H2 Physics Revision Topic : Nuclear Physics

Structured Questions Name: ______________________

1

Plutonium-239 has a half-life of 2.41×10^4 years. It decays to uranium-235 by alpha emission.

(a) **(i)** State what is meant by the half-life of plutonium-239.

....

.... [1]

(ii) A radioactive sample currently contains 6.2×10^{-9} kg of plutonium-239. Calculate the mass of plutonium-239 the sample would have contained 2000 years ago.

mass = ... kg [2]

(iii) Calculate the current activity of the sample of plutonium-239.

[3]

1 **(iv)** The count rate of the plutonium sample was measured and used to calculate its activity. The value obtained for the activity of the sample was different from the calculated value obtained in **(a)(iii)**.

Give two reasons to account for this difference.

1. ....

....

2. ....

.... [2]

(b) Data for the nuclei involved in the decay of plutonium-239 are given in Fig. 4.1.

nucleus	mass / u
α-particle $^{4}_{2}He$	4.00271
uranium-235 $^{235}_{92}U$	235.04393
plutonium-239 $^{239}_{94}Pu$	239.05216

Fig. 4.1

(i) Calculate the amount of energy released from the decay of a single plutonium-239 nucleus.

energy = ... J [3]

(ii) State two harmful effects of being exposed to the radiation from the plutonium sample.

1. ....

....

2. ....

.... [2]

1

(iii) State and explain whether a person standing 40 cm away from the plutonium sample is likely to experience harmful effects due to the radiation from the plutonium sample.

....

.... [1]

(d) Uranium-235 has a half-life of 7.04×10^8 years, decaying by alpha emission to form an isotope of thorium. The isotope of thorium has a half-life of 25.5 h, decaying by beta emission to form an isotope of protactinium.

(i) Determine the number of protons and neutrons in the protactinium nucleus formed.

number of protons = ...

number of neutrons = ...

[2]

(ii) Trace amounts of the thorium isotope can still be found in samples of uranium which are 1000 years old.

Suggest an explanation for this phenomenon.

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.... [2]

1

(e) Fig. 4.2 shows a graph of the variation with mass number of the binding energy per nucleon.

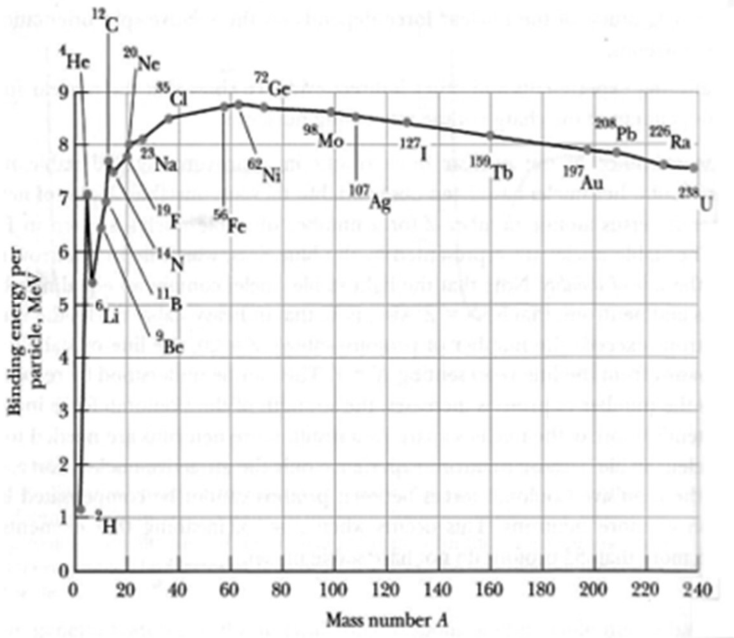

Fig. 4.2

With reference to Fig. 4.2, explain why fusion reactions of plutonium-239 and uranium-235 are not associated with a release of energy.

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.... [2]

2 **(a) (i)** Fig. 9.1 shows the path of an alpha particle as it scatters off a gold nucleus in the Rutherford's scattering experiment.

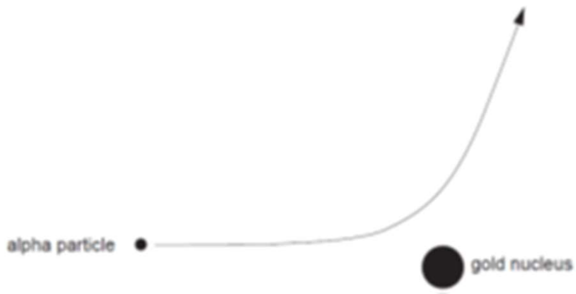

Fig. 9.1

1. Explain why the alpha particle follows the path as shown in Fig. 9.1

....

....

....[2]

2. On Fig. 9.1, sketch the path of an alpha particle with the same initial path, but less kinetic energy. [2]

(ii) The alpha particles in this experiment originated from the decay of a radioactive nuclide. Suggest two reasons why beta particles from a radioactive source would be inappropriate for this type of scattering experiment.

....

....

....[2]

(b) (i) In Fig. 9.2, an alpha particle on path **Q** has a head-on collision with a lithium nucleus $^{7}_{3}Li$.

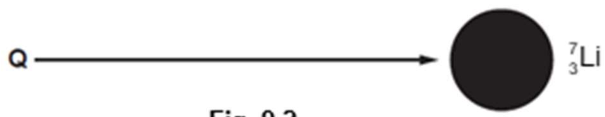

Fig. 9.2

This alpha particle gets to within a distance of 4.2 x10^{-15} m from the centre of the nucleus.

2

1. By discussing the energy changes of the alpha particle as it moves towards the centre of the nucleus, explain why it needs a **minimum** energy to get so close to the centre of the nucleus.

....

....

....[2]

2. Show that this minimum energy of the alpha particle is 3.3×10^{-13} J.

[2]

(ii) When the alpha particle gets to within 4.2×10^{-15} m of the centre of the nucleus, the following nuclear reaction takes place.

$$^{4}_{2}He + ^{7}_{3}Li \rightarrow ^{10}_{5}B + ^{1}_{0}n$$

Fig. 9.3 gives the masses of the particles involved in the nuclear reaction.

particle	mass / u
$^{4}_{2}He$	4.0015
$^{7}_{3}Li$	7.0144
$^{10}_{5}B$	10.0011
$^{1}_{0}n$	1.0087

Fig. 9.3

1. Show that there is a decrease of mass of about 1×10^{-29} kg as a result of this reaction.

[2]

2. Calculate the maximum possible energy of a neutron ejected from the target when the alpha particles in the beam have an energy of 3.3×10^{-13} J.

maximum possible energy = ...J[3]

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

....

....[1]

(ii) Fig. 9.4 shows the variation with nucleon number (mass number) A of the binding energy per nucleon E_B of nuclei.

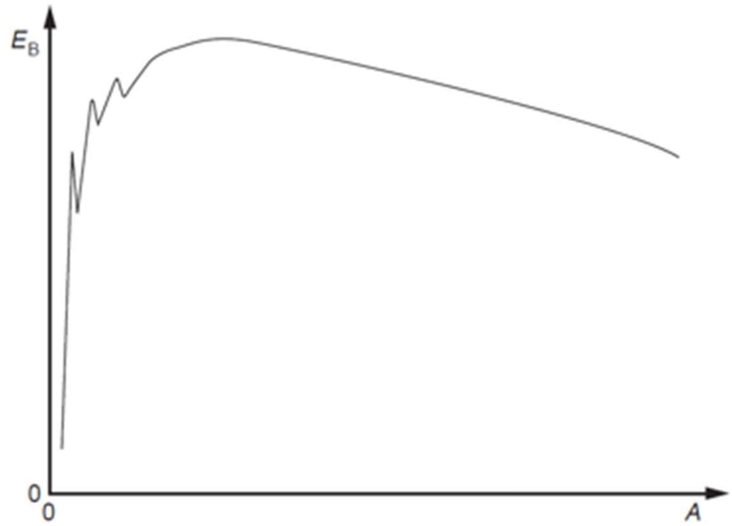

Fig. 9.4

One particular fission reaction may be represented by the nuclear equation

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

On Fig. 9.4, 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]

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

....

....

....[2]

[Total: 20]

3 **(a)** An isotope of Americium, ${}^{241}_{95}\mathrm{Am}$, has a half-life of 432.2 years. It undergoes spontaneous nuclear decay and may be represented by the equation

$${}^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\mathrm{He}$$

where Neptunium ${}^{237}_{93}\mathrm{Np}$ is a daughter nuclide.

(i) Define *half-life*.

....

.... [2]

(ii) Explain what is meant by *spontaneous decay*.

....

.... [1]

(iii) Calculate the decay constant of ${}^{241}_{95}\mathrm{Am}$.

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

(iv) Calculate the activity of 1.00 g of ${}^{241}_{95}\mathrm{Am}$.

activity = ... Bq [3]

3 **(v)** Calculate in MeV the total kinetic energy of the decay products, given the following data:

Nuclide	Atomic mass / u
$^{241}_{95}Am$	241.0568229
$^{237}_{93}Np$	237.0481673
$^{4}_{2}He$	4.0026032

total kinetic energy = …………………… MeV [3]

(b) The variation with nucleon number A of the binding energy per nucleon B_E is shown in Fig. 9.1.

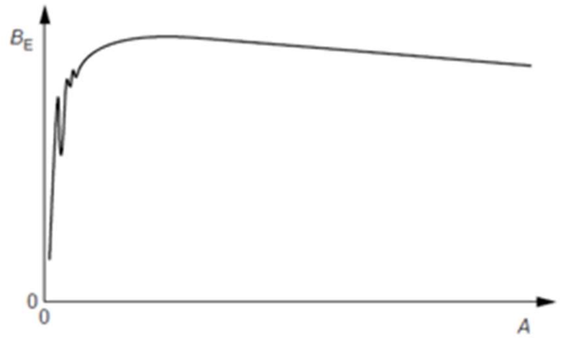

Fig. 9.1

Using Fig. 9.1, explain why fusion of nuclei having high nucleon numbers is not associated with a release of energy.

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……

……

…… [3]

3 **(c)** One possible nuclear reaction involves the bombardment of a stationary nitrogen-14 nucleus by an α-particle to form oxygen-17 and another particle.

(i) Complete the nuclear equation for this reaction.

$$^{14}_{7}\text{N} + {}^{\cdots\cdots}_{\cdots\cdots}\alpha \rightarrow {}^{17}_{8}\text{O} + \cdots\cdots\cdots\cdots$$ [2]

(ii) The total mass-energy of the nitrogen-14 nucleus and the α-particle is less than that of the particles resulting from the reaction. This mass-energy difference is 1.1 MeV.

1. Suggest how it is possible for mass-energy to be conserved in this reaction.

....

.... [1]

2. Calculate the speed of an α-particle having kinetic energy of 1.1 MeV.

speed = ... m s^{-1} [4]

4 **(a)** **(i)** Explain what is meant by *half-life*.

....

....[1]

(ii) Explain what is meant by *decay constant*.

....

....[2]

(iii) Write down the nuclear notation of a nuclide with particular reference to lithium (Li) nucleus containing 3 protons and 4 neutrons.

State the meaning of any number that you write down. [2]

(b) Naturally occurring radioactivity results in the emission of three types of ionising radiation - alpha, beta and gamma.

Distinguish between the three types in terms of their relative charges, masses and speeds.

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.... [6]

4 **(c)** In the early years of this century Mdm Curie drew an illustration similar to the Fig. 8.1 below which indicated how the three radiations travelled in air in a uniform magnetic field.

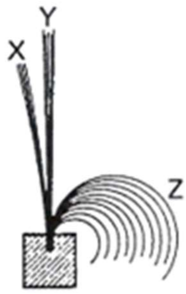

Fig. 8.1

(i) Identify the radiations X, Y and Z.

X: ....

Y: ....

Z: ....

[3]

(ii) Explain what is shown by the fact that the lines for X all have approximately the same length.

....

....[2]

(iii) Explain what is shown by the fact that the lines for Z have different curvatures?

....

....

....[2]

(iv) Give two reasons why it is difficult, if not impossible, to take a photograph which is like the figure.

1. ....

....

2. ....

....

[2]

[Total: 20]

5 **(a)** Distinguish between a *nucleon*, a *nucleus* and a *nuclide*.

....

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....

.... [3]

(b) When beryllium is bombarded with α-particles of energy 8.0×10^{-13} J, carbon atoms are produced, together with a very penetrating radiation. The nuclear reaction might be

EITHER **(1)** $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{13}_{6}C + \gamma$

OR **(2)** $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$

(i) Explain what is meant by $^{13}_{6}C$.

....

.... [1]

(ii) The energy of the penetrating radiation is found to be at least 8.8×10^{-12} J for each γ or $^{1}_{0}n$ produced. Explain whether equations **(1)** and **(2)** are valid.

nuclide	mass / u
$^{9}_{4}Be$	9.0150
$^{4}_{2}He$	4.0040
$^{13}_{6}C$	13.0075

[4]

5 **(c)** Fig. 9.1 gives the activity of Dubnium-268 measured over a period of 15 days.

Time / day	Activity / Bq
0	76 300
1	44 490
2	25 940
3	15 120
4	8 815
5	5 140
6	3 000
7	1 747
8	1 018
9	594
10	346
11	203
12	120
13	67
14	40
15	20

Fig. 9.1

(i) 1. Explain what is meant by the term decay constant.

....

.... [1]

2. State the equation relating decay constant λ to half-life $t_{\frac{1}{2}}$.

....

.... [1]

(ii) Without plotting a graph, deduce the half-life of Dubnium-268.

half-life of B = ... days [3]

5

(iii) Suggest an appropriate graph to plot to deduce the half-life of Dubnium-268 and explain how the half-life can be deduced from the graph.

....

.... [3]

(iv) Explain why it is necessary to ensure that the readings are taken at the same time each day.

....

.... [1]

(v) Explain if the following statement is accurate:

"After 14 days, the activity of Dubnium-268 is 40 Bq. After 15 days, the activity is 20 Bq. The half-life of Dubnium-268 is therefore 1 day."

....

....

....

....

....

.... [3]

[Total: 20]

6 **(a)** The Sun is a star that comprises mainly of hydrogen nuclei (protons). It derives its large radiative power from nuclear fusion. The nuclear reactions responsible for energy generation in the Sun, collectively known as the proton-proton chain reactions, are listed as follows:

I. ${}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{2}_{1}\text{H} + {}^{0}_{1}e +$ other radiations

II. ${}^{2}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} +$ energy

III. ${}^{3}_{2}\text{He} + {}^{3}_{2}\text{He} \rightarrow {}^{4}_{2}\text{He} + n\ {}^{A}_{1}\text{Y} +$ energy

where ${}^{0}_{1}e$ denotes a positron. A positron is a particle with the same mass as an electron but having a charge of $+e$.

(i) For reaction III, identify the number n and name the particle Y

n = ... [1]

Y = ... [1]

(ii) Deuterons (${}^{2}_{1}\text{H}$) are produced in reaction I. Suggest a reason why reactions II and III are observed in the formation of helium-4 instead of the following one:

$${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + \text{ energy}$$

.... [1]

(iii) Reactions I to III can be combined into one overall reaction:

$$4\,{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2\,{}^{0}_{1}e + \text{ energy}$$

It is given that

mass of proton: 1.007276 u
mass of alpha particle: 4.001506 u
mass of positron: 0.000585 u

where u is the atomic mass unit.

Calculate the amount of energy released in one such reaction.

energy = ... J [3]

(b) The Earth is at a distance of 1.5×10^{11} m away from the Sun. The maximum intensity of sunlight at the Earth's surface can reach as high as 1400 W m^{-2} at normal incidence.

(i) Use the above information to determine the amount of energy generated by the Sun in one second.

energy generated per second = ... W [2]

6

(ii) Hence, determine

1. the number of nuclear reactions described in **(a)(iii)** that occur in the Sun every second.

reactions per second = ... [1]

2. the time taken for the Sun to be depleted of hydrogen, assuming that the total mass of the hydrogen in the Sun is now 2.0×10^{30} kg and the rate of nuclear reactions remain constant until all the hydrogen is depleted.

time taken = ... s [2]

(c) Apart from electromagnetic radiation, the Sun also showers the Earth with a large number of protons with very high kinetic energy. When these protons collide with the atoms in the atmosphere, they produce neutrons which in turn react with nitrogen in the air to form carbon-14:

$$^{14}_{7}\text{N} + ^{1}_{0}\text{n} \rightarrow ^{14}_{6}\text{C} + ^{1}_{1}\text{H}$$

Carbon-14 is radioactive with a half-life of 5730 years. In atmospheric carbon dioxide, about 1 out of 10^{12} carbon atoms are carbon-14. During photosynthesis, green plants take in carbon dioxide and convert them into carbon compounds. Because the mixing of carbon-14 with carbon-12 is efficient, all living things have the same ratio of carbon-14 to carbon-12.

(i) Define *half-life*.

.... [1]

(ii) Carbon-14 decays spontaneously into nitrogen-14. Write down the equation for this reaction.

[1]

(iii) The radioactivity of a 33.3 g piece of charcoal, assumed to be pure carbon, found from the remains of an ancient campfire is measured to be 0.4 counts per second. This value was derived from a measurement of 240 decays over 10 minutes.

1. Explain why, for this piece of charcoal, it is a good experimental practice to measure the number of decays over 10 minutes rather than 1 minute or 1 second.

.... [2]

2. In living wood, 1 out of 10^{12} carbon atoms are carbon-14. Show that the number of carbon atoms in this piece of charcoal is about 1.67×10^{24}. Hence estimate the age of this piece of charcoal.

age = ... years [5]

[Total: 20]

7 The isotope Iron-59 is a β-emitter with a half-life of 45 days. In order to estimate engine wear, an engine component is manufactured from iron throughout which the isotope Iron-59 has been uniformly distributed. The mass of the engine component is 2.4 kg and its initial activity is 8.5×10^7 Bq.

The component is installed in the engine 60 days after manufacture of the component, and then the engine is tested for 30 days. During the testing period, any metal worn off the component is retained in the surrounding oil. Immediately after the test, the oil is found to have a total activity of 880 Bq.

Calculate

(a) **(i)** the decay constant for the isotope Iron-59,

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

(ii) the total activity of the component when it was installed,

activity = ... Bq [2]

(iii) the mass of iron worn off the component during the test.

mass of iron = ... g [4]

7 **(b)** State and explain how your results in **(a) (iii)** will change if background radiation is included in the total activity of 880 Bq.

....

....

....

....

....

.... [2]

8 During radioactive decay, which is spontaneous and random, γ-ray (gamma ray) photons may be emitted. When these photons are incident on a sodium iodide crystal, some of the photons may be absorbed in the crystal. The absorption of a γ-ray photon causes the emission of a short pulse of light known as a scintillation. The scintillations may be detected and converted into electrical pulses using *a photomultiplier tube*, which, when connected to a counter, gives the *count rate* and enables γ-ray *activity* to be measured. The arrangement is illustrated in Fig. 8.1.

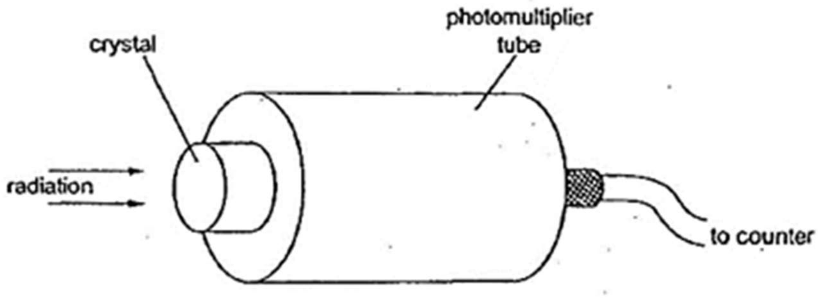


Fig. 8.1

The crystals used in such counters may be of different shapes. Fig. 8.2 shows a solid cylindrical crystal.

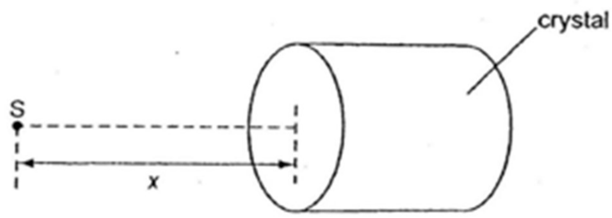


Fig. 8.2

The small γ-ray source S is placed a distance x in front of one face of the crystal. The source is assumed to emit photons uniformly in all directions. Not all of the emitted photons will be absorbed by the crystal. The efficiency Q of detection is defined by the equation

$$Q = \frac{\text{number of photons producing scintillations in the crystal}}{\text{total number of photons emitted by the source}}$$

(a) By reference to the passage, explain what is meant by

(i) *count rate*

....

....

....

.... **[1]**

8 **(ii)** *activity*

....

....

.... [1]

(b) Suggest two reasons why the γ-ray photons emitted by the source are not all absorbed in the crystal.

1. ....

....

....

.... [1]

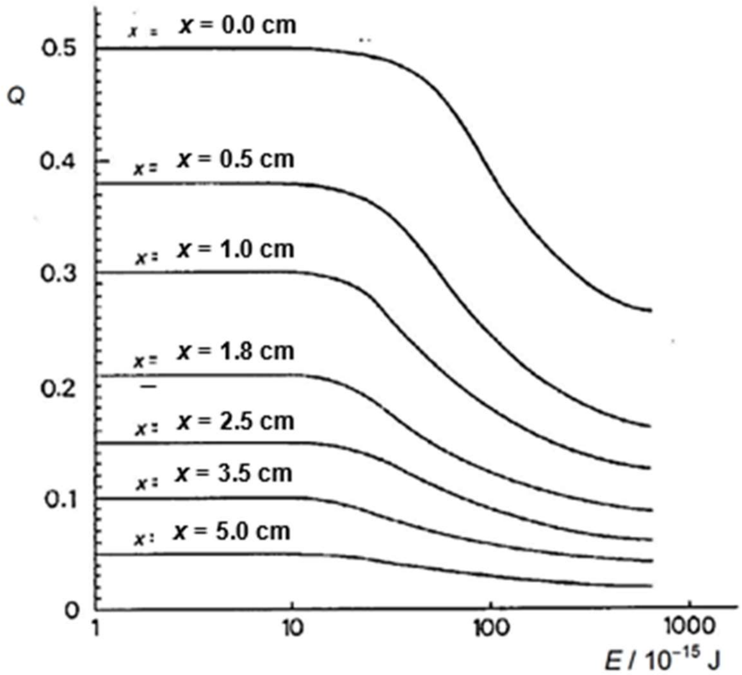
2. ....

....

....

.... [1]

(c) Fig. 8.3 shows the variation with γ-ray photon energy E of the efficiency Q. Curves are drawn for various values of the distance x of the source S from the face of the crystal.



8

Fig. 8.3

(i) Suggest why at any one particular value of energy, the efficiency Q decreases as x increases.

....

....

....

....

....

....

.... [3]

(ii) With reference to Fig. 8.3 and considering γ-ray photons of energy 8×10^{-15} J, complete Fig. 8.4 with corresponding values of Q with for γ-ray photons of this energy.

Q	x / cm

[2]

Fig. 8.4

8 **(d)** **(i)** Use your values in Fig. 8.4 to draw a graph of Q against *x* in Fig. 8.5.

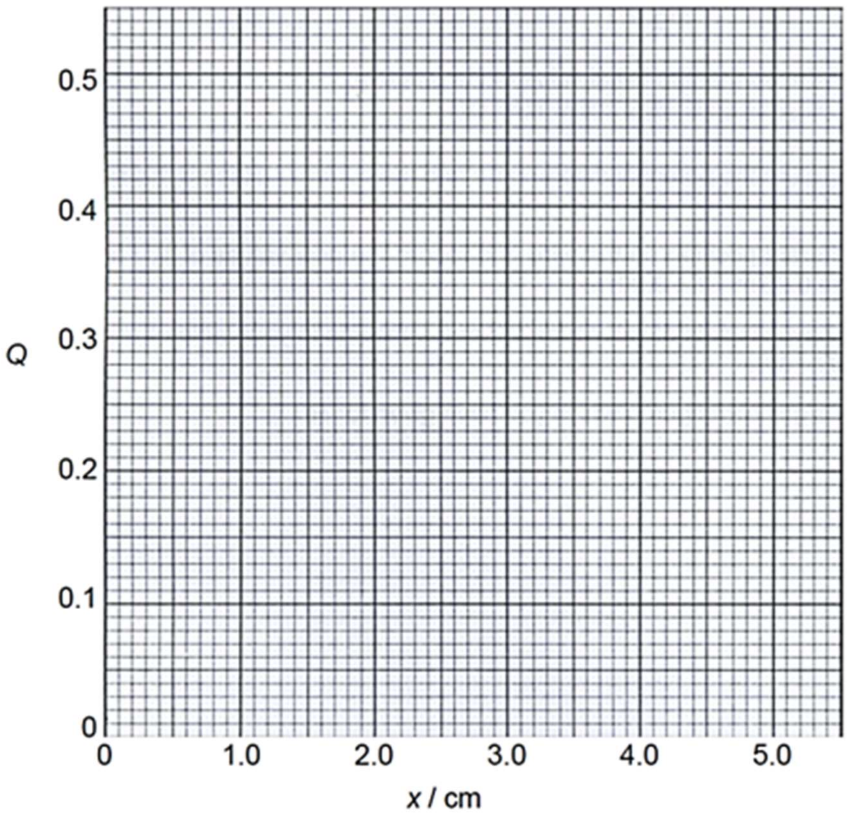


Fig. 8.5

[2]

(ii) Use Fig. 8.5 to determine the rate of change of Q with *x* when *x* = 0.5 cm.

rate of change = ... cm^{-1} [4]

8

(iii) It may be deduced from Fig. 8.5 that Q is related to x by an expression of the form

$$Q = ae^{-bx}$$

where a and b are constants.

Explain how Fig. 8.5 shows this.

....

....

....

....

.... [2]

(e) **(i)** Suggest why the maximum efficiency that can be achieved with low-energy γ-ray photons using the crystal illustrated in Fig. 8.2 is 0.50.

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.... [2]

(ii) A second crystal consists of a hollow cylinder, as shown in Fig. 8.6.

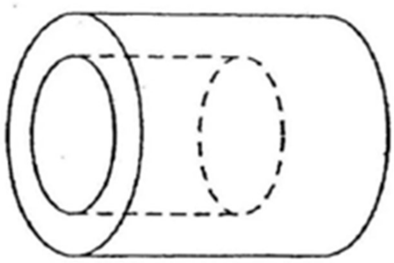


Fig. 8.6

State the effect of this change of shape on the maximum efficiency Q of the detector if the source is placed inside the hollow region.

....

.... [1]

9 **(a)** The world's largest nuclear fusion reactor experiment ITER is currently under construction in southern France. An electrically charged hydrogen gas will be heated to extremely high temperature, when fusion begins to take place. The binding energy per nucleon changes after the reaction. The fusion reaction involves isotopes of hydrogen, deuterium (^2_1H) and tritium (^3_1H) and the release of energy.

$$^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + \text{X}$$

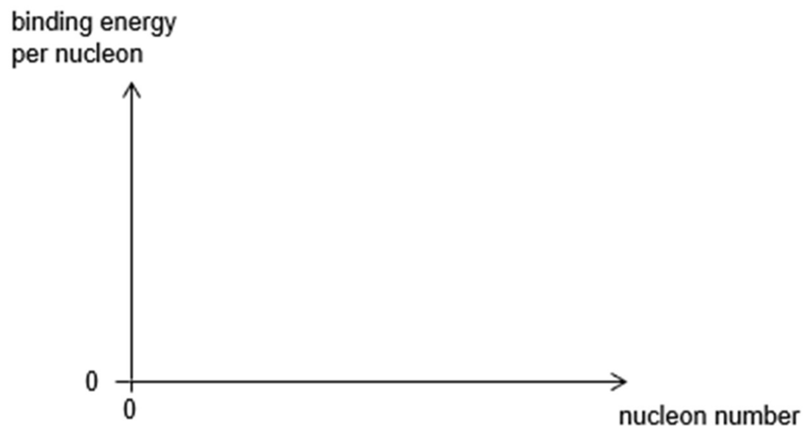
(i) Explain what is meant by *binding energy* of a nucleus.

....

....

.... [2]

(ii) On Fig. 8.1, sketch a graph to show the variation with nucleon number of the binding energy per nucleon.



[1]

Fig. 8.1

(iii) Explain why fusion of nuclei having high nucleon numbers is not associated with a release of energy.

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....

.... [2]

(iv) State what is particle X.

.... [1]

9 (v) Suggest an advantage of nuclear fusion as a source of energy production.

....

....

.... [1]

(vi) Calculate the amount of energy produced by 15 kg of appropriate mixture of the isotopes of hydrogen. The following data are provided:

	Mass
$^{2}_{1}H$	2.0141 u
$^{3}_{1}H$	3.0160 u
$^{4}_{2}He$	4.0026 u
$^{1}_{1}H$	1.0073 u
$^{1}_{0}n$	1.0087 u
$^{-1}_{0}e$	0.0005 u

energy = ... J [4]

(b) (i) "Uranium-238 is an *alpha-emitter* of *half life* 4.5×10^{9} years."

Explain what is meant by the terms in italics in the above statement.

....

....

....

.... [2]

9 **(ii)** An alpha-emitting Uranium-238 radioactive source is placed inside an ionization chamber. It produces an ionization current of 2.4×10^{-6} A. If each alpha particle produces on average 2.0×10^{5} ion pairs, determine the activity of the source. (Assume that the ions are singly-charged and that all ions are collected.)

activity = ... Bq [3]

(iii) The abundance of Uranium-238 in naturally-occurring uranium minerals on Earth is 99.28%. This means that there are 99.28 atoms of Uranium-238 for every 100 atoms of all uranium isotopes. The abundance of Uranium-235 is 0.72%. The decay constant of Uranium-238 is 15.5×10^{-11} year^{-1} and the decay constant of Uranium-235 is 98.5×10^{-11} year^{-1}.

In the early twentieth century, Rutherford assumed that at the time of the formation of the Earth's crust, an equal amount of each isotope was present. Making this assumption, determine the age of the Earth.

age = ... years [4]

[Total: 20]

10 **(a)** Describe how two samples, one emitting alpha particles, and the other emitting beta particles can be distinguished through a simple school laboratory experiment, using a Geiger-Muller (GM) tube connected to a ratemeter.

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....

....[3]

(b) Radon (Rn) decays spontaneously with a half-life of 52 s to form polonium (Po) and polonium in turn decays spontaneously with a half-life of 0.16 s to form lead (Pb).

$$^{220}_{86}\text{Rn} \xrightarrow[52\text{ s}]{\text{X}} {}^{216}_{84}\text{Po} \xrightarrow[0.16\text{ s}]{} {}^{212}_{82}\text{Pb}$$

(i) Define the terms ***activity*** and ***decay constant***.

....

....

....

....[2]

(ii) State the identity of the particle labelled **X** and write down the first decay equation in the series in (b).

....

....[2]

10 **(iii)** Suppose the activity of radon, Rn, is determined by measuring the number of particles X emitted. Explain how the decay of $^{216}_{84}Po$ will affect the measurement.

....

....

....

....[3]

(c) Radioactive isotopes are often introduced into the body through the bloodstream. Their spread through the body can then be monitored by detecting the appearance of radiation in different organs. Iodine-131 (^{131}I), a beta emitter with a half-life of 8.04 days, is one such tracer. Suppose a scientist introduces a sample of ^{131}I with an activity of 375 Bq into the body and watches it spread to the organs.

(i) Discuss the difference between a photoelectron and a beta-particle by making reference to their origin.

....

....

....[2]

(ii) Assuming that all of the ^{131}I atoms in the sample went to the thyroid gland, calculate the decay rate in the thyroid 2.5 weeks later. Assume that none of the ^{131}I is eliminated by the body through physiological means.

Decay rate = ____________ Bq[3]

10 **(iii)** Calculate the mass of ^{131}I required to produce an activity of 375 Bq.

Mass = __________ kg[3]

(d) State one similarity and one difference between radioactive decay and nuclear fission.

....

....

....

....[2]