16

(a) Inside the fuel rods of a certain nuclear reactor, uranium-235 undergoes *neutron-induced fission*. This is stimulated by *thermal neutrons* which have entered the fuel rod. Explain what is meant by neutron-induced fission and thermal neutrons.

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....[4]

(b) A $^{235}_{92}U$ nucleus undergoes the following reaction

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{146}_{57}La + ^{87}_{35}Br + 3^{1}_{0}n + \text{energy.}$$

The nucleus of $^{235}_{92}U$ has a binding energy of 1770 MeV. The binding energies of nuclei of $^{146}_{57}La$ and $^{87}_{35}Br$ are respectively 1210 MeV and 760 MeV.

Show that the energy released in this fission process is 3.20×10^{-11} J.

[3]

(c) Each fuel rod contains 4.20 kg of fuel. 3.00% of this mass is uranium-235.

(i) Show that the number of uranium-235 atoms in each fuel rod is about 3×10^{23}.

[2]

(ii) Calculate the total amount of energy available from this fuel rod.

energy = ... J [1]

(iii) Half of this energy is released in 3.00 years. Calculate the mean power generated by this fuel rod during this period.

1 year = 3.16×10^7 s

power = ... W [2]

[Total: 12]

17 This is a question about nuclear fusion.

(b) The following series of reactions occur inside the Sun.

(i) Two hydrogen-1 nuclei fuse to produce a hydrogen-2 (deuterium) nucleus and a positron.

(ii) The hydrogen-2 nucleus fuses with another hydrogen-1 nucleus to produce helium-3.

(iii) Two helium-3 nuclei then fuse to give helium-4 and two hydrogen-1 nuclei.

Write nuclear equations to represent these reactions.

(i) ....[1]

(ii) ....[1]

(iii) ....[1]

(c) Use your answers to **(i)**, **(ii)** and **(iii)** to deduce an equation which summarises the fusion of hydrogen-1 nuclei to form a helium-4 nucleus.

....

....

....

....

....

....

....[2]

[Total: 12]

18

(a) There are six quarks. In the list below, the first two have been named.
Complete the list by naming the remaining **four**.

1. up
2. down
3. ....
4. ....
5. ....
6. ....

[2]

(b) State the quark composition of

the neutron ....[1]

the proton ....[1]

(c) **(i)** Distinguish between the two types of β-decay.

....

....[1]

(ii) Nitrogen-14 ($^{14}_{7}N$) can be formed as a result of two β-decay reactions.

1. β-decay of carbon-14 ($^{14}_{6}C$)

2. β-decay of oxygen-14 ($^{14}_{8}O$)

Write nuclear equations for these two reactions.

1. ....

....

2. ....

....

[2]

(iii) In each of the reactions in **(ii)**, state the name of the other particle which is produced.

1. ....

2. ....

[2]

(iv) Show that reaction 1 in part **(ii)** is equivalent to the decay of a neutron into a proton and an electron.

....

....

....

....

....[2]

(v) Describe the decay reaction referred to in **(iv)** in terms of quarks.

....

....[1]

[Total: 12]

19

Rhodium-45 decays to palladium-46 by emitting an electron from the nucleus. Fig. 6.1 shows the proton number, neutron number and nuclear mass for these two nuclides.

	proton number	neutron number	nuclear mass / u
rhodium (Rh)	45	60	104.905 44
palladium (Pa)	46	59	104.904 83

Fig. 6.1

The electron has a mass of 0.000 55 u.

(a) Write a nuclear equation which represents the decay process.

....

....[1]

(b) Calculate the mass difference in u for this decay process.

mass difference = ... u [2]

(c) Calculate the energy equivalent in J of this mass difference.

energy = ... J [3]

(d) Assuming that the electron gains **all** of this energy in the form of kinetic energy, calculate the speed of the electron.

speed = ... m s^{-1} [2]

(e) State **two** reasons why, in practice, the speed of the electron may be less than the value you have calculated in **(d)**.

1. ....

....

2. ....

....
[2]

[Total: 10]

20

In this question, four marks are available for the quality of written communication.

(a) Define the term *activity* as used for a sample of radioactive material. Discuss physical factors which do and do not affect the activity of the sample.

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.... [6]

(b) Uranium can change into other nuclides by two processes, *radioactive decay* and *fission*. For these processes, describe **two** similarities and **two** differences between them.

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.... [6]

Quality of Written Communication [4]

[Total: 16]

21

The radius r of a nucleus is related to its mass number A by the equation

$$r = r_0 A^{\frac{1}{3}}$$

where r_0 is a constant.

(a) On Fig. 1.1, sketch a graph of r against A.

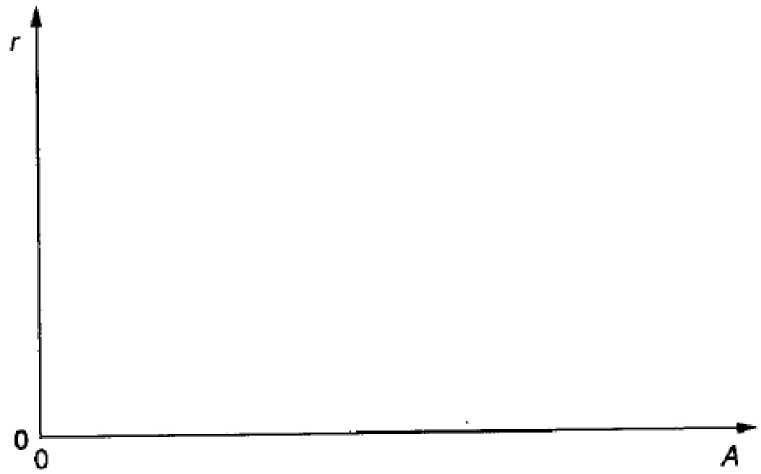

Fig. 1.1

[2]

(b) State the significance of r_0.

....

....[1]

(c) An oxygen nucleus consists of 8 protons and 8 neutrons. Its radius is 3.53×10^{-15} m.

Show that r_0 is 1.4×10^{-15} m.

[1]

(d) A gold nucleus consists of 79 protons and 118 neutrons.

Calculate the radius of the gold nucleus.

radius = ... m [2]

(e) **(i)** Estimate the volume of a hydrogen nucleus.

volume = ... m^3 [2]

(ii) Briefly discuss whether the volume of an oxygen nucleus is exactly 16 times as great as the volume of a hydrogen nucleus. You may assume that the radii of the proton and the neutron are the same.

....

....

....[2]

[Total: 10]

22

(a) Natural uranium consists of a mixture of the isotopes uranium-238 and uranium-235.

State **one** similarity and **one** difference between a $^{238}_{92}U$ nucleus and a $^{235}_{92}U$ nucleus.

similarity ....

....

difference ....

....

[2]

(b) Both $^{238}_{92}U$ and $^{235}_{92}U$ nuclei can absorb a neutron. For each type of nucleus, write an equation which represents the reaction.

Reaction 1

$^{238}_{92}U$ ....

....

Reaction 2

$^{235}_{92}U$ ....

....
[2]

(c) The product of Reaction 1 undergoes a β^- decay to form a neptunium (Np) nucleus. The Np nucleus then undergoes a further β^- decay to form a plutonium (Pu) nucleus.

(i) Write nuclear equations to represent these two decays.

....

....

....

....[2]

(ii) Name the other particle which is emitted at the same time as a β^- particle.

....[1]

(d) The product of Reaction 2 undergoes a fission reaction.

(i) What are the products of a fission reaction?

....

....[2]

(ii) Fig. 2.1 shows the variation with mass number of the relative yield of fission products.

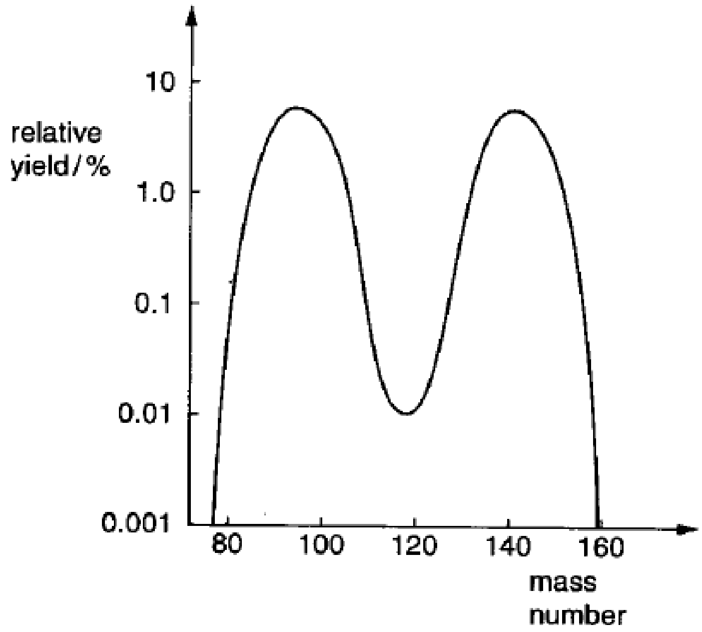

Fig. 2.1

State the approximate percentage of fissile nuclei which split into *equal* parts.

percentage = ...% [1]

(iii) Explain why the graph is symmetrical.

....

....

....[2]

[Total: 12]

23

This question is about hadrons.

(a) **(i)** Name the force that holds together the hadrons in a nucleus.

....[1]

(ii) On Fig. 5.1, sketch a graph to show how this force varies with the distance between two nucleons. Label the axes to show where the force is attractive and where it is repulsive.

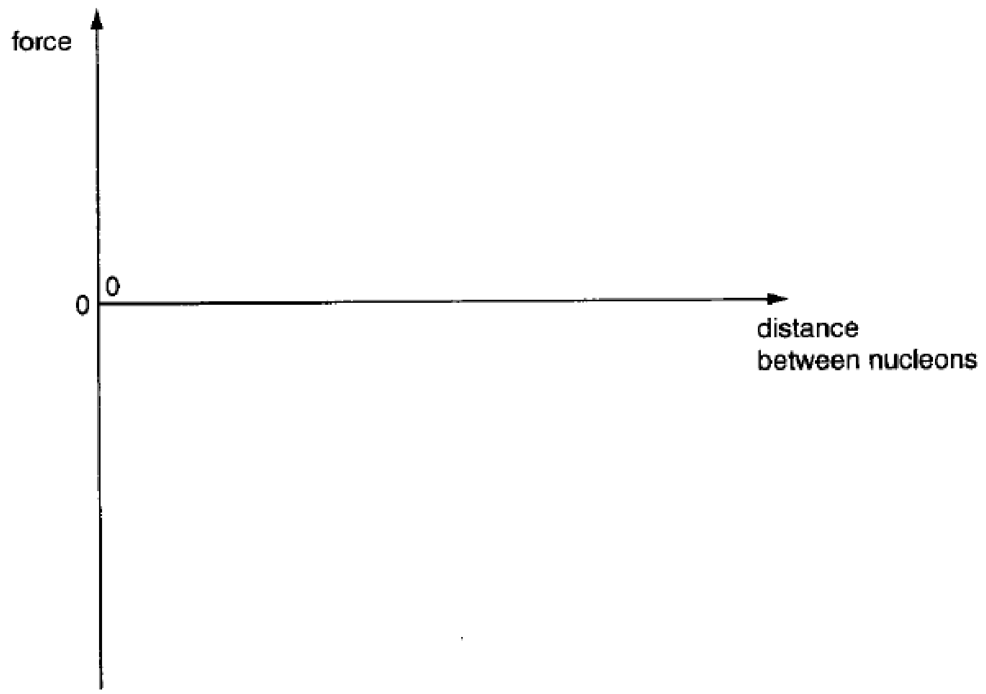

Fig. 5.1

[3]

(c) Two other kinds of hadron are the π^0 and π^- particles. Each of these has a baryon number of zero and strangeness of zero. By writing number equations for the values of charge, baryon number and strangeness, explain whether the reaction

$$\pi^- + p^+ \rightarrow n^0 + \pi^0$$

may take place.

....

....

....

....

....

....[4]

[Total: 13]

24

(a) The radioactive nuclide $^{238}_{92}U$ decays by alpha-particle emission. The newly formed nuclide X is also unstable and decays by a different radioactive emission to a third nuclide Y. Y then decays to become another isotope of uranium, $^{234}_{92}U$.

(i) Explain the meaning of the term *isotope*.

....

.... [1]

(ii) Write down suitable symbols in the form $^{238}_{92}U$ for

an α-particle ....

a β-particle .... [2]

(iii) Show how $^{238}_{92}U$ can become the isotope $^{234}_{92}U$ after three decays.

[3]

(b) **(i)** The radioactive decay law can be written in the form

$$N = N_0 e^{-\lambda t}.$$

Explain the meaning of each of the following symbols.

N ....

N_0 ....

λ ....

.... [3]

(ii) The uranium isotope $^{235}_{92}U$ was present at the formation of the Earth. Since then, the nuclei of this isotope have been decaying according to the decay law.

Calculate the fraction *f* of the original quantity of $^{235}_{92}U$ which remains on the Earth today.

half-life of $^{235}_{92}U = 7.1 \times 10^8$ y

age of the Earth = 4.6×10^9 y

f = ... [3]

[Total: 12]

25

Fig. 1.1 shows how the strong interaction (strong force) between two neutrons varies with the distance between their centres.

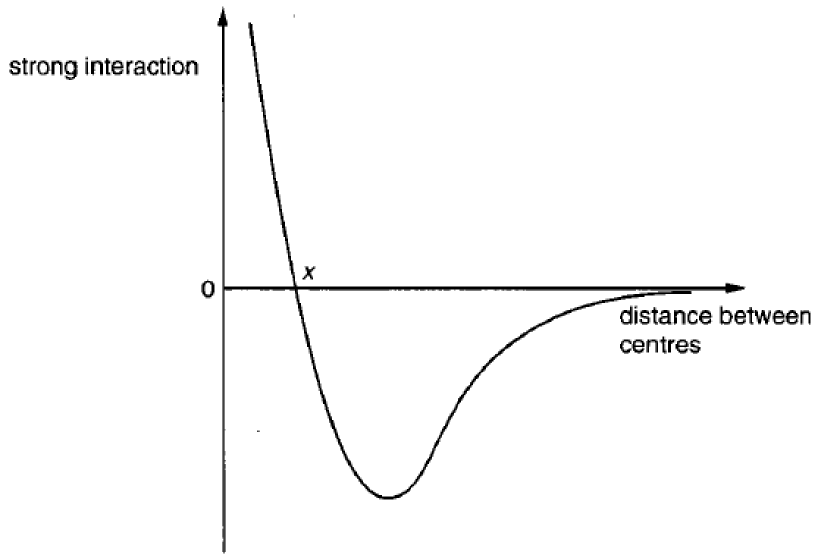

Fig. 1.1

(a) Explain why *x* indicates the equilibrium separation of two neutrons in a nucleus.

....

....[1]

(b) For two **neutrons**, $x = 0.82 \times 10^{-15}$ m.
For two **protons** at a separation of 0.82×10^{-15} m, calculate the electrostatic force between them.

force = ... N [3]

(c) **(i)** On Fig. 1.1, label a point P which indicates a possible equilibrium separation for two **protons**. Explain your reasoning.

....

....

....

....

....[4]

(ii) Estimate the size of the strong force for two **protons** at their equilibrium separation. Give a reason for your answer.

....

....

....

....[2]

[Total: **10**]

26

(a) Describe the mechanism of nuclear fission that occurs inside a nuclear reactor. Your description should make clear how the fission process is caused and how a chain reaction occurs. Use nuclear equations to illustrate the processes you are describing.

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....[6]

27

This question is about the properties of particles in a plasma.

(a) The total kinetic energy E_k of the particles in a plasma at temperature T is

$$E_k = 2.1 \times 10^{-23} nT$$

where n is the number of particles in the plasma.

(i) Calculate the kinetic energy of one particle of a plasma at 3.0×10^8 K.

kinetic energy = ... J [1]

(ii) State with a reason whether the value you have calculated in **(i)** represents the kinetic energy of every particle of the plasma.

....

....

....[1]

(b) Two deuterium nuclei (^2_1H) move with equal speeds towards each other along the same straight line until they come to rest.

Fig. 3.1

(i) Explain why each nucleus decelerates.

....

....

....[2]

(ii) On the axes of Fig. 3.2, sketch a graph which shows how the velocity *v* of one of these nuclei varies with time *t* during its deceleration.

Fig. 3.2 [2]

(iii) Each of the two nuclei has the kinetic energy calculated in **(a)(i)**. When they come to rest their total potential energy is about 1.3×10^{-14} J.
Explain why.

....

....

....[2]

(iv) The electric potential energy E_P of two particles carrying charges Q_1 and Q_2 at separation r is given by

$$E_P = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}.$$

Calculate the separation of the deuterium nuclei when they come to rest.

separation = ... m **[2]**

(c) When two deuterium nuclei fuse, the products are a helium-3 nucleus ($^3_2$He) and a neutron. Write a nuclear equation for this reaction.

[1]

[Total: 11]

28 The atomic masses of five nuclides in unified atomic mass units, u, are plotted against proton number in Fig. 6.1. The arrows indicate the direction of nuclear decay processes.

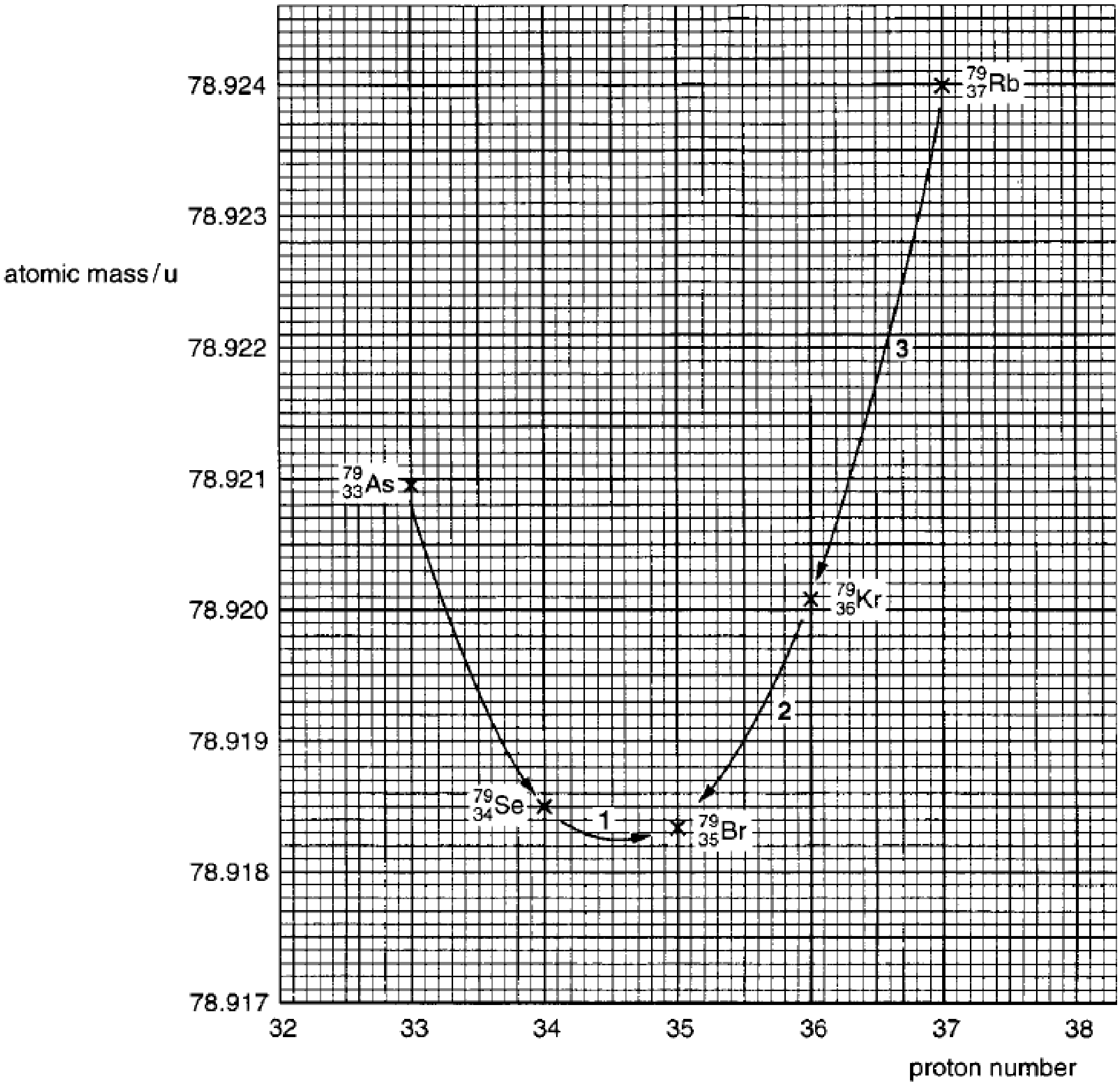

Fig. 6.1

(a) Complete Fig. 6.2 to show the numbers of protons and neutrons in the nuclei of $^{79}_{34}Se$, $^{79}_{35}Br$ and $^{79}_{36}Kr$.

	number of protons	number of neutrons
$^{79}_{34}Se$	....	....
$^{79}_{35}Br$	....	....
$^{79}_{36}Kr$	....	....

Fig. 6.2 [1]

(b) Name the particles which are emitted in the decay processes labelled **1** and **2** on Fig. 6.1.

1 ....

2 ....[2]

(c) **(i)** Write an equation to represent the decay process labelled **3** on Fig. 6.1.

[2]

(ii) State the kind of nuclear force which is responsible for this decay process.

....[1]

(iii) Use Fig. 6.1 to determine the loss of mass in the decay process referred to in **(i)**.

mass = ... u [1]

(iv) Hence calculate the energy in joules released in this decay process.

energy = ... J [3]

(v) Explain why the $^{79}_{36}Kr$ nucleus has only a small fraction of the kinetic energy released in this decay process.

....

....

....[2]

[Total: 12]

29

(a) Explain what is meant by *nuclear fission*.

....

.... [1]

(b) A possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{98}_{*}Sr + ^{*}_{54}Xe + 2^{1}_{0}n$$

(i) The two asterisks (*) represent two numbers missing from the right hand side of the nuclear reaction.

Write down the missing nucleon (atomic mass) number ....

and the missing proton (atomic) number .... [2]

(ii) The total mass of the compound nucleus $^{236}_{92}U$ before fission is 236.053 u. The total mass of the fission products is 235.840 u. Show that the energy released in the fission process is about 3×10^{-11} J.

[3]

(c) Suppose that 0.001 kg of uranium-235 could be persuaded to fission completely.

(i) Show that the energy released would be about 8×10^{10} J.

[2]

(ii) Estimate the mass of water that the released energy could raise from 20 °C to its normal boiling point.

specific heat capacity of water = 4200 J $kg^{-1} K^{-1}$

mass = ... kg [3]

[Total: 11]

30

(a) The charge and mass of each of the three types of ionising radiations emitted by radioactive substances can be given in terms of the fundamental charge e and the mass m_e of an electron or the mass m_p of a proton. Using these symbols, complete the table below.

radiation	charge	mass
α		
β		
γ		

[3]

(b) Alpha particles do not penetrate more than a few centimetres of air. Fig. 6.1 shows how the mean range of alpha particles depends on their kinetic energy at emission.

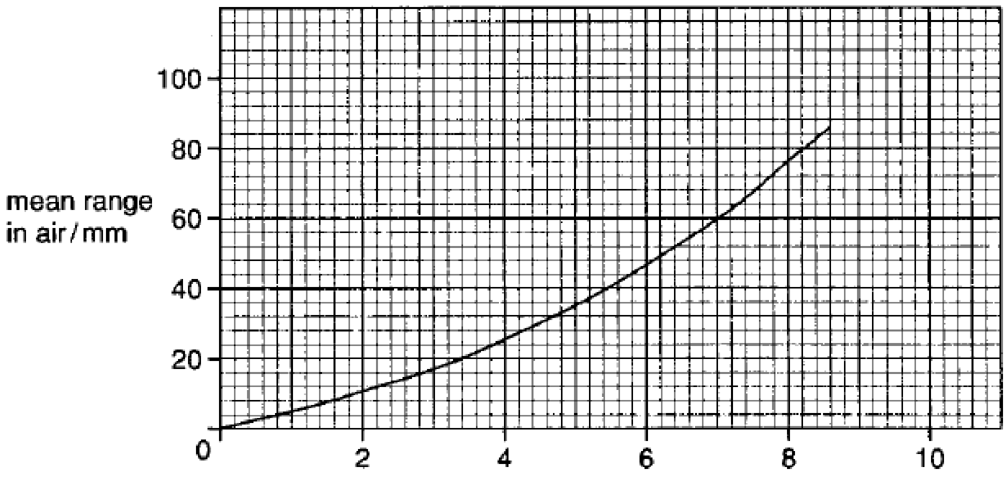

Fig. 6.1

(i) Use the graph to find the range of alpha particles emitted with an energy of 5.0 MeV.

range = ... mm **[1]**

(ii) Calculate the initial speed of a 5 MeV alpha particle.

1 MeV = 1.6×10^{-13} J

speed = ... m s^{-1} **[3]**

(iii) Explain how alpha particles lose kinetic energy as they travel through the air.

....

....

....

.... [2]