PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 11: NUCLEAR RADIATION

NUCLEAR RADIATION AND RADIOACTIVE DECAY

SCORE	PERCENTAGE
/384	%

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Q1.

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 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 = 1 mark)

Q2. 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)

Q3.

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.

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(Total for question = 3 marks)

Q4.

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)

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(Total for question = 5 marks)

Q5.

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 5×10^{-18} s^{-1}

half-life of uranium = 1.41×10^{17} s

(2)

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(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)

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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)

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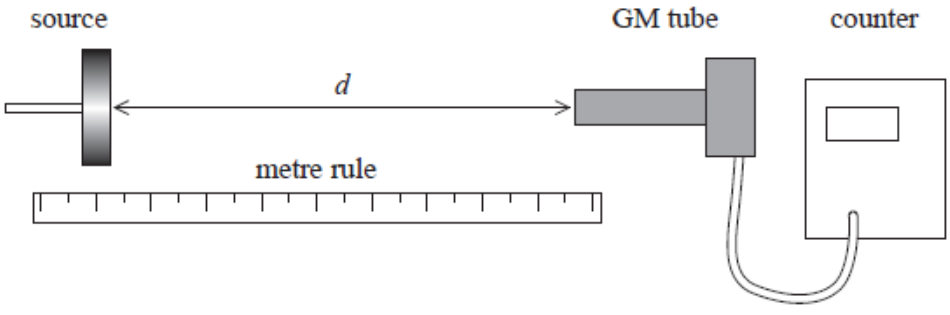
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(Total for question = 10 marks)

Q6.

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.

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(Total for question = 2 marks)

Q7.

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)

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.

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)

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

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

(3)

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(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)

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

(2)

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(Total for question = 10 marks)

Q9.

In an experiment to measure the activity of a radioactive source the measured activity should always be corrected by

☒ **A** adding the background count.

☒ **B** adding the background count rate.

☒ **C** subtracting the background count.

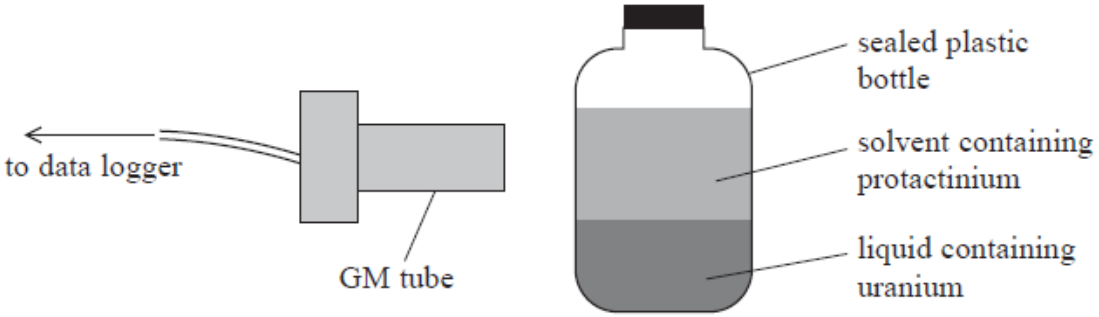
☒ **D** subtracting the background count rate.

(Total for question = 1 mark)

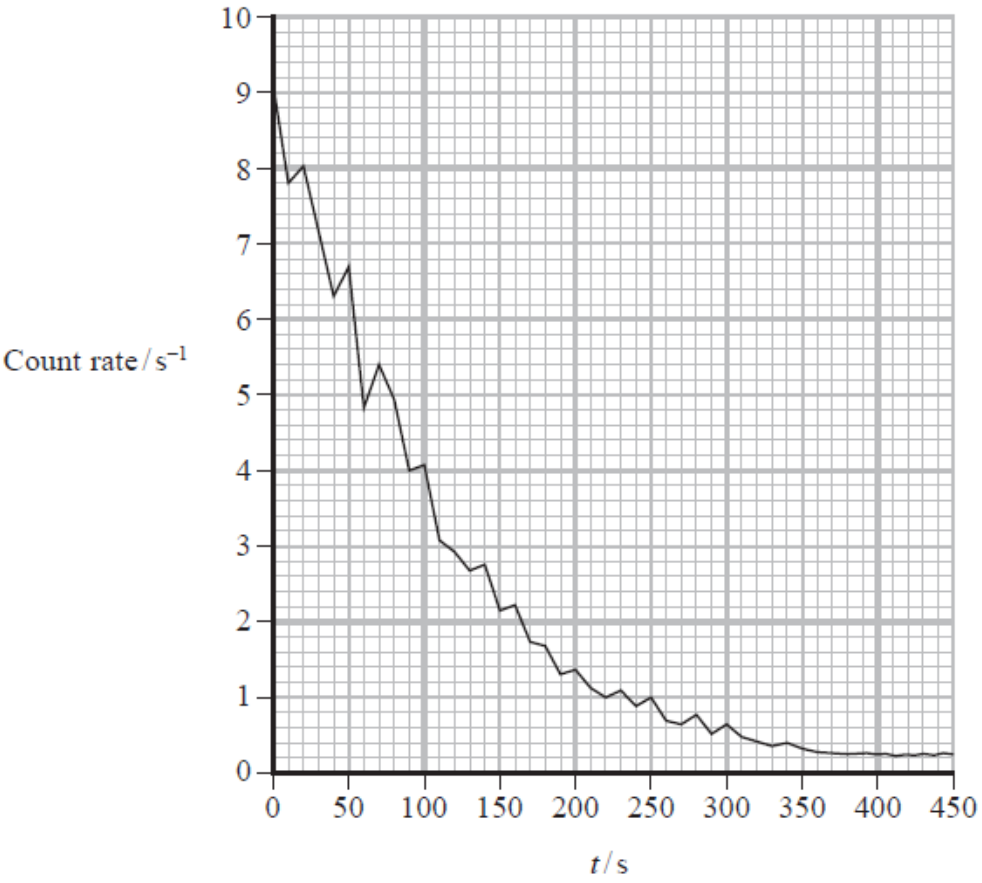
Q10.

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.



The data logger output is shown below.



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

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Half-life of protactinium = ...

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

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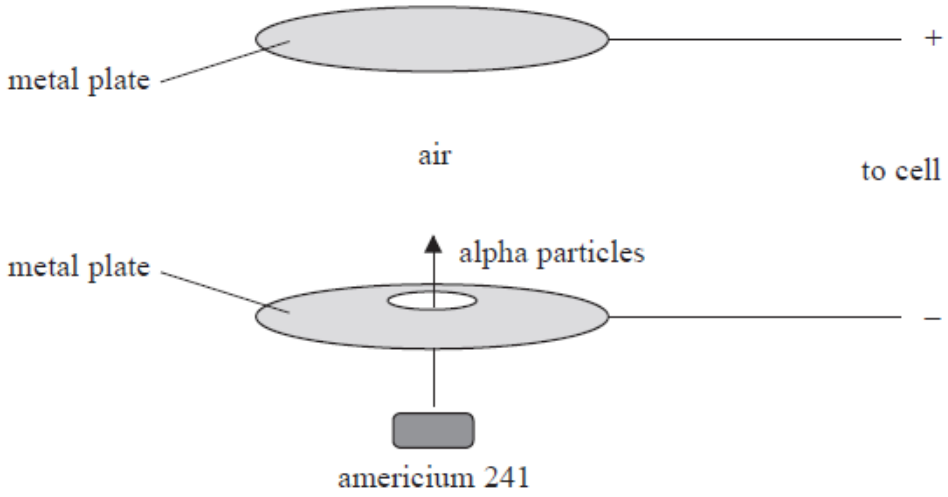
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(Total for question = 6 marks)

Q1.

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)

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

(1)

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

(2)

Random

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Spontaneous

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

(2)

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

(Total for question = 7 marks)

Q2.

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)

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(Total for question = 5 marks)

Q3.

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)

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(Total for question = 2 marks)

Q4.

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 5×10^{-18} s^{-1}

half-life of uranium = 1.41×10^{17} s

(2)

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(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)

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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)

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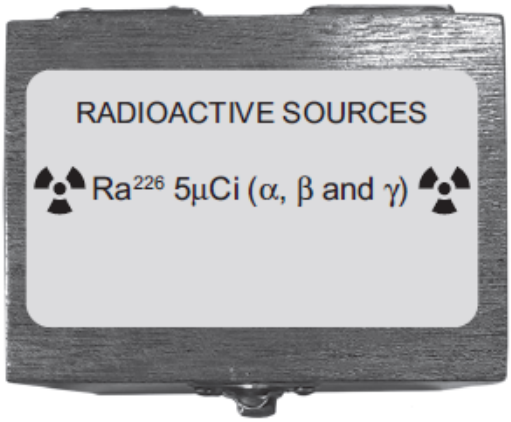
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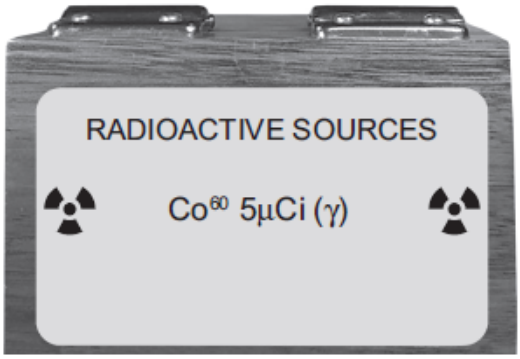
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(Total for question = 10 marks)

Q5.

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)

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

Q6.

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.

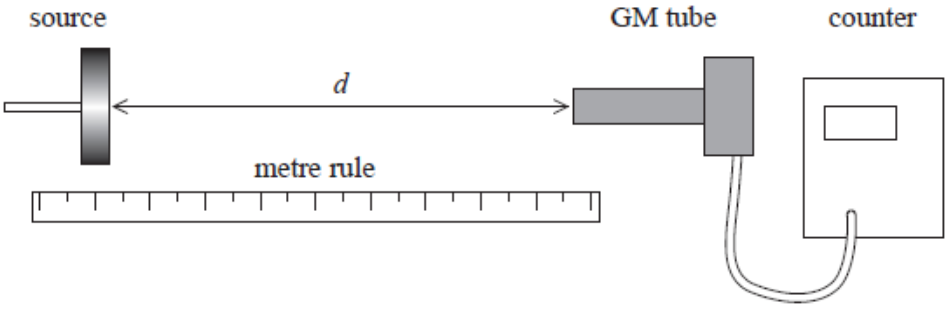


Figure 1

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.

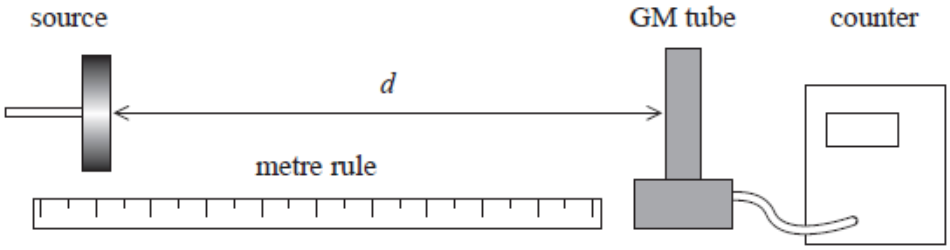


Figure 2

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)

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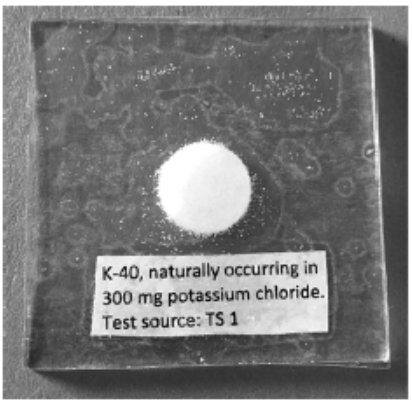
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(Total for question = 2 marks)

Q7.

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)

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

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

(3)

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(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)

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

(2)

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(Total for question = 10 marks)

Q8.

When a photographic film that is not exposed to light is placed near to a source of ionising radiation the film darkens.

(a) (i) State what is meant by ionising radiation.

(1)

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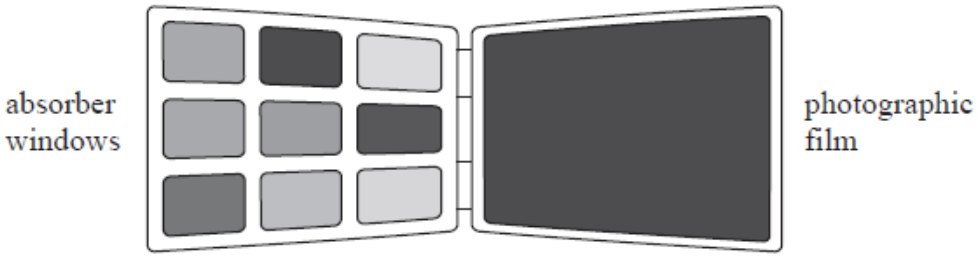
(ii) Complete the table to show α, β, and γ radiations in order of increasing ionising power.

(1)

Least ionising ⟶ Most ionising		

(b) In a physics lesson some students are learning about the use of a film badge to monitor exposure to ionising radiation.

Each absorber window is made from a different material and the type of radiation can be determined from the extent to which the film is darkened.



film badge

The students are asked to predict what would happen if α, β, and γ radiations were incident upon absorber windows made from paper, aluminium and lead.

(i) Complete the table to show the penetration of α, β, and γ radiations through each material.

Use the words "passes through" or "stopped".

(3)

	Paper	0.5 cm aluminium	0.5 cm lead
α radiation		stopped	
β radiation			stopped
γ radiation	passes through		

(ii) In a nuclear power plant there may be other radiation present which would **not** be detected by a film badge.

Suggest what type of radiation this is and why it would not be detected by a film badge.

(2)

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(Total for question = 7 marks)

Q9.

The ionising properties of radiations determine their penetrating power.

Which of the following statements is correct?

☒ **A** α-particles are not very ionising so they are stopped by thin paper.

☒ **B** α-particles are very ionising so can only travel a few centimetres in air

☒ **C** γ-radiation is very penetrating because it is very ionising

☒ **D** γ-radiation is not very penetrating because it is very ionising

(Total for question = 1 marks)

Q10. On 1st November 2006, the former Russian spy Alexander Litvinenko fell ill. Twenty one days later he died from the radiation effects of polonium-210. Experts suggest that as little as 0.89 μg of polonium-210 would be enough to kill, although Mr Litvinenko's death was linked to a much larger dose of the radioactive isotope. Traces of the isotope were later found in washrooms at five locations around London visited by the Russian.

Polonium-210 has a half life of 138 days.

(a) (i) In a 0.89 μg sample of polonium-210 there are 2.54×10^{15} atoms of polonium. Show that the decay constant for polonium-210 is about 6×10^{-8} s^{-1}, and hence calculate the activity of a sample of this size.

(4)

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Activity = ...

(ii) Calculate the fraction of polonium-210 nuclei that have decayed after a time of 21 days.

(3)

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Fraction decayed = ...

(b) Polonium-210 emits alpha particles. Explain why polonium-210 is virtually harmless unless it is taken into the body.

(2)

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(c) (i) Complete the equation below for the decay of polonium.

(2)

$$^{210}_{84}\text{Po} \rightarrow \text{____}\text{Pb} + \text{____}\alpha$$

(ii) State why the Pb nuclei would recoil from the alpha particles emitted during the decay.

(1)

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(d) Radioactive decay is said to occur spontaneously and randomly. Explain what is meant by spontaneous and random in this context.

(2)

Spontaneous

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Random

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(e) Suggest why traces of the isotope were found in locations visited by the Russian.

(2)

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(Total for Question = 16 marks)

Q11.

Positron emission tomography (PET) is a nuclear medicine imaging technique. Pairs of gamma rays, produced when positrons from a radioisotope annihilate with electrons, are detected to form the image.

Radioisotopes used in PET scanning are typically isotopes with short half-lives such as carbon-11. Carbon-11 has a half-life of 1220 s and decays by positron emission to stable boron-11. Positrons are the antiparticles to electrons.

(a) Explain what is meant by a radioactive atom.

(2)

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(b) Complete the equation for the decay of carbon-11.

$$^{11}_{6}\mathrm{C} \rightarrow \text{.....}\mathrm{B} + \text{.....}\mathrm{e}^{+} + {}^{0}_{0}\nu_{e}$$

(2)

(c) Calculate the energy in joules released in a positron decay of carbon-11.

	Mass / MeV/c^2
positron	0.511
carbon	10 253.6
boron	10 252.2

(3)

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Energy = ... J

(d) Explain why carbon-11 is a relatively safe radioisotope to use within the body.

(2)

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(e) A patient was injected intravenously with a radioactive compound containing carbon-11 with an activity of 1.58×10^6 Bq.

The sample was prepared 3600 s before it was administered to the patient.

Calculate the activity of the sample when it was prepared.

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Activity of the sample = ...

(Total for Question = 13 marks)

Q12.

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



The school is required to make a safety inspection of the sources every year.

(i) Explain how the sources can be tested to ensure that each source is in the correct container.

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(ii) Explain a safety precaution that must be applied during this procedure.

(2)

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Q13.

A radioactive source is placed a few cm away from a detector. There is no change in the count rate when a thin aluminium foil is placed between the source and the detector, but the count rate is reduced to the background rate when a 0.5 cm aluminium plate is introduced.

These observations show that the source must be emitting

☒ **A** alpha and beta radiation.

☒ **B** beta and gamma radiation.

☒ **C** beta radiation only.

☒ **D** gamma radiation only.

(Total for Question = 1 mark)

Q14.

The table below gives the range and number of ion pairs per centimetre produced by β particles, compared to α particles of the same energy.

Select the row from the table which shows the correct comparison.

	Range of β particles	Number of ion pairs per centimetre
☐ A	greater	greater
☐ B	smaller	greater
☐ C	greater	smaller
☐ D	smaller	smaller

Q15.

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 (☒).

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 = 1 mark)

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)

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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)

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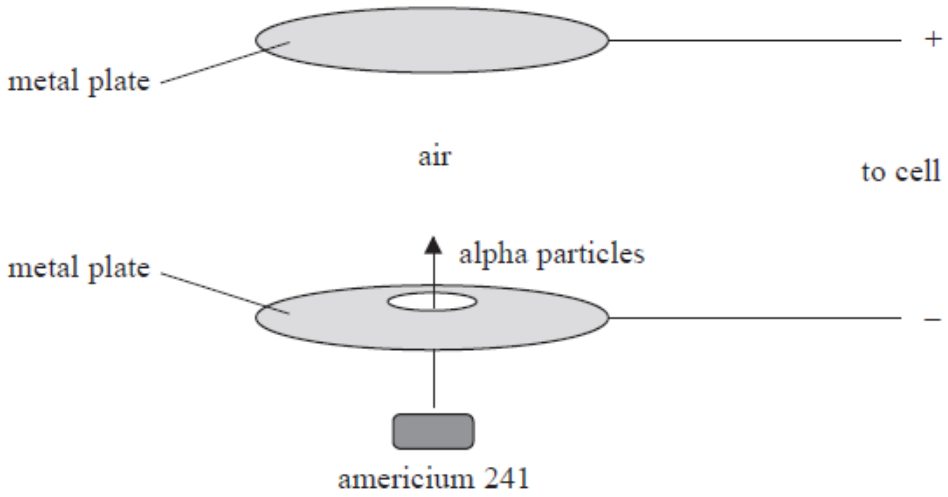
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(Total for question = 5 marks)

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)

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.....

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

(1)

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

(2)

Random

.....

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Spontaneous

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

(2)

$$\underline{\quad}^{241}\mathrm{Am} \rightarrow \underline{\quad}_{93}\mathrm{Np} + \underline{\quad}\alpha$$

(Total for question = 7 marks)

Q3.

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.

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

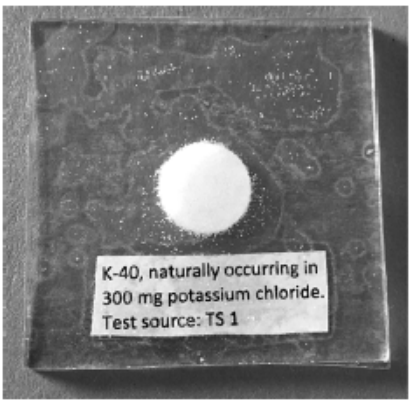
(2)

$$\underline{\quad}_{37}\mathrm{Rb} \rightarrow \underline{\quad}^{87}\mathrm{Sr} + \underline{\quad}\beta^- + \bar{\nu}_e$$

(Total for question = 2 marks)

Q4.

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)

$$^{40}_{19}\text{K} \rightarrow \text{____Ca} + \text{____}\beta$$

(Total for question = 2 marks)

Q5.

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 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.

$$^{137}_{55}\text{Cs} \rightarrow \text{____Ba} + \text{____}\beta^- + {}^{0}_{0}\overline{\nu}_{\text{e}}$$

(2)

(ii) An activity of 2.35 × 1012 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)

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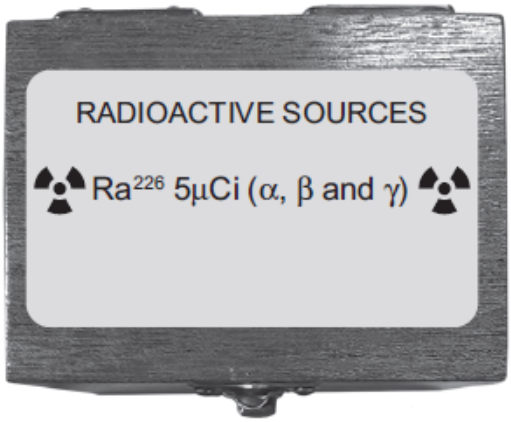
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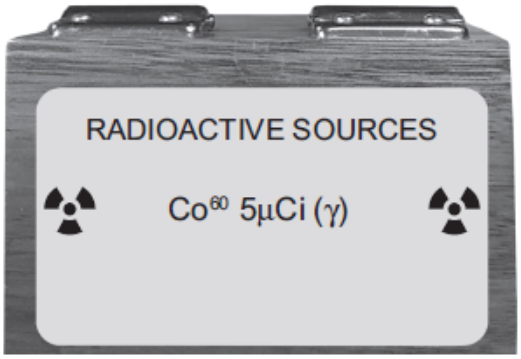
Time = ... years

(Total for question = 6 marks)

Q6.

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)

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

Q7.

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

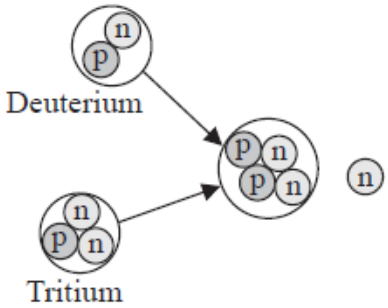
"Every year, one typical coal-fired power station devours several million tonnes of fuel and produces even more carbon dioxide. That volume of carbon dioxide is damaging the atmosphere and, in the longer term, the fuel will run out. It is clear that the world needs an alternative for generating energy.

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)

$$\text{.....}^{\text{.....}}\text{H} + \text{.....}^{\text{.....}}\text{H} \rightarrow \text{.....}^{\text{.....}}\text{He} + \text{.....}^{\text{.....}}\text{n}$$

(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)

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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)

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(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)

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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)

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(Total for question = 15 marks)

Q8.

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)

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(Total for question = 4 marks)

Q9.

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

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

☒ **A** 226 88Ra → 206 82Pb + 3α + 8β⁻

☒ **B** 226 88Ra → 206 82Pb + 4α + 5β⁻

☒ **C** 226 88Ra → 206 82Pb + 5α + 4β⁻

☒ **D** 226 88Ra → 206 82Pb + 5α + 6β⁻

(Total for question = 1 mark)

Q10.

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

The nucleus formed is

☒ **A** $^{233}_{95}Am$

☒ **B** $^{235}_{93}Np$

☒ **C** $^{227}_{89}Ac$

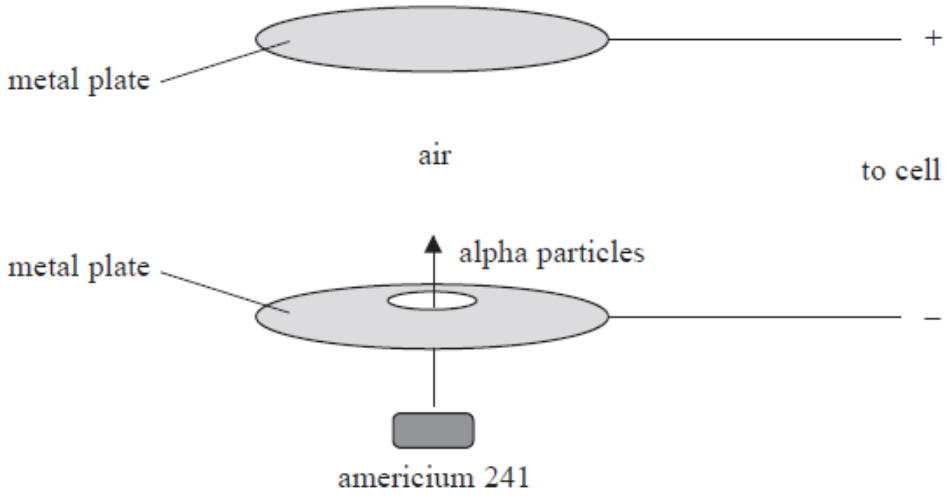
☒ **D** $^{229}_{87}Fr$

(Total for question = 1 mark)

Q1.

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)

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

(1)

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

(2)

Random

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Spontaneous

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

(2)

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

(Total for question = 7 marks)

Q2.

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

☒ **A** nothing can influence the decay.

☒ **B** the decay is random.

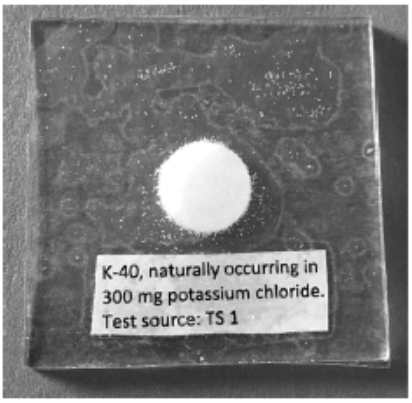
☒ **C** the decay can be predicted.

☒ **D** the decay is exponential.

(Total for question = 1 marks)

Q3.

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)

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

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

(3)

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(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)

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

(2)

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(Total for question = 10 marks)

Q4. On 1st November 2006, the former Russian spy Alexander Litvinenko fell ill. Twenty one days later he died from the radiation effects of polonium-210. Experts suggest that as little as 0.89 μg of polonium-210 would be enough to kill, although Mr Litvinenko's death was linked to a much larger dose of the radioactive isotope. Traces of the isotope were later found in washrooms at five locations around London visited by the Russian.

Polonium-210 has a half life of 138 days.

(a) (i) In a 0.89 μg sample of polonium-210 there are 2.54×10^{15} atoms of polonium. Show that the decay constant for polonium-210 is about 6×10^{-8} s^{-1}, and hence calculate the activity of a sample of this size.

(4)

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Activity = ...

(ii) Calculate the fraction of polonium-210 nuclei that have decayed after a time of 21 days.

(3)

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Fraction decayed = ...

(b) Polonium-210 emits alpha particles. Explain why polonium-210 is virtually harmless unless it is taken into the body.

(2)

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(c) (i) Complete the equation below for the decay of polonium.

(2)

$$^{210}_{84}\text{Po} \rightarrow \text{.....Pb} + \text{.....}\alpha$$

(ii) State why the Pb nuclei would recoil from the alpha particles emitted during the decay.

(1)

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(d) Radioactive decay is said to occur spontaneously and randomly. Explain what is meant by spontaneous and random in this context.

(2)

Spontaneous

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Random

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(e) Suggest why traces of the isotope were found in locations visited by the Russian.

(2)

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(Total for Question = 16 marks)

Q5.

Positron emission tomography (PET) is a nuclear medicine imaging technique. Pairs of gamma rays, produced when positrons from a radioisotope annihilate with electrons, are detected to form the image.

Radioisotopes used in PET scanning are typically isotopes with short half-lives such as carbon-11. Carbon-11 has a half-life of 1220 s and decays by positron emission to stable boron-11. Positrons are the antiparticles to electrons.

(a) Explain what is meant by a radioactive atom.

(2)

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(b) Complete the equation for the decay of carbon-11.

$$^{11}_{6}C \rightarrow \text{.....}B + \text{.....}e^{+} + {}^{0}_{0}\nu_{e}$$

(2)

(c) Calculate the energy in joules released in a positron decay of carbon-11.

	Mass / MeV/c^2
positron	0.511
carbon	10 253.6
boron	10 252.2

(3)

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Energy = ... J

(d) Explain why carbon-11 is a relatively safe radioisotope to use within the body.

(2)

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(e) A patient was injected intravenously with a radioactive compound containing carbon-11 with an activity of 1.58×10^6 Bq.

The sample was prepared 3600 s before it was administered to the patient.

Calculate the activity of the sample when it was prepared.

(4)

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Activity of the sample = ...

(Total for Question = 13 marks)

Q6.

In a famous thought experiment, Schrödinger imagined that a cat is locked in a box, along with a radioactive atom that is connected to a tube containing a deadly poison. If the atom decays, it causes the tube to smash and the cat to die.

The random nature of radioactive decay means that the radioactive atom will

☒ **A** decay after one half-life.

☒ **B** probably decay after one half-life.

☒ **C** have a fixed probability of decaying in a given time interval.

☒ **D** have a number of possible decay paths.

(Total for Question = 1 mark)

Q7.

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

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

(6)

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(Total for question = 6 marks)

Q8.

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

State what is meant by spontaneous decay.

(1)

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(Total for question = 1 mark)

Q9.

Radioactive decay is said to be a spontaneous process.

This means that

☒ **A** we cannot know when a nucleus will decay.

☒ **B** we cannot know which nucleus will decay next.

☒ **C** we cannot know how many nuclei will decay.

☒ **D** we cannot influence when a nucleus will decay.

(Total for question = 1 mark)

Q10.

In March 2011, a nuclear meltdown occurred at the Fukushima Nuclear Power Plant and radioactive materials were released into the environment.

A month later, seaweed off the coast near Long Beach, California was found to be contaminated with iodine-131, a radioisotope that decays by emitting β particles. In one sample the activity was found to be 2.5 Bq per gram of dry seaweed.

(a) State what is meant by the activity of a radioactive source.

(1)

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(b) A Geiger counter is used to measure the count from a sample of seaweed over a period of 10 minutes. The corrected readings obtained are shown in the table below.

Corrected count 1	Corrected count 2	Corrected count 3	Corrected count rate / Bq
3820	3830	3825	6.38

(i) State why the readings obtained from the Geiger counter have to be corrected.

(1)

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(ii) Explain why the radioactive count is repeated.

(2)

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(iii) The measurements were repeated with the same sample of seaweed 30 days later. Calculate the new corrected count rate of the sample.

half-life of iodine-131 = 8.0 days

(3)

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New corrected count rate = ...

(iv) There is a moderate risk to the public from the accumulation of iodine-131 in the seaweed. Explain why.

(2)

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(Total for question = 9 marks)

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)

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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)

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(Total for question = 5 marks)

Q2.

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 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.

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)

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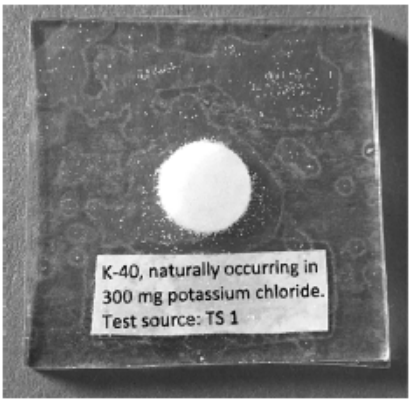
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(Total for question = 6 marks)

Q3.

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)

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(Total for question = 1 mark)

Q4.

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)

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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)

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(Total for question = 6 marks)

Q5.

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 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.

$$^{137}_{55}\mathrm{Cs} \rightarrow \text{____}\mathrm{Ba} + \text{____}\beta^{-} + {}^{0}_{0}\overline{\nu}_{e}$$

(2)

(ii) An activity of 2.35 × 1012 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)

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Time = ... years

(Total for question = 6 marks)

Q6.

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 5×10^{-18} s^{-1}

half-life of uranium = 1.41×10^{17} s

(2)

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(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)

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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)

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(Total for question = 10 marks)

Q7.

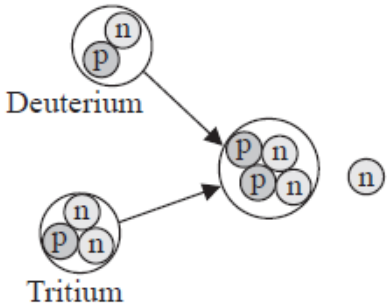
The following passage is adapted from a recent article in a British newspaper:

"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)

$$\text{.....H} + \text{.....H} \rightarrow \text{.....He} + \text{.....n}$$

(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)

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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)

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(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)

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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)

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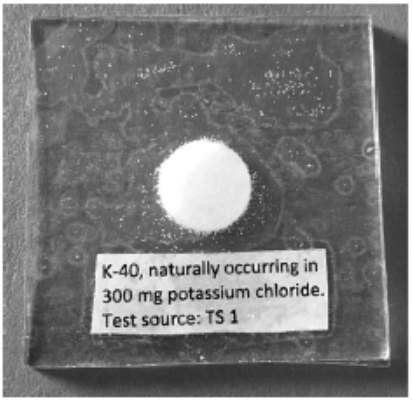
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(Total for question = 15 marks)

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.

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)

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

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

(3)

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(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)

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

(2)

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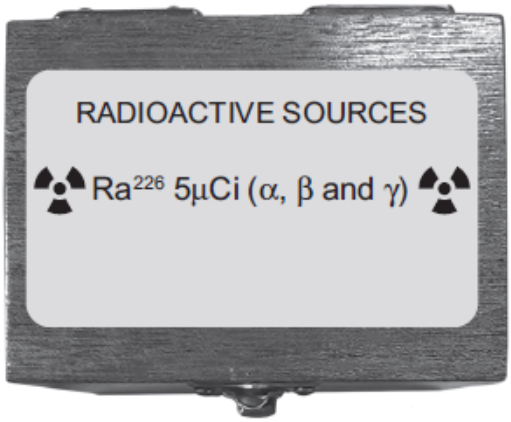
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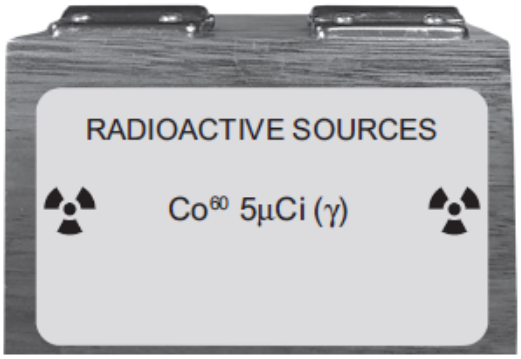
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(Total for question = 10 marks)

Q9.

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)

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Year = ...

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

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Q10.

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 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)

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(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 1.00×10^5 Pa.

(4)

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Volume = ...

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

(3)

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Root mean square speed = ...

(Total for question = 11 marks)

Q11. On 1st November 2006, the former Russian spy Alexander Litvinenko fell ill. Twenty one days later he died from the radiation effects of polonium-210. Experts suggest that as little as 0.89 μg of polonium-210 would be enough to kill, although Mr Litvinenko's death was linked to

a much larger dose of the radioactive isotope. Traces of the isotope were later found in washrooms at five locations around London visited by the Russian.

Polonium-210 has a half life of 138 days.

(a) (i) In a 0.89 μg sample of polonium-210 there are 2.54×10^{15} atoms of polonium. Show that the decay constant for polonium-210 is about 6×10^{-8} s^{-1}, and hence calculate the activity of a sample of this size.

(4)

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Activity = ...

(ii) Calculate the fraction of polonium-210 nuclei that have decayed after a time of 21 days.

(3)

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Fraction decayed = ...

(b) Polonium-210 emits alpha particles. Explain why polonium-210 is virtually harmless unless it is taken into the body.

(2)

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(c) (i) Complete the equation below for the decay of polonium.

(2)

$$^{210}_{84}\mathrm{Po} \rightarrow \ ^{\ldots\ldots}_{\ldots\ldots}\mathrm{Pb} + \ ^{\ldots\ldots}_{\ldots\ldots}\alpha$$

(ii) State why the Pb nuclei would recoil from the alpha particles emitted during the decay.

(1)

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(d) Radioactive decay is said to occur spontaneously and randomly. Explain what is meant by spontaneous and random in this context.

(2)

Spontaneous

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Random

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(e) Suggest why traces of the isotope were found in locations visited by the Russian.

(2)

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(Total for Question = 16 marks)

Q12.

Pions (π^+, π^-, π^0) are created in the upper atmosphere when cosmic rays collide with protons. Pions are unstable and decay rapidly.

(a) Pions are the lightest of the hadrons. Charged pions (π^+ and π^-) decay to produce muons which then decay to positrons or electrons.

(i) A positive pion π^+ has a quark composition $u\bar{d}$.

State with a justification the possible quark compositions of a neutral pion π^0.

(2)

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(ii) Muons are examples of leptons whereas pions are examples of mesons.
State a structural difference between leptons and mesons.

(1)

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(b) Muons with a speed of 0.99*c* travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

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(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.

half-life of muon = 2.2 μs

(4)

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Fraction = ...

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

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(Total for question = 11 marks)

Q13.

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

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

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(Total for question = 6 marks)

Q14.

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.

(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)

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Number of nuclei = ...

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

(3)

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Time = ... years

(Total for question = 6 marks)

Q15.

Radioactive isotopes are often used as markers, so that chemical substances can be traced around the body. In one medical procedure tritium is used as a means of studying protein absorption by the intestine.

A patient was given a sample containing the tritium to drink and then monitored. The initial activity of the sample was 3450 Bq.

Tritium is a beta-emitter with a half-life of 3.89×10^{8} s.

(a) State what is meant by the activity of a radioactive source.

(1)

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(b) Show that the decay constant of the tritium is about 1.8×10^{-9} s^{-1} and hence calculate the number of tritium nuclei in the initial sample.

(3)

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Number of nuclei = ...

(c) (i) Show that the time taken for the activity of the sample to fall to 10% of its initial value is about 40 years.

(3)

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(ii) Comment on the time given in (c) (i).

(1)

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(Total for question = 8 marks)

Q16.

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

(4)

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(Total for question = 4 marks)

Q17.

The Sun is believed to be about 4.5 billion years old. To determine this, scientists measure the ratios of the lead isotopes found in meteorites. Since uranium undergoes radioactive decay in a chain to eventually become an isotope of lead, the ratios of lead isotopes can be used to find the age of a meteorite.

(i) $^{238}_{92}U$ decays to $^{206}_{82}Pb$ via the emission of α and β^- radiation.

In the transition of U-238 to Pb-206 eight alpha decays must occur.

State the number of beta decays that must occur. Justify your answer.

(2)

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Number of β^- decays = ...

(ii) One isotope produced in the chain is thorium-230, which decays to an isotope of radium with a half-life of 75,000 years.

Calculate the time in years it would take for 90% of an initial sample of thorium to have decayed.

(4)

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Time taken = ... years

(Total for question = 6 marks)

Q18.

*****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.

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(Total for question = 6 marks)

Q19.

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 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_R + N_S).

From the analysis of the sample, it was determined that $\frac{N_S}{N_R} = 0.0532$

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)

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(Total for question = 5 marks)

Q20.

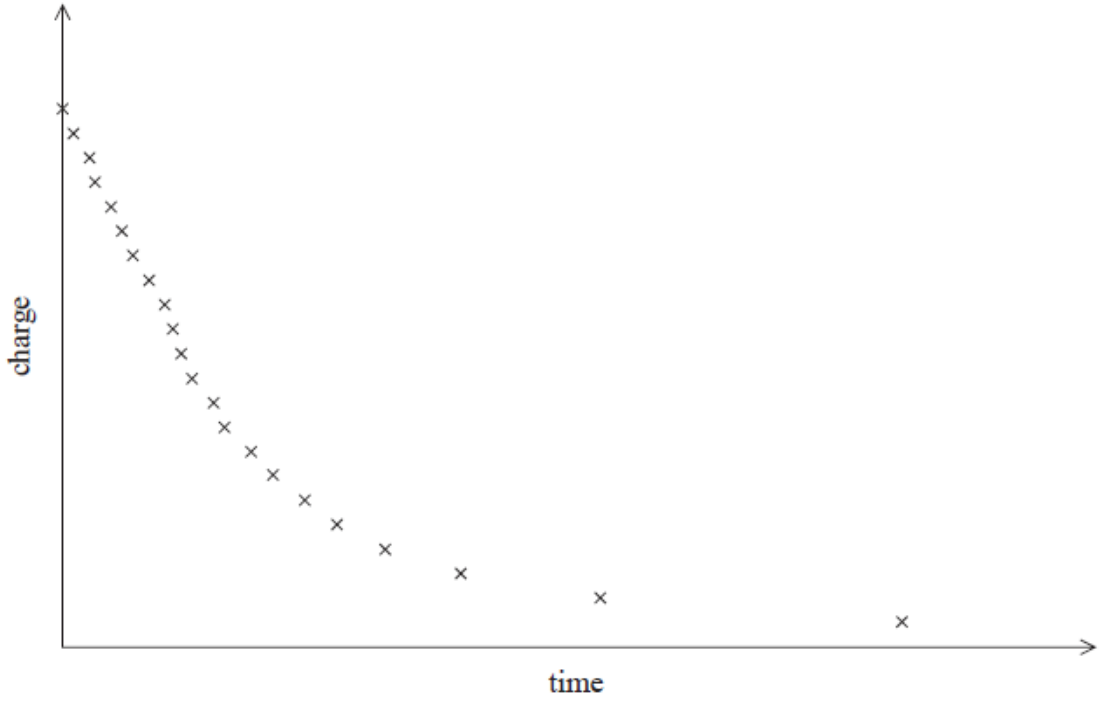
A coulombmeter is used to measure charge.



In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

For one sheet of zinc, the charge at different times was measured.

The following graph was obtained.



A student suggests that this is an exponential decay curve.
Explain how this suggestion could be tested.

(3)

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(Total for question = 3 marks)