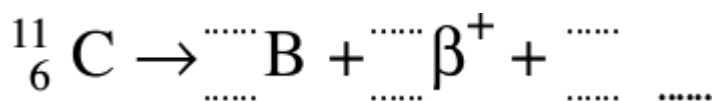


1

Complete the following equation showing the β^+ decay of carbon-11.



(Total 3 marks)

2

The decay of a radioactive substance can be represented by the equation

$$A = A_0 e^{-\lambda t}$$

where A = the activity of the sample at time t

A_0 = the initial activity at time $t = 0$

λ = the decay constant

The half life, $T_{1/2}$ of the radioactive substance is given by

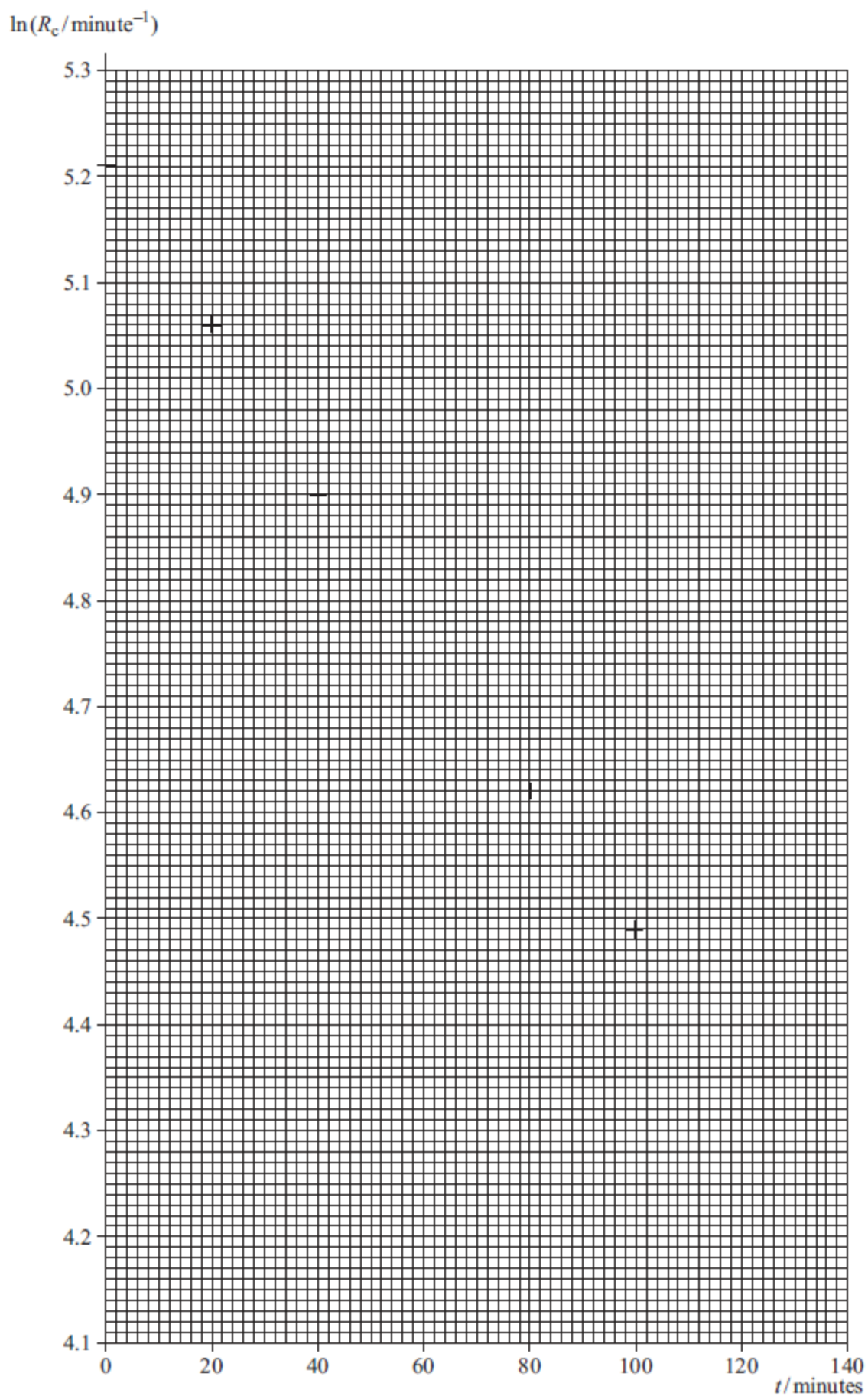
$$T_{1/2} = \frac{\ln(2)}{\lambda}$$

An experiment was performed to determine the half-life of a radioactive substance which was a beta emitter. The radioactive source was placed close to a detector. The total count for exactly 5 minutes was recorded. This was repeated at 20 minute intervals. The results are shown in the table below.

time, t / minutes	total count, C , recorded in 5 minutes	count rate, R / counts minute ⁻¹	corrected count rate, R_C / counts minute ⁻¹	$\ln(R_C / \text{minute}^{-1})$
0	1016	203	183	5.21
20	892	178	158	5.06
40	774	155	135	4.90
60	665	133	113	4.73
80	608	122	102	4.62
100	546	109	89	4.49

- (a) A correction has been made to the count rate, R , to give the corrected count rate, R_C . Explain why this correction has been made and deduce its value from the table.

(2)



(b) Draw an appropriate straight line through the plotted points.

- (c) Determine the gradient G of your graph.

(3)

- (d) Use your graph to determine the half-life in minutes of the radioactive substance used in this experiment.

half-life, $T_{1/2}$ _____ minutes

(2)

- (e) Due to the nature of a radioactive decay there will be an uncertainty in the total count recorded. What type of error is this called?

(1)

- (f) (i) It can be shown that the error in the total count C , is given by

$$\text{uncertainty in total count } C = \pm \sqrt{C}$$

Using data from the table, calculate the uncertainty **in the smallest total count, C .**

(1)

- (ii) Hence calculate the percentage uncertainty **in the smallest total count, C .**

(1)

- (iii) Another student performed the same experiment with identical equipment but took total counts over a 1 minute period rather than a 5-minute period. The total count, C , at 140 minutes was equal to 84 counts. Estimate the percentage uncertainty in this total count, and hence explain the advantage of using a larger time.

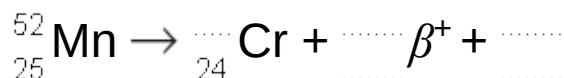
(2)

(Total 13 marks)

3

A nuclide of manganese ($^{52}_{25}\text{Mn}$) undergoes beta⁺ decay to form a nuclide of chromium (Cr).

- (a) Complete the equation for this decay process.



(2)

- (b) State the name of the exchange particle involved in this beta⁺ decay.

(1)

(Total 3 marks)

Radioisotope thermoelectric generators (RTGs) are electrical generators powered by radioactive decay. As a radioisotope decays some of the energy released is converted into electricity by means of devices called thermocouples. In this way RTGs have been used as power sources in satellites, space probes and heart pacemakers.

The Cassini space probe was launched in 1997. It carried three RTGs each containing 11 kg of a nuclear fuel, plutonium oxide (a compound having two oxygen atoms combined with every plutonium-238 atom). In 1997, when the probe was launched, the power released from one gram of plutonium oxide was 500 mW.

Plutonium-238 ${}_{94}^{238}\text{Pu}$ is an alpha emitter, decaying into uranium(U).
The half-life of the decay is 87.7 years.

mass of one mol of plutonium-238 = 238 g

mass of one mol of oxygen atoms = 16 g

- (a) State and explain why environmentalists might have been concerned by the use of such a large quantity of plutonium-238.

(2)

- (b) State and explain whether the activity of a given number of atoms of plutonium is affected when they are in the form of plutonium oxide.

(2)

- (c) (i) Calculate the decay constant, in s^{-1} , for plutonium-238.

decay constant _____ s^{-1}

(2)

- (ii) Calculate the number of plutonium-238 atoms in the total mass of the plutonium oxide in the Cassini probe at the beginning of its mission.

number of plutonium-238 atoms _____

(5)

- (iii) Calculate the initial activity of the plutonium-238 in the Cassini probe.
Give a suitable unit for your answer.

initial activity of plutonium-238 _____ unit _____

(3)

- (d) (i) Write a nuclear equation for the $^{238}_{94}\text{Pu}$ decay.

(2)

- (ii) Assume the power released by the RTGs' fuel originated as the kinetic energy of the alpha particles emitted in the decay of $^{238}_{94}\text{Pu}$.

Calculate the maximum kinetic energy of each alpha particle.

kinetic energy of alpha particle _____ J

(4)

(Total 20 marks)

5

The age of an ancient boat may be determined by comparing the radioactive decay of $^{14}_6\text{C}$ from living wood with that of wood taken from the ancient boat.

A sample of 3.00×10^{23} atoms of carbon is removed for investigation from a block of living wood. In living wood one in 10^{12} of the carbon atoms is of the radioactive isotope $^{14}_6\text{C}$, which has a decay constant of $3.84 \times 10^{-12} \text{ s}^{-1}$.

- (a) What is meant by the decay constant?

(1)

- (b) Calculate the half-life of $^{14}_6\text{C}$ in years, giving your answer to an appropriate number of significant figures.

$$1 \text{ year} = 3.15 \times 10^7 \text{ s}$$

answer = _____ years

(3)

- (c) Show that the rate of decay of the $^{14}_6\text{C}$ atoms in the living wood sample is 1.15 Bq.

(2)

- (d) A sample of 3.00×10^{23} atoms of carbon is removed from a piece of wood taken from the ancient boat. The rate of decay due to the $^{14}_6\text{C}$ atoms in this sample is 0.65 Bq. Calculate the age of the ancient boat in years.

answer = _____ years

(3)

- (e) Give **two** reasons why it is difficult to obtain a reliable age of the ancient boat from the carbon dating described.

(2)

(Total 11 marks)

- 6** (a) $^{212}_{83}\text{Bi}$ can decay into $^{208}_{82}\text{Pb}$ by a β^- followed by an α decay, or by an α followed by a β^- decay. One or more of the following elements is involved in these decays:

$^{200}_{80}\text{Hg}$, $^{201}_{81}\text{Tl}$, $^{208}_{84}\text{Po}$, $^{210}_{85}\text{At}$.

Write out decay equations showing each stage in both of these decays.

First decay path

Second decay path

(6)

- (b) (i) Describe how you would perform an experiment that demonstrates that gamma radiation obeys an inverse square law.

- (ii) Explain why gamma radiation obeys an inverse square law but alpha and beta radiation do not.

(9)

(Total 15 marks)

7

- (a) Calculate the radius of the ${}_{92}^{238}\text{U}$ nucleus.

$$r_0 = 1.3 \times 10^{-15} \text{ m}$$

(2)

- (b) At a distance of 30 mm from a point source of γ rays the corrected count rate is C . Calculate the distance from the source at which the corrected count rate is $0.10 C$, assuming that there is no absorption.

(2)

- (c) The activity of a source of b particles falls to 85% of its initial value in 52 s. Calculate the decay constant of the source.

(3)

- (d) Explain why the isotope of technetium, $^{99}\text{Tc}_m$, is often chosen as a suitable source of radiation for use in medical diagnosis.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

(3)

(Total 10 marks)

8

- (a) Suggest **two** reasons why an α particle causes more ionisation than a β particle of the same initial kinetic energy.

You may be awarded marks for the quality of written communication in your answer.

(2)

- (b) A radioactive source has an activity of 3.2×10^9 Bq and emits α particles, each with kinetic energy of 5.2 MeV. The source is enclosed in a small aluminium container of mass 2.0×10^{-4} kg which absorbs the radiation completely.

- (i) Calculate the energy, in J, absorbed from the source each second by the aluminium container.

- (ii) Estimate the temperature rise of the aluminium container in **1 minute**, assuming no energy is lost from the aluminium.

specific heat capacity of aluminium = $900 \text{ J kg}^{-1} \text{ K}^{-1}$

(5)

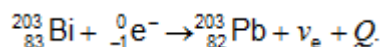
(Total 7 marks)

- 9 The sodium isotope $^{24}_{11}\text{Na}$ is a radioactive isotope that can be produced by bombarding the aluminium isotope $^{27}_{13}\text{Al}$ with neutrons. Which line, **A** to **D**, in the table correctly represents the production of $^{24}_{11}\text{Na}$ from the aluminium isotope $^{27}_{13}\text{Al}$ and its subsequent decay?

	production	decay
A	$^{27}_{13}\text{Al} + {}^1_0\text{n} \rightarrow {}^{24}_{11}\text{Na} + {}^4_2\alpha$	$^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + {}^0_{-1}\beta + \nu$
B	$^{27}_{13}\text{Al} + {}^1_0\text{n} \rightarrow {}^{24}_{11}\text{Na} + {}^4_2\alpha$	$^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + {}^0_{-1}\beta + \bar{\nu}$
C	$^{27}_{13}\text{Al} + {}^1_0\text{n} \rightarrow {}^{24}_{11}\text{Na} + {}^3_2\text{He}$	$^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + {}^0_{-1}\beta + \nu$
D	$^{27}_{13}\text{Al} + {}^1_0\text{n} \rightarrow {}^{24}_{11}\text{Na} + {}^3_2\text{He}$	$^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + {}^0_{-1}\beta + \bar{\nu}$

(Total 1 mark)

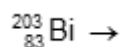
- 10 (a) The nuclide $^{203}_{83}\text{Bi}$ can decay by *electron capture* to become an isotope of lead as shown in the following equation,



- (i) Explain what is meant by electron capture.

- (ii) Give **one** reason why electromagnetic radiation is emitted following this process.

- (iii) Give the equation for another process in which $^{203}_{83}\text{Bi}$ is converted into an isotope of lead.



(5)

- (b) The nuclide $^{203}_{83}\text{Bi}$ is also an α particle emitter. An initial measurement of the α particle activity of a sample of this isotope gives a corrected count rate of $1200 \text{ counts s}^{-1}$. After an interval of 24 hours the corrected rate falls to $290 \text{ counts s}^{-1}$. Assume that corrections have been made for the radiation both from daughter products and background radiation.

- (i) Show that the decay constant of $^{203}_{83}\text{Bi}$ is about $1.6 \times 10^{-5} \text{ s}^{-1}$.

- (ii) Calculate the half-life of this sample.

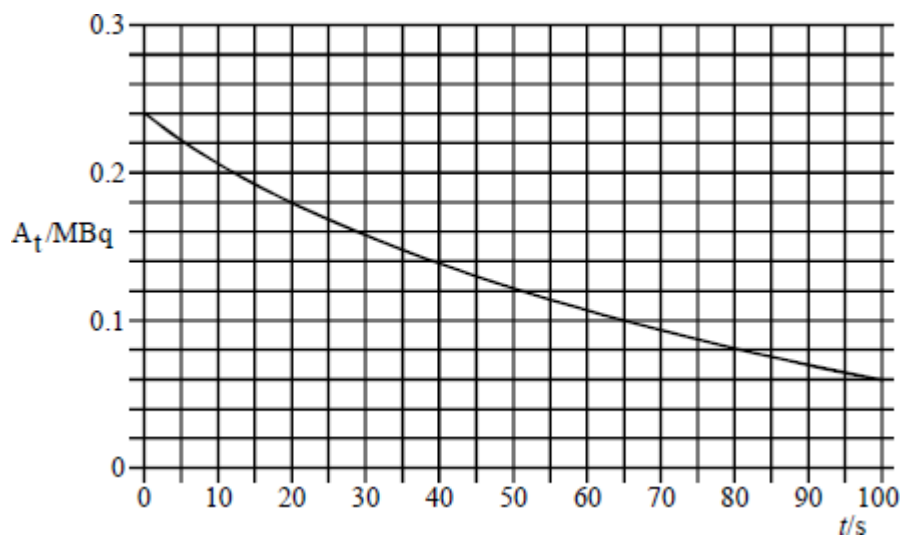
- (iii) Calculate the number of $^{203}_{83}\text{Bi}$ nuclei in the sample when the corrected count rate was $1200 \text{ counts s}^{-1}$.

(5)

(Total 10 marks)

11

A radioactive nuclide decays by emitting α particles. The graph shows how the rate of decay A_t of the source changes with time t .



(a) Determine

(i) the half-life of the nuclide,

(ii) the decay constant,

(iii) the initial number of undecayed nuclei present at time $t = 0$.

(5)

(b) Each decay releases 1.0×10^{-12} J. For the time interval between $t = 30$ s and $t = 80$ s, calculate

(i) the number of nuclei which decay,

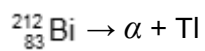
(ii) the energy released.

(4)

(Total 9 marks)

12

(a) When an α particle is emitted from a nucleus of the isotope ${}^{212}_{83}\text{Bi}$, a nucleus of thallium, Tl, is formed. Complete the equation below.



(2)

(b) The α particle in part (a) is emitted with 6.1 MeV of kinetic energy.

- (i) The mass of the α particle is 4.0 u. Show that the speed of the α particle immediately after it has been emitted is $1.7 \times 10^{-7} \text{ m s}^{-1}$. Ignore relativistic effects.

- (ii) Calculate the speed of recoil of the daughter nucleus immediately after the α particle has been emitted. Assume the parent nucleus is initially at rest.

(6)

(Total 8 marks)

13

- (a) A solar panel of area 2.5 m^2 is fitted to a satellite in orbit above the Earth. The panel produces a current of 2.4 A at a potential difference of 20 V when solar radiation is incident normally on it.

- (i) Calculate the electrical power output of the panel.

- (ii) Solar radiation on the satellite has an intensity of 1.4 kW m^{-2} . Calculate the efficiency of the panel.

(4)

- (b) The back-up power system in the satellite is provided by a radioactive isotope enclosed in a sealed container which absorbs the radiation from the isotope. Energy from the radiation is converted to electrical energy by means of a thermoelectric module.

- (i) The isotope has an activity of $1.1 \times 10^{14} \text{ Bq}$ and produces α particles of energy 5.1 MeV . Show that the container absorbs energy from the α particles at a rate of 90 J s^{-1} .

- (ii) The isotope has a half-life of 90 years. Calculate the decay constant λ of this isotope.

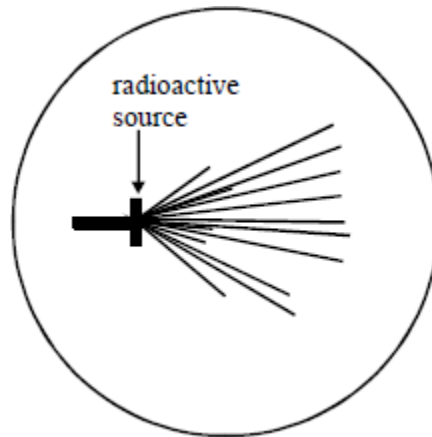
- (iii) The mass number of the isotope is 239.
Calculate the mass of isotope needed for an activity of 1.1×10^{14} Bq.

(7)

(Total 11 marks)

14

- (a) The diagram is copied from a photograph taken of a cloud chamber containing a small radioactive source.



- (i) What type of radiation is emitted from the source?
- (ii) State and explain what can be deduced about the energy of the particles emitted by the source.

(4)

- (b) Plutonium-239 is a radioactive isotope that emits α particles of energy 5.1 MeV and decays to form a radioactive isotope of uranium. This isotope of uranium emits α particles of energy 4.5 MeV to form an isotope of thorium which is also radioactive.

(i) Write down an equation to represent the decay of plutonium-239.

(ii) Write down an equation to represent the decay of the uranium isotope.

(iii) Which of the two radioactive isotopes, plutonium-239 or the uranium isotope, has the longer half-life? Give a reason for your answer.

(iv) Explain why thorium is likely to be a β^- emitter.

(5)

(Total 9 marks)

15

(a) (i) What is meant by the *random nature* of radioactive decay?

- (ii) Explain what is meant by each of the following.

isotopes _____

radioactive half-life _____

radioactive decay constant _____

(6)

- (b) The radioactive isotope of iodine ^{131}I has a half-life of 8.04 days. Calculate

- (i) the decay constant of ^{131}I ,

- (ii) the number of atoms of ^{131}I necessary to produce a sample with an activity of 5.0×10^4 disintegrations s^{-1} (Bq),

- (iii) the time taken, in hours, for the activity of the same sample of ^{131}I to fall from 5.4×10^4 disintegrations s^{-1} to 5.0×10^4 disintegrations s^{-1} .

(6)

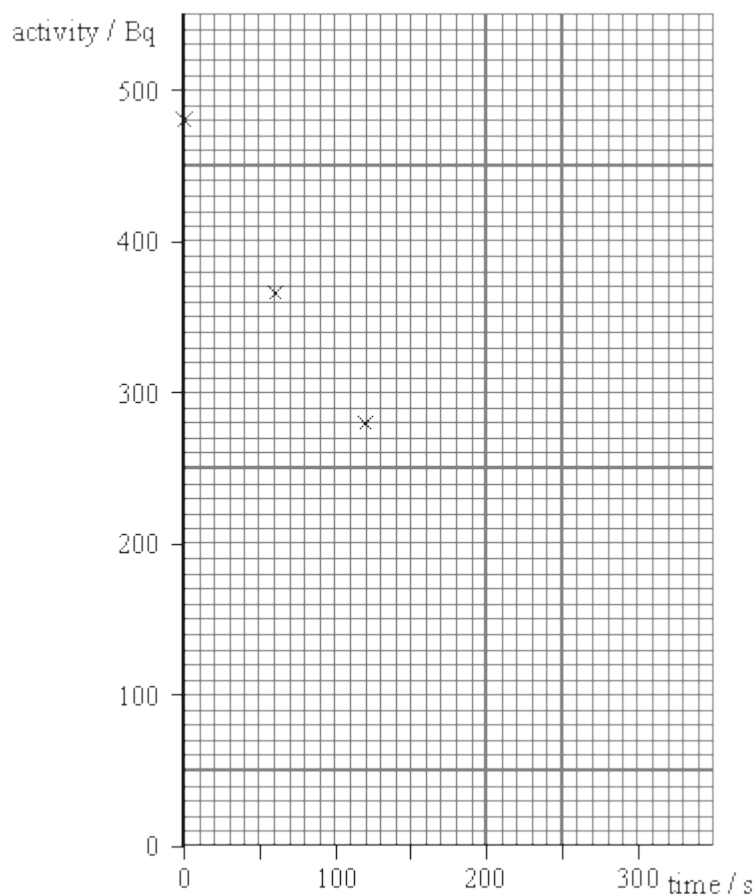
(Total 12 marks)

16

The table below gives the values for the activity of a radioactive isotope over a period of a few minutes.

time/s	0	60	120	180	240	300
activity/Bq	480	366	280	214	163	124

- (a) Complete the graph below by plotting the remaining points and drawing an appropriate curve.



(3)

- (b) Use the graph to determine the half-life of the isotope.

half-life _____

(3)

- (c) Initially there were 1.1×10^5 atoms of the isotope present. Calculate the decay probability of the isotope.

decay probability _____

(2)

(Total 8 marks)

17

A student attempted to determine the *half-life* of a radioactive substance, which emits α particles, by placing it near a suitable counter. He recorded C , the number of counts in 30 s, at various times, t , after the start of the experiment.

The results given in the table were obtained.

t / minute	0	10	20	30	40	50	60
number of counts in 30 s, C	60	42	35	23	18	14	10
$\ln C$							

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

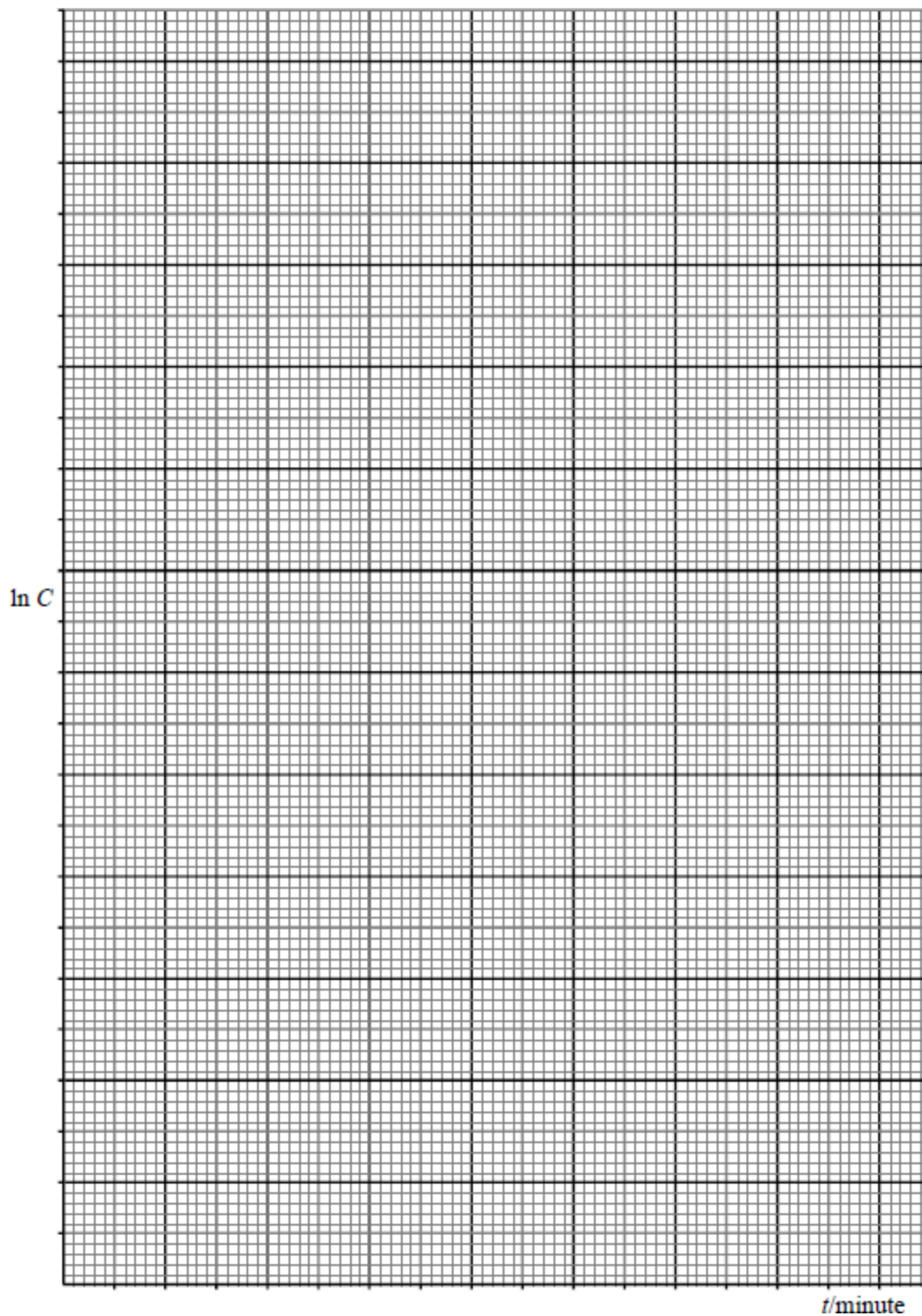
(1)

(b) Complete the table.

(1)

(c) On the grid below

- (i) plot $\ln C$ against t ,
- (ii) draw the best straight line through your points,
- (iii) determine the gradient of your graph.



(5)

- (d) (i) Show that the decay constant of the substance is equal to the magnitude of the gradient of your graph.

- (ii) Calculate the half-life of the substance.

(3)

- (e) This particular experiment is likely to lead to an inaccurate value for the half-life. Suggest **two** ways in which the accuracy of the experiment could be improved.

(2)

- (f) The age of a piece of bone recovered from an archaeological site may be estimated by ^{14}C dating. All living organisms absorb ^{14}C but there is no further intake after death. The proportion of ^{14}C is constant in living organisms.

A 1 g sample of bone from an archaeological site has an average rate of decay of 5.2 Bq due to ^{14}C . A 1 g sample of bone from a modern skeleton has a rate of decay of 6.5 Bq. The counts are corrected for background radiation.

Calculate the age, in years, of the archaeological samples of bone.

half-life of ^{14}C = 5730 years

(4)

(Total 16 marks)

18

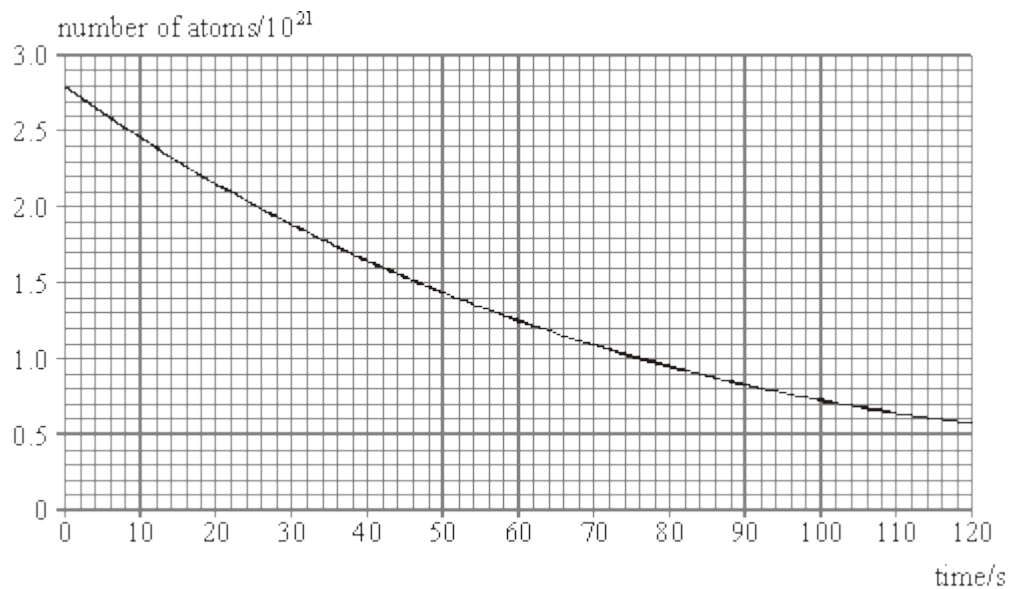
- (a) (i) Alpha and beta emissions are known as *ionising radiations*. State and explain why such radiations can be described as *ionising*.

(2)

- (ii) Explain why beta particles have a greater range in air than alpha particles.

(2)

- (b) The figure below shows the variation with time of the number of Radon (^{220}Ra) atoms in a radioactive sample.



- (i) Use the graph to show that the half-life of the decay is approximately 53 s. Show your reasoning clearly.

(3)

- (ii) The probability of decay (decay constant) for ^{220}Ra is $1.3 \times 10^{-2} \text{ s}^{-1}$. Use data from the graph to find the activity of the sample at a time $t = 72 \text{ s}$.

activity _____

(3)

(Total 10 marks)

19

- (a) Carbon-14 (${}^{14}_6\text{C}$) decays with the emission of a beta particle to form nitrogen (N).

Nitrogen has a proton number of 7. Write down the full nuclear equation that describes this decay.

(3)

- (b) A sample of pure ${}^{14}_6\text{C}$ contains 6.3×10^{19} carbon atoms each with a decay probability of $3.8 \times 10^{-12} \text{ s}^{-1}$.

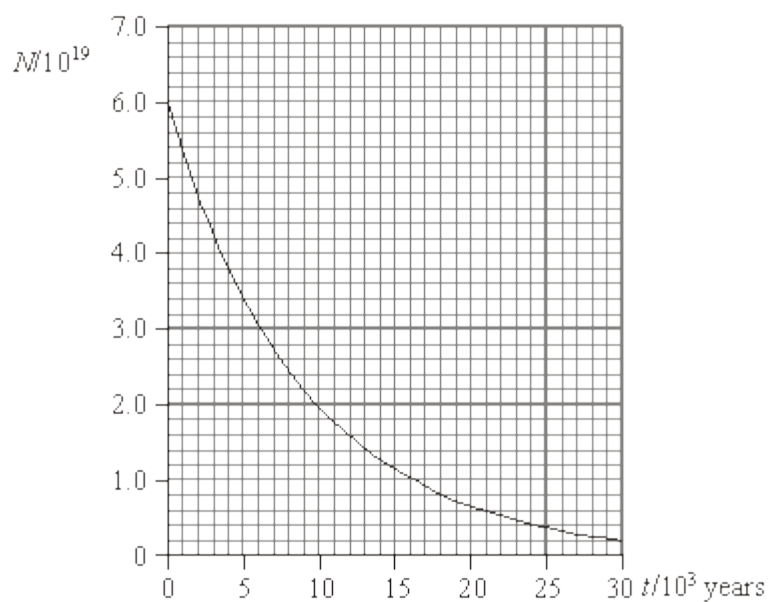
- (i) State the S.I. unit of activity.

- (ii) Calculate the initial activity of the sample.

initial activity _____

(3)

- (c) All nuclei of carbon-14 ($^{14}_6\text{C}$) have the same decay probability. Explain how this statement accounts for the observation that the number, N , of radioactive carbon atoms in the sample varies with time, t , as shown in the figure below.



(4)
(Total 10 marks)

20

Americium-241 ($^{241}_{95}\text{Am}$) is a common laboratory source of alpha radiation. It decays spontaneously to neptunium (Np) with a decay constant of $4.8 \times 10^{-11} \text{ s}^{-1}$.

A school laboratory source has an activity due to the presence of americium of $3.7 \times 10^4 \text{ Bq}$ when purchased.

Avogadro constant = $6.0 \times 10^{23} \text{ mol}^{-1}$

one year = $3.2 \times 10^7 \text{ s}$

(a) (i) Calculate the half-life, in years, of americium-241.

(2)

(ii) Calculate the number of radioactive americium atoms in the laboratory source when it was purchased.

(2)

(iii) Calculate the activity of the americium in the laboratory source 50 years after being purchased.

(3)

- (iv) Suggest why the actual activity of the sources is likely to be greater than your answer to part (iii).

(1)

- (b) (i) Use the following data to deduce the energy released in the decay of one americium-241 nucleus.

mass of americium-241 nucleus	$= 4.00171 \times 10^{-25} \text{ kg}$
mass of an alpha particle	$= 0.06644 \times 10^{-25} \text{ kg}$
mass of neptunium nucleus	$= 3.93517 \times 10^{-25} \text{ kg}$
speed of electromagnetic radiation in free space	$= 3.00 \times 10^8 \text{ m s}^{-1}$

(3)

- (ii) Explain what is meant by *decays spontaneously* and how consideration of the masses of particles involved in a proposed decay helps in deciding whether the decay is possible.

(2)

(Total 13 marks)

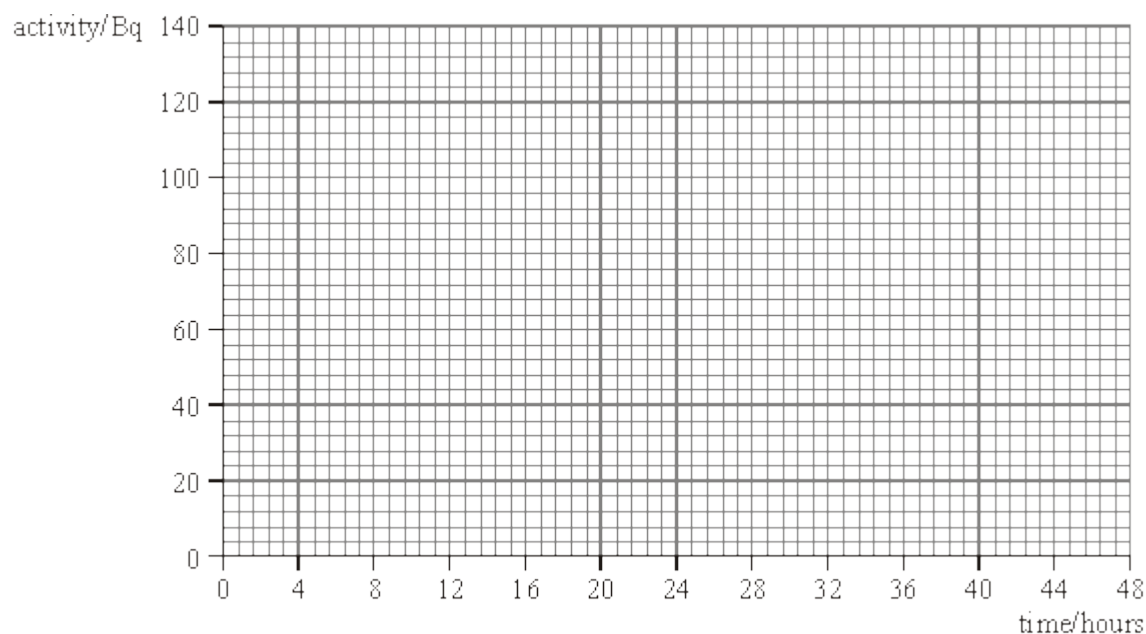
21

A freshly prepared radioactive source that emits negatively charged beta particles (β^-) has an activity of 120 Bq and a half-life of 12 h.

- (a) (i) State the effect on the proton number Z and the nucleon number A when a β^- particle is emitted.

(2)

- (ii) Sketch, on the axes below, a graph that shows how the activity varies during the two days after the source was prepared.



(3)

- (b) (i) The total energy released in each decay is $5.5 \times 10^{-13} \text{ J}$.
Calculate the initial energy produced each second by the source.

initial energy _____ J

(1)

- (ii) **Figure 1** shows the energy spectrum for the beta particles emitted in the decay.

It shows that different energy beta particles are possible.

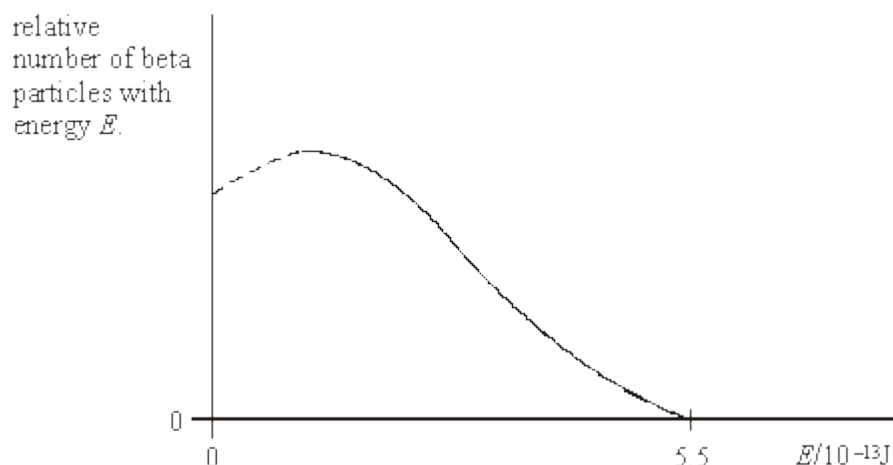


Figure 1

Explain why all the beta particles that are emitted do not have $5.5 \times 10^{-13} \text{ J}$ of energy.

(3)

- (c) The probability of one of the radioactive atoms decaying each second is 1.6×10^{-5} .

How many radioactive atoms are present when the activity is 120 Bq?

number of radioactive atoms _____

(1)

- (d) A scientist undertaking an investigation places the freshly prepared source close to a Geiger-Müller tube as shown in **Figure 2** and records a count rate of 50 counts per second.

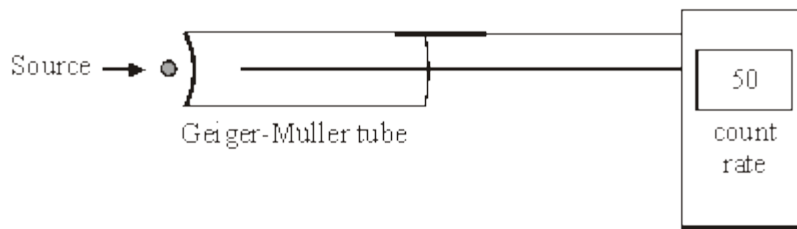


Figure 2

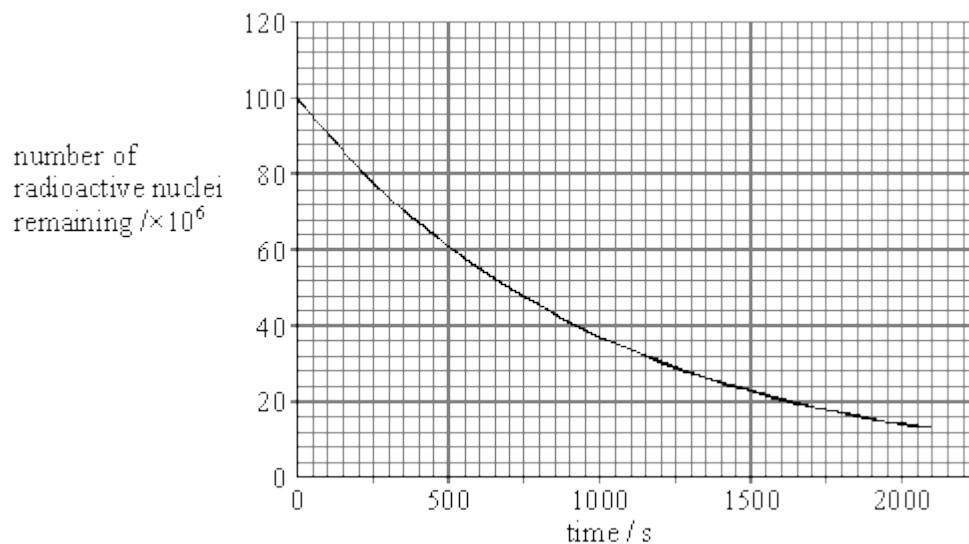
State and explain **two** reasons why the measured count rate is lower than the activity of the source.

(2)

(Total 12 marks)

22

The graph below shows the number of radioactive nuclei remaining in a sample of material against time. The radioactive isotope decays to a non-radioactive element.



- (a) Use the graph to show that, after a time of 500 s, about 6×10^4 nuclei are decaying every second.

(3)

- (b) Calculate the decay probability (decay constant) of a nucleus of the radioactive isotope in the sample.

Decay probability _____

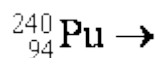
(3)

(Total 6 marks)

23

A nucleus of plutonium (${}_{94}^{240}\text{Pu}$) decays to form uranium (U) and an alpha-particle (α).

- (a) Complete the equation that describes this decay:



(2)

- (b) (i) Show that about 1 pJ of energy is released when one nucleus decays.

mass of plutonium nucleus	$= 3.98626 \times 10^{-25} \text{ kg}$
mass of uranium nucleus	$= 3.91970 \times 10^{-25} \text{ kg}$
mass of alpha particle	$= 6.64251 \times 10^{-27} \text{ kg}$
speed of electromagnetic radiation	$= 2.99792 \times 10^8 \text{ m s}^{-1}$

(3)

- (ii) The plutonium isotope has a half-life of $2.1 \times 10^{11} \text{ s}$. Show that the decay constant of the plutonium is about $3 \times 10^{-12} \text{ s}^{-1}$.

(2)

- (iii) A radioactive source in a school laboratory contains 3.2×10^{21} atoms of plutonium. Calculate the energy that will be released in one second by the decay of the plutonium described in part (b)(i).

(3)

- (iv) Comment on whether the energy release due to the plutonium decay is likely to change by more than 5% during 100 years. Support your answer with a calculation.

(4)

(Total 14 marks)

24

${}_{92}^{238}\text{U}$ is an isotope of uranium which decays through a decay chain to the isotope of lead, ${}_{82}^{206}\text{Pb}$, which is stable. During the sequence of decays, both alpha particles and beta particles are emitted.

- (a) (i) ${}_Z^A\alpha$ represents an alpha particle.

State the values of:

A _____

Z _____

(1)

- (ii) ${}_Z^A\beta$ represents a beta particle.

State the values of:

A _____

Z _____

(1)

- (iii) State and explain how many alpha particles are emitted during the decay chain

between $\frac{N_P}{N_U}$.

(2)

- (iv) State and explain how many beta particles are emitted during the decay chain between ${}^{238}_{92}\text{U}$ and ${}^{206}_{82}\text{Pb}$.

(2)

- (b) The decay of uranium can be used to measure the age of rocks. A rock, which contained N_0 atoms of ${}^{238}_{92}\text{U}$ when it was formed, will contain N_U atoms of the isotope at a later time t .

- (i) The relationship between N_0 , N_U and t is:

$$N_U = N_0 e^{-\lambda t}$$

State the meaning of the decay constant, λ .

(1)

- (ii) Because the half-life of ${}^{238}_{92}\text{U}$ is much longer than that of any other member of the decay chain, it may be assumed that the number of atoms of ${}^{206}_{82}\text{Pb}$ present at time t is equal to the number of atoms ${}^{238}_{92}\text{U}$ which have decayed. Show that the ratio of the number of lead atoms (N_P) to the number of uranium atoms at time t is given by:

$$\frac{N_P}{N_U} = e^{\lambda t} - 1$$

(2)

- (iii) The half-life of ${}^{238}_{92}\text{U}$ is 4.5×10^9 year. Calculate the age of a rock sample which contains 4.2 parts per million of ${}^{238}_{92}\text{U}$ and 0.62 parts per million of ${}^{206}_{82}\text{Pb}$.

(4)

- (iv) The above analysis assumes that the rock contained no lead when it was formed. State and explain the effect on the estimated age if the rock had contained lead when it was formed.

(2)

- (v) State reasons why the measurement of the amount of uranium in a rock sample would be inaccurate when performed by a radiation counting technique.

(2)

(Total 17 marks)

25

The radioisotope iodine-131 ($^{131}_{53}\text{I}$) is used in medicine to treat over-active thyroid glands. It decays into an *isotope* of xenon (Xe) by β^- emission with a *half-life* of 8.1 days. The xenon subsequently emits a γ ray.

- (a) Explain what is meant by:

- (i) *isotope*;

(2)

- (ii) *half-life*.

(1)

- (b) Write down the equation which represents the nuclear reaction.

(3)

- (c) Calculate the time (in days) for a sample of iodine to decay to 1% of its initial activity.

(4)

- (d) State and explain which decay product can be detected outside the body during treatment.

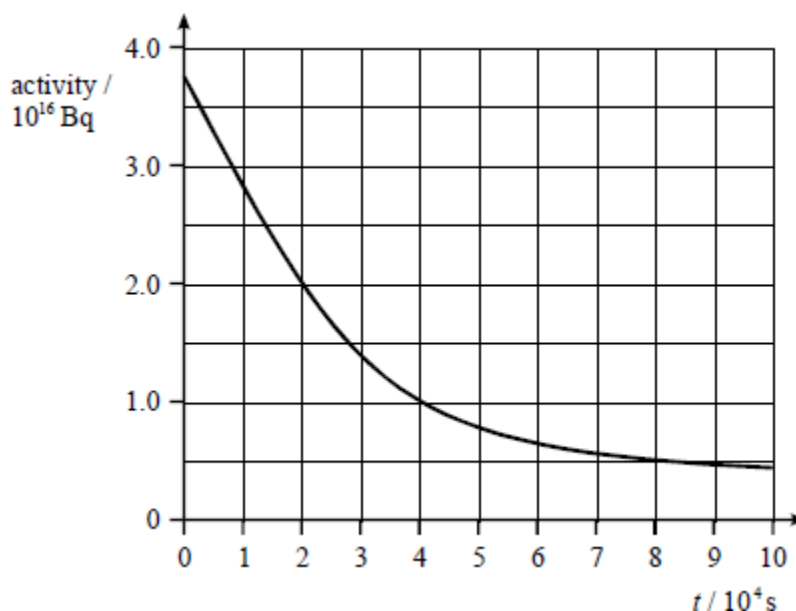
(2)

(Total 12 marks)

26

An isotope of technetium is a gamma emitter used by doctors as a tracer in the human body. It is injected into the patient's blood stream. Scanners outside the body measure the gamma activity, enabling the blood flow to be monitored.

- (a) The graph shows the variation of activity with time, t , for a sample of the isotope.



- (i) Use data from the graph to determine the half-life of the technetium isotope.

(3)

- (ii) The decay constant of the technetium isotope is $3.2 \times 10^{-5} \text{ s}^{-1}$. Use data from the graph and the equation $A = \lambda N$ to calculate the number of nuclei of the radioactive technetium isotope present at time $t = 0$.

(2)

- (b) (i) State why an alpha emitter would not be suitable in this application.

(1)

- (ii) State why the half-life of the technetium isotope makes it suitable for this application.

(1)

- (c) State and explain how the presence of the technetium isotope may do some damage to the patient.

(2)

(Total 9 marks)

27

The actinium series of radioactive decays starts with an isotope of uranium, nucleon (mass) number 235, proton (atomic) number 92.

Which line in the table shows the nucleon number and proton number of the isotope after the emission of 5 α particles and 2 β^- particles?

	Nucleon number	proton number
A	213	82
B	215	80
C	215	84
D	227	87

(Total 1 mark)

28

A small portion of the hydrogen in air is the isotope tritium ${}^3_1\text{H}$. This is continually being formed in the upper atmosphere by cosmic radiation so that the tritium content of air is constant. Tritium is a beta emitter with a half-life of 12.3 years.

- (a) (i) Write down the symbols for the **two** isotopes of hydrogen, the atoms of which have lower masses than those of tritium.

(1)

- (ii) Write down the nuclear equation that represents the decay of tritium using the symbol **X** for the daughter nucleus.

(2)

(iii) Calculate the decay constant for tritium in year^{-1} .

(1)

- (b) When wine is sealed in a bottle no new tritium forms and the activity of the tritium content of the wine gradually decreases with time. At one time the activity of the tritium in an old bottle of wine is found to be 12% of that in a new bottle. Calculate the approximate age of the old wine.

(3)

- (c)
- | | |
|--|---------------------------------------|
| mass of a tritium nucleus | = 3.016050 u |
| mass of a proton | = 1.007277 u |
| mass of a neutron | = 1.008665 u |
| atomic mass unit, u | = 1.660566×10^{-27} kg |
| speed of electromagnetic radiation in free space | = 3.0×10^8 m s ⁻¹ |

Calculate:

- (i) the mass change, in kg, when a tritium nucleus is formed from its component parts,

(2)

- (ii) the binding energy, in J, of a tritium nucleus.

(2)

(Total 11 marks)

Mark schemes

1

boron numbers correct: $A = 11$; $Z = 5$

B1

β^+ correct: $A = 0$; $Z = (+)1$

B1

ν_e (not anti neutrino) with numbers correct: 0,0

B1

3

[3]

2

(a) Background radiation ✓

Background count = 20 count/minute unit required ✓

Ignore any –ve sign for background count

Must be written to 2 sf

2

(b) Correct line of best fit ✓

The line must be a straight line (as instructed), with approximately an equal number of points on either side of the line.

1

(c) Triangle drawn with smallest side at least 8 cm ✓
(or 8 grid squares)

correct values read from graph ✓

gradient = $-0.00698 (\pm 0.00030) \text{ min}^{-1}$ ✓

must have –ve sign and must be to 2 or 3 sf ✓

Gradient must lie within limits stated. No ecf from incorrectly read values unless it falls within stated limits. No unit penalty.

3

(d) Recognises gradient = $(-)\lambda$ or

Uses gradient for value of $\lambda = 7.0 (\pm 0.30) \times 10^{-3} \text{ minute}^{-1}$ ✓

$T_{1/2} = 99 \text{ minutes}$ to 2 or 3 sf ✓

*For 1st mark accept evidence that value of gradient has been substituted into correct formula for half life. No penalty for missing –ve sign. Allow ect from incorrect gradient value.
Unit penalty if half life has been calculated in different unit (to minutes stated in question)*

2

(e) Random ✓

1

- (f) (i) Uncertainty = $(\pm \sqrt{429}) = \pm 21$

No sf penalty ✓

Details of calculation not required. Marks can be awarded for correct numerical answers. Also no penalty for quoting uncertainty or % uncertainty without '±'.

1

- (ii) % uncertainty = $\pm 4.9\%$ ✓

No sf penalty. (Note that % uncertainty in total count is same as % uncertainty in corresponding count rate.)

Accept also 4.8% (number achieved keeping all sig figs in calculator)

No penalty for omitting % or '±'.

No sf penalty

1

- (iii) % uncertainty for 84 counts is $\pm 10.9\%$ ✓

Taking data over larger time period / larger total count will have smaller percentage uncertainty. ✓

Accept $\pm 11\%$

No penalty for omission of ± sign. No sf penalty for estimated % uncertainties.

2

[13]

3

- (a) correct numbers for beta+ (0, (+)1) and chromium (52)

B1

(electron) neutrino with correct numbers (0,0)

B1

2

- (b) W^+/W^- /(intermediate vector) boson (not Z boson)

B1

1

[3]

4

- (a) plutonium is toxic/large mass of plutonium

B1

harmful if released into atmosphere/explosion occurred

B1

alphas dangerous when ingested/during launch etc

B1

max2

(b) unaffected

B1

chemical bonding involves electrons (atomic)
radioactivity is nuclear (nuclei)/same number of nuclei
present

B1

2

(c) (i) $T_{1/2} = \ln 2 / \lambda$

C1

$$2.51 \times 10^{-10}$$

A1

2

(ii) molar mass calculated (0.270 kg)

C1

use of 33 kg

C1

number of moles in sample (122.2)

C1

multiplication of value by Avogadro's number

C1

$$7.36 \times 10^{25}$$

A1

5

(iii) (c) (i) $\times$ (c) (ii)

C1

$$1.83 \times 10^{16} \text{ Bq}$$

A1

Bq

B1

3

(d) (i) uranium correct (234,92)

B1

alpha correct (4,2) – accept He or α symbol

B1

2

(ii) use of 1 g generating 500 mW

C1

16500 W total

C1

recognition that activity $\times$ energy of one alpha = power

C1

9.00×10^{-13} (J)

A1

4

[20]

5

(a) probability of decay per unit time/given time period

or fraction of atoms decaying per second

or the rate of radioactive decay is proportional to the number of (unstable) nuclei

and nuclear decay constant is the constant of proportionality **(1)**

1

(b) use of $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

$T_{\frac{1}{2}} = \ln 2 / 3.84 \times 10^{-12} \text{ s}$ **(1)** ($1.805 \times 10^{11} \text{ s}$)

$= (1.805 \times 10^{11} / 3.15 \times 10^7) = 5730 \text{ y}$ **(1)**

answer given to 3 sf **(1)**

3

(c) number of nuclei = $N = 3.00 \times 10^{23} \times 1/10^{12}$ **(1)**

(= 3.00×10^{11} nuclei)

(using $\frac{\Delta N}{\Delta t} = -\lambda N$)

rate of decay = $3.84 \times 10^{-12} \times 3.00 \times 10^{11}$ **(1)**

(= 1.15 Bq)

2

(d) ($N = N_0 e^{-\lambda t}$ and activity is proportional to the number of nuclei $A \propto N$ use of $A = A_0 e^{-\lambda t}$)

$0.65 = 1.15 \times e^{-3.84 \times 10^{-12} t}$ **(1)**

$$t = \frac{\ln\left(\frac{1.15}{0.65}\right)}{3.84 \times 10^{-12}} \text{ or } \frac{\ln\left(\frac{0.651}{1.15}\right)}{-3.84 \times 10^{-12}}$$

$t = 4720 \text{ y}$ **(1)**

3

- (e) the boat may have been made with the wood some time after the tree was cut down

the background activity is high compared to the observed count rates

the count rates are low or sample size/mass is small or there is statistical variation in the recorded results

possible contamination

uncertainty in the ratio of carbon-14 in carbon thousands of years ago

any two **(1)(1)**

2

[11]

6

- (a) number correct for alpha **(1)**

number correct for beta **(1)**

alpha decay first goes via Tl **(1)**

numbers correct for Tl (208, 81) **(1)**

beta decay first goes via Po **(1)**

numbers correct for Po (212, 84) **(1)**

6

- (b) (i) use of GM tube + counter/rate-meter **(1)**
 measurement of count rate **(1)**
 at range of distances + suitable ruler or tape measure **(1)**
 specifies suitable range **(1)**
 determines background & corrects **(1)**
 safety precaution given **(1)**
 graph of count rate or corrected count rate against $1/d^2$ **(1)**

max 6

- (ii) gamma not absorbed **(1)**
 spreads uniformly from a point
 source/spherically symmetrically **(1)**
 area over which it spreads is proportional
 to radius squared **(1)**
 alpha and beta are absorbed in addition to spreading out **(1)**

max 3

[15]

7

- (a) $R (= r_0 A^{1/3}) = 1.3 \times 10^{-5} \times (238)^{1/3}$ **(1)**
 $= 8.0(6) \times 10^{-15} \text{m}$ **(1)**

2

- (b) (use of inverse square law e.g. $\frac{I_1}{I_2} = \left(\frac{x_1}{x_2}\right)^2$ gives)

$$10 = \left(\frac{x_2}{0.03}\right)^2 \quad \textbf{(1)}$$

$$x = 0.095 \text{ m} \quad \textbf{(1)}$$

(0.0949 m)

2

- (c) (use of $A = A_0 \exp(-\lambda t)$ gives) $0.85 = 1.0 \exp(-\lambda 52)$ **(1)**

$$\lambda = \frac{\ln(100/0.85)}{52} \quad \textbf{(1)}$$

$$= 3.1(3) \times 10^{-3} \text{s}^{-1} \quad \textbf{(1)}$$

3

- (d) it only emits γ rays **(1)**
 relevant properties of γ radiation e.g. may be detected outside
 the body/weak ioniser and causes little damage **(1)**
 it has a short enough half-life and will not remain active
 in the body after use **(1)**
 it has a long enough half-life to remain active during diagnosis **(1)**
 the substance has a toxicity that can be tolerated by the body **(1)**
 it may be prepared on site **(1)**

any three **(1)(1)(1)**

3

[10]

8

(a) reasons:

 α particle has much more mass/momentum than β particle α particle has twice as much charge as a β particle α particle travels much slower than a β particle any **two (1) (1)**2
QWC 1

(b) (i) energy absorbed per sec (= energy released per sec)

$$= 3.2 \times 10^9 \times 5.2 \times 10^6 \times 1.6 \times 10^{-19} \text{ (1)}$$

$$= 2.7 \times 10^{-3} \text{ (J) (1) } (2.66 \times 10^{-3} \text{ (J)})$$

(ii) temperature rise in 1 minute $\left(= \frac{\text{energy absorbed in 1 minute}}{\text{mass} \times \text{specific heat capacity}} \right)$

$$= \frac{2.7 \times 10^{-3} \times 60}{0.20 \times 10^{-3} \times 900} \text{ (for numerator) (1) (for denominator) (1)}$$

$$= 0.90 \text{ K (or } ^\circ\text{C) (1)}$$

(allow C.E. for incorrect value in (i))

5

[7]**9**

B

[1]**10**(a) (i) (inner) orbiting electron [or electron surrounding the nucleus] **(1)**
captured by a proton (in the nucleus) **(1)**
converted into a neutron **(1)**

The Quality of Written Communication marks are awarded for the quality of answers to this question.

(ii) daughter nuclide / nucleus / atom might be excited and
energy given up as electromagnetic radiation
[or orbiting electrons drop down to fill space (left by captured electron)] **(1)**

The Quality of Written Communication marks are awarded for the quality of answers to this question.

(iii) ${}_{83}^{205}\text{Bi} \rightarrow {}_{82}^{203}\text{Pb} + {}_1^0\beta^+ \text{ (1) } + \nu_{(e)} \text{ (1) } (+Q) \text{ [allow } {}_1^0e^+ \text{ for } {}_1^0\beta^+]$

max 5

- (b) (i) (use of $N = N_0 e^{-\lambda t}$ and $N \propto \text{activity}$ gives)
 $290 = 1200 \exp(-\lambda \times 24 \times 60 \times 60)$ **(1)**
 $\lambda = \frac{\ln(1200/290)}{24 \times 60 \times 60}$ **(1)** ($= 1.64 \times 10^{-5} \text{ s}^{-1}$)
- (ii) (use of $T_{1/2} = \ln 2 / \lambda$ gives) $T_{1/2} = \frac{\ln 2}{1.64 \times 10^{-5}}$ **(1)**
 $= 4.2(3) \times 10^4 \text{ s}$ **(1)** ($= 11.(7) \text{ hr}$)
 (use of $\lambda = 1.6 \times 10^{-5} \text{ s}^{-1}$ gives $T_{1/2} = 4.3 \times 10^4 \text{ s}$ or 12 hr)
- (iii) (use of $\frac{\Delta N}{\Delta t} = \lambda N$ gives) $(-)1200 = (-)1.64 \times 10^{-5} N$ **(1)**
 $N = 7.3(2) \times 10^7$ (nuclei) **(1)**
 (use of $\lambda = 1.6 \times 10^{-5} \text{ s}^{-1}$ gives $N = 7.5 \times 10^7$ (nuclei))

max 5

[10]

11

- (a) (i) $T_{1/2} = 50 \text{ s}$ **(1)** (from graph)
- (ii) $\lambda = \frac{\ln 2}{50}$ **(1)** $= 0.014 \text{ s}^{-1}$ **(1)**
- (iii) $N = \frac{A_0}{\lambda}$ **(1)** $= \frac{2.4 \times 10^5}{0.014} = 1.7(1) \times 10^7$ **(1)**
- (b) (i) elapsed time = 50 s = 1 half-life **(1)**
 $N_{30} = N_0 e^{-30\lambda}$ **(1)** $= 1.71 \times 10^7 e^{-30 \times 0.014} = 1.12 \times 10^7$ **(1)**
 $\therefore$ no. decayed from $t = 30 \text{ s}$ to $t = 80 \text{ s}$ is $\frac{1.12 \times 10^7}{2} = 0.56 \times 10^7$ **(1)**
 [alternative (b)(i)]
 $N_{30} = N_0 e^{-30\lambda}$ and $N_{80} = N_0 e^{-80\lambda}$ **(1)**
 give 1.12×10^7 **(1)** and 0.56×10^7 **(1)**
 number decayed ($= 1.12 \times 10^7 - 0.56 \times 10^7$) $= 0.56 \times 10^7$ **(1)**
- (ii) energy released $= 0.56 \times 10^7 \times 1.0 \times 10^{-12} = 5.6 \times 10^{-6} \text{ J}$ **(1)**

(max 4)

[9]

12

- (a) ${}_{83}^{212}\text{Bi} \rightarrow {}_2^4\alpha + {}_{81}^{208}\text{Tl}$
 either **(1)** (for both atomic mass numbers, 4 and 208)
 and **(1)** (for both atomic numbers, 2 and 81)
 [or **(1)** for ${}_{81}^{208}\text{Tl}$ and incorrect α]

- (b) (i) $E_k = (\frac{1}{2}mv^2) = 6.1 \times 10^6 \times 1.6 \times 10^{-19}(\text{J})$ **(1)**
substitution for $m = 4.0 \times 1.66 \times 10^{-27}(\text{kg})$ **(1)**

$$v = \left(\frac{2 \times 6.1 \times 10^6 \times 1.6 \times 10^{-19}}{4.0 \times 1.66 \times 10^{-27}} \right)^{1/2} \quad \textbf{(1)} (= 1.7 \times 10^7 \text{ m s}^{-1})$$

- (ii) correct use of conservation of momentum $m_{\text{Tl}} v_{\text{recoil}} = m_{\alpha} v$ **(1)**
substitution of $m_{\text{Tl}} = 208u$ **(1)**
(allow C.E. for mass = 208)

$$v_{\text{recoil}} = \frac{4 \times 1.7 \times 10^7}{208} = 3.3 \times 10^5 \text{ m s}^{-1} \quad \textbf{(1)}$$

(allow C.E. for value of v)

6

[8]

13

- (a) (i) (use of $P = VI$ gives) $P (= 2.4 \times 20) = 48 \text{ W}$ **(1)**
(ii) incident (solar) power $(= 1.4 \times 2.5) = 3.5 \text{ (kW)}$ **(1)**

$$\text{efficiency} = \frac{48}{3500} \quad \textbf{(1)}$$

$$= 0.014 \quad \textbf{(1)} \quad (\text{or } 1.4\%)$$

$$[\text{or efficiency} = \frac{48}{2.5} / 1400]$$

(allow C.E. for incorrect values of input and output power)

4

- (b) (i) in 1 s source emits 1.1×10^{14} particles **(1)**
energy emitted in 1 s $= 1.1 \times 10^{14} \times 5.1 \times 1.6 \times 10^{-13} (\text{J})$ **(1)** $(= 90 \text{ J})$

$$(ii) \quad T_{1/2} = \frac{\ln 2}{\lambda} + \text{correct use or } \lambda = \frac{\ln 2}{90 \times 365 \times 24 \times 3600} \quad \textbf{(1)}$$

$$= 2.44 \times 10^{-10} \text{ s}^{-1} \quad \textbf{(1)}$$

$$[\text{or } \lambda = \frac{\ln 2}{90} = 7.7 \times 10^{-3} \text{ yr}^{-1}]$$

$$(iii) \text{ no. of nuclei } \left(= \frac{\text{activity}}{\text{decay constant}} = \frac{11 \times 10^{14}}{2.44 \times 10^{-10}} \right) = 4.5(1) \times 10^{23} \text{ (1)}$$

(allow C.E. for incorrect value of λ in (ii))

$$\text{mass of isotope} = \frac{4.51 \times 10^{23} \times 0.239}{6.02 \times 10^{23}} \text{ (1)}$$

$$= 0.18 \text{ kg (1)}$$

(allow C.E. for incorrect no. of nuclei)

7

[11]

14

(a) (i) alpha (1)

(ii) two different track lengths (1)

short range particles have lower energy than long range particles (1)

particles in each range have same energy (1)

(4)

(b) (i) ${}_{94}^{239}\text{Pu} \rightarrow {}_{92}^{235}\text{U} + \alpha \text{ (1) (+Q)}$

(ii) ${}_{92}^{235}\text{U} \rightarrow {}_{90}^{231}\text{Th} + \alpha \text{ (1) (+Q)}$

(iii) U-235 (1)

because of the inverse relationship

between half-life and alpha particle energy (1)

(iv) because the Th-90 nucleus is neutron-rich compared

with U-235 [or Pu-239] (1)

(5)

[9]

15

- (a) (i) which atom decays **(1)**
at what time is chance **(1)**
- (ii) isotopes are (different forms) of same element **(1)**
same proton number, Z , different nucleon number, A
[or with same number of protons but different number of neutrons] **(1)**
- half-life is time for number of nuclei to halve [or to halve activity] **(1)**
for a particular isotope **(1)**

$$\frac{dN}{dt} = -\lambda N \text{ (1)}$$

λ is constant of proportionality [or probability of decay] **(1)**
[or λ is probability of decay **(1)** in unit time **(1)**]

max 6

(b) (i) $\lambda = \frac{\ln 2}{8.04 \times 24 \times 3600} \text{ (1)} = 1.0 \times 10^{-6} \text{ s}^{-1} \text{ (1)}$

(ii) $N = \frac{5.0 \times 10^4}{1.0 \times 10^{-6}} \text{ (1)} = 5.0 \times 10^{10}$

(iii) $\ln \left(\frac{N_0}{N} \right) = \lambda t \text{ (1)}$

$$t = \frac{\ln \left(\frac{5.4 \times 10^{10}}{5.4 \times 10^{10}} \right)}{1.0 \times 10^{-6}} \text{ (1)} = 7.7 \times 10^4 \text{ s (1)}$$

$$= \frac{7.7 \times 10^4}{3600} = 21(.4) \text{ (hour) (1)}$$

max 6

[12]**16**

- (a) all plots correct to $\frac{1}{2}$ small square
deduct 1 mark for one incorrect, 2 marks for 2+ incorrect

B2

line appropriate

B1

- (b) one correct determination from correct numbers

B1

$$154 \pm 10 \text{ s}$$

B1

two correct determinations and average

B1

3

- (c) (use of $A = \lambda N$) $480 = \lambda \times 1.1 \times 10^{-5}$

$$[allow \lambda = \ln 2/t_{1/2}]$$

C1

$$4.4 \times 10^{-3} \text{ s}^{-1} [4.36]$$

A1

2

[8]

17

- (a) time for half of (active) nuclei (of radioactive substance) to decay (1)

(1)

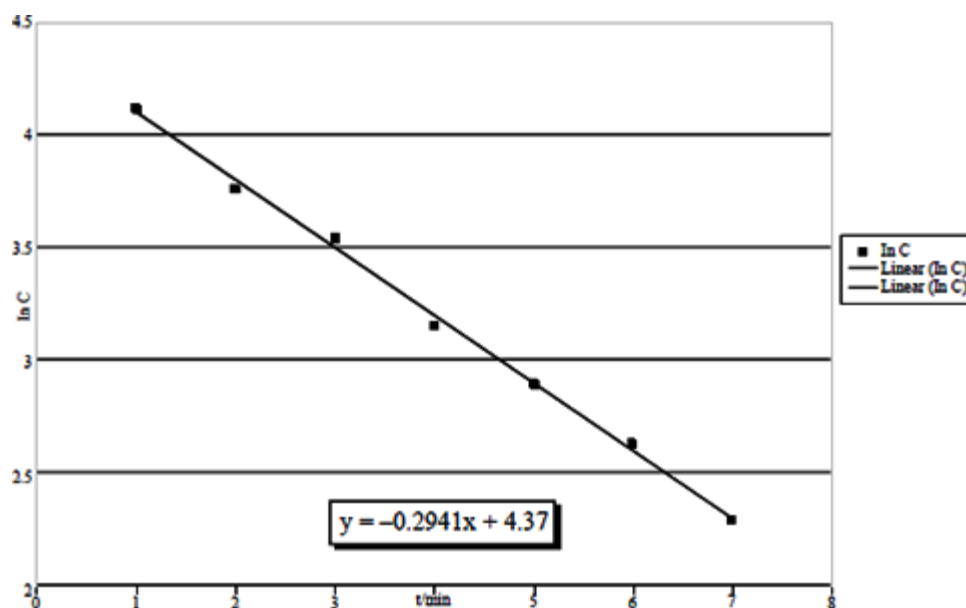
- (b)

t / minute	0	10	20	30	40	50	60
number of counts in 30s, C	60	42	35	23	18	14	10
$\ln C$	4.094	3.738	3.555	3.135	2.890	2.639	2.303

Correct values of $\ln C$ above (1)

(1)

- (c) (i) seven points correctly plotted **(1)** **(1)** [six points correct **(1)**]



- (ii) best straight line through points **(1)**

sensible scale **(1)**

- (iii) from sensible triangle on graph **(1)**

gradient = $-$ **(1)** 0.030 [0.294] **(1)** (min^{-1})

(max 5)

- (d) (i) $C = C_0 e^{-\lambda t}$, $\ln C - \ln C_0 = -\lambda t$
hence using $y = mx + c$, $\lambda = (-)\text{gradient}$ **(1)**

- (ii) half-life = $\frac{\ln 2}{\lambda} = \frac{0.693}{0.03}$ **(1)** = 23 min **(1)**

(3)

- (e) count over longer period than half minute [or repeat experiment] **(1)**

use stronger source **(1)**

use background count correctly **(1)**

(max 2)

- (f) for ^{14}C , $\lambda = \frac{0.693}{T_{1/2}} = 1.21 \times 10^{-4} \text{ (year)}$ **(1)**

$$-\lambda t \left(= \ln \frac{R}{R_0} \right) = \ln \left(\frac{5.2}{6.5} \right) \text{ **(1)** } = -0.223 \text{ **(1)**}$$

$$t = \frac{0.223}{1.21 \times 10^{-4}} = 1840 \text{ (year)} \text{ **(1)**}$$

(4)

18

- (a) (i) remove electrons from atoms

B1

by colliding with them/knocking into them

B1

2

- (ii) fewer collisions per metre

B1

because beta particles are smaller/less ionising
(accept smaller charge) **not** less mass

B1

so lose energy over a larger distance

B1

max 2

- (b) (i) one correct construction shown on graph (52 s – 53 s)

M1

at least one other determination visible on graph

M1

averaging process shown

A1

3

(ii) $N = 1.08 \text{ to } 1.1 \times 10^{21}$ (condone errors in powers of 10)

B1

$$A = \lambda N$$

C1

$1.4(3) \times 10^{19} \text{ Bq}$ (allow decays/second) **allow ecf for minor error in N**

A1

or

attempt to find gradient at 72 s

correct extraction from a tangent of graph

$1.3 \text{ to } 1.5 \times 10^{19} \text{ Bq}$ (allow decays / second)

3

[10]

19

(a) ${}^{14}_7\text{N}$ on rhs

B1

${}^0_{-1}\text{e}/{}^0_{-1}\beta$ on rhs

B1

antineutrino shown

B1

3

(b) (i) Becquerel/Bq

B1

(ii) $6.3 \times 10^{19} \times 3.8 \times 10^{-12}$

C1

3

$= 2.4 \times 10 + [\text{no unit required}]$

A1

(c) **route A**

activity is proportional to the number of atoms

B1

activity is the change in the number of atoms per second

B1

max 2 from:

graph shows:

N decreases as activity decreases

B1

Max 4

exponential

B1

constant half life

B1

gradient decreases as N decreases

B1

or

route B

defines half life in words or by example

B1

$t_{1/2}$ related to λ

B1

Max 4

same λ implies constant $t_{1/2}$

B1

graph shows constant half-life behaviour

B1

20

- (a) (i) half life = 1.44×10^{10} s or half life = $0.69/\lambda$ or $\ln 2/\lambda$

C1

450 (449) y (or 460(456)y if they use 3.15×10^7 s = 1y)

A1

2

- (ii) $A = \lambda N$

C1

7.7×10^{14}

A1

2

- (iii) $A = A_0 e^{-\lambda t}$

C1

correct substitution ($A = 3.7 \times 10^4 e^{-4.8 \times 10^{-11} \times 50 \times 3.2 \times 10^7}$)

C1

3.4×10^4 Bq

A1

3

- (iv) the decay products/neptunium may also be radioactive

B1

1

- (b) (i) attempt to determine mass change or quotes $E = mc^2$

C1

mass change = 1.00×10^{-29} kg

C1

9.0×10^{-13} J or 5.63 MeV

(condone correct answer in J followed by incorrect attempt to convert to MeV)

A1

3

- (ii) decays without the need for any external stimulus
(owtte)

B1

mass of products must be less than original mass
(of nucleus for possible spontaneous decay)

B1

2

[13]

21

- (a) (i) Z increases by 1

B1

A remains the same

B1

2

- (ii) Correct curvature starting at 120 Bq

B1

60 (or $0.5 \times$ their start value) at 12 h days later

B1

30 (or half their value at 12 h)
and continuing to fall thereafter approximately
exponentially

B1

3

(b) (i) $6.6 \times 10^{-11} \text{ J (s}^{-1}\text{)}$ $(120 \times 5.5 \times 10^{-13})$

B1

1

- (ii) another particle is emitted in each decay (not gamma radiation)
or
the nucleus recoils

B1

anti-neutrino emitted (this would get first and second mark 2 marks)

B1

the other particle/neutrino/antineutrino/nucleus takes some/varying amounts of the energy

B1

3

(c) 7.5×10^6

B1

1

- (d) Particles are emitted in all directions/particles do not all go to detector

B1

Detector only detects some of the particles **that enter it**/mention of dead time or recovery time
(not detector does not detect all the particles - this adds nothing)

B1

Some particles are absorbed by the window

B1

max 2

[12]

22

(a) Appropriate method

B1

sensible and correct readoffs

B1

correct evaluation from readoffs

B1

3

(b) correct readoff on y-axis

B1

use of $\lambda = A/N$

C1

correct evaluation from readoff [condone use of 6.0 here]

or determines $T_{1/2}$ /uses $T_{1/2} = 0.69/\lambda$ / $\lambda = 0.69/725$

A1

3

[6]

(a) $^{236}_{92}\text{U}$

B1

$4/2/\alpha$ [$4/2/\text{He}$]

B1

(b) (i) Equation correct **or** Evaluates mass difference

B1

$(1.349 \times 10^{-29} \text{ kg})$

Uses $E = mc^2$

B1

to yield energy (1.21 pJ)

B1

(ii) uses $t_{1/2} = [\log_e 2/\lambda] = 0.69/2.1 \times 10^{11}$

M1

to yield $\lambda = 3.29 \times 10^{-12} \text{ s}^{-1}$

C1

(iii) uses $A = \lambda N$ [= 1.05×10^{10}] **or** $N_1 = N_0 e^{-\lambda t}$

C1

uses $A \times 1.21 \times 10^{-12}$ **or** $(N_0 - N_1) \times 1.21 \times 10^{-12}$

C1

= 12.7 mJ

A1

(iv) $A = A_0 e^{-\lambda t}$

C1

$$0.95 = e^{-3.29 \times 10^{-12} t} \text{ [or log expression]}$$

C1

$$t = 1.56 \times 10^{10} \text{ s} = 495 \text{ years}$$

C1

correct deduction from candidate answer

B1

or

$$100 \text{ y} = 3.19 \times 10^9 \text{ s}$$

C1

$$A = A_0 e^{-\lambda t} = 1.056 \times 10^{10} e^{-0.0104} \text{ [ecf from first mark]}$$

C1

$$A = 1.046 \times 10^{10} \text{ [ecf from first mark]}$$

C1

Change is 1 part in 105 OWTTE so no significant change

B1

or

Half life calc/fractional change/ 2^n /99% left so no sig change

or

further alternative

[14]

24

(a) (i) $A = 4; Z = 2$

B1

(1)

(ii) $A = 0; Z = -1$

B1

(1)

(iii) 8 alphas c.a.o.

B1

explanation consistent with their (i) / correct equations including values of A and Z

B1

(2)

(iv) 6 betas e.c.f.

B1

explanation consistent with their (i) and (ii) / correct equations including values of A and Z

B1

(2)

- (b) (i) probability of a nucleus decaying per unit time **or**
ratio of activity to number of nuclei (of that type) present **or**

$$\lambda = (-) \frac{1}{N} \frac{dN}{dt} \text{ with terms defined } \mathbf{or}$$

$$\frac{0.69(3)}{t_{1/2}} \text{ with terms defined}$$

B1

(1)

- (ii) $N_P = N_0 - N_0 e^{-\lambda t} / N_U = (N_U + N_P) e^{-\lambda t} / N_P = N_0 - N_U$

B1

correct manipulation

B1

(2)

- (iii) $N_P / N_U = 0.62 / 4.2$

C1

$$\lambda = (\ln 2) / 4.5 \times 10^9$$

or

$$0.69 / 4.5 \times 10^9$$

C1

correct manipulation of logs

C1

$$9.0 \times 10^8 \text{ y} / 8.96 \times 10^8 \text{ y}$$

A1

look for alternative approach based on $N_0 = 4.82$ and then
use of $N = N_0 e^{-\lambda t}$

(4)

- (iv) age will be overestimated

B1

not all of the Pb is the result of uranium decay or words to that effect

B1

(2)

- (v) change of count rate for U will be small as half life is large

B1

comment about background count (rate) or background radiation

B1

absorption in sample

B1

presence of other radioactive nuclides / daughter nuclei

B1

max 2

25

- (a) (i) nuclides or atoms of same element **or** same proton / atomic number
not just 'same element'
different mass / nucleon number or numbers of neutrons

B1
B1

(2)

- (ii) time taken for half the sample **or** half the number of nuclei
(not just 'atoms') to decay or activity to fall to half initial value

B1

(1)

- (b) $^{131}_{54}\text{Xe}$
 $^{0}_{-1}\text{e}$ **or** $^{0}_{-1}\beta$

B1
B1
B1

(3)

- (c) $A / A_0 = 0.01$ **or** $A = 1$ **and** $A_0 = 100$

C1

$$\lambda = 0.69 / 8.1 \text{ **or** } \lambda = \frac{\ln 2}{T_{1/2}} \text{ **or** } \lambda = \frac{0.69}{T_{1/2}} \text{ **or** } 0.086 \text{ (0.0856)}$$

attempt to take logs

C1

54 days (53.8)

A1

(for between 6 and 7 half-lives, 50% $\rightarrow$ 25% $\rightarrow$ 12.5%)

C1

(4)

- (d) γ radiation detected

M1

 β^- cannot penetrate tissue **or** γ can penetrate tissue

A1

(2)

[12]

26

- (a) (i) correct construction method seen on graph
or quotes appropriate values from the graph

C1

 2.0×10^4 s to 2.4×10^4 s allow 1 or 2 s.f.

A1

repeats and averages

B1

(3)

- (ii) $A = 3.7$ or 3.8×10^{16} (Bq) at $t = 0$

C1

 1.2×10^{21}

A1

(2)

(b) (i) alpha will not penetrate the body or risk to patient from ionisations

B1
(1)

(ii) long enough half life to make measurements / short enough half life so does not remain long in body

B1
(1)

(c) causes ionisations / damage
to cell / cell nucleus / body tissue / DNA

B1
B1
(2)

[9]

27 C

[1]

28 (a) (i) ${}^1_1\text{H}$ and ${}^2_1\text{H}$ or ${}^1_1\text{H}$ and ${}^2_1\text{D}$ condone H_1^1 etc

B1
(1)

(ii) ${}^3_1\text{H} \rightarrow \text{X} + \beta$

${}^3_1\text{H} \rightarrow {}^3_2\text{X}(\text{or He}) + {}^0_{-1}\beta \text{ (or } {}^0_{-1}\text{e)}$

M0

Z correct throughout

A1

A correct throughout

A1
(2)

(iii) 0.056(4) (no unit penalty)

B1
(1)

(b) $A = A_0 e^{-\lambda t}$

C1

$12 = 100e^{-\lambda t}$ or other progress toward answer

C1

38 (40) y allow e.c.f. from (iii)

A1

or evidence of working in half-lives

C1

statement that age is $3 \times T_{\frac{1}{2}}$

C1

age ≈ 37 y

A1

or $A = N_0 e^{-\lambda t}$ (using **incorrect** formula from sheet)

C1

$$\lambda N = N_0 e^{-\lambda t} \text{ and } \frac{N}{N_0} = 0.12 \text{ or } \frac{A}{A_0} = 0.12$$

C1

$$t = 89 \text{ y}$$

A1

(3)

(c) (i) (mass of proton + 2 × mass of neutron – mass of tritium) = 0.0086 u

B1

multiplies any mass in u by 1.660566×10^{-27}

A1

$$1.42 \times 10^{-29} \text{ kg}$$

(no significant figure penalty) (no unit penalty) (condone –ve answer)

(2)

(ii) $E = mc^2$

C1

$$E = 1.28 \times 10^{-12} \text{ J}$$

(no unit penalty) (allow e.c.f. from (i) for m in kg) (condone –ve answer)

A1

or using recall of $u = 931 \text{ MeV}$

$$\text{energy change in MeV} = 8.557 \times 931 = 7.97 \text{ MeV}$$

C1

$$\text{energy change in J} = 7.97 \times 1.6 \times 10^{-19} = 1.27 \times 10^{-12} \text{ J}$$

A1

(2)

[11]