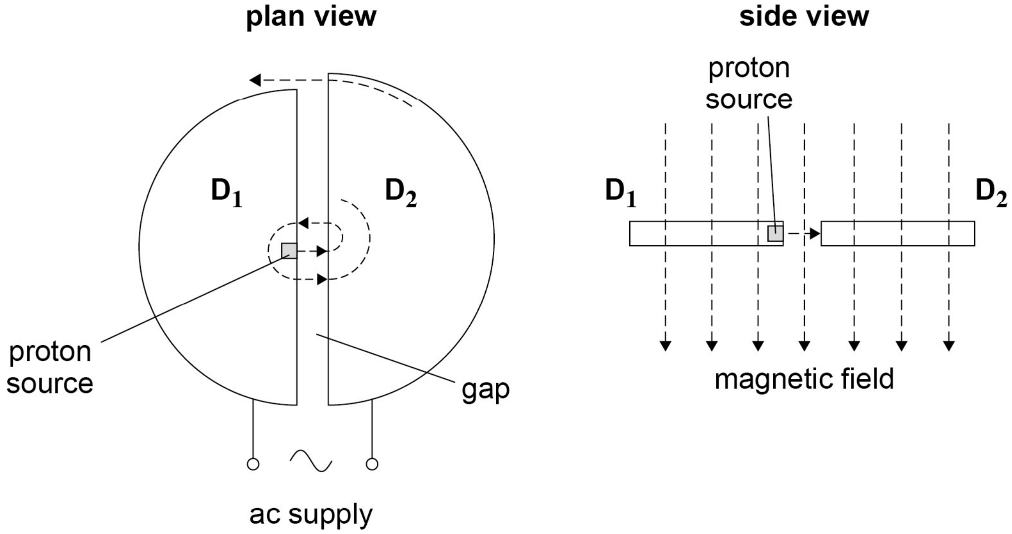
Do not write outside the box

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' $\mathbf{D_1}$ and $\mathbf{D_2}$. 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]

____

____

____

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Question 5 continues on the next page

Turn over ►

Do not write outside the box

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]

Do not write outside the box

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 = ____________________

10

Turn over ►

Do not write outside the box

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

$$^{3}_{2}\mathrm{He} + ^{17}_{8}\mathrm{O} \rightarrow ^{20}_{10}\mathrm{Ne}$$

Table 2 gives data for these nuclei.

Table 2

Nucleus	**Mass / u**
$^{3}_{2}\mathrm{He}$	3.01603
$^{17}_{8}\mathrm{O}$	16.99913
$^{20}_{10}\mathrm{Ne}$	19.99244

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

[2 marks]

energy released = ____________________ J

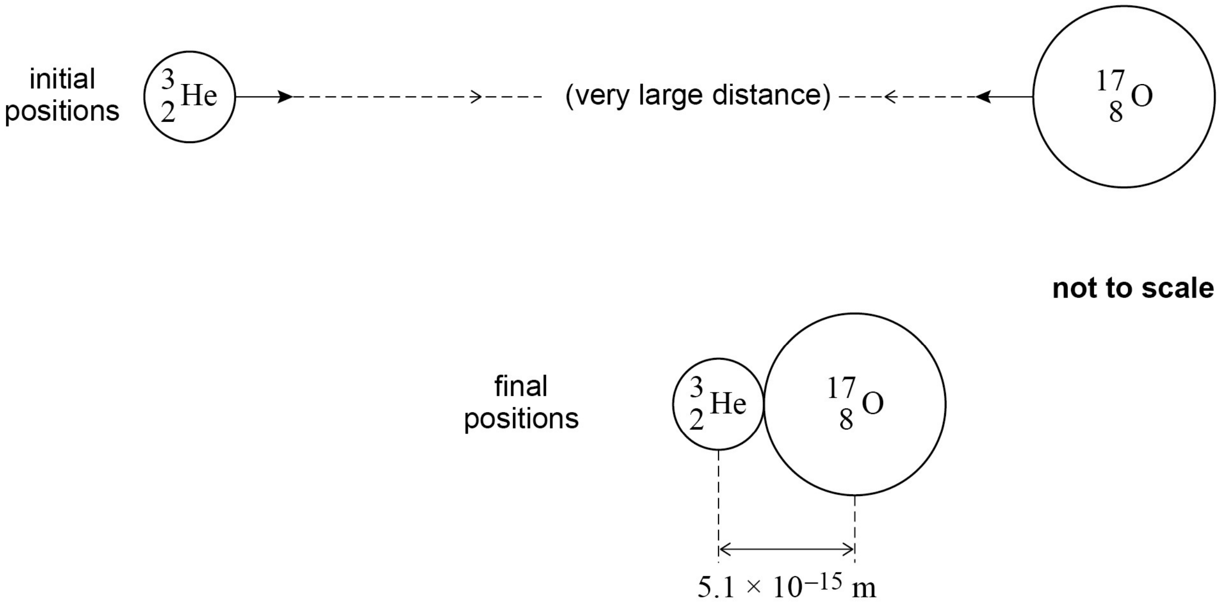
Do not write outside the box

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 5.1×10^{-15} 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

Do not write outside the box

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 $^{3}_{2}\text{He}$.

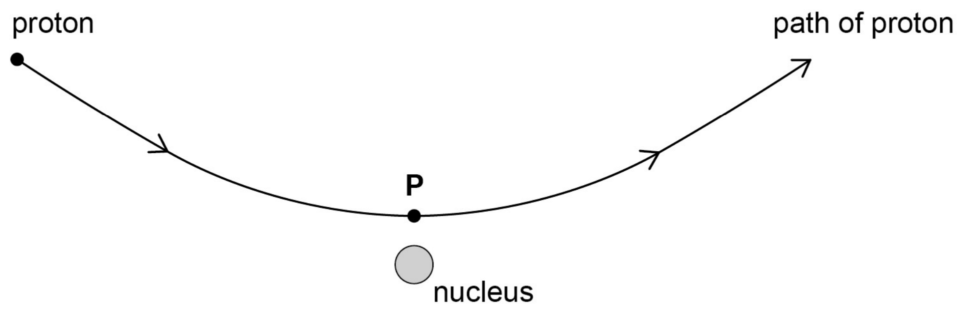
[3 marks]

9

END OF SECTION A

Do not write outside the box

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]

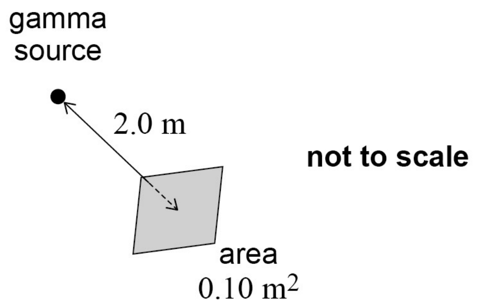
A Its rate of change of momentum is at a minimum.

B Its kinetic energy is at a minimum.

C Its potential energy is at a maximum.

D Its acceleration is at a maximum.

2 7 The diagram shows an area of 0.10 m^2 normal to a line connecting it to a point source of gamma radiation. The source emits photons uniformly in all directions.
The area and the source are separated by a distance of 2.0 m.



The source emits 5000 gamma photons per second.

How many photons pass through the area every second?

[1 mark]

A 500

B 250

C 10

D 2.5

Do not write outside the box

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

What is the maximum power output of the reactor?

[1 mark]

A 2.3×10^{8} W ⬭

B 1.4×10^{11} W ⬭

C 8.1×10^{11} W ⬭

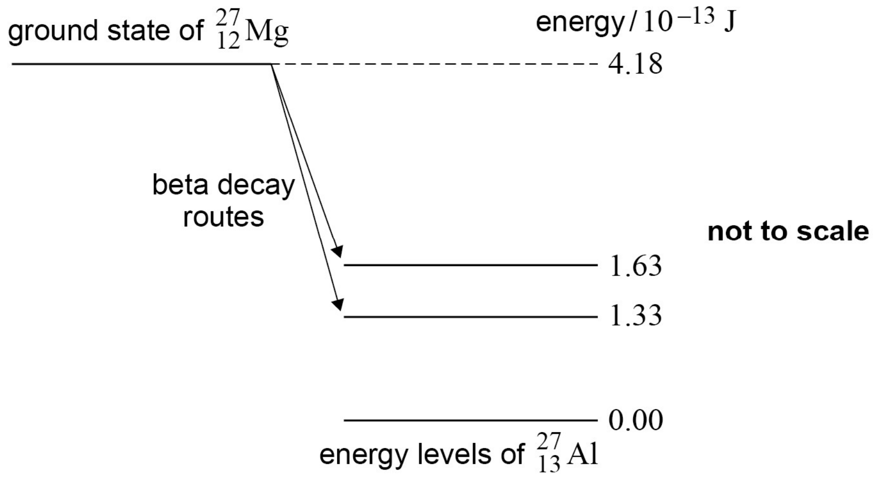
D 2.9×10^{15} W ⬭

Turn over for the next question

Do not write outside the box

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 ⬭

25

END OF QUESTIONS