Name: ____

Topic 11: Nuclear Radiation Part 1

Date:

Time:

Total marks available:

Total marks achieved: ______

Questions

Q1.

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.

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 $^{238}_{92}U$ becomes the lead isotope $^{206}_{82}Pb$ through a series of radioactive decays.

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

(2)

....

....

....

....

Number of α particles = ...

Number of β particles = ...

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

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

There was no lead in the rock when it formed, so all the $^{206}_{82}Pb$ in the sample is a product of $^{238}_{92}U$ 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)

....

....

....

....

....

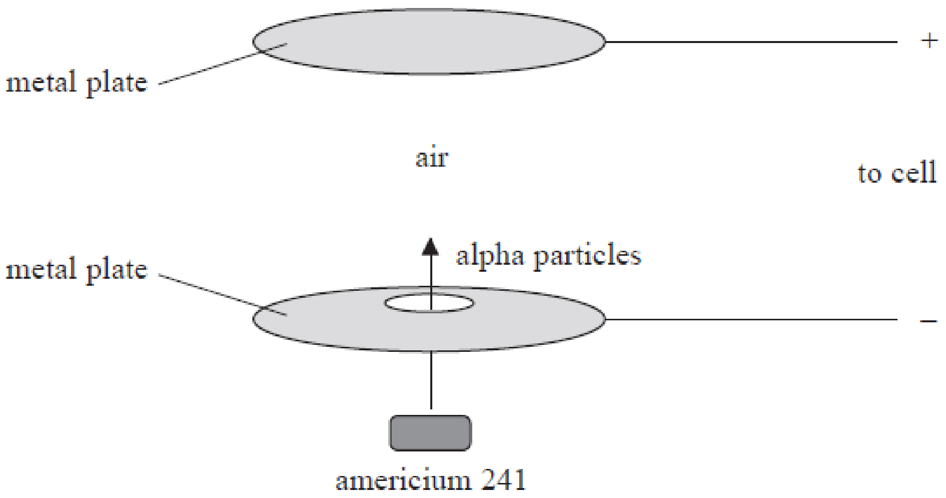
....

(Total for question = 5 marks)

Q2.

Some types of smoke detector contain a radioactive isotope of americium, ^{241}Am. The nuclei of ^{241}Am decay by emitting an alpha particle.

The diagram shows part of a smoke detector.
The detectors use a small amount of ^{241}Am to make the air between two metal plates conduct charge.



(a) (i) Explain why a stream of alpha particles will cause charge to flow between the metal plates.

(2)

....

....

....

....

(ii) Suggest how smoke particles entering the space between the plates will cause the current to decrease.

(1)

....

....

(b) (i) The decay of ^{241}Am is said to be random and spontaneous.
State what is meant by random and spontaneous.

(2)

Random

....

....

Spontaneous

....

....

(ii) Complete the equation for the decay of ^{241}Am.

(2)

$$^{241}_{\dots}\text{Am} \rightarrow {}^{\dots}_{93}\text{Np} + {}^{\dots}_{\dots}\alpha$$

(Total for question = 7 marks)

Q3.

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 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)

....

....

....

....

....

....

....

....

....

....

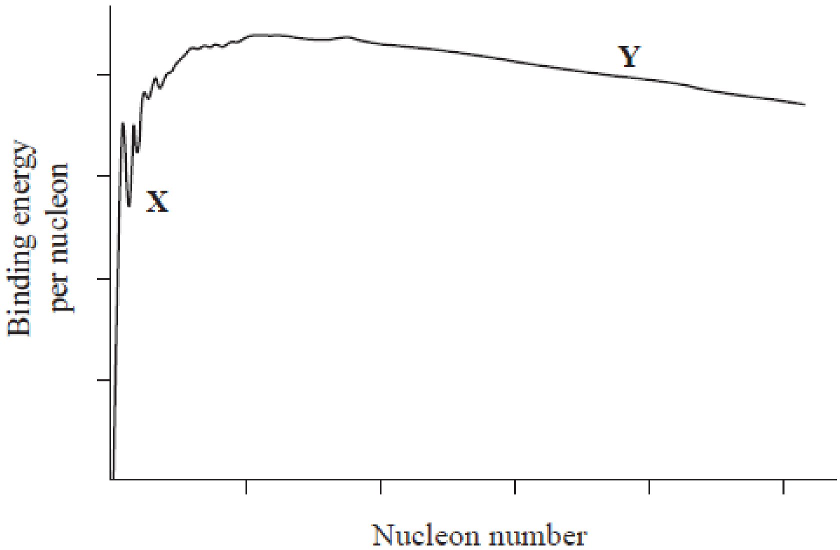
Speed of alpha particle = ...

(Total for question = 5 marks)

Q4.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 = 1 mark)

Q5. When measuring the count rate from a radioactive source it is usual to also measure the background count rate.

The background count rate must be

☒ **A** as large as possible for an accurate experiment.

☒ **B** measured when the source is in place.

☒ **C** recorded for the same time as the count rate.

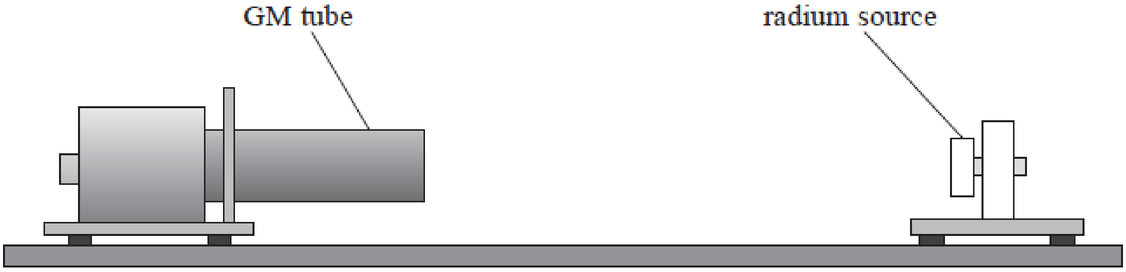
☒ **D** subtracted from the count rate measured from the source.

(Total for Question = 1 mark)

Q6.

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

Criticise the student's method for determining the count at this position.

(3)

....

....

....

....

....

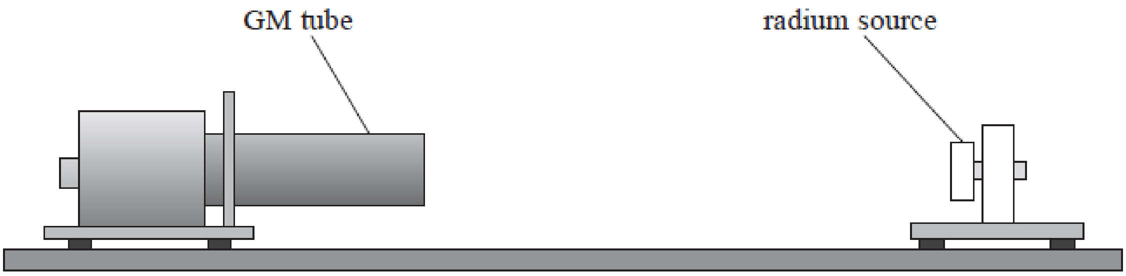
....

(Total for question = 3 marks)

Q7.

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

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)

....

....

....

....

....

....

....

....

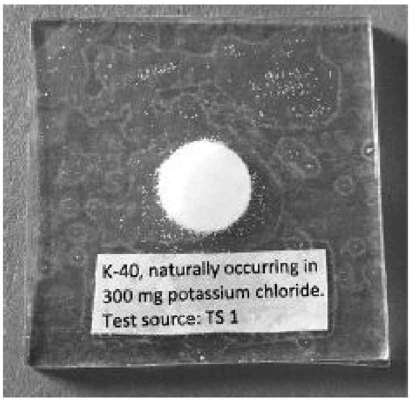
....

....

(Total for question = 5 marks)

Q8.

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.

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 = 1 mark)

Q9.

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 = 1 mark)

Q10.

In a nuclear fission reaction in power station, a slow-moving neutron is absorbed by a nucleus of U-235
The fission reaction produces nuclei of barium-141 and krypton-92

The equation for the reaction is:

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

Use the data in the table to calculate the energy, in joules, released in this fission reaction.

(3)

	Mass/u
neutron	1.008665
uranium-235	235.0439
barium-141	140.9144
krypton-92	91.9262

....

....

....

....

....

....

....

....

Energy = ... J

(Total for question = 5 marks)

Q11.

(a) In 1939 Hans Bethe published a paper describing the fusion processes in stars.

In the proton-proton cycle, hydrogen is converted to helium in stages. The nuclear equation below represents one of the stages.

$$^{7}_{3}\text{Li} + {}^{\cdots}_{\cdots}\text{X} \rightarrow 2 \times {}^{4}_{2}\text{He}$$

(i) Complete the equation and identify X.

(2)

X is ....

(ii) Calculate, in joules, the energy emitted in this stage of the cycle.

(3)

	Mass / MeV/c^2
Proton	938.3
Neutron	939.6
Helium	3727.4
Lithium	6533.8

....

....

....

....

....

....

Energy = ... J

(b) In 1967 Bethe received a Nobel Prize in Physics for his work on understanding the fusion processes in stars.

Explain why sustainable fusion has not yet been achieved for the generation of electrical power.

(4)

....

....

....

....

....

....

....

Q12.

All living organisms contain ^{12}C and radioactive ^{14}C. The concentration of ^{14}C in the organism is maintained whilst the organism is alive, but starts to fall once death has occured.

(a) The count rate obtained from wood from an old Viking ship is 14.7 min^{-1} per gram of wood, after being corrected for background radiation. The corrected count rate from similar living wood is 16.5 min^{-1} per gram of wood

Calculate the age of the ship in years.

^{14}C. has a half life of 5700 years.

(4)

....

....

....

....

....

....

....

....

Age of ship = ...years

(b) The concentration of ^{14}C in living organisms might have been greater in the past.

Explain how this would affect the age that you have calculated.

(2)

....

....

....

....

....

....

(Total for question = 6 marks)

Q13.

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.

Give reasons why the sealed plastic bag is suitable for collecting the gas.

(2)

....

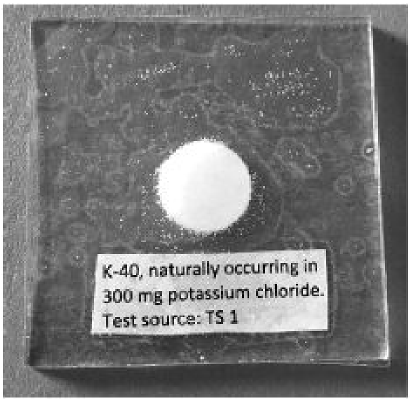
....

....

(Total for question = 2 marks)

Q14.

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.

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

Complete the nuclear equation for this decay.

(2)

$$^{40}_{19}\text{K} \rightarrow {}^{\cdots}_{\cdots}\text{Ca} + {}^{\cdots}_{\cdots}\beta$$

(Total for question = 2 marks)

Q15.

A number of conditions must be met if the fusion of hyrdrogen nuclei is to occur. Which condition, in a sample of hydrogen, is **not** neccesary for nuclear fusion to occur

☒ **A** very high density

☒ **B** very high mass

☒ **C** very high pressure

☒ **D** very high temperature

(Total for question = 1 marks)

Q16.

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.

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

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)

....

....

....

....

....

....

(Total for question = 2 marks)

Q17.

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.

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

half-life of uranium = 1.41×10^{17} s

(2)

....

....

....

....

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

area of GM tube window = 6.36×10^{-5} 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)

....

....

....

....

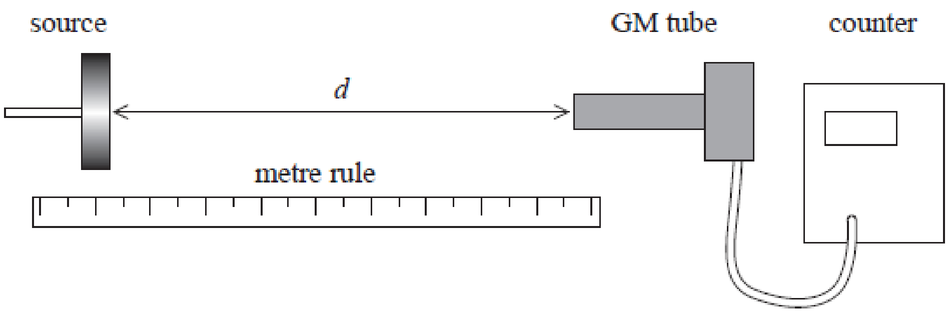
....

....

(Total for question = 10 marks)

Q18.

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.

Describe how to determine the corrected count rate from the source.

(2)

....

....

....

....

(Total for question = 2 marks)

Q19.

Radioactive decay is sometimes described as being spontaneous. In this context spontaneous means

- **A** nothing can influence the decay.
- **B** the decay is random.
- **C** the decay can be predicted.
- **D** the decay is exponential.

(Total for question = 1 marks)

Q20.

The photograph shows the containers of two radioactive sources kept in a school.

The isotope Ra 226 undergoes a series of decays until it produces the stable isotope Pb 206.

Determine the number of α particles and β particles emitted during this process to complete the nuclear equation.

(3)

....

....

....

$$^{226}_{88}\text{Ra} \rightarrow \, ^{206}_{82}\text{Pb} + \ldots\ldots \times \ldots\ldots\ \alpha + \ldots\ldots \times \ldots\ldots\ \beta$$

Q21.

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.

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 = 5 marks)

Q22.

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.

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

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

Show that a single fusion reaction releases about 3×10^{-12} 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)

....

....

....

....

....

....

....

....

(Total for question = 4 marks)

Q23.

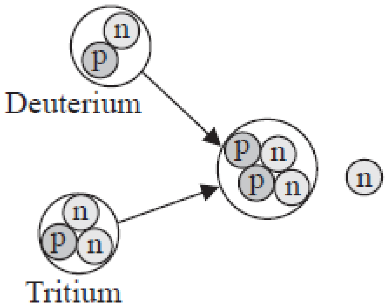
The following passage is adapted from a recent article in a British newspaper:

"Every year, one typical coal-fired power station devours several million tonnes of fuel and produces even more carbon dioxide. That volume of carbon dioxide is damaging the atmosphere and, in the longer term, the fuel will run out. It is clear that the world needs an alternative for generating energy.

Nuclear fusion looks like offering a solution to the problem. Using the equivalent of a bath tub of water, fusion has the potential to deliver the same amount of energy as 100 tonnes of coal. There would be no carbon dioxide emission, it would be inherently very safe, and would not produce any significant radioactive waste."

(Adapted from an article in The Observer newspaper, Sunday 16th September 2012)

(a) The latest proposed fusion reactor will fuse deuterium and tritium, which are isotopes of hydrogen. This fusion reaction is illustrated below.



(i) Complete the nuclear equation below to represent this fusion reaction.

(2)

$$^{\dots}_{\dots}\text{H} + ^{\dots}_{\dots}\text{H} \rightarrow ^{\dots}_{\dots}\text{He} + ^{\dots}_{\dots}\text{n}$$

(ii) Calculate the energy released in the fusion of one deuterium nucleus with one tritium nucleus.

Particle	Mass / GeV/c^2
Proton	0.938272
Neutron	0.939566
Deuterium	1.875600
Tritium	2.808900
Helium	3.727400

(2)

....

....

....

Energy released = ...

(iii) Explain why most of the energy released in the fusion of one deuterium nucleus with one tritium nucleus is transferred to kinetic energy of the neutron.

(3)

....

....

....

....

....

....

(b) A sample of tritium is produced. Tritium is unstable and decays by β^- emission with a half-life of 12.3 years.

Calculate the time taken, in years, for the activity of the sample to fall to 10% of its initial value.

(3)

....

....

....

....

....

....

....

....

....

Time taken = ... years

*(c) The article states that "it would be inherently very safe, and would not produce any significant radioactive waste."

Comment on this statement and outline the technical difficulties of producing a practical nuclear fusion reactor.

(5)

....

....

....

....

....

....

....

....

....

....

(Total for question = 15 marks)

Q24.

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.

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

(3)

....

....

....

....

....

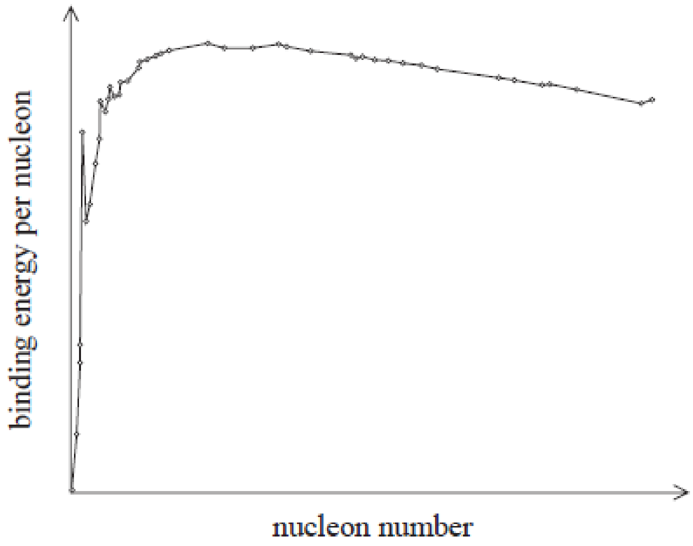
....

(Total for question = 3 marks)

Q25.

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.

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)

....

....

....

....

....

....

(Total for question = 3 marks)

Q26.

The photograph shows a tea cup on a saucer.

© Inter Ikea Systems B.V.

A student notices that walking with this sort of tea cup when it is filled with tea is particularly difficult to do without spilling it.

While walking, the tea starts to oscillate from side to side in the cup, rapidly increasing in amplitude and spilling over the edge.

The student develops the hypothesis that spillage occurs most when the frequency of the steps taken by a person matches the natural frequency of oscillation of tea in the cup.

(a) Explain whether the student's hypothesis is supported by relevant physics.

(4)

....

....

....

....

....

....

....

....

(Total for question = 4 marks)

Q27.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 = 1 mark)

Q28.

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.

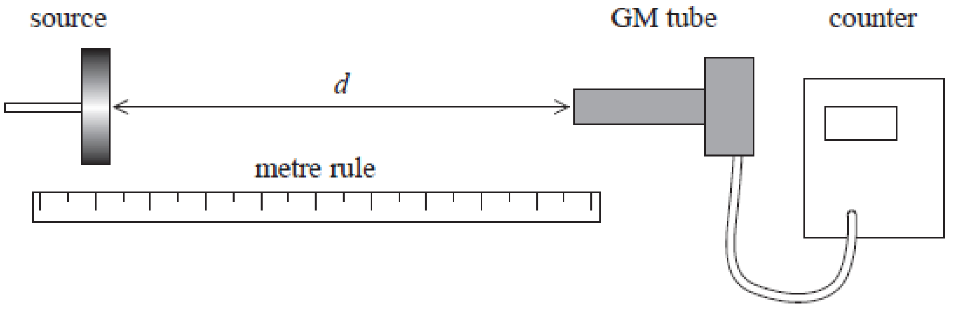


Figure 1

The student recorded the count for 2 minutes.

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

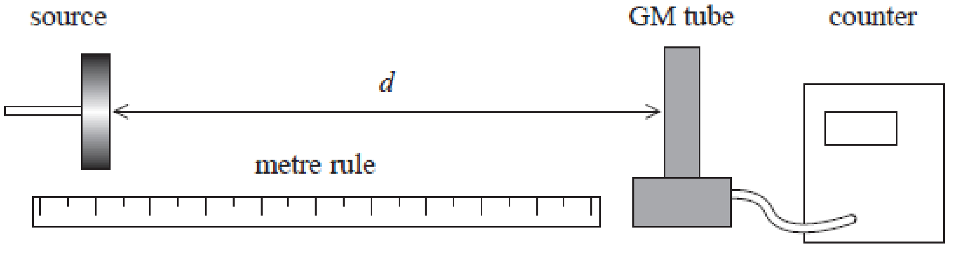


Figure 2

It is suggested that the investigation into the way in which gamma radiation spreads out from a source, using the apparatus as shown in **Figure 2**, could be carried out successfully using a radium-226 source.

Radium-226 emits α, β and γ radiation.

Justify this suggestion.

(2)

....

....

....

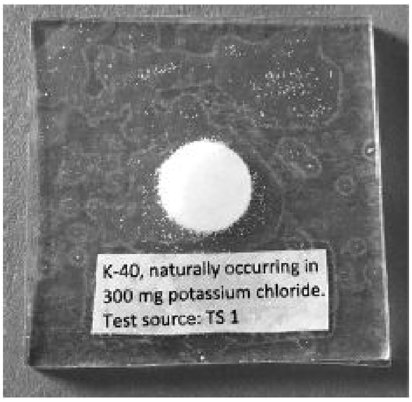
....

....

(Total for question = 2 marks)

Q29.

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 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)

....

....

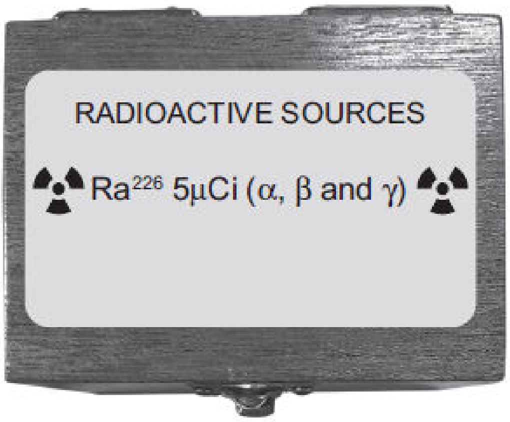
....

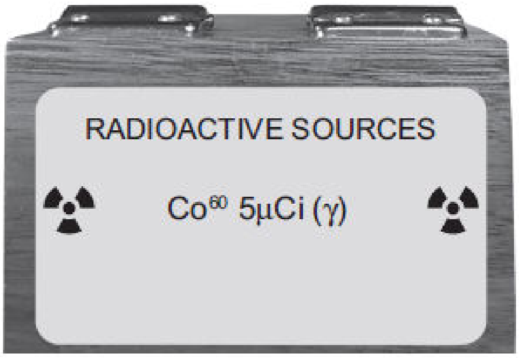
....

(Total for question = 10 marks)

Q30.

The photograph shows the containers of two radioactive sources kept in a school.





The sources are tested every year and a record of the activity of the sources has to be kept.

The school has incomplete records. The table shows the test entries for cobalt for 2015 and for a year X, which is the year the source was purchased.

Year	Background: counts in 60 s	Source: counts in 60 s
X	22	12227
2015	15	322

The school records show that sources were purchased in 1980, 1987 and 1995, but there is no record of which source was purchased in which year.

(i) Determine the age of the cobalt source in order to establish in which year the school purchased this source.

half-life of Co 60 = 5.3 years

(5)

....

....

....

....

....

....

....

....

....

....

Year = ...

(ii) Explain a factor that may affect the reliability of this date.

(2)

....

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• 8 alpha (1) • 6 beta (1)	Example of calculation 238–206 = 32 32 ÷ 4 = 8 alpha 92–82 = 10, 8 × 2 = 16 16 – 10 = 6 beta	2
(ii)	• Use of $\ln 2 = t_{½} \times \lambda$ (1) • Use of $N = N_0 e^{-\lambda t}$ (1) • $t = 4.3 \times 10^9$ (year) (1)	Example of calculation $\ln 2 = 4.47 \times 10^9$ year $\times \lambda$ $\lambda = 1.55 \times 10^{-10}$ year^{-1} $53 = 103\ e^{-1.55 \times 10^{-10}\ \text{year}^{-1} \times t}$ $\ln 53 = \ln 103 - 1.55 \times 10^{-10}$ year$^{-1} \times t$ $t = 4.3 \times 10^9$ year	3

Q2.

Question Number	Answer		Mark
(a)(i)	Alpha particles ionise the air **Or** alpha particles strip electrons from air molecules The ions/electrons move (in the electric field between the plates)	 (1) (1)	2
(a)(ii)	Smoke particles capture electrons (and reduce the free charge able to move) **Or** alpha particles collide with smoke particles and reduce amount of ionisation	 (1)	1
(b)(i)	Random means we cannot identify which atom/nucleus will be the next to decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction that will decay in the next time interval Spontaneous means that the decay cannot be influenced by any (external) factors.	 (1) (1)	2
(b)(ii)	$_{95}\text{Am} \rightarrow {}^{237}\text{Np} + {}^{4}_{2}\alpha$ Top line correct Bottom line correct	 (1) (1)	2
	Total for question		7

Q3.

Question Number	Acceptable answers		Additional guidance	Mark
	• Calculates change in mass • Converts from u to kg • Use of $\Delta E = c^2 \Delta m$ • Use of $E_k = \frac{1}{2} mv^2$ • $v = 1.4 \times 10^7 \text{ m s}^{-1}$	(1) (1) (1) (1) (1)	Example of calculation $\Delta m = 238.0003u - (233.9942 + 4.0015)u$ $= 0.00463 \times 1.66 \times 10^{-27}$ kg $= 7.636 \times 10^{-30}$ kg $\Delta E = (3.00 \times 10^8 \text{ m s}^{-1})^2 \times 7.636 \times 10^{-30}$ kg $= 6.872 \times 10^{-13}$ 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

Q4.

Question Number	Acceptable answer	Additional guidance	Mark
	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**

Q5.

Question Number	Answer	Mark
	D	**1**

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• 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)		**3**

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
	MAX 5 An explanation that makes reference to the following points: • The student has calculated the coun 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)		5

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	• so the proportion of unstable nuclei does not change significantly over time **Or** activity does not change significantly over time (1)		1

Q9.

Question Number	Acceptable answer	Additional guidance	Mark
	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

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
	• Calculation of mass difference in kg **(1)** • Use of $E = c^2 \Delta m$ **(1)** • $E = 2.77 \times 10^{-11}$ J **(1)**	Example of calculation: (235.0439 + 1.008665) u – (140.9144 + 91.9262+ (3×1.008665)) u = 0.186u (0.1860 u × 1.66 × 10^{-27} kg) × (3 × 10^8 m $s^{-1})^2$ = 2.77 × 10^{-11} J	**3**

Q11.

Question Number	Answer		Mark
(a)(i)	$^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathbf{X} \rightarrow 2 \times {}^{4}_{2}\mathrm{He}$	(1)	
	X is a proton [Accept X is hydrogen/H]	(1)	**2**
(a)(ii)	Attempt at calculation of mass difference	(1)	
	Use of 1 MeV = 1.60 × 10^{-13} J	(1)	
	$\Delta E = 2.77 \times 10^{-12}$ (J)	(1)	**3**
	Example of calculation: $\Delta m = 6533.8\mathrm{MeV/c^2} + 938.3\mathrm{MeV/c^2} - (2 \times 3727.4\mathrm{MeV/c^2}) = 17.3\mathrm{MeV/c^2}$ $\Delta E = 17.3\mathrm{MeV}$ $\Delta E = 17.3\mathrm{MeV} \times 1.60 \times 10^{-13}\,\mathrm{J\,MeV^{-1}} = 2.768 \times 10^{-12}\,\mathrm{J}$		
(b)	**Max 4**		
	• Extremely high temperature and density needed	(1)	
	• High temperature because nuclei need high energy to overcome the (electrostatic) repulsive force	(1)	
	• Since nuclei must come very close for fusion to occur **Or** since nuclei must come close enough for (strong) nuclear force to act	(1)	
	• Very high density is needed to maintain a sufficient collision rate	(1)	
	• Reference to extreme conditions leading to containment problems	(1)	**4**

Q12.

Question Number	Answer		Mark
(a)	Use of $\lambda = \ln 2/t_{1/2}$ $\lambda = 1.22 \times 10^{-4}$ (yr^{-1}) [$\lambda = 3.86 \times 10^{-12}$ (s^{-1}), $\lambda = 2.31 \times 10^{-10}$ (min^{-1})] Use of $A = A_0 e^{-\lambda t}$ $t = 950$ (yr) [if $\lambda = 1.2 \times 10^{-4}$, then $t = 960$ (yr)] [credit answers that use a constant ratio method to find the number of half lives elapsed] Example of calculation $\lambda = \frac{0.693}{5700\ \text{yr}} = 1.22 \times 10^{-4}\ \text{yr}^{-1}$ $14.7\,\text{s}^{-1} = 16.5\,\text{s}^{-1} \times e^{-1.22\times10^{-4}\ \text{yr}^{-1} \times t}$ $t = \frac{\ln\left(\frac{14.7\,\text{s}^{-1}}{16.5\,\text{s}^{-1}}\right)}{-1.22 \times 10^{-4}\ \text{yr}^{-1}} = 947\ \text{yr}$	(1) (1) (1) (1)	4
(b)	Initial value of count rate should be bigger than 16.5 min^{-1} **Or** greater count rate from living wood in the past [e.g. A/A_0 smaller] **Or** initial value of count rate underestimated in the calculation **Or** Initial number of undecayed atoms greater [e.g. N/N_0 smaller] Age of sample has been underestimated **Or** ship is older than 950 yr **Or** sample has been decaying for a longer time [If a calculation has been carried out to show that a greater value of initial activity leads to a greater age, then award both marks]	(1) (1)	2

Q13.

Question Number	Acceptable answers		Additional guidance	Mark
	• Alpha won't penetrate the plastic so the gas can't escape • Alpha won't penetrate the plastic so there is no risk	(1) (1)	For MP1, accept answers in terms of the small range of alpha particles in the air in the bag	2

Q14.

Question Number	Acceptable answers		Additional guidance	Mark
	• top: 40, 0 • bottom: 20, -1	(1) (1)		2

Q15.

Question Number	Answer	Mark
	B	1

Q16.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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

Q17.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use of $\ln 2 = \lambda t_{1/2}$ • $\lambda = 4.92 \times 10^{-18}$ (s^{-1})	(1) (1)	Example of calculation $\lambda = \ln 2 / 1.41 \times 10^{17}$ s $= 4.92 \times 10^{-18}\ s^{-1}$	2
(ii)	• Calculate rate = counts / time • Subtract background radiation • Use of $A = -\lambda N$ • Calculates $N \times$ atomic mass • Calculates percentage by mass • Answer = 0.17% (ecf for λ from (a)(i))	(1) (1) (1) (1) (1) (1)	Example of calculation background rate = 525 / (10 × 60) s = 0.875 s^{-1} vase count rate = 3623 / (5 × 60) s = 12.077 s^{-1} corrected rate = 11.2 s^{-1} for whole vase = 11.2 s^{-1} × 0.0177 m^2 / 6.36 × 10^{-5} m^2 = 3117 s^{-1} N = 3117 / 4.91 × 10^{-18} s^{-1} = 6.348 × 10^{20} Mass = 6.348 × 10^{20} × 238 × 1.66 × 10^{-27} kg = 2.51 × 10^{-4} kg Percentage = 2.51 × 10^{-4} kg × 100 / 0.149 = 0.17%	6
(iii)	Max 2 from: • Alpha particles could have been absorbed by the glass • Alpha particles will be emitted in all directions, not just towards the detector • Some alpha particles could have been detected from other parts of the vase • The count could include radiation from decay products • Some alpha particles could be absorbed by the GM tube window	 (1) (1) (1) (1) (1)		2

Q18.

Question Number	Acceptable Answer		Additional Guidance	Mark
	A description that makes reference to the following: • (Remove the source and) record background count for specified time and subtract from equivalent quantity • Divide by time to give a count rate.	 (1) (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

Q19.

Question Number	Answer	Mark
	A	1

Q20.

Question Number	Acceptable answers	Additional guidance	Mark
	• correct values of *A* and *Z* for α and β • 5 α • 4 β	<u>Example of calculation:</u> $^{226}_{88}Ra \rightarrow {}^{206}_{82}Pb + x\,{}^{4}_{2}\alpha + y\,{}^{0}_{-1}\beta$ $226 - 206 = 4x$ $x = 5$ $88 - 82 - (5 \times 2) = -y$ $y = 4$ $^{226}_{88}Ra \rightarrow {}^{206}_{82}Pb + 5\,{}^{4}_{2}\alpha + 4\,{}^{0}_{-1}\beta$	**(3)**

Q21.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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)	$\Delta m = 225.97713\text{u} - (221.97040\text{u} + 4.00151\text{ u})$ $= 5.22 \times 10^{-3}\text{ u} = 5.22 \times 10^{-3} \times 1.66 \times 10^{-27}\text{ kg} = 8.67 \times 10^{-30}\text{ kg}$ $\Delta E = c^2\Delta m = (3 \times 10^8\text{ m s}^{-1})^2 \times 8.67 \times 10^{-30}\text{ kg} = 7.80 \times 10^{-13}\text{ J}$ ΔE in MeV $= 7.80 \times 10^{-13}\text{ J} \div 1.6 \times 10^{-19}\text{ C}$ $= 4.87$ MeV	5

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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)	Example of calculation $\Delta m = ((2.013553 + 3.015501) - (4.001506 + 1.008665))u$ $= 0.01883 \times 1.66 \times 10^{-27}$ kg $= 3.13 \times 10^{-29}$ kg $\Delta E = (3.00 \times 10^8 \text{ m s}^{-1})^2 \times 3.13 \times 10^{-29}$ kg $= 2.8 \times 10^{-12}$ J	4

Q23.

Question Number	Answer		Mark
(a)(i)	Top line correct Bottom line correct $^2_1\text{H} + ^3_1\text{H} \rightarrow ^4_2\text{He} + ^1_0\text{n}$	(1) (1)	2
(a)(ii)	Attempt at mass deficit calculation $\Delta E = 0.0175$ GeV (accept 2.8×10^{-12} J) Example of calculation: $\Delta m = (3.7274 + 0.939566 - 2.8089 - 1.8756)\ \text{GeV/c}^2 = 0.0175\ \text{GeV/c}^2$ $\Delta E = 0.0175$ GeV	(1) (1)	2
(a)(iii)	Momentum is conserved Mass of neutron is smaller, so speed is greater $E_k = ½ mv^2$, so E_k is larger **Or** Momentum is conserved $E_k = p^2/2m$ m of neutron is smaller, so E_k is larger	(1) (1) (1) (1) (1) (1)	3

(b)	Use of $\lambda = \frac{\ln 2}{t_{½}}$ (1) Use of $A = A_0 e^{-\lambda t}$ (1) t = 41 (years) (1) Example of calculation: $\lambda = \frac{\ln 2}{t_{½}} = \frac{0.693}{12.3\text{ year}} = 0.0563\text{ year}^{-1}$ $A = A_0 e^{-\lambda t} \quad \therefore t = \frac{\ln\left(\frac{A}{A_0}\right)}{-\lambda} = \frac{\ln(0.1)}{-0.0563\text{ year}^{-1}} = 40.9\text{ years}$		3

* (c)	**QWC – Work must be clear and organised in a logical manner using technical wording where appropriate** There is little possibility of a runaway fusion reaction (unlike fission) (1) There would not be any radioactive waste produced in the fusion process **Or** the flux of neutrons would produce radioactive isotopes when absorbed by materials in the reactor (1) A very/extremely high temperature (plasma) is required (1) Plasma must not touch reactor walls, so strong magnetic fields are required (1) If plasma touches the walls of the reactor its temperature falls (and fusion stops) (1)		5
	Total for question		**15**

Q24.

Question Number	Acceptable answers	Additional guidance	Mark
	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

Q25.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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**

Q26.

Question number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • Resonance is occurring… **(1)** • …when the driving frequency/forced vibration (at walking frequency) matches the natural frequency … **(1)** • …energy transfer is maximum **(1)** • Supporting the observation that the amplitude rapidly increases **(1)**		**4**

Q27.

Question Number	Acceptable answer	Additional guidance	Mark
	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**

Q28.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• α-particles would only travel a few cm (in air), and so wouldn't reach the GM-tube • β-particles would probably not pass through the sides of the GM-tube, and so wouldn't be detected so suggestion is correct.	(1) (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

Q29.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use of ratio of atoms and atoms per g • Number of nuclei = 2.9×10^{17}	(1) (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

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	• use of $\ln 2 = \lambda t_{1/2}$ • use of activity = λN (ecf from (b)(i)) • activity = 5.1 (Bq) (use of show that value gives 5.3 Bq)	(1) (1) (1)	$\ln 2 = \lambda \times 1.25 \times 10^{9}$ years $= \lambda \times (1.25 \times 10^{9} \times 365 \times 24 \times 60 \times 60)$ 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 Bq	3

Question Number	Acceptable answers		Additional guidance	Mark
(iii)	• use of count rate = (counts – background counts) / time • calculates percentage of activity from (b)(ii) **Or** applies 7.5% to activity from (b)(ii) • Comparative statement consistent with their values	(1) (1) (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) ÷ 600 s = 0.04 Bq 0.04 Bq × 100 ÷ 5.1 Bq = 0.78 % (ecf from (b)(ii) for MP3)	3

Question Number	Acceptable answers	Additional guidance	Mark
(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

Q30.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• subtracts background from counts in 60 s (1) • use of half life × λ = ln 2 (1) • use of $A = A_0 e^{-\lambda t}$ (1) • correct logarithmic conversion (1) • year = 1987 (1)	Example of calculation: 12227 - 22 = 12205 322 - 15 = 307 $307 = 12205 \times e^{-\ln 2 t / 5.3\text{ y}}$ $\ln 307 = \ln 12205 - \ln 2 \times t / 5.3\text{ y}$ t = 28 years Year = 2015 - 28 = 1987	**(5)**

Question Number	Acceptable answers		Additional guidance	Mark
(ii)	An explanation that makes reference to one of the following pairs:			
	• if the measurement in 2015 were at a larger distance than X, the count rate would be less	(1)	Allow reverse arguments	
	• the source would appear to be older than it really is	(1)		
	OR • 307 is a relatively small count	(1)		
	• the equations apply for large numbers of decays therefore you cannot be sure of the accuracy of the age	(1)		
	OR • if the sensitivity of the GM tube were greater in 2015, the count rate would be larger	(1)		
	• the source would appear to be younger than it really is	(1)		**(2)**