For Examiner's Use

1 An α-particle and a β-particle are both travelling along the same path at a speed of $1.5 \times 10^6\,\mathrm{m\,s^{-1}}$.

They then enter a region of uniform magnetic field as shown in Fig. 5.1.

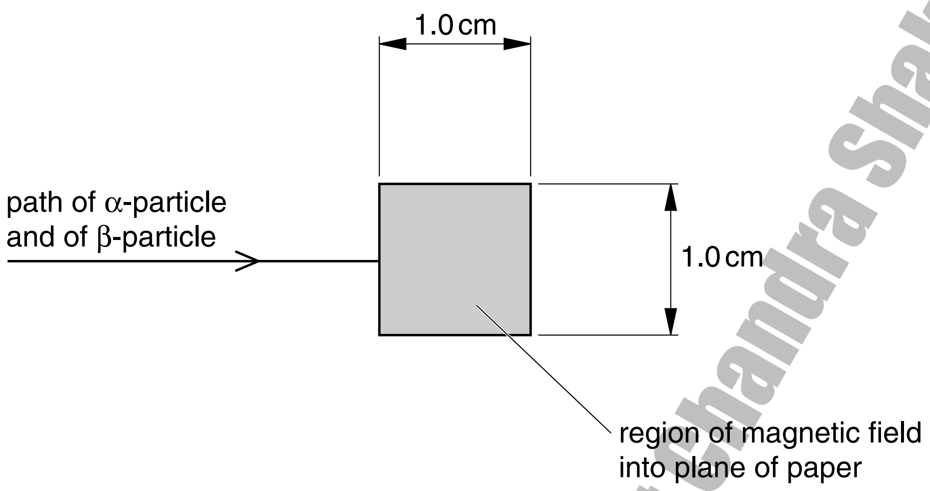


Fig. 5.1

The magnetic field is normal to the path of the particles and is into the plane of the paper.

(a) Show that, for a particle of mass m and charge q travelling at speed v normal to a magnetic field of flux density B, the radius r of its path in the field is given by

$$r = \frac{mv}{Bq}.$$

[3]

(b) Calculate the ratio

$$\frac{\text{radius of path of the } \alpha\text{-particle}}{\text{radius of path of the } \beta\text{-particle}}.$$

ratio = ……………………………………. [3]

(c) The magnetic field has flux density 1.2 mT. Calculate the radius of the path of

(i) the α-particle,

radius = …………………………….. m

(ii) the β-particle.

radius = ……………………………... m
[3]

(d) The magnetic field extends over a region having a square cross-section of side 1.0 cm (see Fig. 5.1). Both particles emerge from the region of the field.

On Fig. 5.1,

(i) mark with the letter **A** the position where the emergent α-particle may be detected,

(ii) mark with the letter **B** the position where the emergent β-particle may be detected.
[3]

2 Fig. 8.1 shows the variation with nucleon number of the binding energy per nucleon of a nucleus.

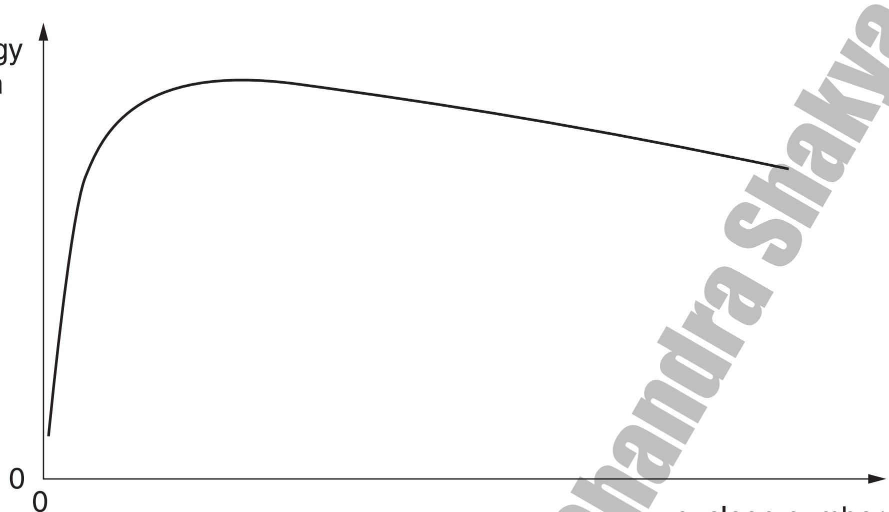


Fig. 8.1

(a) On Fig. 8.1, mark with the letter S the position of the nucleus with the greatest stability. [1]

(b) One possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2^{1}_{0}n.$$

(i) On Fig. 8.1, mark possible positions for

1. the Uranium-235 ($^{235}_{92}U$) nucleus (label this position U),

2. the Krypton-90 ($^{90}_{36}Kr$) nucleus (label this position Kr). [1]

(ii) The binding energy per nucleon of each nucleus is as follows.

$^{235}_{92}U$: 1.2191×10^{-12} J

$^{144}_{56}Ba$: 1.3341×10^{-12} J

$^{90}_{36}Kr$: 1.3864×10^{-12} J

Use these data to calculate

1. the energy release in this fission reaction (give your answer to three significant figures),

energy = ... J [3]

2. the mass equivalent of this energy.

mass = ... kg [2]

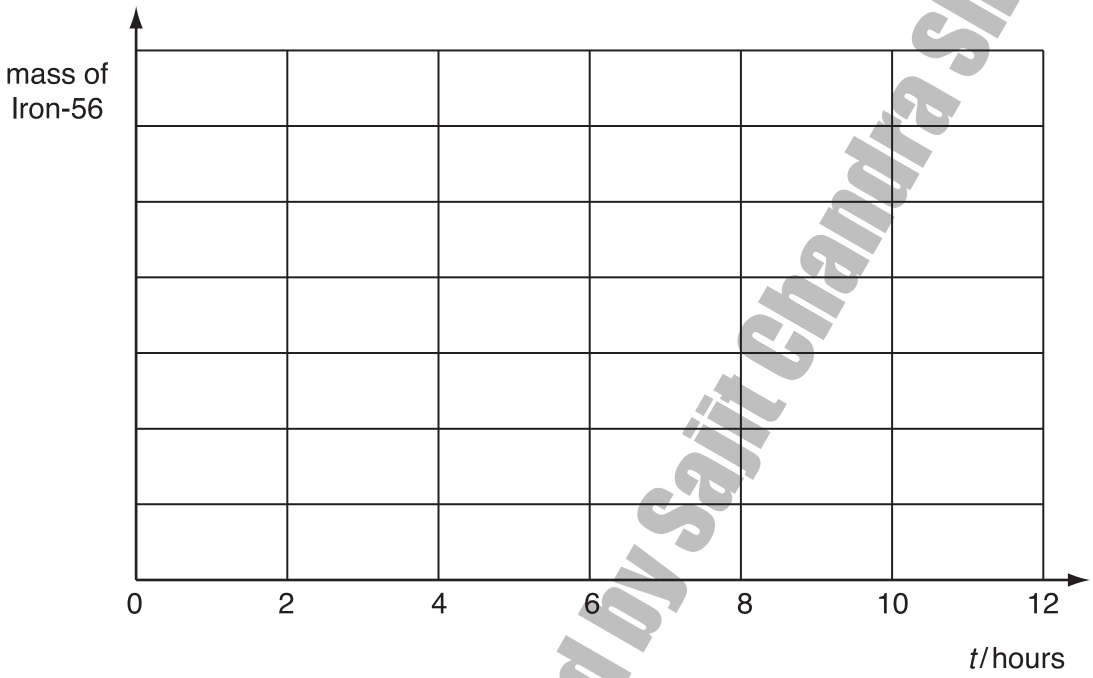
(iii) Suggest why the neutrons were not included in your calculation in **(ii)**.

....

.... [1]

3 The isotope Manganese-56 decays and undergoes β-particle emission to form the stable isotope Iron-56. The half-life for this decay is 2.6 hours.
Initially, at time t = 0, a sample of Manganese-56 has a mass of 1.4 μg and there is no Iron-56.

(a) Complete Fig. 7.1 to show the variation with time t of the mass of Iron-56 in the sample for time t = 0 to time t = 11 hours.



[2]

Fig. 7.1

(b) For the sample of Manganese-56, determine

(i) the initial number of Manganese-56 atoms in the sample,

number = ...[2]

(ii) the initial activity.

activity = ... Bq [3]

(c) Determine the time at which the ratio

$$\frac{\text{mass of Iron-56}}{\text{mass of Manganese-56}}$$

is equal to 9.0.

time = ... hours [2]

For Examiner's Use

4 **(a)** Define the *decay constant* of a radioactive isotope.

....

....

.... [2]

(b) Strontium-90 is a radioactive isotope having a half-life of 28.0 years. Strontium-90 has a density of $2.54\,g\,cm^{-3}$.

A sample of Strontium-90 has an activity of 6.4×10^{9} Bq. Calculate

(i) the decay constant λ, in s^{-1}, of Strontium-90,

λ = ... s^{-1} [2]

(ii) the mass of Strontium-90 in the sample,

mass = ... g [4]

(iii) the volume of the sample.

volume = ... cm^3 [1]

(c) By reference to your answer in **(b)(iii)**, suggest why dust that has been contaminated with Strontium-90 presents a serious health hazard.

....

....

.... [2]

For Examiner's Use

5 A positron ($^{0}_{+1}e$) is a particle that has the same mass as an electron and has a charge of $+1.6 \times 10^{-19}$ C.
A positron will interact with an electron to form two γ-ray photons.

$$^{0}_{+1}e + ^{0}_{-1}e \rightarrow 2\gamma$$

Assuming that the kinetic energy of the positron and the electron is negligible when they interact,

(a) suggest why the two photons will move off in opposite directions with equal energies,

....

....

....

....

....

.... [3]

(b) calculate the energy, in MeV, of one of the γ-ray photons.

energy = ... MeV [3]

6 **(a)** A sample of a radioactive isotope contains N nuclei at time t. At time $(t + \Delta t)$, it contains $(N - \Delta N)$ nuclei of the isotope.

For the period Δt, state, in terms of N, ΔN and Δt,

(i) the mean activity of the sample,

activity = ... [1]

(ii) the probability of decay of a nucleus.

probability = ... [1]

(b) A cobalt-60 source having a half-life of 5.27 years is calibrated and found to have an activity of 3.50×10^5 Bq. The uncertainty in the calibration is ±2%.

Calculate the length of time, in days, after the calibration has been made, for the stated activity of 3.50×10^5 Bq to have a maximum possible error of 10%.

time = ... days [4]

For Examiner's Use

7 **(a)** Define the term radioactive *decay constant*.

....

....

....[2]

(b) State the relation between the activity A of a sample of a radioactive isotope containing N atoms and the decay constant λ of the isotope.

....[1]

(c) Radon is a radioactive gas with half-life 56 s. For health reasons, the maximum permissible level of radon in air in a building is set at 1 radon atom for every 1.5×10^{21} molecules of air. 1 mol of air in the building is contained in $0.024\,m^3$.

Calculate, for this building,

(i) the number of molecules of air in $1.0\,m^3$,

number = ...

(ii) the maximum permissible number of radon atoms in $1.0\,m^3$ of air,

number = ...

(iii) the maximum permissible activity of radon per cubic metre of air.

activity = ... Bq
[5]

8 The isotopes Radium-224 ($^{224}_{88}Ra$) and Radium-226 ($^{226}_{88}Ra$) both undergo spontaneous α-particle decay. The energy of the α-particles emitted from Radium-224 is 5.68 MeV and from Radium-226, 4.78 MeV.

(a) **(i)** State what is meant by the *decay constant* of a radioactive nucleus.

....

....

....[2]

(ii) Suggest, with a reason, which of the two isotopes has the larger decay constant.

....

....

....

....[3]

(b) Radium-224 has a half-life of 3.6 days.

(i) Calculate the decay constant of Radium-224, stating the unit in which it is measured.

decay constant = ...[2]

(ii) Determine the activity of a sample of Radium-224 of mass 2.24 mg .

activity = ... Bq [4]

For Examiner's Use

(c) Calculate the number of half-lives that must elapse before the activity of a sample of a radioactive isotope is reduced to one tenth of its initial value.

number of half-lives = ...[2]

9 Fig. 7.1 illustrates the variation with nucleon number A of the binding energy per nucleon E of nuclei.

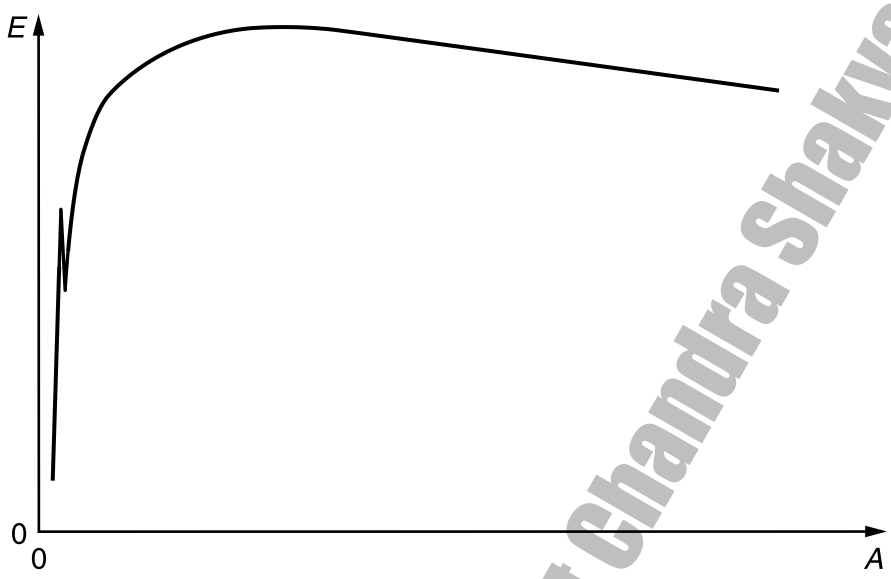


Fig. 7.1

(a) **(i)** Explain what is meant by the *binding energy* of a nucleus.

....

....

.... [2]

(ii) On Fig. 7.1, mark with the letter S the region of the graph representing nuclei having the greatest stability. [1]

(b) Uranium-235 may undergo fission when bombarded by a neutron to produce Xenon-142 and Strontium-90 as shown below.

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{142}_{54}\text{Xe} + {}^{90}_{38}\text{Sr} + \text{neutrons}$$

(i) Determine the number of neutrons produced in this fission reaction.

number = ... [1]

(ii) Data for binding energies per nucleon are given in Fig. 7.2.

isotope	binding energy per nucleon / MeV
Uranium-235	7.59
Xenon-142	8.37
Strontium-90	8.72

Fig. 7.2

Calculate

1. the energy, in MeV, released in this fission reaction,

energy = ………………………… MeV [3]

2. the mass equivalent of this energy.

mass = …………………………….. kg [3]

10 Uranium-234 is radioactive and emits α-particles at what appears to be a constant rate.

A sample of Uranium-234 of mass 2.65 μg is found to have an activity of 604 Bq.

(a) Calculate, for this sample of Uranium-234,

(i) the number of nuclei,

number = ... [2]

(ii) the decay constant,

decay constant = ... s^{-1} [2]

(iii) the half-life in years.

half-life = ... years [2]

(b) Suggest why the activity of the Uranium-234 appears to be constant.

....

.... [1]

(c) Suggest why a measurement of the mass and the activity of a radioactive isotope is not an accurate means of determining its half-life if the half-life is approximately one hour.

....

.... [1]

11 **(a)** Explain what is meant by the *binding energy* of a nucleus.

....

.... [1]

(b) Fig. 7.1 shows the variation with nucleon number (mass number) A of the binding energy per nucleon E_B of nuclei.

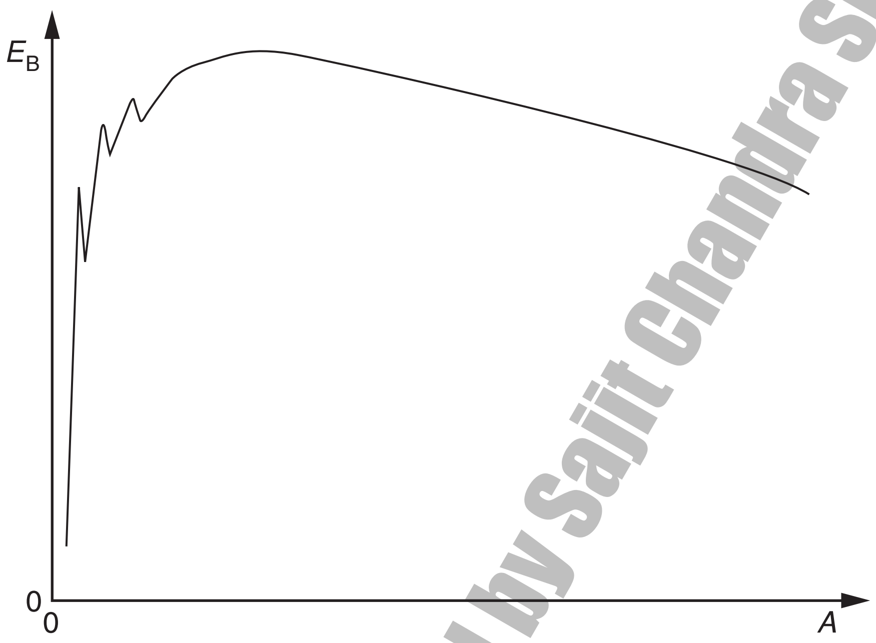


Fig. 7.1

One particular fission reaction may be represented by the nuclear equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n.$$

(i) On Fig. 7.1, label the approximate positions of

1. the uranium ($^{235}_{92}U$) nucleus with the symbol U,

2. the barium ($^{141}_{56}Ba$) nucleus with the symbol Ba,

3. the krypton ($^{92}_{36}Kr$) nucleus with the symbol Kr. [2]

(ii) The neutron that is absorbed by the uranium nucleus has very little kinetic energy. Explain why this fission reaction is energetically possible.

....

....

.... [2]

(c) Barium-141 has a half-life of 18 minutes. The half-life of Krypton-92 is 3.0 s.
In the fission reaction of a mass of Uranium-235, equal numbers of barium and krypton nuclei are produced.
Estimate the time taken after the fission of the sample of uranium for the ratio

$$\frac{\text{number of Barium-141 nuclei}}{\text{number of Krypton-92 nuclei}}$$

to be approximately equal to 8.

time = ... s [3]

12 Two deuterium ($^2_1$H) nuclei are travelling directly towards one another. When their separation is large compared with their diameters, they each have speed *v* as illustrated in Fig. 5.1.

Fig. 5.1

The diameter of a deuterium nucleus is 1.1×10^{-14} m.

(a) Use energy considerations to show that the initial speed *v* of the deuterium nuclei must be approximately $2.5 \times 10^6\,\text{m s}^{-1}$ in order that they may come into contact.
Explain your working.

[3]

(b) For a fusion reaction to occur, the deuterium nuclei must come into contact.
Assuming that deuterium behaves as an ideal gas, deduce a value for the temperature of the deuterium such that the nuclei have an r.m.s. speed equal to the speed calculated in **(a)**.

temperature = ... K [4]

(c) Comment on your answer to **(b)**.

....

....[1]

13 The controlled reaction between deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) has involved ongoing research for many years. The reaction may be summarised as

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

where Q = 17.7 MeV.

Binding energies per nucleon are shown in Fig. 8.1.

	binding energy per nucleon / MeV
$^{2}_{1}H$	1.12
$^{1}_{0}n$	–
$^{4}_{2}He$	7.07

Fig. 8.1

(a) Suggest why binding energy per nucleon for the neutron is not quoted.

....

.... [1]

(b) Calculate the mass defect, in kg, of a helium $^{4}_{2}He$ nucleus.

mass defect = ... kg [3]

(c) (i) State the name of the type of reaction illustrated by this nuclear equation.

.... [1]

(ii) Determine the binding energy per nucleon, in MeV, of tritium ($^{3}_{1}H$).

binding energy per nucleon = ... MeV [3]

For Examiner's Use

14 **(a)** State what is meant by the *decay constant* of a radioactive isotope.

....

....

.... [2]

(b) Show that the decay constant λ is related to the half-life $t_{\frac{1}{2}}$ by the expression

$$\lambda t_{\frac{1}{2}} = 0.693.$$

[3]

(c) Cobalt-60 is a radioactive isotope with a half-life of 5.26 years (1.66×10^{8} s).

A cobalt-60 source for use in a school laboratory has an activity of 1.8×10^{5} Bq.

Calculate the mass of cobalt-60 in the source.

mass = ... g [3]

15 Americium-241 is an artificially produced radioactive element that emits α-particles. A sample of americium-241 of mass 5.1 μg is found to have an activity of 5.9×10^5 Bq.

For Examiner's Use

(a) Determine, for this sample of americium-241,

(i) the number of nuclei,

number = ... [2]

(ii) the decay constant,

decay constant = ... s^{-1} [2]

(iii) the half-life, in years.

half-life = ... years [2]

(b) Another radioactive element has a half-life of approximately 4 hours. Suggest why measurement of the mass and activity of a sample of this element is not appropriate for the determination of its half-life.

....

.... [1]

16 **(a)** Explain what is meant by the *potential energy* of a body.

For Examiner's Use

....

....

.... [2]

(b) Two deuterium ($^{2}_{1}H$) nuclei each have initial kinetic energy E_K and are initially separated by a large distance.
The nuclei may be considered to be spheres of diameter 3.8×10^{-15} m with their masses and charges concentrated at their centres.
The nuclei move from their initial positions to their final position of just touching, as illustrated in Fig. 4.1.

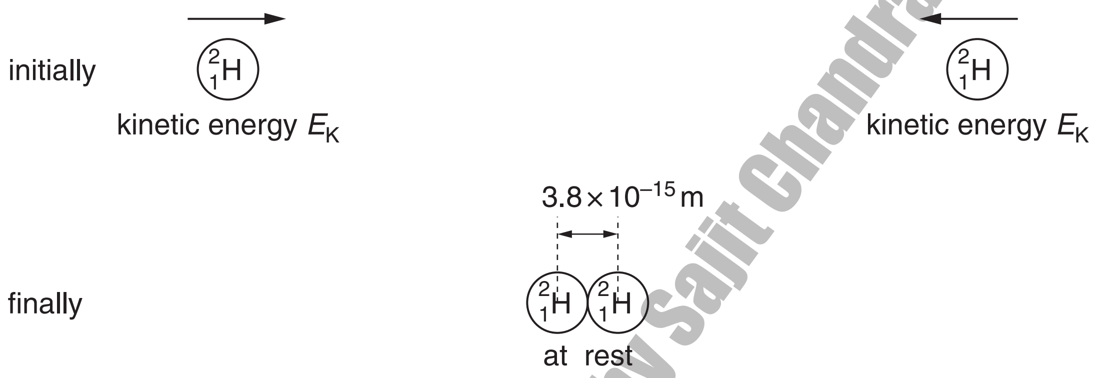


Fig. 4.1

(i) For the two nuclei approaching each other, calculate the total change in

1. gravitational potential energy,

energy = ... J [3]

2. electric potential energy.

energy = ... J [3]

For Examiner's Use

(ii) Use your answers in **(i)** to show that the initial kinetic energy E_K of each nucleus is 0.19 MeV.

[2]

(iii) The two nuclei may rebound from each other. Suggest one other effect that could happen to the two nuclei if the initial kinetic energy of each nucleus is greater than that calculated in **(ii)**.

....

.... [1]

17 A π^0 meson is a sub-atomic particle.
A stationary π^0 meson, which has mass 2.4×10^{-28} kg, decays to form two γ-ray photons.
The nuclear equation for this decay is

$$\pi^0 \rightarrow \gamma + \gamma.$$

(a) Explain why the two γ-ray photons have the same energy.

....

....

....[2]

(b) Determine, for each γ-ray photon,

(i) the energy, in joule,

energy = ... J [2]

(ii) the wavelength,

wavelength = ... m [2]

(iii) the momentum.

momentum = ... N s [2]

18 Americium-241 is an artificially produced radioactive element that emits α-particles. A sample of americium-241 of mass 5.1 μg is found to have an activity of 5.9×10^5 Bq.

(a) Determine, for this sample of americium-241,

(i) the number of nuclei,

number = ... [2]

(ii) the decay constant,

decay constant = ... s^{-1} [2]

(iii) the half-life, in years.

half-life = ... years [2]

(b) Another radioactive element has a half-life of approximately 4 hours. Suggest why measurement of the mass and activity of a sample of this element is not appropriate for the determination of its half-life.

....

.... [1]

8 In some power stations, nuclear fission is used as a source of energy.

For Examiner's Use

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

....

....

.... [2]

(b) The nuclear fission reaction produces neutrons. In the power station, the neutrons may be absorbed by rods made of boron-10.
Complete the nuclear equation for the absorption of a single neutron by a boron-10 nucleus with the emission of an α-particle.

$${}^{10}_{5}\text{B} + \ldots\ldots\ldots\ldots \rightarrow {}^{\ldots}_{3}\text{Li} + \ldots\ldots\ldots\ldots$$ [3]

(c) Suggest why, when neutrons are absorbed in the boron rods, the rods become hot as a result of this nuclear reaction.

....

....

....

.... [3]

8 **(a)** The variation with nucleon number A of the binding energy per nucleon B_E of nuclei is shown in Fig. 8.1.

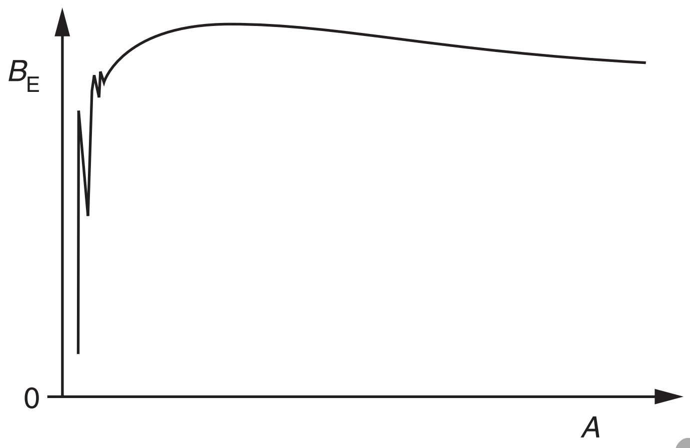


Fig. 8.1

On Fig. 8.1, mark the approximate positions of

(i) iron-56 (label this point Fe), [1]

(ii) zirconium-97 (label this point Zr), [1]

(iii) hydrogen-2 (label this point H). [1]

(b) **(i)** State what is meant by *nuclear fission*.

....

....

.... [2]

(ii) By reference to Fig. 8.1, explain how fission is energetically possible.

....

....

....

.... [2]

8 **(a)** State what is meant by the *binding energy* of a nucleus.

....

....

.... [2]

(b) Show that the energy equivalence of 1.0 u is 930 MeV.

[3]

(c) Data for the masses of some particles and nuclei are given in Fig. 8.1.

	mass / u
proton	1.0073
neutron	1.0087
deuterium ($^{2}_{1}H$)	2.0141
zirconium ($^{97}_{40}Zr$)	97.0980

Fig. 8.1

Use data from Fig. 8.1 and information from **(b)** to determine, in MeV,

(i) the binding energy of deuterium,

binding energy = ... MeV [2]

(ii) the binding energy **per nucleon** of zirconium.

For Examiner's Use

binding energy per nucleon = ... MeV [3]