



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Nuclear Radiation (11)

A Level Physics Topic 11

34 questions · 221 marks · Mark schemes included

A Level only content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

 [guidemygrades.com](https://www.guidemygrades.com)

 [@Guidemygrades](https://www.instagram.com/Guidemygrades)

 [@Guidemygrades](https://www.twitter.com/Guidemygrades)

 [@Guidemygrades](https://www.youtube.com/Guidemygrades)

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

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.

QUESTION	SOURCE	MARKS	PAGE
11.1 NUCLEAR RADIATION, DECAY EQUATIONS AND BACKGROUND RADIATION		11 Qs · 46 marks	4
1. Q5	A Level Paper 2 June 2018	1	5
2. Q7	A Level Paper 2 June 2018	1	6
3. Q4	A Level Paper 2 June 2019	1	7
4. Q10	A Level Paper 2 October 2020	1	8
5. Q10	A Level Paper 2 June 2022	1	9
6. Q10	A Level Paper 2 June 2023	1	10
7. Q3	A Level Paper 2 June 2024	1	11
8. Q2 <i>also Topic 1</i>	A Level Paper 3 November 2021	8	12
9. Q7	A Level Paper 3 June 2024	9	14
10. Q4 <i>also Topic 1</i>	A Level Paper 3 June 2025	9	16
11. Q10 <i>also Topic 1</i>	A Level Paper 3 June 2017	13	18
11.2 RADIOACTIVE DECAY, ACTIVITY AND HALF-LIFE		15 Qs · 139 marks	21
12. Q7	A Level Paper 2 June 2023	1	22
13. Q8	A Level Paper 2 June 2025	1	23
14. Q13	A Level Paper 2 June 2022	4	24
15. Q4 <i>also Topic 9</i>	A Level Paper 3 October 2020	6	25
16. Q4	A Level Paper 3 November 2021	7	26
17. Q18	A Level Paper 2 June 2025	7	27
18. Q8	A Level Paper 3 June 2022	8	28
19. Q21	A Level Paper 2 June 2022	10	30
20. Q18	A Level Paper 2 June 2018	11	32
21. Q16	A Level Paper 2 October 2020	12	34
22. Q19	A Level Paper 2 June 2017	13	38
23. Q18	A Level Paper 2 June 2019	13	41
24. Q19	A Level Paper 2 June 2024	14	43
25. Q20	A Level Paper 2 November 2021	15	46
26. Q12	A Level Paper 3 June 2022	17	49
11.3 BINDING ENERGY, FISSION AND FUSION		8 Qs · 36 marks	52
27. Q3	A Level Paper 2 June 2019	1	53
28. Q2	A Level Paper 2 October 2020	1	54
29. Q6	A Level Paper 2 June 2022	1	55
30. Q6	A Level Paper 2 June 2024	1	56



QUESTION	SOURCE	MARKS	PAGE
31. Q14	A Level Paper 2 June 2017	6	57
32. Q13 <i>also Topic 10</i>	A Level Paper 2 November 2021	6	58
33. Q13	A Level Paper 2 June 2023	6	59
34. Q18	A Level Paper 2 October 2020	14	61



QUESTIONS

34 questions · 221 marks · 3 sub-topics



SUB-TOPIC 11.1

NUCLEAR RADIATION, DECAY EQUATIONS AND BACKGROUND RADIATION

Sub-topic 11.1 · 11 questions · 46 marks · lowest tariff first



- 5 Select the row of the table that describes the relative ionisation and relative penetration of nuclear radiations.

	Most ionising	Most penetrating
☐ A	α	α
☐ B	α	γ
☐ C	γ	α
☐ D	γ	γ

(Total for Question 5 = 1 mark)



7 A nucleus of protactinium, ${}_{91}^{231}\text{Pa}$, decays by emitting an α particle.

The nucleus formed is

- ☐ A ${}_{95}^{233}\text{Am}$
- ☐ B ${}_{93}^{235}\text{Np}$
- ☐ C ${}_{89}^{227}\text{Ac}$
- ☐ D ${}_{87}^{229}\text{Fr}$

(Total for Question 7 = 1 mark)



- 4 The radium isotope $^{226}_{88}\text{Ra}$ is unstable and undergoes a series of α and β^- emissions until a stable isotope of lead $^{206}_{82}\text{Pb}$ is formed.

Which of the following nuclear equations correctly shows the number of α and β^- emissions?

- ☐ A $^{226}_{88}\text{Ra} \rightarrow ^{206}_{82}\text{Pb} + 3\alpha + 8\beta^-$
- ☐ B $^{226}_{88}\text{Ra} \rightarrow ^{206}_{82}\text{Pb} + 4\alpha + 5\beta^-$
- ☐ C $^{226}_{88}\text{Ra} \rightarrow ^{206}_{82}\text{Pb} + 5\alpha + 4\beta^-$
- ☐ D $^{226}_{88}\text{Ra} \rightarrow ^{206}_{82}\text{Pb} + 5\alpha + 6\beta^-$

(Total for Question 4 = 1 mark)



10 A detector is placed 30 cm from a gamma source, the count rate is 64 counts per minute.

The detector is then placed 60 cm from the source. The background rate is presumed to be a constant 24 counts per minute.

Which of the following gives the expected counts per minute?

☐ **A** 16

☐ **B** 32

☐ **C** 34

☐ **D** 44

(Total for Question 10 = 1 mark)



- 10** A student used a Geiger-Müller (GM) tube to determine a value for the background count. He recorded the count for 2 minutes, every 15 minutes, as shown in the table.

Time/min	Count for 2 min
0	34
15	39
30	28

The counts are not the same.

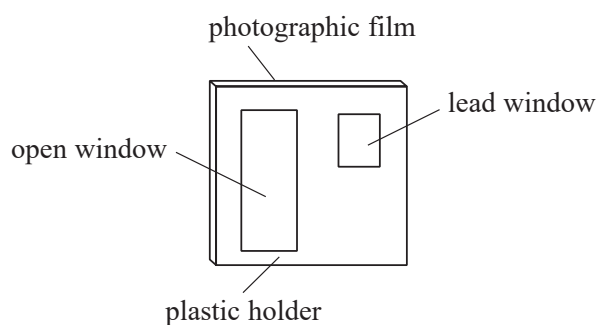
Which of the following is the reason for this?

- ☐ **A** The background count rate is random.
- ☐ **B** The counter is incorrectly calibrated.
- ☐ **C** The temperature has not stayed constant.
- ☐ **D** There is a systematic error in the measurement.

(Total for Question 10 = 1 mark)

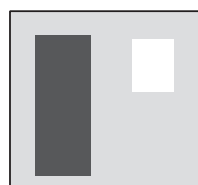


- 10** A radioactivity monitoring badge is worn by people who might be exposed to radiation. The badge is made from photographic film wrapped in thin paper and then held in a plastic holder that has an open window and a lead window, as shown.

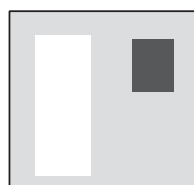


The film gets darker when exposed to ionising radiation.

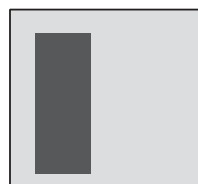
Which of the following represents the film after the badge is exposed to beta radiation?



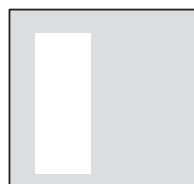
☐ A



☐ B



☐ C



☐ D

(Total for Question 10 = 1 mark)

- 3 The isotope ${}^{221}_{87}\text{Fr}$ undergoes a series of alpha and beta decays before forming ${}^{205}_{81}\text{Tl}$.

Which row of the table shows the number of alpha and beta particles emitted during the decays?

	Alpha	Beta
☐ A	3	2
☐ B	3	6
☐ C	4	2
☐ D	4	6

(Total for Question 3 = 1 mark)



- 2 A student used a Geiger-Müller (GM) tube to determine the activity of a radium source. Radium emits α , β , and γ radiation.

He positioned the source 20 cm from the GM tube, as shown, and recorded the count for 1 minute. He repeated the measurement and calculated a mean count.



The student recorded the following results.

Count 1	Count 2	Mean count
183	178	181

- (a) Criticise the student's method for determining the count at this position.

(3)

.....

.....

.....

.....

.....

.....

(b) From his results the student determined that the activity of the source was 3.0 Bq.

Comment on his value for the activity of the source.

(5)

(Total for Question 2 = 8 marks)



- 7 Radon is a radioactive gas. One isotope of radon, $^{220}_{86}\text{Rn}$, decays to polonium, Po, by emitting an alpha particle.

(a) Complete the nuclear equation for the decay of radon.

(2)



(b) Radon is produced in the ground and escapes into the atmosphere.

Explain why this is a safety hazard.

(2)

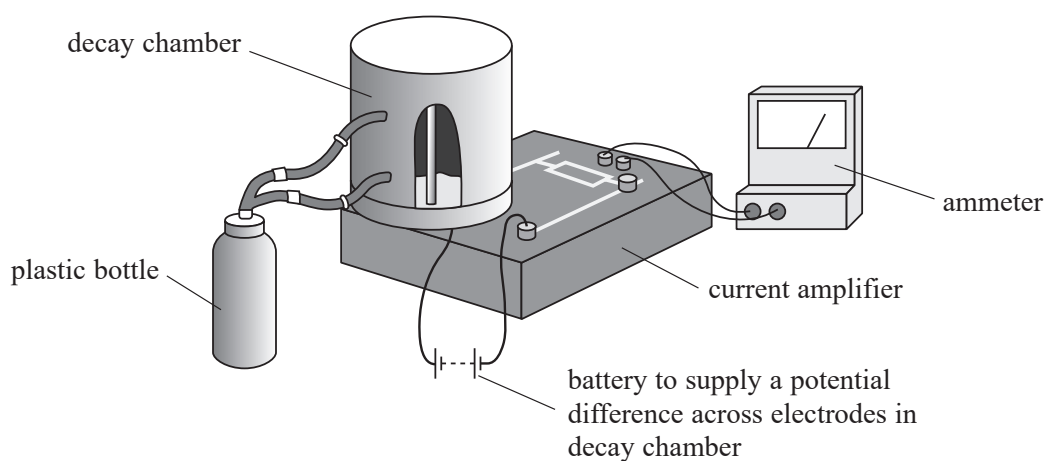
.....

.....

.....

.....

- (c) The diagram shows apparatus for monitoring the decay of radon in the laboratory. Radon gas is produced in the plastic bottle from the decay of radium. A small amount of radon is then inserted into the decay chamber by squeezing the plastic bottle. A current is produced between two electrodes inside the chamber. This current is amplified and recorded by the ammeter.



- (i) Explain why a current is produced in the decay chamber.

(2)

- (ii) A teacher is demonstrating the operation of the decay chamber to her class. She squeezes the bottle to introduce radon into the chamber.

She claims that within 450 s the activity of the radon in the chamber will be less than 1% of its initial value.

Assess whether her claim is correct.

half-life of radon = 55.6 s

(3)

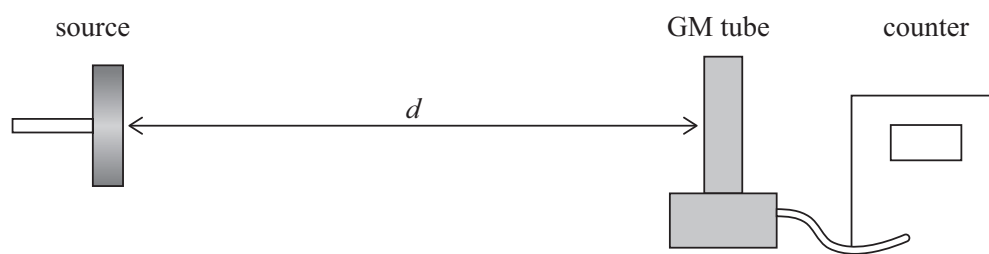
(Total for Question 7 = 9 marks)



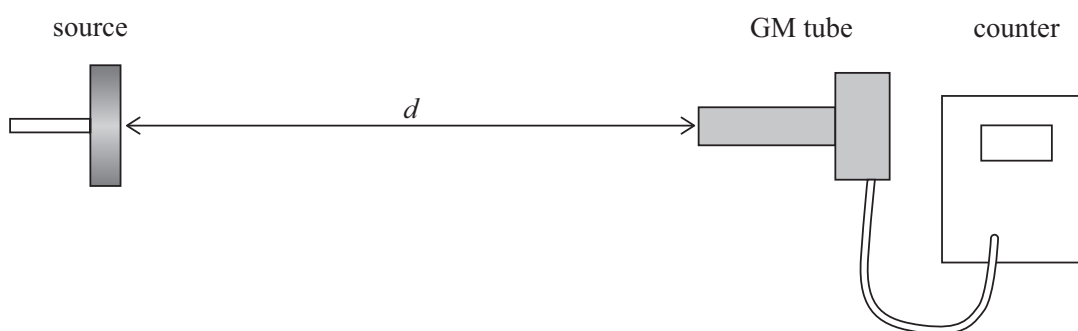
4 Two students, A and B, used a cobalt-60 source to investigate the inverse square law for a gamma radiation source. Cobalt-60 is a pure gamma emitter.

(a) The cobalt-60 source was placed in a source holder. A Geiger-Müller (GM) tube was connected to a counter and placed a short distance d away.

(i) Student A set up the apparatus as shown.



Student B used the same distance d but rotated the GM tube by 90° , as shown below.



Both students recorded the count for 2 minutes.

Deduce which set-up will lead to a smaller percentage uncertainty in the count rate.

(3)

.....

.....

.....

.....

.....

.....

- (ii) Explain two modifications to the experimental method which would improve the accuracy of the data.

(4)

- (b) Student A suggests that the investigation into the inverse square law for a gamma radiation source could be carried out successfully using a radium-226 source.

Radium-226 emits alpha and beta radiation as well as gamma radiation.

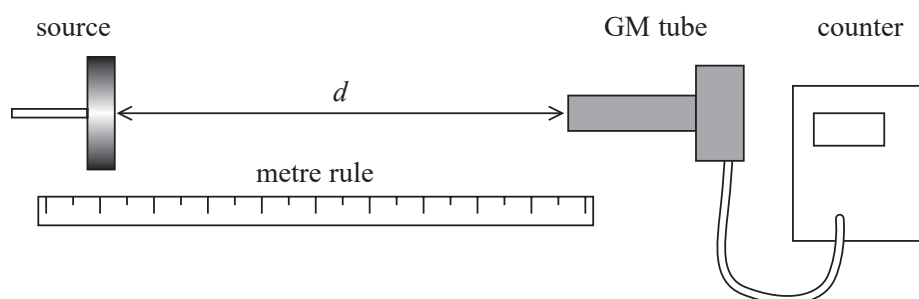
Explain **one** modification that would be necessary if a radium-226 source were to be used.

(2)

(Total for Question 4 = 9 marks)



- 10 A student investigated the way in which gamma radiation spreads out from a source. He placed a cobalt-60 source in a source holder and set up a Geiger-Müller (GM) tube a short distance d away. He connected the GM tube to a counter as shown.



The student recorded the count for 2 minutes.

- (a) Describe how to determine the corrected count rate from the source.

(2)

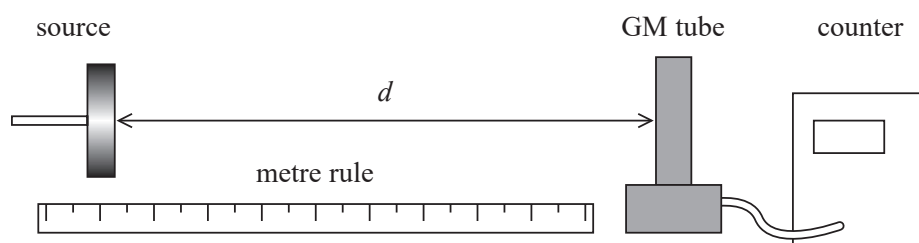
.....

.....

.....

.....

- (b) His teacher turned the GM tube through 90° so that the side of the tube faced the source as shown below.



- (i) Explain why this arrangement could lead to more accurate data.

(2)

.....

.....

.....

.....

.....

- (ii) Explain another modification to the experimental method which would improve the accuracy of the data.

(2)

.....

.....

.....

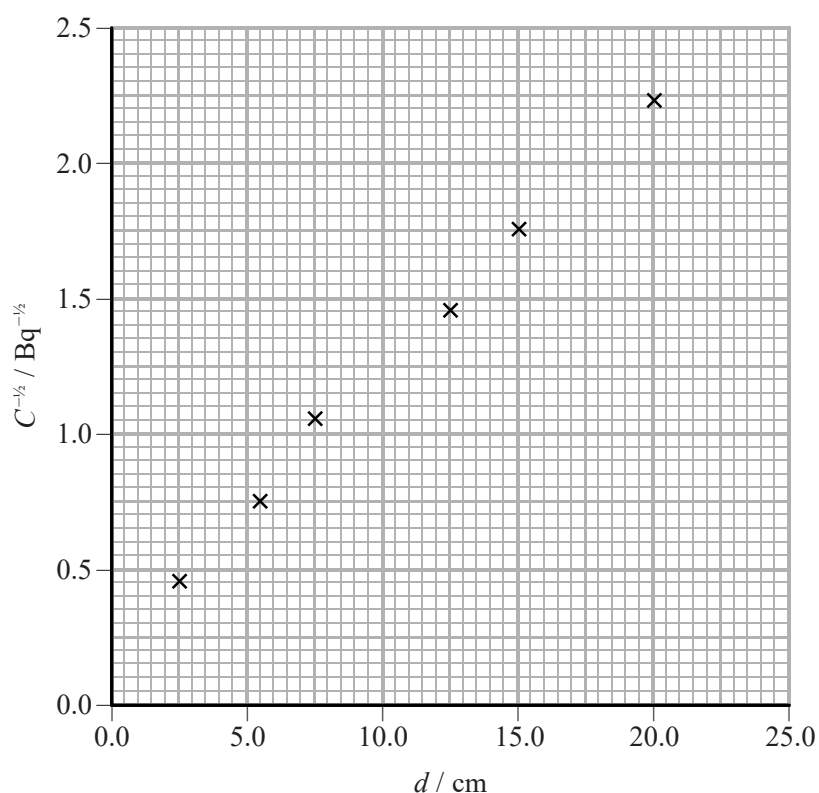
.....

- (c) The variation in the intensity of gamma radiation with distance from a point source should obey an inverse square law. If this is the case, then the count rate C should vary with d according to the equation

$$C = \frac{K}{4\pi d^2}$$

where K is a constant.

The student plotted $\frac{1}{\sqrt{C}}$ against d and obtained the following graph.



- (i) Draw a line of best fit on the graph.

(1)



- (ii) The student concluded that the graph was consistent with the gamma radiation intensity obeying an inverse square law.

Discuss the extent to which the data obtained supports the student's conclusion.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (d) It is suggested that the investigation into the way in which gamma radiation spreads out from a source, using the apparatus as shown in (b), could be carried out successfully using a radium-226 source.

Radium-226 emits α , β and γ radiation.

Justify this suggestion.

(2)

.....

.....

.....

.....

.....

.....

(Total for Question 10 = 13 marks)



SUB-TOPIC 11.2

RADIOACTIVE DECAY, ACTIVITY AND HALF-LIFE

Sub-topic 11.2 · 15 questions · 139 marks · lowest tariff first



7 Carbon-14 is a radioactive isotope with a decay constant of $1.2 \times 10^{-4} \text{ year}^{-1}$.

The fossil of a plant contains 24% of the amount of carbon-14 that would have been present when the plant was alive.

Which of the following expressions gives the age of the fossil in years?

☐ A $1.2 \times 10^{-4} \times \ln \frac{1}{0.24}$

☐ B $1.2 \times 10^{-4} \times \ln \frac{0.76}{0.24}$

☐ C $\frac{1}{1.2 \times 10^{-4}} \times \ln \frac{1}{0.24}$

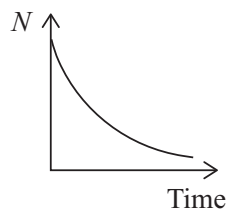
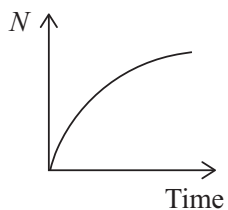
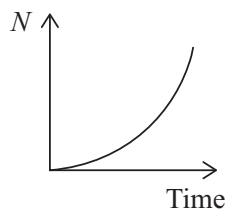
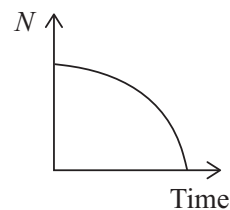
☐ D $\frac{1}{1.2 \times 10^{-4}} \times \ln \frac{0.76}{0.24}$

(Total for Question 7 = 1 mark)



- 8 Some rocks contain polonium. The polonium is radioactive, and decays to a stable isotope of lead.

Which of the following graphs shows how the number N of lead atoms produced from the decay of polonium varies with time?

**A****B****C****D**

- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 8 = 1 mark)

- 13** Actinium-225 and bismuth-210 are radioactive isotopes. A sample of each isotope is prepared so that each sample has the same number of nuclei initially.

Explain why the activity of each sample would be the same after 10 days.

half-life of actinium-225 = 10 days

half-life of bismuth-210 = 5 days

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 13 = 4 marks)



- *4 Radium is a radioactive element. The most common isotope of radium has a half-life of almost two thousand years. A sample of radium can remain at a higher temperature than its surroundings for a long period of time.

Explain how a sample of radium is able to release significant amounts of energy over a long period of time.

(6)

(Total for Question 4 = 6 marks)



4 Radioactive decay is often described in textbooks as a spontaneous, random process.

(a) State what is meant by spontaneous decay.

(1)

*(b) Explain why there is an exponential decrease in the rate of decay for a sample containing a large number of unstable nuclei.

(6)

(Total for Question 4 = 7 marks)



- 18** Glaciers are massive bodies of slowly moving ice. Over time, a fine sediment forms on the surface of a glacier. The sediment contains radioactive isotopes.

Caesium-137, ^{137}Cs , is a common radioisotope found in the sediment.

- (a) Complete the following nuclear equation to represent the decay of caesium.

(2)



- (b) The concentration of ^{137}Cs on a Norwegian glacier was investigated.

half-life of $^{137}\text{Cs} = 9.5 \times 10^8 \text{ s}$

- (i) The activity of ^{137}Cs was determined to be $2.5 \times 10^4 \text{ Bq}$ per kg of sediment.

Calculate the number of atoms of ^{137}Cs in 1 kg of sediment.

(3)

.....

.....

.....

.....

.....

Number of atoms of $^{137}\text{Cs} = \dots\dots\dots$

- (ii) Calculate the time taken for 10% of the ^{137}Cs atoms to have decayed.

(2)

.....

.....

.....

.....

.....

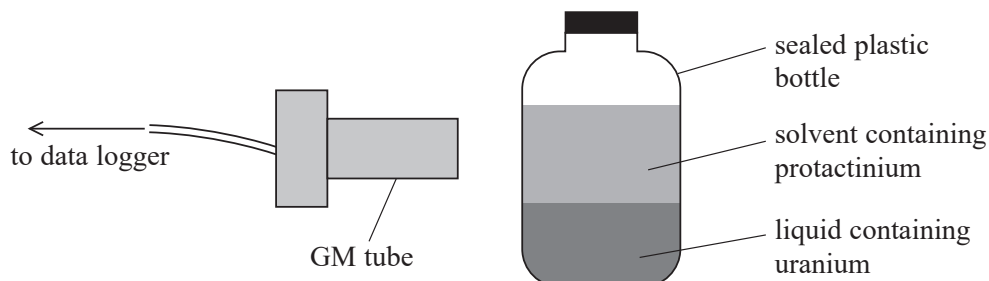
Time taken = ...

(Total for Question 18 = 7 marks)



- 8 A teacher demonstrated the decay of protactinium using a Geiger-Müller (GM) tube connected to a data logger.

A sealed plastic bottle contains a solvent floating above a liquid containing a uranium salt. Protactinium is produced from the decay of uranium and is present in the solvent as shown.



- (a) Deduce whether alpha radiation or beta radiation from the inside of the bottle is detected by the GM tube.

(2)

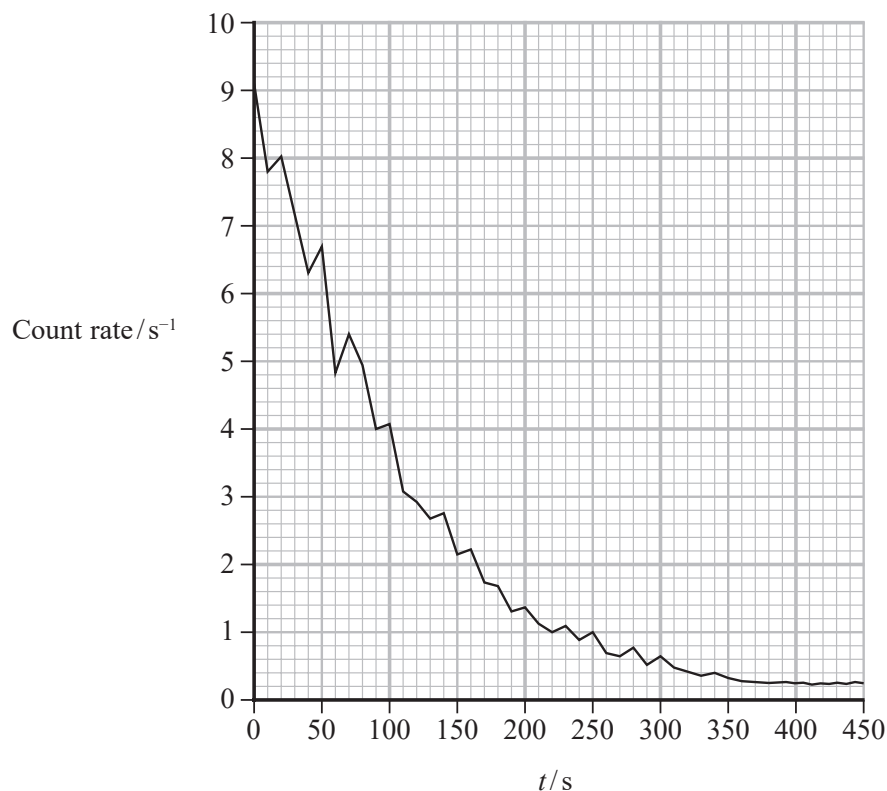
.....

.....

.....

.....

- (b) The data logger output is shown below.



(i) Determine the half-life of the protactinium.

(4)

Half-life of protactinium = ...

(ii) Explain why the count rate doesn't reach zero.

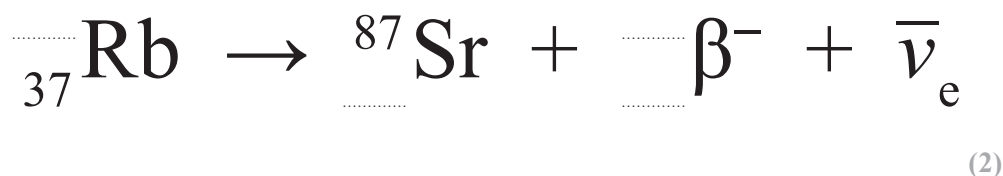
(2)

(Total for Question 8 = 8 marks)



21 A hundred years ago, a method to determine the age of certain rocks was developed. An unstable isotope of rubidium is present in some rocks when they form. Over time the rubidium decays to a stable isotope of strontium.

- (a) Rubidium decays to strontium via β^- decay. Complete the nuclear equation representing the decay.



- (b) A sample of Moon rock from the Apollo 11 mission was analysed to determine the age of the rock. When the sample was analysed the number of rubidium atoms was N_{R} and the number of strontium atoms was N_{S} .

As strontium atoms have all been produced from the decay of rubidium, the original number of rubidium atoms in the sample was $(N_{\text{R}} + N_{\text{S}})$.

From the analysis of the sample, it was determined that $\frac{N_{\text{S}}}{N_{\text{R}}} = 0.0532$

Deduce whether this ratio is consistent with the Earth and the Moon forming at the same time.

age of Earth = 4.5×10^9 years

half-life of rubidium isotope = 4.88×10^{10} years

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



(c) Give a reason why the half-life of the rubidium isotope is hard to determine.

(1)

(d) Recent investigations suggest that the half-life of the rubidium isotope may be larger than the traditionally accepted value.

Explain how this would affect the ages obtained by this dating method.

(2)

(Total for Question 21 = 10 marks)



- 18** Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

- (a) (i) In a sample of 1.0 g of phosphogypsum, the activity of radium-226 is 1.3 Bq.

Calculate the number of nuclei of radium-226 in this sample.

(3)

.....

.....

.....

.....

.....

.....

.....

Number of nuclei = ...

- (ii) Calculate the time in years it would take before this sample reached the permitted level of decay rate.

(3)

.....

.....

.....

.....

.....

.....

.....

Time = ...years



(b) Radium-226 decays to radon-222 by alpha emission.

Determine the energy released in MeV in the decay of a single nucleus of radium-226.

(5)

mass of radium-226 nucleus = 225.97713 u

mass of radon-222 nucleus = 221.97040 u

mass of α particle = 4.00151 u

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Energy released = ...MeV

(Total for Question 18 = 11 marks)



- 16** Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

- (a) The rock sample contains uranium. The radioactive decay of uranium allows it to be used to determine the time since the rock was formed on the Earth.

- (i) The uranium isotope $^{238}_{92}\text{U}$ becomes the lead isotope $^{206}_{82}\text{Pb}$ through a series of radioactive decays.

Calculate the number of α particles and the number of β particles emitted for one nucleus of $^{238}_{92}\text{U}$ to decay to become a nucleus of $^{206}_{82}\text{Pb}$.

(2)

.....

.....

.....

.....

Number of α particles = ...

Number of β particles = ...



(ii) The half-life of ${}_{92}^{238}\text{U}$ is 4.47×10^9 years.

The half-lives of the other stages in the decay to ${}_{82}^{206}\text{Pb}$ are relatively so short that they can be ignored.

There was no lead in the rock when it formed, so all the ${}_{82}^{206}\text{Pb}$ in the sample is a product of ${}_{92}^{238}\text{U}$ decay. In the sample, for every 103 uranium nuclei present at the start, 50 are now lead nuclei.

Show that the age of the sample is about 4×10^9 years.

(3)



- (b) The gravitational potential between the Earth and the Moon due to the combined effect of their gravitational fields increases to a maximum value of -1.28 MJ kg^{-1} at a point between them.

Calculate the minimum speed at which a rock would have to leave the Earth in order to reach the Moon.

In your calculation, you may assume the rock has zero kinetic energy when it has maximum potential energy.

$$\text{mass of Earth} = 5.97 \times 10^{24} \text{ kg}$$

$$\text{radius of Earth} = 6370 \text{ km}$$

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Minimum speed = ...



- (c) Four billion years ago, the Moon had a different orbital period, because it was closer to the Earth than it is today.

Calculate the period of the Moon's orbit four billion years ago, when the radius of its orbit was 1.34×10^8 m.

mass of Earth = 5.97×10^{24} kg

(3)

Period = ...

(Total for Question 16 = 12 marks)



- 19 A school science department keeps a sample of potassium chloride to use as a test source for Geiger-Müller tubes.



Potassium contains 0.012% of the unstable isotope potassium-40.

- (a) Potassium-40 undergoes β^- decay, producing a stable isotope of calcium.

Complete the nuclear equation for this decay.

(2)



- (b) A teacher makes some measurements using the potassium chloride test source to determine whether a Geiger-Müller tube is sufficiently efficient at detecting β radiation.

- (i) The potassium chloride sample has a mass of 300 mg.
Show that the number of nuclei of potassium-40 in the sample is about 3×10^{17} .

number of potassium nuclei in 1 g of potassium chloride = 8.1×10^{21}

(2)

.....

.....

.....

.....

- (ii) Show that the activity of this sample is about 5 Bq.

half-life of potassium-40 = 1.25×10^9 years

(3)

- (iii) With no sample in front of the Geiger-Müller tube, a count rate of 15 counts per minute is recorded. When the potassium chloride test sample is placed next to the Geiger-Müller tube 176 counts are recorded in a period of 10 minutes.

A detector is considered efficient if it detects at least 7.5% of beta emissions from the source.

Determine whether this Geiger-Müller tube can be considered efficient.

(3)

- (iv) Explain a possible reason why only a low proportion of the decays are detected.

(2)



- (c) The science department also has a sample of strontium-90. This undergoes beta decay with a half-life of 29 years.

State why the half-life of potassium-40 makes the potassium chloride a more suitable material than strontium-90 for the test.

(1)

(Total for Question 19 = 13 marks)



- 18** An old type of camping lamp used a ‘gas mantle’. The gas mantle is heated by the gas flame on the lamp and emits a bright white light. Gas mantles used to contain thorium-230.

Thorium-230 decays by alpha emission to form an isotope of radium. A student keeps a radioactive gas mantle in a sealed polythene bag. The student suggests that over a period of a year a significant volume of helium gas will be collected, since an alpha particle is a helium nucleus.

- (a) Give reasons why the sealed plastic bag is suitable for collecting the gas.

(2)

- (b) A particular gas mantle contains 5.18×10^{-5} g of thorium-230.

- (i) Show that the activity of the thorium-230 in the mantle is about 4.0×10^4 Bq.

230 g of thorium-230 contains 6.02×10^{23} atoms

half-life of thorium-230 = 75 400 years

number of seconds in 1 year = 3.15×10^7

(4)



- (ii) Determine the volume of helium gas that could be collected in a year as a result of alpha emission.

Assume that the temperature is 22.0°C and the pressure is $1.00 \times 10^5 \text{ Pa}$.

(4)

Volume = ...

- (iii) Calculate the root mean square speed of the atoms in the helium gas at a temperature of 22.0°C .

(3)

Root mean square speed = ...

(Total for Question 18 = 13 marks)



19 Nuclear decay is described as being spontaneous and random.

(a) (i) State what is meant by spontaneous and random in this context.

(2)

(ii) Explain why the decay constant of an isotope can be determined even though nuclear decay is random.

(2)



- (b) A radioactive source used in a school laboratory emits alpha and beta radiation.

Describe how the percentage of the activity due to beta radiation may be determined using a Geiger–Müller tube and ratemeter.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

- (c) Americium-241 is used in schools as a source of alpha radiation.

A pure americium-241 source was bought 34 years ago by a school.

- (i) Determine the percentage of the initial activity that would be expected today for the americium-241 source.

half-life of americium-241 = 432 years

(3)

.....

.....

.....

.....

.....

.....

Expected percentage of initial activity = ...



- (ii) The decay products of americium are unstable and undergo a series of further decays.

The table shows the first three decays in this sequence.

Isotope	Decay product	Emission	Half-life
americium-241	neptunium-237	alpha	432 years
neptunium-237	protactinium-233	alpha	2 100 000 years
protactinium-233	uranium-233	beta	27 days

A student states, “Protactinium-233 emits beta particles when it decays, so by now the americium-241 source bought 34 years ago will be emitting a significant amount of beta radiation.”

Discuss the student’s statement.

(3)

.....

.....

.....

.....

.....

.....

(Total for Question 19 = 14 marks)

20 The photograph shows a vase made of uranium glass. Uranium glass is radioactive.



Uranium glass usually contains a maximum of 2% uranium. Uranium glass made in the early part of the 20th century can contain up to 25% uranium.

A student carried out an investigation to determine the percentage of uranium in the glass.

The student measured the count rate by placing a Geiger Muller (GM) tube against the vase at a single position. This value was used to calculate the decay rate for the whole vase.

(a) (i) Show that the decay constant for uranium is about $5 \times 10^{-18} \text{ s}^{-1}$

half-life of uranium = $1.41 \times 10^{17} \text{ s}$

(2)

.....

.....

.....

.....

(ii) Calculate the percentage of uranium, by mass, in the glass.

area of GM tube window = $6.36 \times 10^{-5} \text{ m}^2$

surface area of vase = 0.0177 m^2

background count rate = 525 counts in 10 minutes

count rate when GM tube next to vase = 3623 counts in 5 minutes

mass of vase = 149 g

mass of uranium atom = 238 u

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Percentage of uranium = ...

(iii) The uranium decays by emitting alpha particles.

Criticise the method used to determine the percentage of uranium in the vase.

(2)

.....

.....

.....

.....

.....

.....

.....



(b) A uranium nucleus decays to thorium by emission of an alpha particle.

It can be assumed that all the energy of the decay is transferred to kinetic energy of the alpha particle.

Calculate the speed of the emitted alpha particle.

mass of uranium nucleus = 238.0003 u

mass of thorium nucleus = 233.9942 u

mass of alpha particle = 4.0015 u

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Speed of alpha particle = ...

(Total for Question 20 = 15 marks)

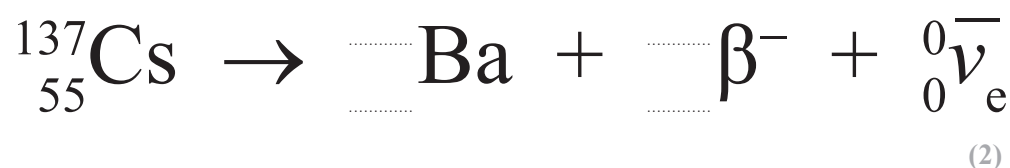


12 In 2011, a tsunami was caused by a massive earthquake centred some distance off the coast of Japan. The tsunami caused a cooling system failure at the Fukushima Nuclear Power Plant. This resulted in a nuclear meltdown and radioactive materials were released into the surroundings.

- (a) A reservoir beside one of the reactor buildings contained a large volume of water. In 2013, this water was found to have an extremely high concentration of caesium-137.

Caesium-137 is a radioactive isotope of caesium.

- (i) Complete the nuclear equation for the decay of caesium-137.



- (ii) An activity of 2.35×10^{12} Bq per m^3 of water in the reservoir was measured. It is suggested that a safe level for the activity of all water in the reservoir would be 100 Bq.

Calculate the time in years for the caesium-137 to decay to a safe level.

volume of water in reservoir = 5000 m^3

half-life of caesium-137 = 30 years

(4)

.....

.....

.....

.....

.....

.....

.....

Time = ... years



- (b) The most common radionuclide amongst the fission products in the fuel was iodine-131, which decays with a half-life of 8.0 days to form a stable isotope of the gas xenon.

Deduce whether enough xenon would have collected in 32 days to exert a pressure of 1.0×10^5 Pa in a volume of 450 m^3 . Assume that no gas escapes.

temperature = 20°C

initial number of iodine nuclei = 1.25×10^{28}

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



SUB-TOPIC 11.3

BINDING ENERGY, FISSION AND FUSION

Sub-topic 11.3 · 8 questions · 36 marks · lowest tariff first



- 3 In both nuclear fission and nuclear fusion there are changes in the binding energy per nucleon. This releases energy.

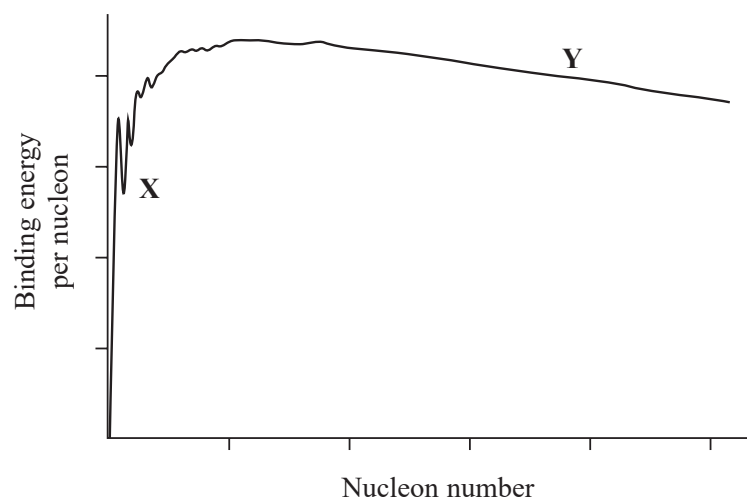
Which row of the table correctly shows the change in binding energy per nucleon for both processes?

	Nuclear fission	Nuclear fusion
☐ A	decrease	decrease
☐ B	decrease	increase
☐ C	increase	decrease
☐ D	increase	increase

(Total for Question 3 = 1 mark)



2 The diagram shows binding energy per nucleon against nucleon number for atomic nuclei.



Which line of the table correctly identifies the process that would increase stability for nuclei in the positions indicated by X and Y?

	X	Y
☐ A	nuclear fission	nuclear fission
☐ B	nuclear fission	nuclear fusion
☐ C	nuclear fusion	nuclear fission
☐ D	nuclear fusion	nuclear fusion

(Total for Question 2 = 1 mark)

6 In a particular radioactive decay, there is a mass decrease equivalent to 0.05 u.

Which of the following expressions gives the energy released in MeV?

☐ A $\frac{0.05 \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}}$

☐ B $\frac{0.05 \times 1.67 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-19}}$

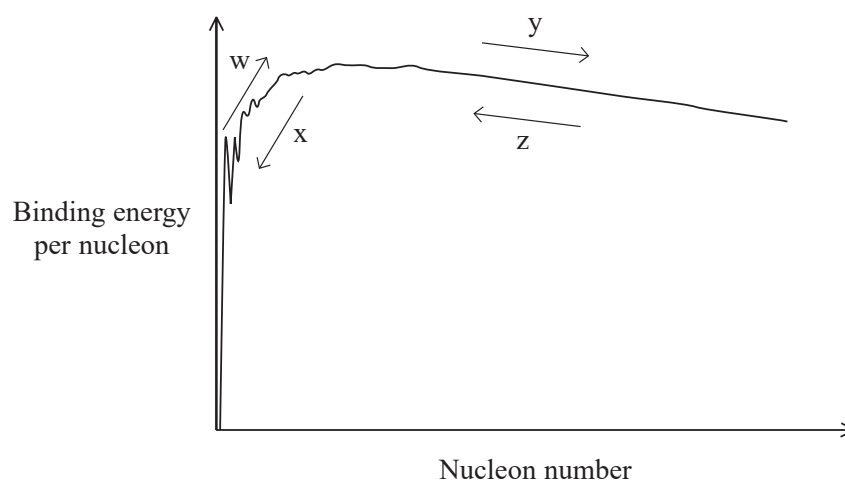
☐ C $\frac{0.05 \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-13}}$

☐ D $\frac{0.05 \times 1.67 \times 10^{-27} \times (3 \times 10^8)^2}{1.6 \times 10^{-13}}$

(Total for Question 6 = 1 mark)



- 6 The graph shows how binding energy per nucleon varies with nucleon number for atomic nuclei. The arrows w, x, y and z represent changes in binding energy per nucleon and nucleon number.



Fission and fusion of nuclei may result in the release of energy.

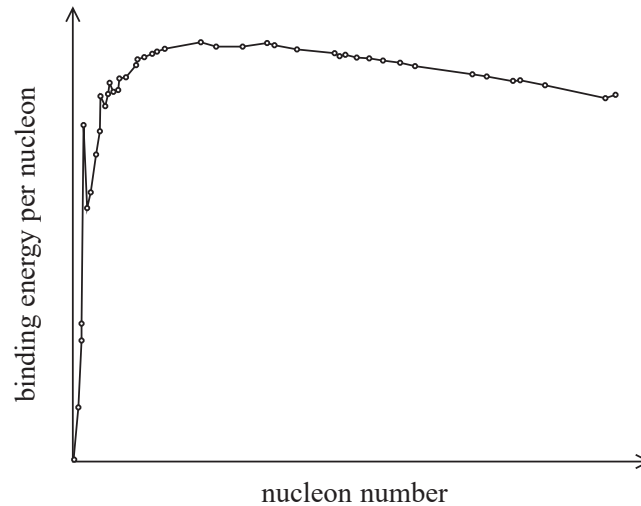
Which row of the table gives the arrows representing energy release by fission and fusion?

		Fission	Fusion
☐	A	x	w
☐	B	x	y
☐	C	z	w
☐	D	z	y

(Total for Question 6 = 1 mark)

14 Nuclear fusion involves small nuclei joining to make larger nuclei. Nuclear fission involves large nuclei splitting to become smaller nuclei. Both of these processes release energy.

(a) The graph shows how the binding energy per nucleon varies with nucleon number for a range of isotopes.



Use the binding energy per nucleon curve to explain how fusion and fission both release energy.

(3)

.....

.....

.....

.....

.....

.....

(b) Explain the conditions required to bring about and maintain nuclear fusion.

(3)

.....

.....

.....

.....

.....

.....

(Total for Question 14 = 6 marks)



***13** The energy radiated by stars is released by nuclear fusion.

Explain the conditions required to bring about and maintain nuclear fusion in stars.

(Total for Question 13 = 6 marks)



13 A fusion research centre was opened in Rotherham in 2021. The centre has a device which tests materials in the extreme conditions found inside a fusion reactor.

(a) Describe the extreme conditions inside a fusion reactor.

(3)

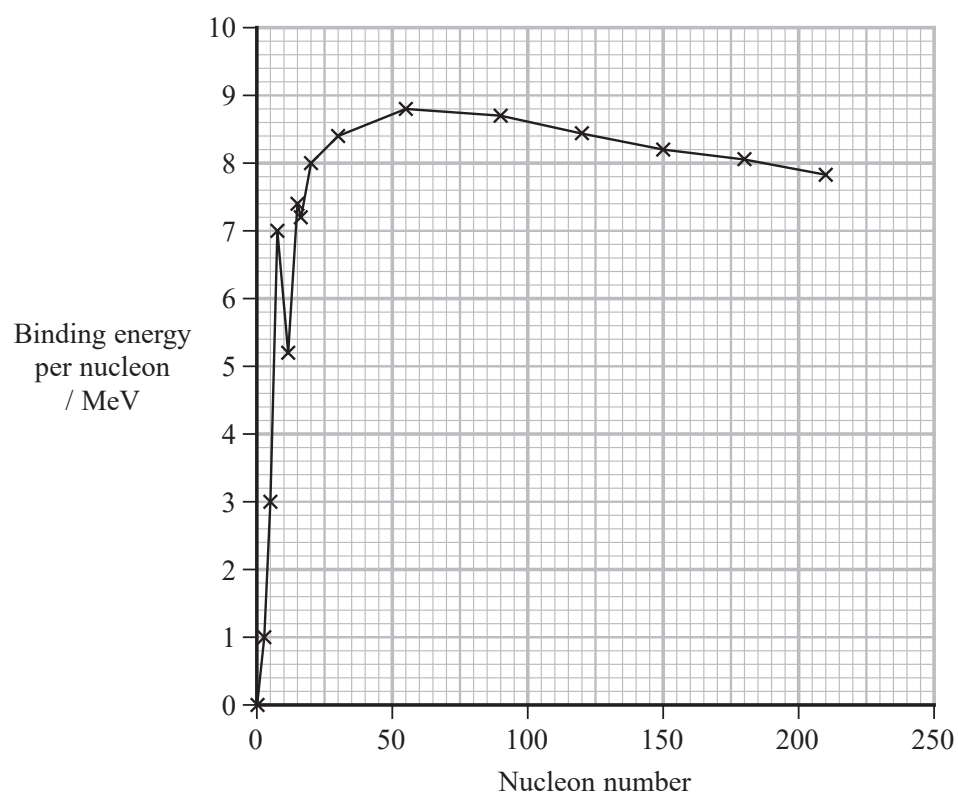
.....

.....

.....

.....

(b) The graph shows how the binding energy per nucleon varies with nucleon number for a range of nuclides.



Explain why the fusion of nuclei can produce large amounts of energy. Your answer should refer to information from the graph.

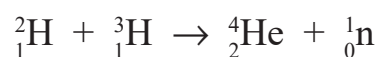
(3)

(Total for Question 13 = 6 marks)



18 At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

- (a) In a fusion experiment at CCFE, ions of two isotopes of hydrogen fuse to produce helium ions and fast-moving neutrons.



Show that a single fusion reaction releases about $3 \times 10^{-12} \text{ J}$ of energy.

mass of ${}^2_1\text{H} = 2.013553 \text{ u}$

mass of ${}^3_1\text{H} = 3.015501 \text{ u}$

mass of ${}^4_2\text{He} = 4.001506 \text{ u}$

mass of ${}^1_0\text{n} = 1.008665 \text{ u}$

(4)

.....

.....

.....

.....

.....

.....

.....

.....



- (b) Fusion occurs naturally in the core of stars.

Explain why very high densities of matter and very high temperatures are needed to bring about and maintain nuclear fusion in stars.

(2)

.....

.....

.....

.....

.....

.....

- (c) In a plasma experiment 5.0 mg of deuterium, an isotope of hydrogen, occupies a volume of 98 m^3 . The temperature of deuterium is raised to $1.3 \times 10^8 \text{ K}$. In this experiment, the deuterium behaves as an ideal gas.

- (i) Calculate the pressure due to the deuterium ions.

mass of deuterium ion = $3.3 \times 10^{-27} \text{ kg}$

(3)

.....

.....

.....

.....

.....

.....

Pressure = ...



- (ii) Calculate the root mean square speed of the deuterium ions at this temperature.

(2)

.....

.....

.....

Root mean square speed = ...

- (iii) The temperature of the plasma is monitored using the Doppler effect. Light from a laser is directed into the plasma and the wavelength of the light reflected is measured.

The Doppler shift observed when light is reflected by a deuterium ion is twice the Doppler shift that would be observed for a source of light moving at the same speed as the deuterium ion.

Calculate the maximum wavelength of light that would be detected after reflection from a deuterium ion moving at $1.5 \times 10^6 \text{ m s}^{-1}$.

wavelength of laser light = 1064 nm

(3)

.....

.....

.....

.....

Maximum wavelength detected = ...

(Total for Question 18 = 14 marks)



MARK SCHEMES

official mark schemes



5	The only correct answer is B because alpha is the most ionising and gamma is the most penetrating A is not correct because although alpha is the most ionising, gamma and not alpha is the most penetrating C is not correct because alpha, not gamma, is the most ionising and gamma, not alpha is the most penetrating D is not correct because alpha, not gamma is the most ionising, even though gamma is the most penetrating		1
---	---	--	---



7	The only correct answer is C emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2 A is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been increased by 2 and the proton number has been increased by 4 B is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been increased by 4 and the proton number has been increased by 2 D is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been decreased by 2 and the proton number has been decreased by 4		1
---	---	--	---



Question Number	Acceptable answer	Additional guidance	Mark
4	C	The only correct answer is C : mass decrease by $20 \rightarrow 5 \alpha$, which is a charge decrease of 10, but total charge decrease is 6, so 4β A is not correct because there are too few alpha and too many beta B is not correct because there are too few alpha and too many beta D is not correct because there are too many beta	1



10	C	The only correct answer is C because the corrected count rate at 30 cm is 40 counts per minute, the corrected rate at twice the distance is a quarter of this value, which is 10 counts per minute, and adding the background gives the value of 34 A is not the correct answer because it is 16 C is not the correct answer because it is 32 D is not the correct answer because it is 44	1
----	---	---	---

(Total for Multiple Choice Questions = 10 marks)



10	The only correct answer is A <i>B is incorrect because an incorrect calibration would give a consistently high or low reading</i> <i>C is incorrect because temperature does not affect the background count rate</i> <i>D is incorrect because a systematic error would be a constant difference between the actual and the recorded count rate</i>	1
----	---	---

(Total for Multiple Choice Questions = 10 marks)



10	The only correct answer is A B is not correct as the open window section of film will be dark and the lead window section of film will be white C is not correct as the open window section of film will be dark and the lead window section of film will be white D is not correct as the open window section of film will be dark and the lead window section of film will be white		1
----	--	--	---

(Total for Multiple Choice Questions = 10 marks)



Question Number	Answer	Mark
3	The only correct answer is C <i>A is not correct because the atomic mass number must decrease by 16, which corresponds to 4 alpha decays</i> <i>B is not correct because the atomic mass number must decrease by 16, which corresponds to 4 alpha decays</i> <i>D is not correct because the atomic number would decrease by 8 due to alpha decay, then increase by 6 due to beta decay</i>	1



Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	- Counting for 1 minute is too short a time Or he should count for at least 3 minutes (1) - He hasn't recorded the background count rate (1) - More than one reading taken and a mean calculated Or should have taken more than two readings (to calculate mean) (1)	To be marked holistically (with(b))	3
2(b)	MAX 5 An explanation that makes reference to the following points: - The student has calculated the count rate rather than the activity of the source (1) - The counts haven't been corrected for background (so there is systematic error in his data) (1) - The GM tube is too far away from the source (1) α-radiation won't reach the GM-tube as it only has a short range in air (1) - Radiation spreads out from the source, so not all the emitted radiation reaches the GM-tube (1) - GM tube won't detect all the gammas which enter it (1)	To be marked holistically (with(a))	5

(Total for Question 2 = 8 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)	- Top line correct (1) - Bottom line correct (1)	${}_{86}^{220}\text{Rn} \rightarrow {}_{84}^{216}\text{Po} + {}_2^4\alpha$	2
7(b)	- Radon gas can be breathed in and can cause damage to living cells Or Once radon is inside the body the alpha particles/radiation can cause damage to living cells (1) - Because alpha (particles) highly ionising (1)	Accept the idea of damage e.g. causing mutations/cancer etc. Must have stated that this happens inside the body	2
7(c)(i)	- The alpha particles ionise the air (inside the chamber) (1) - This produces (moving) electrons inside the chamber (1)	If no other marks scored, allow MAX 1 for alpha particles are charged and attracted to (negative) electrode and current produced	2
7(c)(ii)	- Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) - Use of $A = A_0 e^{-\lambda t}$ (1) % activity remaining = 0.4 % (<1%), so claim is correct Or time to decay to 1% = 370 s (<450 s), so claim is correct (1)	Allow application of constant ratio rule <u>Example of calculation</u> $\lambda = \frac{\ln 2}{55.6 \text{ s}} = 0.0125 \text{ s}^{-1}$ $\% \text{ activity remaining} = 100e^{-0.0125 \text{ s}^{-1} \times 450 \text{ s}} = 0.37$	3

(Total for Question 7 = 9 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)(i)	- The detector area exposed to γ-radiation is larger in the set-up of Student A (1) - So the count (rate) will be greater (at a given distance from the source) (1) - Hence (the percentage uncertainty will be smaller for) Student A (1)	<u>Alternative MP1 and MP2</u> d should be measured to the middle of the counter (1) - The error (or uncertainty) in d is reduced in set-up of Student A (1) MP3 dependent on MP1 and MP2	3
4(a)(ii)	An explanation that makes reference to the following points: - Record the background count (rate) and subtract from recorded count (rate) (1) - Gives count (rate) of source only Or As background count adds to the count from the source (1) - Record the count for a longer time (1) - As this will increase the total count (at a given distance) (1)	Allow “Adds a systematic error” <u>Alternative MP3 and MP4</u> - Repeat the measurement of the count and calculate a mean (1) - As radioactive decay is random (1)	4
4(b)	An explanation that makes reference to the following points: - Place an aluminum sheet between the source and the detector (1) - As this will absorb/block the alpha and beta radiation emitted by the source (1)	Allow up to 3 mm of lead	2

(Total for Question 4 = 9 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	A description that makes reference to the following: (Remove the source and) record background count for specified time and subtract from equivalent quantity (1) - Divide by time to give a count rate. (1)	There needs to be two clear steps. Subtract a count from a count, or a count rate from a count rate and divide a count by time to obtain a count rate.	2
10(b)(i)	Either - The GM-tube has a low efficiency for γ-ray detection (1) Or there is an increased area exposed to γ-rays (1) (So) placing the tube side on to the radiation would increase the count rate (1) Or - The γ-radiation could be detected anywhere inside the GM-tube (1) - So placing the tube side on to the radiation would reduce the uncertainty in the distance measurement (1)	For low efficiency, accept GM tube poor at detecting γ -rays.	2
10(b)(ii)	- Record the count (at least) twice and then determine an average count rate (1) Or record the count for a much longer time (1) - This reduces the effect of (random) errors in the measurement of the count rate (1)		2



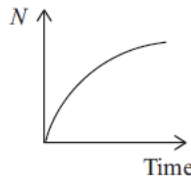
10(c)(i)	Mean straight line with positive intercept on the y-axis (1)		1
10(c)(ii)	$C = \frac{K}{4\pi d^2}$ used to show $\frac{1}{\sqrt{C}} \propto d$ (1) - Or identifies gradient as $\sqrt{\frac{4\pi}{K}}$ which is constant (1) - Since graph is a straight line, data is consistent with this (1) - However, line doesn't pass through the origin (1) - This indicates a <u>systematic</u> error in measuring the distance (1)		4
10(d)	α-particles would only travel a few cm (in air), and so wouldn't reach the GM-tube (1) β-particles would probably not pass through the sides of the GM-tube, and so wouldn't be detected so suggestion is correct. (1)	Accept a reference to α-particles not passing through the side of the tube (even if they reached it when d was small) and so not contributing to the count (rate) For 2 marks expect a valid conclusion, as well as a statement of the likelihood of the α-particles and β-particles contributing to the count (rate)	2

(Total for Question 10 = 13 marks)



7	The only correct answer is C A is not correct as $t = \frac{1}{\lambda} \times \ln \frac{N_0}{N}$ and $N_0 = 1$ B is not correct as $t = \frac{1}{\lambda} \times \ln \frac{N_0}{N}$ and $N_0 = 1$ D is not correct as $t = \frac{1}{\lambda} \times \ln \frac{N_0}{N}$ and $N_0 = 1$		1
---	--	--	---



8	The only correct answer is B  A is not correct because the number of lead atoms increases over time C is not correct because the number of lead atoms must increase at a decreasing rate D is not correct because the number of lead atoms increases over time	1
---	---	---



Question Number	Acceptable answers	Additional guidance	Mark
13	An explanation that makes reference to the following points: - Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) (Hence) initial activity of Ac is 50% that of Bi (1) Or (Hence) decay constant of Ac is 50% that of Bi (1) - Applies one or two half lives to show fraction of initial activity/number after 10 days for one isotope (1) Or Use of exponential decay equation to show fraction of initial activity/number after 10 days for one isotope (1) - Demonstrates quantitatively that both isotopes have the same activity (1)	<u>Alternative approach:</u> $\lambda_{Ac} = \frac{\ln 2}{10} \quad A_{Ac} = \lambda_{Ac} N = \frac{\ln 2}{10} \times N$ After 10 days $A_{Ac} = \frac{1}{2} \times \frac{\ln 2}{10} \times N = \frac{\ln 2}{20} \times N$ $\lambda_{Bi} = \frac{\ln 2}{5} \quad A_{Bi} = \lambda_{Bi} N = \frac{\ln 2}{5} \times N$ After 10 days $A_{Bi} = \frac{1}{2} \times \frac{1}{2} \times \frac{\ln 2}{5} \times N = \frac{\ln 2}{20} \times N$ $A_{Ac} = A_{Bi}$ MP2 can be awarded for use of both decay constants in exponential decay equations All four marks may be awarded for a full mathematical demonstration, e.g.: $\lambda_{Ac} = \frac{\ln 2}{10} = 0.0693 \text{ day}^{-1} \quad A_{Ac} = \lambda_{Ac} N = 0.0693 \text{ day}^{-1} \times N$ 10 days: $A_{Ac} = \frac{1}{2} \times 0.0693 \text{ day}^{-1} \times N = 0.0345 \text{ day}^{-1} \times N$ $\lambda_{Bi} = \frac{\ln 2}{5} = 0.139 \text{ day}^{-1} \quad A_{Bi} = \lambda_{Bi} N = 0.139 \text{ day}^{-1} \times N$ 10 days: $A_{Bi} = \frac{1}{2} \times \frac{1}{2} \times 0.139 \text{ day}^{-1} \times N = 0.0345 \text{ day}^{-1} \times N$ $A_{Ac} = A_{Bi}$	4

(Total for Question 13 = 4 marks)



Question Number	Acceptable Answer				Additional Guidance	Mark																																																					
*4	<table border="1"><thead><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr></thead><tbody><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></tbody></table> Indicative content: IC1 The rate of decay depends upon the number of unstable nuclei in the sample ($A = -\lambda N$) IC2 Radium has a large half-life, so unstable nuclei are present in the sample for a long time IC3 When a nucleus decays there is a (small) decrease in mass Δm IC4 Energy is released according to $\Delta E = c^2 \Delta m$ IC5 Δm is small but c is large, so a significant amount of energy is released IC6 Energy released by the decay becomes kinetic energy of the atoms in the sample (hence sample is above the temperature of the surroundings)				IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The table shows how the marks should be awarded for indicative content and structure and lines of reasoning. <table border="1"><thead><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr></thead><tbody><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></tbody></table> <table border="1"><thead><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr></thead><tbody><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></tbody></table> IC2: accept idea that it takes a long time to decay for “unstable nuclei are present...or a long period of time” IC3 accept a reference to binding energy increasing		Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	
IC points	IC mark	Max linkage mark	Max final mark																																																								
6	4	2	6																																																								
5	3	2	5																																																								
4	3	1	4																																																								
3	2	1	3																																																								
2	2	0	2																																																								
1	1	0	1																																																								
0	0	0	0																																																								
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																																																										
6	4																																																										
5–4	3																																																										
3–2	2																																																										
1	1																																																										
0	0																																																										
	Number of marks awarded for structure of answer and sustained line of reasoning																																																										
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																																										
Answer is partially structured with some linkages and lines of reasoning	1																																																										
Answer has no linkages between points and is unstructured	0																																																										

6

(Total for Question 4 = 6 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark																																																				
4(a)	decay happens without any external stimulus Or decay is unaffected by external factors (such as temperature) (1)	Do not credit references to the randomness of the decay	1																																																				
*4(b)	This question assesses a student’s ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Indicative content: IC1 There is a fixed probability (λ) of an individual nucleus undergoing decay (in the next second) IC2 For a sample with large number of unstable nuclei there is a predictable pattern IC3 The fraction of nuclei decaying in the next second is equal to the decay constant (λ) IC4 Hence the number of nuclei decaying (in the next second) depends on the number of (unstable) nuclei Or activity = λN IC5 The number of unstable nuclei decreases exponentially (with time) Or number of (unstable) nuclei = $N_0 e^{-\lambda t}$ IC6 So the rate of decay decreases exponentially (with time) Or rate of decay = $A_0 e^{-\lambda t}$	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table><table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning <table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																																																						
6	4																																																						
5–4	3																																																						
3–2	2																																																						
1	1																																																						
0	0																																																						
	Number of marks awarded for structure of answer and sustained line of reasoning																																																						
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																																						
Answer is partially structured with some linkages and lines of reasoning	1																																																						
Answer has no linkages between points and is unstructured	0																																																						
IC points	IC mark	Max linkage mark	Max final mark																																																				
6	4	2	6																																																				
5	3	2	5																																																				
4	3	1	4																																																				
3	2	1	3																																																				
2	2	0	2																																																				
1	1	0	1																																																				
0	0	0	0																																																				

(Total for Question 4 = 7 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
18(a)	- Top line correct - Bottom line correct	<u>Example of equation</u> ${}_{55}^{137}\text{Cs} \rightarrow {}_{56}^{137}\text{Ba} + {}_{-1}^0\beta^{-} + {}_0^0\bar{\nu}_e$	2
18(b)(i)	- Use of $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ - Use of $A = -\lambda N$ $N = \frac{2.5 \times 10^4 \text{ Bq}}{7.30 \times 10^{-10} \text{ s}^{-1}} = 3.4 \times 10^{13}$	<u>Example of calculation</u> $\lambda = \frac{\ln 2}{9.5 \times 10^8 \text{ s}} = 7.30 \times 10^{-10} \text{ s}^{-1}$ $N = \frac{2.5 \times 10^4 \text{ Bq}}{7.30 \times 10^{-10} \text{ s}^{-1}} = 3.42 \times 10^{13}$	3
18(b)(ii)	- Use of $N = N_0 e^{-\lambda t}$ $t = 1.4 \times 10^8 \text{ s}$ (ecf λ from (b)(i))	<u>Example of calculation</u> $0.9 N_0 = N_0 e^{-7.30 \times 10^{-10} \text{ s}^{-1} \times t}$ $\therefore t = \frac{\ln 0.9}{-7.30 \times 10^{-10} \text{ s}^{-1}} = 1.44 \times 10^8 \text{ s}$	2

(Total for Question 18 = 7 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)	α radiation would be absorbed by the plastic bottle (1) β radiation can penetrate the plastic bottle therefore it could/must be β radiation (1)		2
8(b)(i)	- Smooth best fit curve drawn on graph (1) - Time for count rate to fall by half once (1) - Time for count rate to fall by half twice and mean time calculated (1) $t_{1/2} = 60 \text{ s} \rightarrow 80 \text{ s}$ (1)	Alternative approaches for MP2 and MP3 Read 2 values from graph and use exponential equation Or draw tangent to curve at $t = 0$ and read off the time intercept <u>Example of calculation</u> $9.0 \text{ s}^{-1} \rightarrow 4.5 \text{ s}^{-1} \quad t = 75 \text{ s}$ $4.5 \text{ s}^{-1} \rightarrow 2.25 \text{ s}^{-1} \quad t = 75 \text{ s}$ If background count is taken into consideration, t will be lower	4
8(b)(ii)	An explanation that makes reference to the following points: - There will be background radiation (1) Or decay is exponential and so count rate will “never” reach zero - The data logger output includes counts due to background radiation as well as the source radiation (1) Or The count rate can’t be corrected automatically	MP2: accept references to GM-tube	2

(Total for Question 8 = 8 marks)



Question Number	Acceptable answers	Additional guidance	Mark
21 (a)	- Top line correct (1) - Bottom line correct (1)	Example of calculation: ${}_{37}^{87}\text{Rb} \rightarrow {}_{38}^{87}\text{Sr} + {}_{-1}^0\beta^{-} + \bar{\nu}_e$	2
21 (b)	- Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) - Use of $N = N_0 e^{-\lambda t}$ (1) - Use of N_S/N_R to determine N/N_0 (1) $t = 3.7 \times 10^9$ year (1) - Comparison of their value with corresponding value in question and valid conclusion (1) Or - Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) - Use of $N = N_0 e^{-\lambda t}$ (1) - Use of N/N_0 to determine N_S/N_R (1) $\frac{N_S}{N_R} = 0.066$ if $t = \text{age of Earth}$ (1) - Comparison of their value with corresponding value in question and valid conclusion (1)	Example of calculation: $\lambda = \frac{\ln 2}{4.88 \times 10^{10} \text{ year}} = 1.42 \times 10^{-11} \text{ year}^{-1}$ $\frac{N_0}{N} = \frac{N_R + N_S}{N_R} = 1 + \frac{N_S}{N_R} = 1.0532$ $1.0532 = e^{1.42 \times 10^{-11} \text{ year}^{-1} \times t}$ $\therefore t = \frac{\ln(1.0532)}{1.42 \times 10^{-11} \text{ year}^{-1}} = 3.65 \times 10^9 \text{ year}$	5
21 (c)	- Because activity is small (and therefore difficult to measure) - Or because (significant) change in activity would take a long time (to measure) (1)	For activity accept, e.g. count rate, change in activity, decay rate, change in mass For change in activity accept e.g. number of decays, change in mass, change in N,	1



21 (d)	An explanation that makes reference to the following points: (1) Either • $t_{1/2}$ is larger, λ will be smaller (1) • $N = N_0 e^{-\lambda t}$ so the calculated value of time would be greater MP2 dependent upon MP1 OR • If half-life is larger, it would take more time for the ratio $\frac{N_S}{N_R}$ to reach the current value • Hence the rock would be older than originally determined. MP2 dependent upon MP1		2
--------	---	--	---

(Total for Question 21 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
18(a)(i)	- Use of $\lambda t_{1/2} = \ln 2$ (1) - Use of $dN/dt = -\lambda N$ (1) $N = 9.5 \times 10^{10}$ (1)	$\lambda \times (1600 \times 365 \times 24 \times 60 \times 60) \text{ s} = \ln 2$ $\lambda = 1.37 \times 10^{-11} \text{ s}^{-1}$ $1.3 \text{ Bq} = 1.37 \times 10^{-11} \text{ s}^{-1} \times N$ $N = 9.46 \times 10^{10}$	3
18(a)(ii)	- Use of $A = A_0 e^{-\lambda t}$ (1) - Use of $\ln A = \ln A_0 - \lambda t$ or equivalent (1) $t = 8.58 \times 10^{10} \text{ s} = 2700 \text{ years}$ (1)	ecf λ calculated in (i) $\ln 0.4 = \ln 1.3 - 1.37 \times 10^{-11} \text{ s}^{-1} \times t$ $t = 8.58 \times 10^{10} \text{ s} = 2721 \text{ years}$	3
18(b)	- attempt to determine mass difference between radium and radon-plus-alpha (1) - conversion to kg (1) - Use of $\Delta E = c^2 \Delta m$ (1) - Use of 1.6×10^{-19} factor (1) - Answer = 4.87 (MeV) (1)	$\Delta m = 225.97713 \text{ u} - (221.97040 \text{ u} + 4.00151 \text{ u})$ $= 5.22 \times 10^{-3} \text{ u} = 5.22 \times 10^{-3} \times 1.66 \times 10^{-27} \text{ kg}$ $= 8.67 \times 10^{-30} \text{ kg}$ $\Delta E = c^2 \Delta m = (3 \times 10^8 \text{ m s}^{-1})^2 \times 8.67 \times 10^{-30} \text{ kg}$ $= 7.80 \times 10^{-13} \text{ J}$ $\Delta E \text{ in MeV} = 7.80 \times 10^{-13} \text{ J} \div 1.6 \times 10^{-19} \text{ C}$ $= 4.87 \text{ MeV}$	5

(Total for Question 18 = 11 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16 (a) (i)	8 alpha (1) 6 beta (1)	<u>Example of calculation</u> $238 - 206 = 32$ $32 \div 4 = 8$ alpha $92 - 82 = 10, 8 \times 2 = 16$ $16 - 10 = 6$ beta	2
16 (a)(ii)	- Use of $\ln 2 = t_{1/2} \times \lambda$ (1) - Use of $N = N_0 e^{-\lambda t}$ (1) $t = 4.3 \times 10^9$ (year) (1)	<u>Example of calculation</u> $\ln 2 = 4.47 \times 10^9 \text{ year} \times \lambda$ $\lambda = 1.55 \times 10^{-10} \text{ year}^{-1}$ $53 = 103 e^{-1.55 \times 10^{-10} \text{ year}^{-1} \times t}$ $\ln 53 = \ln 103 - 1.55 \times 10^{-10} \text{ year}^{-1} \times t$ $t = 4.3 \times 10^9 \text{ year}$	3
16 (b)	- Use of $V_{\text{grav}} = -GM/R$ (1) - Calculate $\Delta V_{\text{grav}} = V_{\text{grav Moon}} - V_{\text{grav Earth}}$ (1) - Use of $m \Delta V_{\text{grav}} = E_k = \frac{1}{2} mv^2$ (1) $v = 11\,000 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $V_{\text{grav}} = -6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-1} \times 5.97 \times 10^{24} \text{ kg} / 6\,370\,000 \text{ m} = -62.5 \text{ MJ kg}^{-1}$ $\Delta V_{\text{grav}} = -62.5 \text{ MJ kg}^{-1} - (-1.28 \text{ MJ kg}^{-1}) = -61.2 \text{ MJ kg}^{-1}$ $\frac{1}{2} v^2 = 61.2 \text{ MJ kg}^{-1}$ $v = 11\,100 \text{ m s}^{-1}$	4
16(c)	- Use of $F = Gm_1m_2/r^2$ and $F = mv^2/r$ (1) - Use of $v = 2\pi r/T$ (1) $T = 488\,000 \text{ s} = 5.7 \text{ days}$ (1) OR - Use of $F = Gm_1m_2/r^2$ and $F = m\omega^2 r$ - Use of $\omega = 2\pi/T$ $T = 488\,000 \text{ s} = 5.7 \text{ days}$	'Use of' can be with any mass m for the orbiting body, or by algebraic combination with no m <u>Example of calculation</u> $F = GMm/r^2 = mv^2/r$ $GM/r^2 = v^2/r$ $v = 2\pi r/T$ $T^2 = 4\pi^2 r^3 / GM$ $= 4\pi^2 (1.34 \times 10^8 \text{ m})^3 / 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-1} \times 5.97 \times 10^{24} \text{ kg} = 2.39 \times 10^{11} \text{ s}^2$ $T = 488\,000 \text{ s} = 5.7 \text{ days}$	3

(Total for Question 16 = 12 marks)



Question Number	Acceptable answers	Additional guidance	Mark
19(a)	- top: 40, 0 (1) - bottom: 20, -1 (1)		2
19(b)(i)	- Use of ratio of atoms and atoms per g (1) - Number of nuclei = 2.9×10^{17} (1)	$N = 0.3 \text{ g} \times 8.1 \times 10^{21} \text{ g}^{-1} \times 0.012/100$ $= 2.9 \times 10^{17}$	2
19(b)(ii)	- use of $\ln 2 = \lambda t_{1/2}$ (1) - use of activity = λN (ecf from (b)(i)) (1) - activity = 5.1 (Bq) (use of show that value gives 5.3 Bq) (1)	$\ln 2 = \lambda \times 1.25 \times 10^9 \text{ years}$ $= \lambda \times (1.25 \times 10^9 \times 365 \times 24 \times 60 \times 60) \text{ s}$ $\lambda = 1.76 \times 10^{-17} \text{ s}^{-1}$ $A = 1.76 \times 10^{-17} \text{ s}^{-1} \times 2.9 \times 10^{17}$ $= 5.1 \text{ Bq}$	3
19(b)(iii)	- use of count rate = (counts – background counts) / time (1) - calculates percentage of activity from (b)(ii) (1) Or applies 7.5% to activity from (b)(ii) - Comparative statement consistent with their values (1)	MP3 can only be awarded if Activity from (ii) is used. A clear comparison with the corresponding value must be made e.g. percentage = 0.8 % which is < 7.5 % so not efficient Or detects 176 but should detect 379 counts in 10 min, so not efficient Or should detect a rate of at least 0.63 Bq, so not efficient <u>Example of calculation</u> Recorded count rate = $(176 - 150) \div 600 \text{ s}$ $= 0.04 \text{ Bq}$ $0.04 \text{ Bq} \times 100 \div 5.1 \text{ Bq}$ $= 0.78 \%$ (ecf from (b)(ii) for MP3)	3

19(b)(iv)	Max two from • emissions are in all directions (1) • some emitted particles may be absorbed by the material in the sample (1) • some emitted particles may be absorbed by the window (1) • some emitted particles pass (right) through detector (1)		2
19(c)	• so the proportion of unstable nuclei does not change significantly over time (1) Or activity does not change significantly over time		1

(Total for Question 19 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark
18 (a)	- Alpha won't penetrate the plastic so the gas can't escape (1) - Alpha won't penetrate the plastic so there is no risk (1)	For MP1, accept answers in terms of the small range of alpha particles in the air in the bag	2
18(b)(i)	- Calculate no of nuclei (1) - Use of $\ln 2 = t \frac{1}{2} \times \lambda$ (1) - Use of $A = \lambda N$ (1) $A = 3.97 \times 10^4 \text{ Bq}$ (1)	<u>Example of calculation</u> $N = (5.18 \times 10^{-5} \text{ g} / 230 \text{ g}) \times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7) \text{ s} = \ln 2$ $\lambda = 2.92 \times 10^{-13} \text{ s}^{-1}$ $A = 2.92 \times 10^{-13} \text{ s}^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4 \text{ Bq}$	4
18 (b)(ii)	- Calculates decays in one year (ecf from (b)(i)) (1) - Use of $pV = NkT$ (1) - uses $T = 295 \text{ K}$ (1) $V = 5.09 \times 10^{-14} \text{ m}^3$ (1)	<u>Example of calculation</u> ecf λ from (a) decays in one year $= 3.97 \times 10^4 \text{ Bq} \times 3.15 \times 10^7 \text{ s}$ $= 1.25 \times 10^{12}$ $1.00 \times 10^5 \text{ Pa} \times V = 1.25 \times 10^{12} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 295 \text{ K}$ $V = 5.09 \times 10^{-14} \text{ m}^3$	4
18 (b)(iii)	- Use of $\frac{1}{2} m \langle c^2 \rangle = 3/2 kT$ (1) - Or Use of $pV = \frac{1}{3} Nm \langle c^2 \rangle$ (allow ecf for N, V from (b)(ii)) (1) - uses $m = 4u$ (1) $\sqrt{\langle c^2 \rangle} = 1360 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $\frac{1}{2} m \langle c^2 \rangle = 3/2 kT$ $\frac{1}{2} \times (4 \times 1.66 \times 10^{-27} \text{ kg}) \times \langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 295 \text{ K}$ $\langle c^2 \rangle = 1\,840\,000 \text{ m}^2 \text{ s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 1360 \text{ m s}^{-1}$ Accept the use of proton/neutron mass instead of u	3

(Total for Question 18 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark
19(a)(i)	(Spontaneous) – independent of external conditions (1) (Random) – cannot predict when a decay will occur (1)	Accept cannot tell which nucleus will decay next	2
19(a)(ii)	- The probability of decay (in a specified time) may be determined (1) (Probability may be applied accurately because) very large numbers are involved (1)	For MP1 accept reference to the proportion of nuclei decaying at a specified time	2
19(b)	A description that makes reference to the following points: - Measure the background count (rate) (1) - Measure count (rate) from source (1) - Use paper to absorb alpha radiation (1) - Percentage = $\frac{\text{count with paper}(-\text{background rate})}{\text{count from source}(-\text{background rate})} \times 100$ (1)		4
19(c)(i)	- Use of $\ln 2 = \lambda t_{1/2}$ (1) - Use of $A = A_0 e^{-\lambda t}$ (1) - Expected percentage of $A_0 = 95\%$ (1)	<u>Example of calculation</u> $\lambda = \ln 2 / 432 \text{ years} = 1.6 \times 10^{-3} \text{ y}^{-1}$ $A / A_0 = e^{-(1.6 \times 10^{-3} \text{ y}^{-1} \times 34 \text{ y})}$ $(A / A_0) \times 100 \% = 94.7 \%$	3



19(c)(ii)	- Beta is only emitted after the decay of neptunium to protactinium (1) Or Americium and neptunium only emit alpha (1) - The half-life of <u>neptunium</u> is very long (1) - There will only be a very small proportion of protactinium (relative to americium and neptunium), so the suggestion is incorrect Or Only 5% of the americium has decayed so the proportion of protactinium is very small, so the suggestion is incorrect	Accept amount for proportion	3
-----------	--	------------------------------	---

(Total for Question 19 = 14 marks)

TOTAL FOR PAPER 2 = 60 MARKS



Question Number	Acceptable answers	Additional guidance	Mark
20 (a)(i)	- Use of $\ln 2 = \lambda t_{1/2}$ (1) $\lambda = 4.92 \times 10^{-18} \text{ (s}^{-1}\text{)}$ (1)	<u>Example of calculation</u> $\lambda = \ln 2 / 1.41 \times 10^{17} \text{ s}$ $= 4.92 \times 10^{-18} \text{ s}^{-1}$	2
20 (a)(ii)	- Calculate rate = counts / time (1) - Subtract background radiation (1) - Use of $A = -\lambda N$ (1) - Calculates $N \times$ atomic mass (1) - Calculates percentage by mass (1) - Answer = 0.17 % (ecf for λ from (a)(i)) (1)	<u>Example of calculation</u> background rate = $525 / (10 \times 60) \text{ s} = 0.875 \text{ s}^{-1}$ vase count rate = $3623 / (5 \times 60) \text{ s} = 12.077 \text{ s}^{-1}$ corrected rate = 11.2 s^{-1} for whole vase = $11.2 \text{ s}^{-1} \times 0.0177 \text{ m}^2 / 6.36 \times 10^{-5} \text{ m}^2$ $= 3117 \text{ s}^{-1}$ $N = 3117 / 4.91 \times 10^{-18} \text{ s}^{-1} = 6.348 \times 10^{20}$ Mass = $6.348 \times 10^{20} \times 238 \times 1.66 \times 10^{-27} \text{ kg} = 2.51 \times 10^{-4} \text{ kg}$ Percentage = $2.51 \times 10^{-4} \text{ kg} \times 100 / 0.149 = 0.17 \%$	6

20 (a)(iii)	Max 2 from: - Alpha particles could have been absorbed by the glass (1) - Alpha particles will be emitted in all directions, not just towards the detector (1) - Some alpha particles could have been detected from other parts of the vase (1) - The count could include radiation from decay products (1) - Some alpha particles could be absorbed by the GM tube window (1)		2
20 (b)	- Calculates change in mass (1) - Converts from u to kg (1) - Use of $\Delta E = c^2 \Delta m$ (1) - Use of $E_k = \frac{1}{2} mv^2$ (1) $v = 1.4 \times 10^7 \text{ m s}^{-1}$ (1)	Example of calculation $\Delta m = 238.0003u - (233.9942 + 4.0015)u$ $= 0.00463 \times 1.66 \times 10^{-27} \text{ kg}$ $= 7.636 \times 10^{-30} \text{ kg}$ $\Delta E = (3.00 \times 10^8 \text{ m s}^{-1})^2 \times 7.636 \times 10^{-30} \text{ kg}$ $= 6.872 \times 10^{-13} \text{ J}$ $6.872 \times 10^{-13} \text{ J} = \frac{1}{2} (4.0015 u) v^2$ $v = 1.4 \times 10^7 \text{ m s}^{-1}$	5

(Total for Question 20 = 15 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
12(a)(i)	- Top line correct (1) - Bottom line correct (1)	<u>Example of equation</u> ${}_{55}^{137}\text{Cs} \rightarrow {}_{56}^{137}\text{Ba} + {}_{-1}^0\beta^{-} + {}_0^0\bar{\nu}_e$	2
12(a)(ii)	- Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ (1) - Use of 5000 m³ (1) - Use of $A = A_0 e^{-\lambda t}$ (1) $t = 1400$ year (1)	<u>Example of calculation</u> $\lambda = \frac{\ln 2}{30 \text{ year}} = 0.0231 \text{ year}^{-1}$ $100 \text{ Bq} = (5000 \times 2.35 \times 10^{12}) \text{ Bq} \times e^{-0.0231 \text{ year}^{-1} \times t}$ $\therefore t = \frac{\ln (8.51 \times 10^{-15})}{-0.0231 \text{ year}^{-1}} = 1402 \text{ year}$	4
12(b)	- Calculation of number of half-lives elapsed (1) - Use of number of half-lives to calculate number of iodine nuclei remaining (1) - Calculation of number of iodine nuclei decayed (1) - Conversion of temperature to kelvin (1) - Use of $pV = NkT$ (1) - Pressure is 1.1×10^5 Pa (compared with 1.0×10^5) and so there is sufficient gas Or 1.1×10^{28} gas atoms needed to give required pressure compared with 1.2×10^{28} actual gas atoms, so there is sufficient gas (1)	MP1 & MP2: Allow use of $\lambda = \frac{\ln 2}{t_{1/2}}$ and $A = A_0 e^{-\lambda t}$ <u>Example of calculation</u> $N = \frac{N_0}{2^4} = \frac{1.25 \times 10^{28}}{16} = 7.81 \times 10^{26}$ $N = 1.25 \times 10^{28} - 7.81 \times 10^{26} = 1.17 \times 10^{28}$ $p \times 450 \text{ m}^3 = 1.17 \times 10^{28} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times (20 + 273) \text{ K}$ $\therefore p = \frac{4.73 \times 10^7 \text{ J}}{450 \text{ m}^3} = 1.05 \times 10^5 \text{ Pa}$	6

12(c)	- Maximum value of a read from graph [$8 \text{ m s}^{-2} \rightarrow 9 \text{ m s}^{-2}$] (1) - Value for period determined from time for at least 3 cycles (1) - Use of $\omega = \frac{2\pi}{T}$ (1) - Use of $a = (-)A\omega^2 \cos \omega t$ (1) $A = 0.33 \text{ m}$, so report is correct [Accept value for A in range $0.25 \text{ m} \rightarrow 0.40 \text{ m}$ with appropriate conclusion] (1)	<u>Example of calculation</u> $T = \frac{(89.2 - 81.0) \text{ s}}{7} = 1.2 \text{ s}$ $\omega = \frac{2\pi}{1.2 \text{ s}} = 5.2 \text{ rad s}^{-1}$ $x = \frac{a}{\omega^2} = \frac{9 \text{ m s}^{-2}}{(5.2 \text{ rad s}^{-1})^2} = 0.33 \text{ m}$	5
-------	---	---	---

(Total for Question 12 = 17 marks)



Question Number	Acceptable answer	Additional guidance	Mark
3	D	The only correct answer is D : the binding energy per nucleon curve shows an increase for both processes A is not correct because both processes show decreases B is not correct because fission shows a decrease C is not correct because fusion shows a decrease	1



Question Number	Acceptable answer	Additional guidance	Mark
2	C	The only correct answer is C because X is a smaller nucleus for which the binding energy per nucleon could increase through a process of fusion and Y is a larger nucleus for which the binding energy per nucleon could increase through a process of fission A I not correct because it states fission for both X and Y B is not correct because the processes are reversed D is not correct because it states fusion for both X and Y	1



Question Number	Answers	Mark
6	The only correct answer is C <i>A is incorrect because the energy is calculated in eV</i> <i>B is incorrect because the mass and energy conversions are incorrect</i> <i>D is incorrect because the mass conversion is incorrect</i>	1



Question Number	Answer	Mark
6	The only correct answer is C <i>A is not correct because smaller nuclei do not undergo fission</i> <i>B is not correct because larger nuclei do not undergo fusion</i> <i>D is not correct because larger nuclei do not undergo fusion</i>	1



Question Number	Acceptable answers	Additional guidance	Mark
14(a)	- Fusion involves an increase in binding energy (per nucleon) as the number of nucleons increases (1) - Fission involves an increase in binding energy (per nucleon) as the number of nucleons decreases (1) - If binding energy per nucleon increases energy is released in the process (1)	Accept reference to larger/smaller nuclei for number of nucleons increases/decreases	3
14(b)	An explanation that makes reference to: - Identifies (very) high temperature and (very) high density (1) (Very) high temperature to provide enough energy to overcome the (electrostatic) repulsive force between nuclei (1) (Very) high density to give big enough collision rate to maintain reaction (1)	Accept pressure for density in MP1 Accept correct reference to strong force	3

(Total for Question 14 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark																																								
*13	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	The following table shows how the marks should be <table><tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> awarded for structure and lines of reasoning. Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	6
		Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark																																						
		6	4	2	6																																						
		5	3	2	5																																						
		4	3	1	4																																						
		3	2	1	3																																						
		2	2	0	2																																						
		1	1	0	1																																						
		0	0	0	0																																						
			Number of marks awarded for structure of answer and sustained line of reasoning																																								
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																										
Answer is partially structured with some linkages and lines of reasoning	1																																										
Answer has no linkages between points and is unstructured	0																																										



	Indicative content: • Requires a (very) high temperature • Nuclei all have positive charge leading to a large repulsive force between nuclei • At high temperature nuclei have high <u>kinetic</u> energy, sufficient to overcome repulsion • Nuclei must get close enough to fuse (accept reference to close enough for strong force) • Requires (very) high density • Collision rate must be high enough to sustain fusion		
--	--	--	--

(Total for Question 13 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark
13(a)	Max three from: • Very high temperatures (1) • High magnetic flux density (1) • Bombardment by neutrons (1) • Material is a plasma or material is fully ionised (1)	Accept $T \sim 10^7 \text{ K} - 10^8 \text{ K}$ for MP1 Accept conditions for stars: High density High pressure	3
13(b)	An explanation that makes reference to the following points: • Small(er) nuclei fuse to form larger nuclei (1) • The binding energy (per nucleon) increases releasing energy or mass deficit increases and $\Delta E = c^2 \Delta m$ (1) • Comparison of values from the graph (1)	Example comparison: Calculation of $\Delta E_{\text{binding}}$, e.g. From 5.2 MeV at 12 nucleons to 8.7 MeV at 50 nucleons; H to He is 7 MeV;	3

(Total for Question 13 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark
18(a)	- Calculates change in mass (1) - Converts from u to kg (1) - Use of $\Delta E = c^2 \Delta m$ (1) 2.8×10^{-12} J (1)	<u>Example of calculation</u> $\Delta m = ((2.013553 + 3.015501) - (4.001506 + 1.008665))u$ $= 0.01883 \times 1.66 \times 10^{-27} \text{ kg}$ $= 3.13 \times 10^{-29} \text{ kg}$ $\Delta E = (3.00 \times 10^8 \text{ m s}^{-1})^2 \times 3.13 \times 10^{-29} \text{ kg}$ $= 2.8 \times 10^{-12} \text{ J}$	4
18 (b)	- High temperature so sufficient (kinetic) energy to overcome the repulsion between (positively charged) ions/nuclei (1) - High density to ensure ions close enough to each other to maintain collision rate to maintain fusion (1)		2
18 (c)(i)	- Use total mass / mass of D ion (1) - Use of $pV = NkT$ (1) $p = 2.8 \times 10^4 \text{ Pa}$ (1)	<u>Example of calculation</u> $N = 5.0 \times 10^{-6} \text{ kg} / 3.3 \times 10^{-27} \text{ kg} = 1.5 \times 10^{21}$ $p = 1.5 \times 10^{21} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 130\,000\,000 \text{ K} / 98 \text{ m}^3$ $= 2.77 \times 10^4 \text{ Pa}$	3
18 (c)(ii)	- Use of $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ (1) Or $pV = \frac{1}{3} (Nm \langle c^2 \rangle)$ (ecf for N and p from (i)) (1) $\sqrt{\langle c^2 \rangle} = 1.3 \times 10^6 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ $\frac{1}{2} \times (3.3 \times 10^{-27} \text{ kg}) \times \langle c^2 \rangle = \frac{3}{2} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 130\,000\,000 \text{ K}$ $\langle c^2 \rangle = 1.6 \times 10^{12} \text{ m}^2 \text{ s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 1.28 \times 10^6 \text{ m s}^{-1}$	2
18 (c)(iii)	- Use of $\Delta \lambda / \lambda = v/c$ to determine $\Delta \lambda$ (1) - Adds shift to original wavelength (1) $1.075 \times 10^{-6} \text{ m}$ (1)	<u>Example of calculation</u> $\Delta \lambda / 1.064 \times 10^{-6} \text{ m} = 15 \times 10^6 \text{ m s}^{-1} / 3.00 \times 10^8 \text{ m s}^{-1}$ $\Delta \lambda = 5.3 \times 10^{-9} \text{ m}$ $\lambda + 2\Delta \lambda = 1.075 \times 10^{-6} \text{ m}$	3

(Total for Question 18 = 14 marks)

