distance does reduce intensity / inverse square law but 2 m not enough / not be in the room	Condone don't point at people	Not being in the room	Put warning sign on the door	Install permanent warning signs	Store in lead-lined box	increase thickness of lead (condone concrete for mp2)	Put away when not using it	Exclude unnecessary people	Handle with long tongs / forceps / tweezers	need to keep larger distance so use eg robot arms or remote handling Do NOT allow longer tongs	Using a small portable lead screen while source is in use	need a larger / thicker screen	2	1 × AO1b 1 × AO3-2b
Mp1	Mp2																			
Keep distance of at least 2 m / keep a long distance	distance does reduce intensity / inverse square law but 2 m not enough / not be in the room																			
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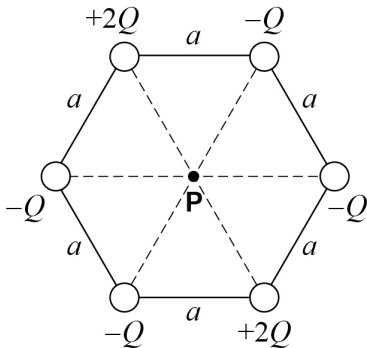


Question	Answers	Additional comments/Guidelines	Mark	AO
07.4	Ionising radiation damages cells/kills cells/causes cancer/causes mutations ✓ comment reflecting balance of risk and benefits when a filling is required e.g. risk of single scan is balanced by the benefits of treating the tooth decay ✓	Example of second point: Condone for mp2 the risk can be minimised by reducing or minimising the number of X-rays taken ignore references to exposure to dentist. “only when necessary” is insufficient for mp2. Condone references to γ for X rays.	2	1 × AO1a 1 × AO1b
Total			10	



Question	Key	Answer
8	B	doubling the volume at constant pressure
9	C	$3.87v$
10	B	400 K
11	B	a decrease in the charge held on the capacitor plates.
12	B	decreasing the frequency of the ac input voltage
13	C	2.5 V div^{-1}
14	D	$25 \quad 0.15\pi$
15	A	doubling the transmission voltage of the cable
16	D	$\frac{Be}{2\pi m_e}$
17	C	7.5 MeV
18	A	${}^{146}_{57}\text{La}$ has the greatest binding energy per nucleon of the three nuclides.
19	C	$2.2 \times 10^{-10} \text{ kg}$
20	D	$r\left(\frac{y}{x}\right)^{\frac{1}{3}}$
21	C	$\frac{R}{2}$



22	B	10^4 m
23	D	The work done moving from Q to R and moving from Q to S is the same.
24	B	the charge stored on a capacitor consisting of two parallel plates of area 1 m^2 separated by 1 m when the potential difference between the plates is 1 V
25	A	$16F$
26	D	
27	B	$1.38 \times 10^{-7} \text{ V m}^{-1}$ downwards
28	A	an electron and a positive pion
29	A	$r < 10^{-14} \text{ m}$
30	C	β^- emission.
31	B	145
32	A	0.23 billion years

03.1	$238 \times 1.661 \times 10^{-27}$ or 3.953×10^{-25} seen OR their mass $\times 3.23 \times 10^{24}$ ✓ 1.28 (kg) ✓ Alternative method` $n = \frac{3.23 \times 10^{24}}{6.02 \times 10^{23}}$ or 5.37 mol seen OR their number of moles $\times 238$ ✓ 1.28 (kg) ✓	Allow use of 1.67×10^{-27} kg Allow inclusion of electron masses. Allow use of 1.673×10^{-27} and 1.675×10^{-27} leading to 1.29	2	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
03.2	$A_0 (= \lambda N) = 8.11 \times 10^{14} \text{ (Bq)} \checkmark$ Any three from: $\checkmark\checkmark\checkmark$ - dividing an output power / A / N / m by 0.0458 or multiplying an input power / α energy / A_0 / N_0 / m_0 by 0.0458 - Use of $A = \frac{\text{any power}}{8.94 \times 10^{-13}}$ or $\frac{\text{any power}}{8.94 \times 10^{-13} \times 0.0458}$ to calculate P or A - use of $t = \frac{\ln(\frac{A}{A_0})}{-\lambda}$ or $t = \frac{\ln(\frac{N}{N_0})}{-\lambda}$ or $t = \frac{\ln(\frac{m}{m_0})}{-\lambda}$ or $t = \frac{\ln(\frac{P}{P_0})}{-\lambda}$ - convert time to years (divide a time by $365 \times 24 \times 60 \times 60$) or decay constant to yr^{-1}. Time = 14.5 (Earth years) $\checkmark$	Condone small rounding errors. $\frac{29.6}{0.0458} = 646 \text{ W}$ $\frac{646}{8.94 \times 10^{-13}} = 7.23 \times 10^{14} \text{ Bq}$ $t = \frac{\ln \frac{7.23}{8.11}}{-2.51 \times 10^{-10}} = 4.58 \times 10^8 \text{ s}$ Allow use of $0.5^{\frac{t}{t_{0.5}}}$ and $t_{0.5} = \frac{\ln 2}{\lambda}$ instead of $e^{-\lambda t}$. Allow conversion of half-life to years. Allow ecf for their A_0 Accept answers that round to 14 or 15 years based on working seen. Missing efficiency results in 404 y.	5	AO2

Question	Answers	Additional comments/Guidance	Mark	AO																									
03.3	Any three from: ✓✓✓ - valid $Q = mc\Delta\theta$ substitution or answer - valid $Q = mL$ substitution or answer 3 valid Q calculations - energy provided by laser between charges ($= 1000 \times 3$) = 3000 (J) OR a valid power calculation for their Q Total energy required = 2900 (J) < 3000 (J) so yes ✓	Ignore PoT in bullet points Heat ice to 0.0 °C: $10^{-3} \times 2100 \times 25 = 52.5 \text{ J}$ Melt ice at 0.0 °C: $10^{-3} \times 334 \times 10^3 = 334 \text{ J}$ Vaporise water at 0.0 °C: $10^{-3} \times 2500 \times 10^3 = 2500 \text{ J}$ Allow $(L_f + L_v)$ in $Q = mL$ as two calculations. Allow any correct comparison for MP4 e.g. <table border="1"> <tr> <td>Energy required</td><td>2887</td><td><</td><td>3000</td><td>J</td></tr> <tr> <td>Powers</td><td>962</td><td><</td><td>1000</td><td>W</td></tr> <tr> <td>Mass of ice</td><td>0.00104</td><td>></td><td>0.001</td><td>kg</td></tr> <tr> <td>time</td><td>2.8865</td><td><</td><td>3</td><td>s</td></tr> <tr> <td>$\Delta\theta$</td><td>79.0</td><td>></td><td>25</td><td>K</td></tr> </table> Allow other valid comparisons.	Energy required	2887	<	3000	J	Powers	962	<	1000	W	Mass of ice	0.00104	>	0.001	kg	time	2.8865	<	3	s	$\Delta\theta$	79.0	>	25	K	4	AO3
Energy required	2887	<	3000	J																									
Powers	962	<	1000	W																									
Mass of ice	0.00104	>	0.001	kg																									
time	2.8865	<	3	s																									
$\Delta\theta$	79.0	>	25	K																									
Total			11																										

Question	Answers	Additional comments/Guidance	Mark	AO
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B



10	C
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31	C	$2.55 \times 10^{-13} \text{ J}$
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29

C (AO1)

the existence of gamma radiation



26	C	0.103 MeV	AO2
		122	122



01.1	Diagram with: Up becoming down ₁ ✓ Electron becoming (electron) neutrino ₂ ✓ W connecting the two, with a boson charge consistent with their diagram ₃ ✓	Accept uud changes to udd. Do not accept capital D for d. Accept e or e ⁻ for electron but reject β ⁻ . Condone ve for ν _e (ie same size e on same line) Accept ν (roman) for ν (greek). Boson charge must be consistent bottom left to top right AND bottom right to top left. Do not accept a change in boson arrow direction in ₃ ✓.	3	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	In order for the nucleus to decay it needs (orbiting) electrons because it (only) decays by electron capture ✓	Treat irrelevant right or wrong comments as neutral. Accept reverse argument. Condone suggestion that probability of electron capture is decreased. Mention of 'ionisation' is neutral.	1	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	Evidence of $22 \times 1.6 \times 10^{-19}$ or 3.52×10^{-18} (to determine charge) OR $\frac{\text{their charge}}{4.8 \times 10^7}$ (to determine mass) $_1\checkmark$ Evidence of calculation leading to 22 neutrons, e.g. number of neutrons = their nucleon number (44) – 22 = 22 (neutrons) $_2\checkmark$	Expect to see mass = $\frac{22 \times 1.6 \times 10^{-19}}{4.8 \times 10^7} = 7.3 \times 10^{-26}$ (kg) number of nucleons = $\frac{7.3 \times 10^{-26}}{1.67 \times 10^{-27}} = 44$ Accept alternatives for the nucleon mass Accept for $_1\checkmark$ the idea that specific charge is $0.5 \times$ specific charge of proton Do not accept '22' without some evidence. Evidence to support $_2\checkmark$ can be seen earlier in the calculation e.g. subtraction of masses.	2	1 × AO2 1 × AO3
Total			6	

Question	Answers	Additional comments/Guidance	Mark	AO
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01.1		Do not credit nucleons. Suggestion of difference in number of protons loses the mark.	1
01.2	131 (nucleons) ✓	If more than one number is given, the nucleon number must be explicit.	1
01.3	The tellurium has 1 more neutron (than iodine-125) ✓ The tellurium has 1 fewer proton (than iodine-125) ✓	Accept reverse arguments. Accept tellurium has 73 neutrons Accept tellurium has 52 protons Condone "proton number". Condone "number of neutrons/protons have increased/decreased <u>by one</u> " Treat any nuclear reactions as neutral. Discussion of electrons in nucleus scores max 1. Accept answer in terms of quarks (one more down and one fewer up). Ignore references to nucleons/mass number.	2

01.4	A (<i>internal conversion</i>: only electron released); <i>beta-decay</i>: (electron and) <u>anti-neutrino</u> released; ✓ B (both statements required for mark) <i>internal conversion</i>: all electrons released will have similar/discrete energies/momenta <i>beta-decay</i>: electrons will have a range of energies/momenta ✓ C (<i>internal conversion</i>: no change in constituents of nucleus/element does not change) <i>beta-decay</i>: neutron converted to proton (allow in terms of quarks)/element changes (to one with (one) more p, different Z, different proton number/different atomic number)) ✓ D (<i>internal conversion</i>: orbital electron lost) <i>beta-decay</i>: electron comes from nucleus / no change in orbital electrons ✓ E (both statements required for mark) <i>internal conversion</i>: mediated by electromagnetic force / virtual photons <i>beta-decay</i>: mediated by weak interaction / W^- ✓	Any 3. Treat each difference, as delimited by the answer book, as a single independent mark. Contradiction within a difference cancels the mark for that difference (on list basis). For a contradiction between separate differences treat the incorrect difference as neutral. Allow: F (both statements required for mark) <i>Internal conversion</i>: may be accompanied by X-ray photon <i>Beta-decay</i>: may be accompanied by gamma photon ✓ Allow “shells” for “orbitals”. Do not award separate marks for force and exchange particle Condone “W boson” or “W particle” but not W^+ and W^-	3
Total			7

Question	Answers	Additional Comments/Guidelines	Mark
	Ray enters (prism) along normal ✓	Allow normal explained eg at right angles <u>to</u> surface	



02.1	down quark changes to up quark ✓	Allow “d→u” Condone udd→uud Condone U for u but not D for d. Do not accept answers with extra particles.	1	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Idea that (graph shows that) beta particles (from C-14) have a range of (kinetic) energies ✓ There is a fixed/maximum/total amount of energy (released by C-14) so there must be another particle that carries the energy differences/missing energy away ✓	A mention of conservation of energy on its own is insufficient for MP2.	2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	neutron ✓	Condone “n” but not “N”. Do not allow “udd”.	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	Calculation of minimum energy produced in annihilation of positron and electron (from rest mass energy $\times 2$) E.g. $2 \times 0.51 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$ ✓ (2 photons produced so) energy per photon = $8.2 \times 10^{-14} \text{ J}$ ✓ Conclusion consistent with their calculated minimum energy. ✓ ALTERNATIVE One calculation of mass equivalence of photon energy ✓ Calculation of remaining mass equivalents OR deduction about the other two photon energies ✓ Only G3 has sufficient energy to have been made in annihilation. ✓	Calculation of the photon energy based on one particle can get MP2. The 'correct' answer would be a conclusion leading to G3 only. If no other mark awarded, award one mark for determining rest energy of positron or electron in J. Allow mass equivalent calculations in (M)eV Allow explanation in terms of positron and electron for annihilation in alternative MP3	3	3 x AO3
Total			7	

Question	Answers	Additional comments/Guidelines	Mark	AO
		Condone POT error in MP1		



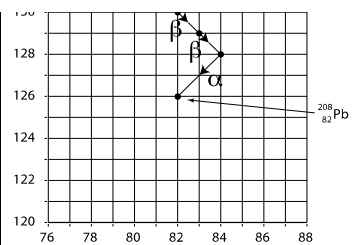
01.1	${}_{19}^{40}\text{K} + {}_{-1}^0e \rightarrow {}_{18}^{40}\text{Ar} + \nu_{(e)} \checkmark \checkmark$	first mark for 40 and 18 second mark for electron neutrino if negative superscript on neutrino mark not awarded	1 1
01.2	is the weak interaction/weak nuclear force $\checkmark$ because involves leptons <u>and</u> hadrons/ because quark character/flavour/identity/type changed $\checkmark$	allow change in quark composition allow second mark if applied to stated interaction e.g. up quark changes to down quark	1 1
01.3	(use of $E=hf$) energy in J = $1.46 \times 10^6 \times 1.6 \times 10^{-19} \checkmark (= 2.336 \times 10^{-13})$ $f = \left(\frac{E}{h}\right) = \frac{2.336 \times 10^{-13}}{6.63 \times 10^{-34}}$ AND $\lambda = \frac{3 \times 10^8}{f}$ OR $\lambda = \left(\frac{hc}{E}\right) = \frac{3 \times 10^8 \times 6.63 \times 10^{-34}}{2.336 \times 10^{-13}}$ seen directly $\checkmark$ $8.51 \times 10^{-13} \text{ m } \checkmark$	1 for the attempt at the conversion to J allowing POT 1 for attempt to sub in hf and c/λ (or hc/λ) allow energy substituted in MeV or eV for second mark 1 for the correct answer (not awarded if eV used or MeV or if POT error) Accept 8.52×10^{-13}	1 1 1
01.4	identifies the decay as beta emission $\checkmark$ <i>so will expect to see:</i> electron released (from nucleus) correct details of how electron detected antineutrino released no photon released } 2 from 4	If state incorrect interaction e.g. beta plus decay the wrong Physics and no consequential error(CE) and therefore zero. If no interaction stated then can score next 2 marks. e.g. cloud chamber or absorption If give correct equation for beta decay award mark for	3

		electron and antineutrino	
Total			10

Question	Answers	Additional Comments/Guidelines	Mark
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07.1



arrows are included but in wrong direction with lines.

2

AO2 1f

07.2	Any 3 marking points from 1 to 5 ¹Strong nuclear force (SNF) affects nucleons or protons and neutrons. ✓ ²SNF attraction extends up to 3 fm (allow 1–4 fm) ✓ ³The SNF is repulsive below about 0.8 fm (allow 0.3 to 1 fm and prevents the nucleus totally collapsing) ✓ ⁴Electromagnetic/electrostatic repulsive force (only) acts between protons ✓ ⁵EM forces are long range/infinite/acts across whole nucleus/acts on all protons(so increases as proton number increases) ✓ PLUS one of following that explains the imbalance More neutrons are needed to hold nucleus together / add to binding force/increase instability/reduce stability (owtte) Or Fewer protons are required so as to reduce the repulsion/reduce instability/increase stability (owtte) ✓	Baryons/hadrons may replace nucleons. If 'strong force' rather than 'strong nuclear force' is used only penalise once. Any wrong statement made in the first group of marking points then this section has a maximum 2 marks out of 3.	Max 4	AO2 1a (x2) AO3 1b (x2)
07.3	${}^{205}_{82}\text{Pb} + {}^0_{-1}\text{e} = {}^{205}_{81}\text{Tl} + \nu_{(\text{e})}$	The electron may be represented by e^- or β^- without the super and subscript.	1	AO2 1f

	✓ mark for full equation	Q may be added to the end of the equation. Encouraged by the following question 'gamma' might appear on the RHS of the equation. Simply ignore gamma.		
07.4	Orbiting electrons in the atom <u>fall</u> (to fill the positions vacated by inner orbiting electrons releasing their energy as em (gamma) radiation, ✓ The excited <u>nucleus</u> emits gamma radiation (as it de-excites)✓	Mark leniently in first mark. Just need to see photons are related to outer electron movement. Allow radiation due to it being above 0 kelvin For the second mark 'nucleus' must be mentioned but electrons must not.	2	AO3 1a AO3 1b
07.5	It is because: It only emits γ -rays. γ -rays are weakly ionising/cause less damage to body than other radiations. γ -rays can penetrate/escape from the body. It has low toxicity. Half-life is short enough not to remain in the body for too long after the medical examination. Half-life is long enough to complete the diagnosis. It can be prepared in the hospital/close to the hospital. Any 2 ✓✓		2	AO1 1a
Total			11	

Keys to Objective Test Questions (each correct answer is worth 1 mark)													
Qu	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans	A	C	C	B	B	A	D	C	B	D	C	A	C
Qu	21	22	23	24	25	26	27	28	29	30	31	32	
Ans	D	D	B	C	C	C	C	A	A	C	C	D	

01.1	${}^4_2\alpha + {}^{234}_{90}\text{Th}$ ✓	1 mark each for alpha and Th; numbers must be correct Must see “+” for full marks Condone He for alpha If no other mark is given, one mark can be awarded if He-3 is used and A and Z are correct MAX 1 for extra particles but condone “+ 2e⁽⁻⁾” (not 2β) Ignore symbol that is used for Thorium	2	2 x AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Idea that a neutron changes to proton/beta minus decay ✓ The particle is W⁻ because This is a weak interaction / it involves the weak force / there is a quark change and indication that charge is conserved ✓	For MP1 condone “down quark changes to up quark”. Evidence for MP1 can be found in the form of equations or diagrams. Second mark requires some explanation of why particle is negative. MAX 1 for a complete consistent inverse interaction leading to W⁺.	2	1 x AO2 1 x AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	(FOR:) Lines C is in (both) hydrogen (and helium spectra) OR Line E is in (both) sodium (and helium spectra)✓ (AGAINST:) Line D is missing (is in neither the hydrogen nor the sodium spectra) ✓	Treat references to A, B and F in FOR or AGAINST as neutral. Must link line to an element Ignore any discussion of any “missing” lines in the helium spectrum. Condone use of 390 / 440 / 490 / 505 / 590 / 670 (nm) for A/B/C/D/E/F Condone emission for absorption	2	2 x AO3



Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Wavelength = 580 nm to 590 nm ✓ Use of $E = hc/(\text{their wavelength})$ ✓ Conversion of their E in J to eV ✓	Expect to see answer in range 2.11 to 2.14 (eV) ✓ When an energy difference between two spectral wavelengths is correctly calculated, only MP2 and MP3 can be scored.	3	1 x AO3 2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Photon is energy carrier OWTTE ✓ In absorption atom becomes excited/moves to higher energy state/level (by absorbing photon) ✓ In emission atom de-excited/moves to lower energy state (by emitting photon) ✓	Condone omission of reference to energy states/levels in either MP2 or MP3 but not both. Treat discussion of any other irrelevant phenomenon or incorrect physics as talk out in that marking point. Allow “energy shell” but not “shell”. Condone electron for atom Suggestions that limit transitions to/from ground state penalise in either MP2 or MP3 once only.	3	3 x AO1
Total			12	

Question	Answers	Additional comments/Guidelines	Mark	AO
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D

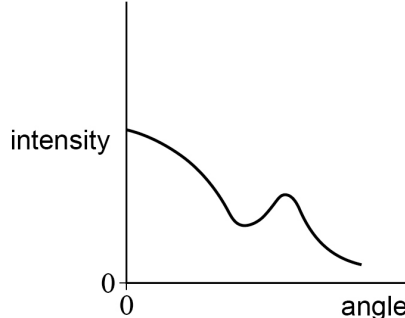


20	D	$r\left(\frac{y}{x}\right)^s$
		R



01.1	Any one from: ✓ • $(\Delta)E_k = (\Delta)E_p$ seen • $E_k = 1.60 \times 10^{-19} \times 5.59 \times 10^6$ or 8.94×10^{-13} seen • $Q_\alpha = 2e$ and $Q_{Au} = 79e$ An energy $= \frac{Q_\alpha Q_{Au}}{4\pi\epsilon_0 r}$ seen in any form ✓ $r \left(= \frac{2 \times 1.60 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 5.59 \times 10^6 \times 1.60 \times 10^{-19}} \right)$ ($\leq$) 4.1×10^{-14} (m) ✓ (allow 1 sf) cao	MP1 may be seen in substitution for r Condone PoT error in MP1 and MP2. In MP2: Allow use of $E = QV$ and $V = \frac{Q}{4\pi\epsilon_0 r}$ with Q_α and Q_{Au} in either order. Condone use of k for $\frac{1}{4\pi\epsilon_0}$ unless contradicted by use of 1.38×10^{-23} Condone use of E_k in MeV. Condone 10^{-14} if supported by some correct substitution. Correct answer to at least 1 SF gains all 3 marks.	3	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Any two from: ✓✓ - Idea that alpha particles give an upper limit on size of the nucleus / estimate is larger than nuclear radius - Idea that (distance of closest approach) depends on the energy of the alpha particle - Idea that recoil of nucleus is ignored - Idea that alpha particle has finite size	Ignore references to shape of nucleus. bullet 1: condone idea that it does not hit the nucleus. Referencing the distance of closest approach is not enough. bullet 2: is for the idea that the closest approach method does not give a single value Condone does not take into account neutrons / only considers charge / only considers number of protons. If no other mark awarded allow max 1 for reference to not taking into account the effect of the strong nuclear force.	2	AO1

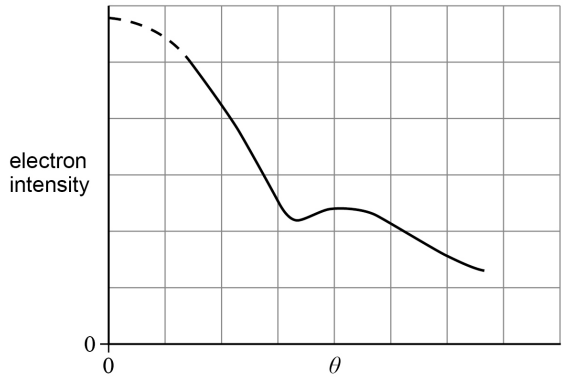
Question	Answers	Additional comments/Guidance	Mark	AO
01.3	When angle = 0 there is a maximum and first minimum is not zero and at least one subsequent smaller maximum ✓ Idea that nuclear radius is determined from (first diffraction) minimum ✓	 Allow subsequent peaks Condone the line meeting the intensity axis at non-zero but negative gradient. Do not allow double slit (even superposed with single slit) or diffraction grating (light-like) patterns. Allow suitable annotation of diagram for answer Ignore any equation given.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Any one of: ✓ • volume of a nucleus is (approximately) spherical • $V = \frac{4}{3}\pi R^3$ or $V = \frac{4}{3}\pi R_0^3 A$ • volume is proportional to A • mass = $A \times$ mass of nucleon • mass (/kg) = $A \times 1.661 \times 10^{-27}$ • mass is proportional to A Density $\left(= \frac{m}{V} \right) = \frac{Am_{(n)}}{\frac{4}{3}\pi R_0^3 A} = \frac{m_{(n)}}{\frac{4}{3}\pi R_0^3}$ AND where all are constants / equation is independent of A. OR Combining of two proportional statements and cancelling of A ✓	Do NOT accept bullets 3, 4,5 or 6 when A is referred to as area, activity or any other incorrect quantity. $R \propto A^{\frac{1}{3}}$ or $R^3 \propto A$ is not enough. Accept alternative values or u in bullet 5	2	AO1
Total			9	

Question	Answers	Additional comments/Guidance	Mark	AO
		Any suggestion that particles do not follow		



06.1	Any two from: ✓✓ • using electrons gives greater resolution (as the wavelength can be made very small) • electrons can get closer to the nuclei (as there is no electrostatic repulsion) • electrons have less recoil (as their mass is small compared to the nucleus) • free electrons are easier to accelerate OR give energy to (as charge-to-mass ratio is higher) • electrons are easier to produce • scattering distributions are easier to interpret OR strong nuclear interaction is not involved • using alpha particles only gives the distance of closest approach/upper limit to the radius.	OWTTE on each advantage Allow reverse arguments	2	AO1 AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	A curved line showing an decrease in intensity with increase in θ. ✓ There is a single non-zero minimum. ✓	Do not allow U-shaped graphs. The initial part of the curve may be absent. Award MAX 1 for a line that covers less than half the θ axis. 	2	AO1 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Density (= mass÷volume) = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi R^3}$ ✓₁ (substituting density = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi \left(R_0 A^{\frac{1}{3}}\right)^3}$) Density = $\frac{3m_{\text{nucleon}}}{4\pi(R_0)^3}$ (in which) all (terms are) constant OR the expression does not depend on A ✓₂	✓₁ Do not accept <i>M</i> unlabelled. Accept <i>m</i> (ie lowercase) unlabelled. Condone <i>m_n</i> (mass of neutron in Data sheet) for <i>m_{nucleon}</i>. Accept only 1.67×10^{-27} (kg) for mass of nucleon (ie to 3 sf). Allow ecf to MP2 for any misrepresentation of <i>m</i> provided it is clear that it signifies mass of a single nucleon. ✓₂ If the constants are identified the equation may be converted into a ratio. The equation may be rearranged to have <i>R₀</i> as the subject with work to show that this is a constant <i>when the density is constant</i>.	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Any one of: ✓ The mass of the nucleus is not exactly $A \times m_{\text{nucleon}}$ (because this ignores the binding energy) OR The volume equation assumes that the nucleus is a perfect sphere (which is not true) OWTTE OR The density equation that uses the nuclear radius formula implies that the density is uniform within a nucleus which is not true. OWTTE OR Protons have a slightly different mass to a neutron	Do not accept “density of individual nucleons can be different from each other”. It is not allowed as it does not occur in the working equation.	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
06.5	$R_0 = \left(\frac{R}{A^{\frac{1}{3}}} = \frac{4.02 \times 10^{-15}}{(35)^{\frac{1}{3}}} \right) = 1.2(3) \times 10^{-15} (\text{m}) \quad \checkmark_1$ Substitutes values into density equation $\checkmark_2$ Density = $2.1 \times 10^{17} (\text{kg m}^{-3}) \quad \checkmark_3$	$\checkmark_2$ e.g. Density = $\left(\frac{\text{mass}}{\text{volume}} = \frac{Am}{\frac{4}{3}\pi R^3} \right) =$ $\frac{35 \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi (4.02 \times 10^{-15})^3}$ $\checkmark_3$ Evidence of a calculation must be given to gain this mark Accept 2.15 but not 2.2	3	AO2 ×3
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
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C



C



B



30	A	$2.3 \times 10^8 \text{ W}$
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31	B	$1.0 \times 10^8 \text{ W}$
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18	A	$^{146}_{57}\text{La}$ has the greatest binding energy per nucleon of the three nuclides.

28

C

4.7 MeV

AO2



31

D

R only

AO1

Total: 25 marks

30

04.1	Either appreciation of mass of He = 4 × mass of neutron OR idea that n and He have equal (and opposite) momenta ✓ Combination of momentum and KE equations (to give idea that KE is inversely proportional to m with same p) and therefore KE of neutron = 4 × KE of He ✓	Expect to see $KE = \frac{p^2}{2m}$	2	AO3
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Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	calculates KE of neutron OR uses mass of neutron from data booklet with <i>their calculated KE</i> in a KE equation ✓ $v = 5.2 \times 10^7 \text{ m s}^{-1}$ ✓	$80\% \times 2.82 \times 10^{-12} = 2.26 \times 10^{-12} \text{ (J)}$ Do not allow use of 2.82×10^{-12} as <i>their calculated KE</i>. $m_n = 1.67(5) \times 10^{-27} \text{ kg}$ Accept answers of 5.18×10^7 or $5.19 \times 10^7 \text{ m s}^{-1}$ Calculator values: 5.1823878×10^7; (using 1.68) 5.1901169×10^7; (using 1.675) 5.1978807×10^7 (using 1.67)	2	AO2
Total			4	

Question	Answers	Additional comments/Guidelines	Mark	AO
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05.1	(using mass defect = $\Delta m = Z m_p + N m_n - M_{\text{Co}}$) $\Delta m = 27 \times 1.00728 + 32 \times 1.00867 - 58.93320$ (u) ✓ $\Delta m = 0.5408$ (u) ✓ Binding Energy = $0.5408 \times 931.5 = 503.8$ (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.	Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0. If subtraction is the wrong way round lose 1 mark. Data may come from rest mass eg $m_n = 939.551$ MeV or 1.675×10^{-27} kg or 1.00867 u. So if kg route used $\Delta m = 8.83 \times 10^{-28}$ kg BE = 7.95×10^{-28} J and 497 MeV. Conversion mark (2 nd) may come from a wrong value worked through. 0.47(5)	3
05.2	$(2.52 - 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J ✓ $7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV ✓ (0.475 MeV)	Correct answer scores both marks.	2
05.3	6 (specific wavelengths)		1
05.4	(longest wavelength = lowest frequency = smallest energy) $(2.29 \times 10^{-13} - 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓ $\lambda (= h c / E) = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 2.3 \times 10^{-14}$ ✓ $\lambda = 8.6 - 8.7 \times 10^{-12}$ (m) ✓ (8.6478×10^{-12} m)	Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state. The allowed energy gaps for CE are: 2.29, 2.06, 1.76, 0.53, 0.30 all $\times 10^{-13}$ J Note substitution rather than calculation gains mark. The final mark must be as shown here and not from a CE above.	3
Total			9

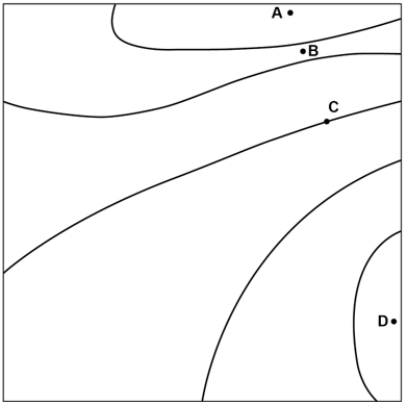
Question	Answers	Additional Comments/Guidelines	Mark
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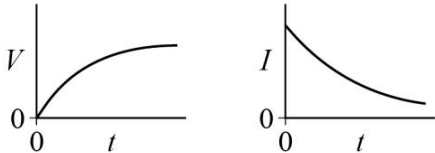
06.1	Total Mass of nuclei is more than the mass of the fusion product ✓₁ Binding energy or Binding energy per nucleon increases when a nucleus is formed by fusion ✓₂	✓₁ Alternatively the B/A of the fusion product is greater than B/A of both the starting nuclei. ✓₂ In order to release energy, the total binding energy of the two nuclei must be less than the binding energy of the nuclide formed	2	3.8.1.6 AO1 1b ×2
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	$(\Delta m = (\text{mass } {}^3_2\text{He} + \text{mass } {}^{17}_8\text{O}) - \text{mass } {}^{20}_{10}\text{Ne})$ $\Delta m = 0.02272 \text{ (u)}$ ✓₁ Energy released = $3.38 \text{ to } 3.40 \times 10^{-12} \text{ J}$ ✓₂ (allow an ecf for the conversion of units)	✓₁ $\Delta m = (3.01603 + 16.99913) - 19.99244 = 0.02272 \text{ u}$ (must have at least 3 sig fig) ✓₂ $\Delta m = 0.02272 \times 1.661 \times 10^{-27} \text{ kg} = 0.02272 \times 1.661 \times 10^{-27} \times (3.00 \times 10^8)^2 \text{ J} = 3.39 \times 10^{-12} \text{ J}$ OR $\Delta m = 0.02272 \times 931.5 \text{ MeV}$ $= 21.16 \times 1.60 \times 10^{-13} \text{ J} = 3.39 \times 10^{-12} \text{ J}$	2	3.8.1.6 AO2 1f ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Mark for use of potential energy formula and identifying the 2(e) and the 8(e) ✓₁ $\left(V = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r} = \frac{2 \times 8 \times (1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 5.1 \times 10^{-15}} \right)$ $V = 7.2(2) \times 10^{-13}$ (J) ✓₂ (correct answer only)	✓₁ condone other numerical errors ✓₂ correct final answer gains both marks	2	3.8.1.5 AO2 1f ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Making reference to the doubling charge which increases the gain in potential energy or force needed (to bring nuclei together) ✓₁ (owtte) (So) the larger charge (of $^{34}_{16}\text{S}$) requires greater kinetic energy or pressure for fusion and decreases the rate of fusion ✓₂ (owtte) Making reference to the larger radius/size of the sulphur nucleus compared to the oxygen nucleus (So) the larger radius (of $^{34}_{16}\text{S}$) (requires smaller kinetic energy or pressure for fusion) and the separation can be larger for fusion to take place so increases the rate of fusion ✓₃ (owtte)	✓₁ no computation is expected Condone increase instead of doubling ✓₃ A full calculation is not expected, such as $\frac{R_S}{R_O} = \sqrt[3]{\frac{A_S}{A_O}} = \sqrt[3]{\frac{34}{17}} = \sqrt[3]{2}$ If no marks are awarded accept number of protons for charge in mp1.	3	3.8.1.5 AO2 1b AO3 1b ×2
Total			9	

Question	Key	Answer
7	A	0.10 kg s^{-1} .
8	B	u
9	B	temperature in $^{\circ}\text{C}$ pressure in Pa
10	A	4.3 m s^{-1}
11	B	
12	B	$4g$
13	A	7.2 J
14	D	a repulsive force of $\frac{3}{4}F$
15	C	10^{36}
16	C	$\frac{QV}{d}$
17	D	72 mm
18	D	$\frac{E}{9} \quad \frac{V}{3}$
19	C	No work is done moving an electron from M to N .

20	D	
21	A	lift upwards away from the wires.
22	A	one
23	D	The peak-to-peak voltage is 650 V.
24	B	$\frac{9}{2}P$
25	B	200 0.45
26	A	Its rate of change of momentum is at a minimum.
27	C	10
28	B	16N
29	C	to decrease neutron speeds
30	A	$2.3 \times 10^8 \text{ W}$
31	C	$2.55 \times 10^{-13} \text{ J}$

06.1	Energy required/work done to separate the nucleus ✓ into its individual nucleons/protons and neutrons ✓ OR Energy given out when a nucleus is formed ✓ from its individual nucleons/protons and neutrons ✓	MP2 can only be awarded when there is some reference to energy via MP1. Alternative words may be used instead of 'separate' but when used they must convey the correct idea. If no other marks are awarded, condone the idea that "binding energy is how much greater the rest energy/mass of the constituent nucleons is than that of the nucleus" for one mark.	2	2 x AO1 3.8.1.6
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	Statement of binding energy/mass defect = (mass of nucleons) – (mass of nucleus) ✓₁ (which may be seen from a full equation with data or implied from clear statements of what numbers represent) Standing alone or contained in the binding energy equation show the total mass of nucleon constituents of $^{56}_{26}\text{Fe}$. ✓₂ the correct binding energy converted to MeV = 490 ± 10 (MeV) Or use of data booklet values and $E=mc^2$ = 340 ± 10 (MeV) ✓₃	Use of Data Booklet values leads to a correct answer of 338 (337.6) MeV. Allow 340 ± 10 RB TO CONFIRM. ✓₁ condone simple numerical errors such as powers of 10 if mark comes from substituted equation. ✓₂ for giving data to at least 4 sig figs but calculations can use less. Examples looked for are $26 \times 1.673 \times 10^{-27} + 30 \times 1.675 \times 10^{-27}$ (= 9.375×10^{-26} kg) OR $26 \times 938.257 + 30 \times 939.551$ (= 52580 MeV) OR $26 \times 1.00728 + 30 \times 1.00867$ (= 56.44938 u) ✓₃ no ecf. and mark is only available if the mass of a neutron and proton are different in part 2. Might see	3	3 x AO2 3.8.1.6

		$(9.375 \times 10^{-26} - 9.288 \times 10^{-26}) \times 931.5 / 1.661 \times 10^{-27}$ $= 488 \pm 2 \text{ MeV}$ OR $52580 - (9.288 \times 10^{-26} \times 931.5 / 1.661 \times 10^{-27})$ $= 492 \pm 2 \text{ MeV}$ OR $\{56.44938 - 9.288 \times 10^{-26} / 1.661 \times 10^{-27}\} \times 931.5$ $= 495 \pm 2 \text{ MeV}$ OR when the calculation involves the use of $E=mc^2$ $338 \pm 2 \text{ MeV}$ Note calculations may vary being dependant on how many sig figs are retained and how many individual stages of calculation are used.		
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Both F_1 and F_2 to be to the right of the peak and marked on the graph or x-axis ✓₁ F_1 and F_2 to be in correct grid regions t symmetrical about half the nucleon number corresponding to X. ✓₂ average binding energy per nucleon 0 50 100 150 200 250 nucleon number pairs of possible F positions which are symmetrical about the X/2. Accuracy - to be in the correct grid column	Note that an F position cannot have a nucleon lower than the peak. So the 3 examples shown indicate the possible range of an answer. The position of F_1 and F_2 are taken from the centre of the cross or blob drawn by the candidate. The range of each grid region includes the boundary dotted line. ✓₁ If it is clear that nucleon numbers of F_1 and F_2 add to 240 give mark The circles shown in the diagram show the horizontal positions – to gain the marks the circles have to be on the line or the x-axis.	2	2 x AO2 3.8.1.6

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	The starting point of the fission fragments is given the first mark $\checkmark_1$ (normally the initial decay mode is) β^- $\checkmark_2$ Moves closer to the stable region as: a neutron changes to a proton OR position (on the graph) moves down and to the right $\checkmark_3$	$\checkmark_1$ fission fragments have a high N/Z ratio OR fission fragments are positioned above/left of the line plot in Fig 11 too many neutrons is not given a mark – high N/Z ratio or neutron rich terms must be used $\checkmark_2$ Mark may be given in isolation but the minus must be indicated The discussion of the decay and positioning of F_1 and F_2 must be the same. Any differences will be marked as a contradiction. $\checkmark_3$ the mark could be seen on Fig 11	3	1 x AO1 2 x AO3 3.8.1.4
Total			10	



Question	Key	Answer
07	A (AO2)	150 K
08	D (AO2)	pressure of the gas internal energy of the gas
09	D (AO2)	$\frac{R}{\sqrt{2}}$ $2M$
10	B (AO1)	$2.7 \times 10^{-6} \text{ rad s}^{-1}$
11	B (AO2)	$\sqrt{2gR}$
12	C (AO2)	$2\pi\sqrt{\frac{R^3}{GM}}$
13	D (AO2)	the orbital period of the satellite
14	A (AO2)	$\frac{R}{8}$
15	B (AO2)	$2\sqrt{2}u$
16	A (AO1)	135 μJ
17	A (AO2)	1.3×10^{-2} X to Y
18	C (AO2)	After a time T the pd across the capacitor is 1.5 V.
19	C (AO2)	$9C$

20	C (AO2)	$2E$
21	D (AO2)	$\frac{1}{e^4}$
22	B (AO2)	$3.9 \times 10^{-2} \text{ T}$
23	B (AO2)	$\frac{1}{4f}$
24	B (AO2)	P
25	C (AO1)	Some particles were deflected through angles greater than 90° .
26	A (AO1)	Is it deflected by a magnetic field? yes yes no
27	C (AO2)	15.6 g
28	B (AO2)	10 s^{-1} and 10^2 s^{-1} .
29	C (AO1)	the existence of gamma radiation
30	D (AO1)	When it is absorbed it makes the absorber radioactive.
31	C (AO1)	Slow neutrons are required for this induced fission.

D



C



29	C	to decrease neutron speeds
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31

C (AO1)

Slow neutrons are required for this induced fission.

33

25

D

gamma radiation from nuclides with a small decay constant.



29

A

to absorb neutrons released from fission

AO1



30

D

slow neutrons to thermal speeds.

AO1



04.1	The idea that the coolant extracts heat from the core and delivers it to the boiler/turbine via a heat exchanger. ✓	OWTTE Condone the omission of the heat exchanger Reject answers which suggest the coolant is turned directly into steam (to drive the turbine).	1	AO1a
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Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	Any two points from the following list ✓✓ • Ability to absorb neutrons (It should not absorb neutrons or should have small neutron absorption cross-section (this is function of moderator)) • Stability under conditions of high temperature and/or high levels of radiation • (It should be) non-corrosive / unreactive / reactivity / inert • (It should have a high) boiling point • (It should have low) viscosity / ability to flow • (It should have a high) specific heat capacity	Condone: (it should have a) • (low) melting point • (high) thermal conductivity. Ignore references to latent heat / cost / flammability / availability / mass / density Apply the list principle.	2	AO1a

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Idea that control rods are inserted (further) / lowered into the core ✓ Decrease the neutron flux in the reactor/core OR decreases the rate of fission reactions (and hence the power output) ✓	OWTTE Condone insert (more) control rods for mp1 Condone for control named material from boron, cadmium, silver, indium. Condone decrease the number of neutrons / absorb neutrons for decrease neutron flux Condone number of fissions for rate of fissions Do not allow reduce the speed of neutrons.	2	1 × AO1a 1 × AO1b
Total			5	

15

Question	Answers	Additional comments/Guidelines	Mark	AO
...	Max 2 ✓✓	...	...	...



06.1	U-235 (absorbs) a neutron with added information ✓₁ U-235/6 then divides/splits and gives out more neutrons ✓₂ U-238 absorbs/scatters <u>neutrons</u> ✓₃	₁ Possible added information : To become U-236 absorbs a slow moving neutron absorbs a thermal neutron If no marks awarded but the first two marking points are made without identifying the isotope give one mark ₃ If the answer implies that U-238 in any way is involved in fission this mark is lost	3	AO2.1e ×2
06.2	Substitution into or manipulation of the equation $N_t = N_0 e^{-\lambda t}$ to give the ratio $\frac{N_0}{N_t}$ with N_t for the present day and N_0 being in the past ✓_{1a} $\left(\frac{N_0}{N_t} = e^{+\lambda t} = e^{+(1.54 \times 10^{-10} \times 2.0 \times 10^9)} = 1.36\right)$ Mass of U-238 (= 1.36×0.993) = 1.35 kg (3 sf) ✓_{2a} OR working with half-lives (Half life = 4.50×10^9 year) Number of half-lives = 4/9 or 0.44 ✓_{1b} $\left(\frac{N_0}{N_t} = 2^{(4/9)} = 1.36\right)$ Mass of U-238 (= 1.36×0.993) = 1.35 kg (3 sf) ✓_{2b}	Must be to 3 sig figs Calculation may be in grams _{1b} Half life = $\ln 2 / 1.54 \times 10^{-10}$ = 4.50×10^9 (year) Number of half-lives = $2.00 \times 10^9 / 4.50 \times 10^9$	2	AO2.1f ×2 M2 ×2

06.3	Ratio $\left(\frac{N_{235}}{N_{238} + N_{235}}\right) = 3.6\% \text{ to } 3.7\%$ so yes ✓ A valid calculation must be performed to gain the mark eg with an ecf from 06.2	$\left(\frac{N_{235}}{N_{238} + N_{235}} = \frac{52}{1400 + 52} \text{ using 06.2 data} \right.$ $\left. = \frac{52}{1350 + 52} \right)$ Condone using ratio $\frac{N_{235}}{N_{238}}$ $\left(\frac{N_{235}}{N_{238}} = \frac{52}{1400} \text{ using 06.2 data} = \frac{52}{1350} \right)$ = 3.7% to 3.9%	1	AO1.1b M2
Total			6	

07.1	Heavy water OR Beryllium / Be OR (normal) Water ✓	Accept D ₂ O and H ₂ O	1	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
07.2	Any two points from: ✓✓ • U-235/Uranium fuel will (be more likely to) absorb the neutron • slow neutrons are less damaging OR cause less fatigue to the structure of the reactor/shielding/etc • slow neutrons (spend longer within the fissionable material and) increase the chance of causing fission • slowing neutrons transfers heat energy to the moderator (which can make heat easier to extract) all points OWTTE	Condone the answer: As an alternative to the first point Fission of U-236 is much more likely. Condone the answer: Absorption by U-238 is less likely.	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
07.3	$\frac{\text{final kinetic energy}}{\text{initial kinetic energy}} = \frac{\left(\frac{1}{2}m_{\text{N}}v^2\right)}{\left(\frac{1}{2}m_{\text{N}}u^2\right)} = \left(\frac{v}{u}\right)^2 = 0.85^2 = 72\% \checkmark_1$ (Hence) proportion of kinetic energy lost = 28% $\checkmark_2$	$\checkmark_1$ can be for any of the terms shown equating to the kinetic energy ratio. $\checkmark_2$ can be an ecf but only for an arithmetic error.	2	AO2 AO3

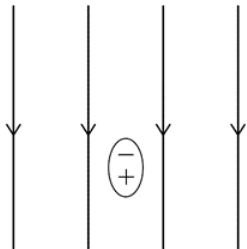
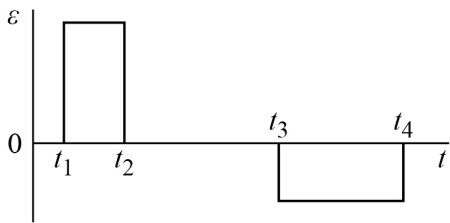


Question	Answers	Additional comments/Guidelines	Mark	AO
07.4	final kinetic energy = $(\frac{3}{2}kT) = 7.2 \times 10^{-21} \text{ (J)}$ ✓₁ initial kinetic energy = $(W = QV) = 1.6 \times 10^{-13} \text{ (J)}$ ✓₂ OR final kinetic energy = 0.045 (eV) ✓₁ initial kinetic energy = $1.0 \times 10^6 \text{ (eV)}$ ✓₂ (Rearranging equation $y = \frac{\ln\left(\frac{E_0}{E_t}\right)}{b}$) $y = 23.(2)$ ✓₃	✓₁₊₂ Both marks must come from the same alternative route and have consistent units (which may not be seen). ✓₁ Initial kinetic energy = $\frac{3}{2} \times 1.38 \times 10^{-23} \times 350 = 7.245 \times 10^{-21} \text{ J}$ $= \frac{7.245 \times 10^{-21}}{1.60 \times 10^{-13}} = 0.045 \text{ eV}$ ✓₂ Using the eV unit alternative the second mark cannot be given without an attempt at the first mark. The $1.0 \times 10^6 \text{ eV}$ can be seen in a later substitution provided eV is used throughout. $\checkmark_3 \quad y = \frac{\ln\left(\frac{1.0 \times 10^6}{0.045}\right)}{0.73} = 23.2$ Condone answer 24 provided it is given as an integer.	3	AO2 ×3

Question	Answers	Additional comments/Guidelines	Mark	AO
07.5	Idea that the model/ Figure 15 shows that low nucleon number (and so low mass) gives a greater change/reduction in speed/KE (in a collision) ✓ Idea that fewer collisions needed (with a low mass number so moderator can be thinner) ✓	Condone the use of nuclear mass instead of mass number.	2	AO2 ×2
Total			10	



Question	Key	Answer
8	C	60 kg
9	C	Charles's Law
10	C	10^{36}
11	B	$\left(\frac{M}{R}\right)^{\frac{1}{2}}$
12	B	$\sqrt{\frac{GM}{(R+h)}}$
13	D	Signals from the satellite can be sent to at any point on the Earth's surface during one orbit.
14	C	$\frac{2Q}{\pi\epsilon_0 d^2}$
15	A	20 μN
16	A	vertically down the plane.
17	C	the electric potential of the sphere.

18	A	
19	C	$4.0 \times 10^{-14} \text{ m}$
20	B	$6.0 \times 10^{-3} \text{ T}$
21	B	The radius of the path followed by an ion is different for each isotope.
22	A	
23	D	$600 \mu\text{V}$
24	D	395 V
25	D	gamma radiation from nuclides with a small decay constant.
26	C	The number of alpha particles deflected backwards is greater than the number that pass straight through the foil.
27	C	0.174 A

28	A	when a particular nucleus will decay.
29	B	β^-
30	C	16 MBq
31	B	$1.0 \times 10^8 \text{ W}$
32	D	6.1×10^8

04.1	(moderator) - the neutron undergoes an elastic <u>collision/bounces off</u> with less speed/kinetic energy ✓ (Any reference to absorption loses the mark)	Must have the idea that the neutron slow because of <u>collisions</u>	1
04.2	(control rod) – the neutron is <u>absorbed</u> ✓	'stopped' will not get the mark. If alternatives are given all must be correct to gain mark.	1
04.3	the neutron is absorbed/U-236 is formed ✓ (causing) the <u>nucleus</u> (of fuel/uranium) to split into (two smaller) daughter nuclei / <u>nuclei</u> / <u>fragments</u> ✓ releasing (several fast-moving) neutrons ✓	1 st mark can use words like absorbed/takes in/ 2 nd mark: alternative words for nuclei are not acceptable (eg daughter <u>products</u>) 3 rd mark 'neutrons' must be plural.	3
04.4	Descriptor	(Bullet point headings are detailed at the bottom end of the table)	Mark
	High Level – Good to Excellent All three bullet points must be addressed. The source must be identified and two stages in the treatment sequence must be given. Finally three problems encountered in the treatment of waste and how the problems are overcome should be stated. (Note discussion of a problem will often cover a stage of the treatment). <i>The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.</i>	6 marks = At least 6 points made coming from all three of the bullet point headings. (note some written points may count as answers to bullet point headings 2 and 3) 5 marks = 5 points made coming from all three of the bullet point headings. To be in this top band communication skills must be good and the ideas easy to follow.	5–6

	Intermediate Level – Modest to Adequate All three bullet points must be addressed. The source must be identified as well a stage in the treatment along with a problem encountered in the treatment of waste and how it is dealt with. One additional piece of information must be made from any of the bullet points listed below to be at the top of this band. <i>The grammar and spelling may have a few shortcomings but the ideas must be clear.</i>	4 marks = 4 points made coming from at least 2 bullet point headings. 3 marks = 3 points made coming from at least 2 bullet point headings. To be in this moderate band communication skills must good enough to understand the ideas easily even if the order is a little unclear.	3–4
	Low Level – Poor to Limited To be at the top of this band two bullet points must be addressed which must include a problem encountered in the treatment of waste and how it is dealt with. A single mark is awarded if any of the information given in the bullet points listed below is given. <i>There may be many grammatical and spelling errors and the information may be poorly organised.</i>	2 marks = Two points made from any bullet point heading. 1 mark = any point made coming from any bullet point heading. Or the script as a whole shows some basic understanding of the issues.	1–2
	The description expected in a competent answer should include: 1st bullet point The (highly radioactive/ most dangerous) waste are the fission fragments from the fission of uranium-235 or from (spent) fuel rods. 2nd bullet point The waste is initially placed in cooling ponds/water (close to the reactor for a number of years)		

	plutonium/uranium is separated to be recycled high level waste is vitrified/made solid into (pyrex) glass then placed in (stainless) steel/lead/concrete cylinders/containers/bunkers to be stored deep underground (simply stating buried/underground is not enough) 3rd bullet point (the problem and its solution must both be given, <u>some</u> examples are given below) the waste is (initially) is very hot/generates heat so has to be placed in water/cooling ponds (to remove the heat) the waste (initially) is highly radioactive and needs to be screened in water/cooling ponds (to absorb the radiation) the waste (initially) is highly radioactive and needs to be remotely handled (to avoid human contact with the waste). In liquid form the (high level) waste may leak hence the need to vitrify (and barrel in steel) The waste will be radioactive for hundreds/thousands of years so storage needs to be stable in a container hence the need to vitrify (and barrel in stainless steel) The waste will be radioactive for hundreds/thousands of years so long term storage needs to be in geologically stable areas (deep underground). Transporting waste presents a potential danger to the public so waste is transported enclosed in impact/crash resistant/extra thick and strong casings Or processed onsite or nearby.		
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Total			11
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Question	Answers	Additional Comments/Guidelines	Mark
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06.1	Or To allow the neutron to be absorbed by the <u>fuel/U-235</u> ✓	alternative. Reject inaccurate descriptions for example ones that imply the neutrons are undergoing fission.	1	AO2-1a-1
06.2	$E_{\text{final}} = (1 - 0.63) E_{\text{incident}}$ or $E_{\text{final}} = 0.37 E_{\text{incident}}$ ✓ ₁ (continuing this idea, $E_1 = (1 - 0.63) E_0$ $E_2 = (1 - 0.63) E_1$ so $E_2 = (1 - 0.63)^2 E_0$ and $E_5 = (1 - 0.63)^5 E_0$ $E_5 = (1 - 0.63)^5 \times 2.0 \times 10^6$) $= 1.4 \times 10^4$ eV ✓ ₂ (1.39×10^4 eV)	If no marks are scored a single mark can be given: if the final answer that has a power of 10 error possibly by not using the M in the eV. OR using 0.63 rather than $(1 - 0.63)$ in the calculation giving the answer $2(.0) \times 10^5$ (eV) ✓ ₂ A correct final answer gains full marks	2	AO2-1b-1 AO2-1f-1 Math2-2
06.3	A link made between the change in kinetic energy or	✓ ₁ Ref. to mass is needed. {Essence of marking point: The mass	2	AO2-1g-1

	momentum to the masses of the (two) particles involved in the collision. ✓₁ A consistent argument that results in a statement 'as nucleon number/number of nucleons in the nucleus increases more collisions are required. ✓₂	determines how much KE/momentum is lost} ✓₂ Ref to nucleon number or equivalent needed but mass is not. {Essence of marking point: If N is high then not much KE is lost so more collisions are needed} An example of an argument could be: More (kinetic) energy is lost when the mass of the moderator atom/nucleus is closer to the mass of the neutron So the number of collisions needed increases with nucleon number		AO3-1a-1
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Question	Answers	Additional Comments/Guidance	Mark	ID details
06.4	Mass difference $= (\text{mass}_U + \text{mass}_n) - (\text{mass}_{Xe} + \text{mass}_{Sr} + 4 \text{ mass}_n)$ $= (235.044 + 1.0087) - (141.930 + 89.908 + 4 \times 1.0087) \checkmark_1$ $= 0.180 \text{ u} \checkmark_2$ {if no unit present take u as the default unit} $(= 0.180 \times 931.5)$ $= 168 \text{ (MeV)} \checkmark_3$	$\checkmark_1$ Mark for word equation or substitution, one neutron may be cancelled from both parts of the subtraction. Condone any simple slip in transferring the numbers. Also the mark can be awarded for giving or comparing the mass on the LHS with the RHS. $\checkmark_2$ Only allow correct answer. $\checkmark_3$ This mark can stand alone for the conversion of any number of u converted to MeV. 2 sig figs is acceptable. The conversion mark can come from any part of this question not just the final line. $\{1 \text{ kg} = 6.02 \times 10^{26}\}$ A correct answer gains all 3 marks.	3	AO2-1f-3 Math2-1
06.5	1. (Small amounts of fossil fuel used) so <u>little</u> greenhouse gas emissions/less global warming/less CO₂/less climate change. {not <u>no</u> greenhouse gas} 2. (Less fossil fuel used) so cleaner air. 3. Small amounts of fuel consumed to get the same/large amount of power/energy. 4. Nuclear power can be produced continuously{condone use of constant} (whereas renewables are dependent on sunlight/wind etc). 5. Some (but not all) nuclear power stations can adjust their output quickly. 6. Benefit of producing medical isotopes.	Just one of the examples may be from the following: At present nuclear fuel is obtained from stable allied countries (as opposed to oil/gas). Facilitates nuclear weapon production. (Less fuel used) so less transportation needed. Examples of rejected ideas because they are incomplete or wrong: Produces more energy. There is more uranium than fossil fuel. Damages the environment less. Provides jobs. More efficient than others.	3	AO1-1a-1 AO3-1a-2

	✓✓✓any three points	Reference to cost. It's a renewable source.		
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Total			11	
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Keys to Objective Test Questions (each correct answer is worth 1 mark)													
Qu	07	08	09	10	11	12	13	14	15	16	17	18	19
Ans	C	B	B	C	D	C	A	B	D	D	D	D	A
Qu	20	21	22	23	24	25	26	27	28	29	30	31	
Ans	C	C	B	B	C	C	D	A	B	D	B	C	



D



D



12	D
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9	C	Charles's Law
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21

B

The radius of the path followed by an ion is different for each isotope.



10

A

energy is conserved.

AO1



27

A

 $2.2 \times 10^{-13} \text{ m}$

AO1



01.1	<u>Award each mark independently</u> Lepton number not conserved therefore not possible✓ Lepton numbers for particles correct ✓ Eg $0 = 1 -1 -1$ (for lepton number) OR $0 = 0 -1 +0$ (for muon lepton number)	Any incorrect quantum number equation (for Q, B or S) loses MP2. Alternative for MP2 reference to missing <u>muon neutrino</u> in order to balance/conserves (muon) lepton number.	2	2× AO1a
01.2	up anti-up AND down anti-down✓	Either order Credit symbols But do not condone any use of capital letter	1	AO1a
01.3	Identification of quarks in either neutral kaon correct, ie kaon $d \bar{s}$ OR anti-kaon $\bar{d} s$ ✓ Identification of quarks in other kaon correct, with statement that they are not the same. ✓	Alternative: Kaon has strangeness +1✓ Anti-kaon has strangeness -1 and is therefore not the same.✓ Allow max 1 if - quark configurations wrong way round. - value of strangeness is wrong way round - statement that strangeness is different without reference to value. - strangeness and quarks given but one of them is incorrect.	2	AO1a AO1b

Question	Answers	Additional comments/Guidelines	Mark	ID details
01.4	<u>Award each mark independently</u> Links hadrons to strong nuclear force (snf) OR identifies snf as forcing holding nucleus together✓ Reason why it cannot be the kaon✓ Reason why it cannot be the muon✓ pion is the particle as it (has mass in range and) is a <u>hadron</u> (and therefore experiences snf) ✓	For MP2: kaon rest energy is not between those of electron and half that of nucleon. (values quoted from data booklet) OR (only) pion and muon have correct rest energy with no mention of kaon. For MP3: muon is a <u>lepton</u> (and does not experience snf) An incorrect statement amount a particle negates the mark for that particle. Rest energies/MeV: kaon 493.821 or 497.762 pion 139.576 or 134.972 muon 105.659 nucleon 938.257 or 939.551	4	AO3.1b
Total			9	

7

Question	Answers	Additional comments/Guidelines	Mark	ID details
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05.1	Force due to uniform <u>magnetic</u> field (is constant and always) at 90° to direction of travel ✓ Identifies this force as the centripetal force for circular/semicircular motion ✓	Reference to velocity will be taken as the velocity of the proton	2	AO1 1a ×2
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Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	(1 electron through 10 kV = 10000 eV 14 MeV by 10000 eV) = 1400 (times) ✓		1	AO2 1f × 1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	$F = Bev$ AND $F = m_p v^2 / R$ ✓ Equates forces giving $v = eBR / m_p$ ✓ $E_k = \frac{1}{2} m_p v^2 = \frac{1}{2} m_p (eBR / m_p)^2$ ✓ $E_k = e^2 B^2 R^2 / 2 m_p$	1st mark for either or both 2nd mark for expression for v 3rd mark for substituting in $\frac{1}{2} m_p v^2$ Condone use of Q or q for e	3	AO2 1d ×3

Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Uses $= \frac{e^2 B^2 R^2}{2m_p}$ to calculate E_k for any one cyclotron in J or eV ✓ Calculates E_k for 3 cyclotrons or argues that as X is just OK, Y will be greater and Z will be less than 11 MeV ✓ <u>So</u> reasoned choice of X ✓ cost/11.7^{1.5} = £2.3 million/10^{1.5} cost = £2.9 million ✓	For X $E_k = \frac{(1.6 \times 10^{-19})^2 \times 1.3^2 \times 0.38^2}{2 \times 1.67 \times 10^{-27}}$ = 1.87×10^{-12} J or 11.7 MeV For Y $E_k = 2.32 \times 10^{-12}$ J or 14.5 MeV or Y must have higher energy because BR and hence $B^2 R^2$ must be greater For Z $E_k = 6.89 \times 10^{-13}$ J 4.3 MeV or by inspection $B^2 R^2$ will be too low to give 11 MeV Or other appropriate method	4	AO2 1h ×1 AO3 1a ×3
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
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