

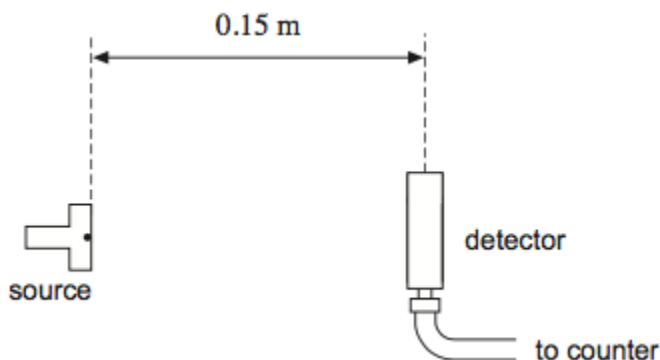
1

- (a) The exposure of the general public to background radiation has changed substantially over the past 100 years.

State **one** source of radiation that has contributed to this change.

(1)

- (b) A student measures background radiation using a detector and determines that background radiation has a mean count-rate of 40 counts per minute. She then places a γ ray source 0.15 m from the detector as shown below.



With this separation the average count per minute was 2050.

The student then moves the detector further from the γ ray source and records the count-rate again.

- (i) Calculate the average count-rate she would expect to record when the source is placed 0.90 m from the detector.

count-rate = _____ min^{-1}

(3)

- (ii) The average count per minute of 2050 was determined from a measurement over a period of 5 minutes. Explain why the student might choose to record for longer than 5 minutes when the separation is 0.90 m.

(1)

- (iii) When the detector was moved to 0.90 m the count-rate was lower than that calculated in part **(b)(i)**. It is suggested that the source may also emit β particles.

Explain how this can be checked.

(2)

(Total 7 marks)

2

- (a) State which type of radiation, α , β or γ ,

- (i) produces the greatest number of ion pairs per mm in air,

- (ii) could be used to test for cracks in metal pipes.

(2)

- (b) Specific radioisotope sources are chosen for tracing the passage of particular substances through the human body.

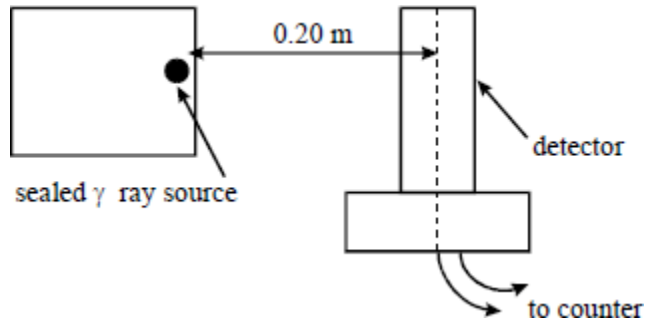
- (i) Why is a γ emitting source commonly used?

- (ii) State why the source should **not** have a very short half-life.

(iii) State why the source should **not** have a very long half-life.

(3)

- (c) A detector, placed 0.20 m from a sealed γ ray source, receives a mean count rate of 2550 counts per minute. The experimental arrangement is shown in the diagram below. The mean background radiation is measured as 50 counts per minute.



Calculate the least distance between the source and the detector if the count rate is not to exceed 6000 counts per minute.

(5)

(Total 10 marks)

3

A radioactive nucleus decays with the emission of an alpha particle and a gamma-ray photon.

- (a) Describe the changes that occur in the proton number and the nucleon number of the nucleus.

proton number _____

nucleon number _____

(2)

- (b) Comment on the relative penetrating powers of the two types of ionizing radiation.

(1)

- (c) Gamma rays from a point source are travelling towards a detector. The distance from the source to the detector is changed from 1.0 m to 3.0 m.

Calculate

intensity of radiation at 3.0 m

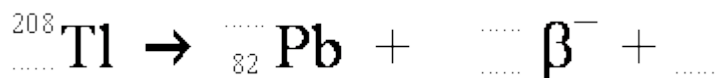
intensity of radiation at 1.0 m

answer _____

(2)

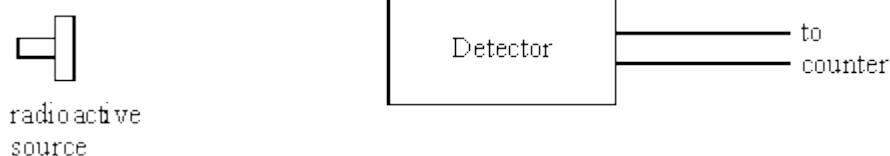
(Total 5 marks)

- 4 Thallium (Tl) decays to a stable form of lead (Pb) with the emission of a β^- particle. Complete the equation below for this decay.



(Total 3 marks)

- 5 A student has access to a radioactive source that decays by emitting alpha, beta and gamma radiation. The student wishes to investigate whether the count rate due to the gamma radiation varies with distance from the source according to an inverse square law and sets up the source and detector as shown in **Figure 1**.



- (a) State and explain how the student can ensure that only gamma radiation is detected during the investigation.

(2)

- (b) The corrected count rate due to gamma radiation is 64 counts per second at a distance of 50 mm from the source. Assuming that an inverse square law is obeyed calculate the expected corrected count rate at a distance of 80 mm from the source.

Count rate at 80 mm _____

(2)

- (c) Using the data from part (b) sketch, on the axes in **Figure 2**, the graph the student would expect if an inverse square law were obeyed. The corrected count rate at 50 mm has been plotted already.

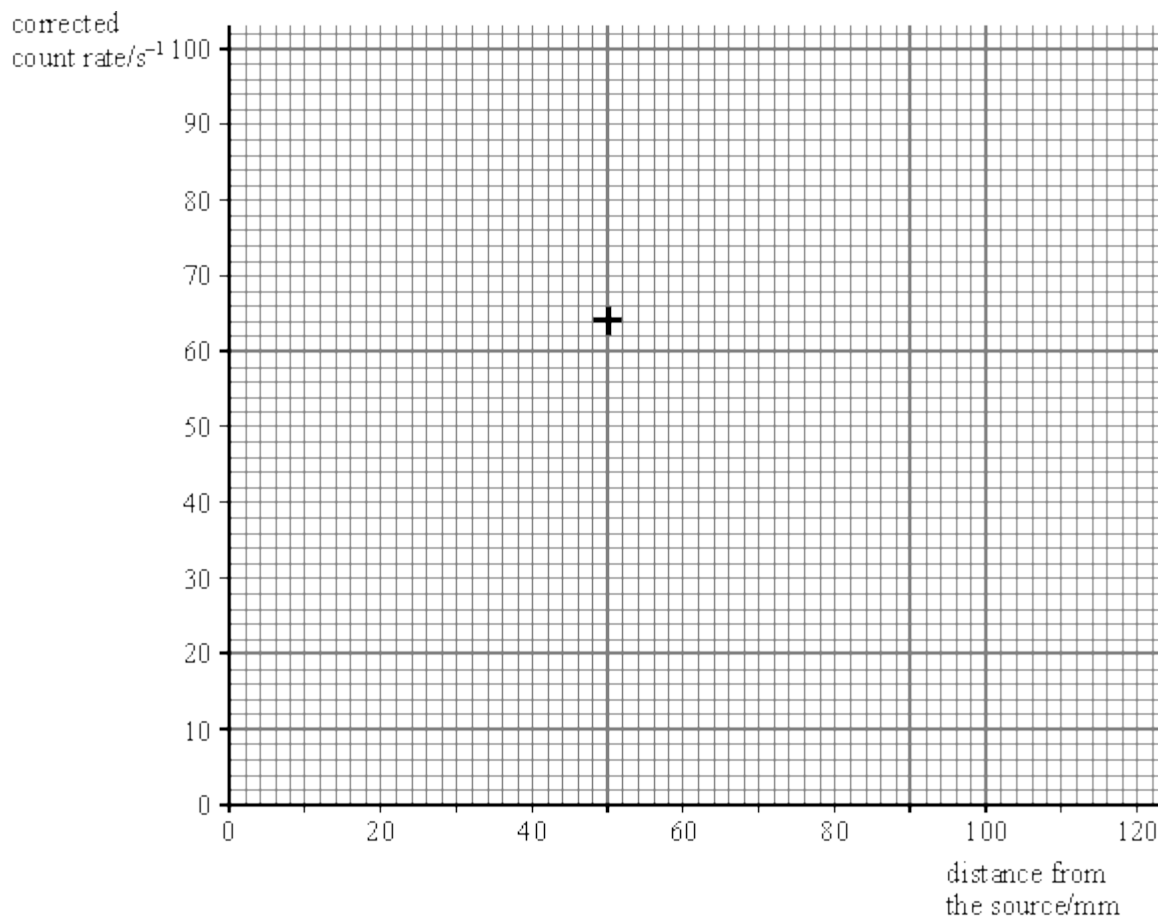


Figure 2

(2)

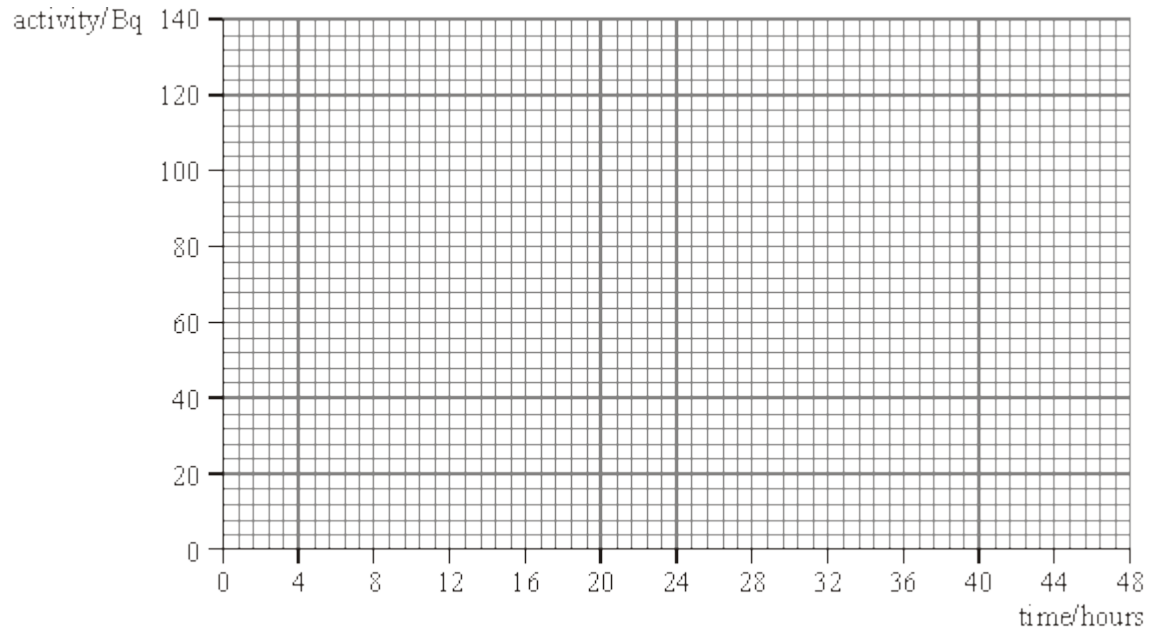
(Total 6 marks)

- 6** 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.

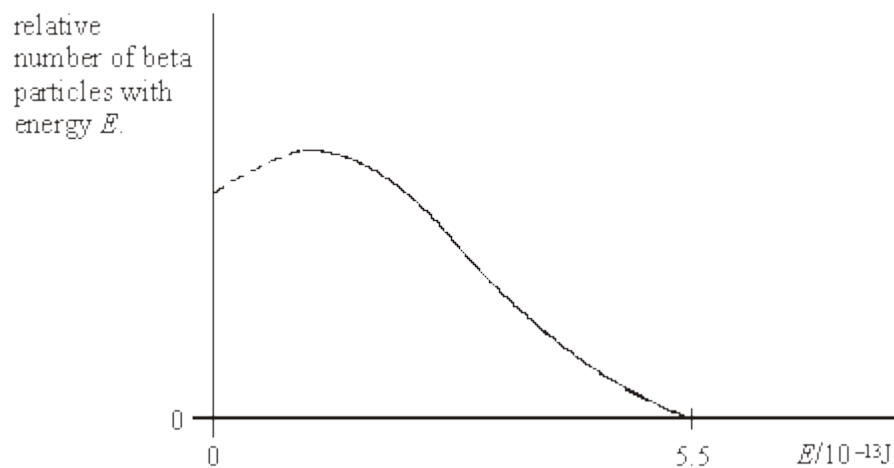


Figure 1

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.

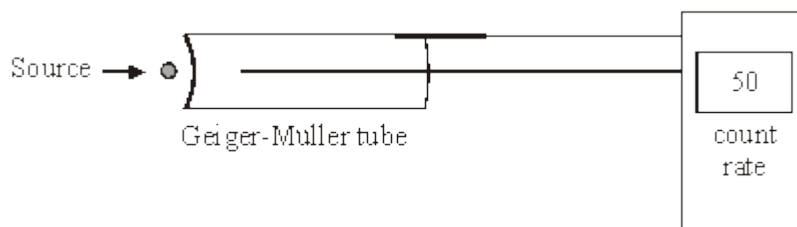


Figure 2

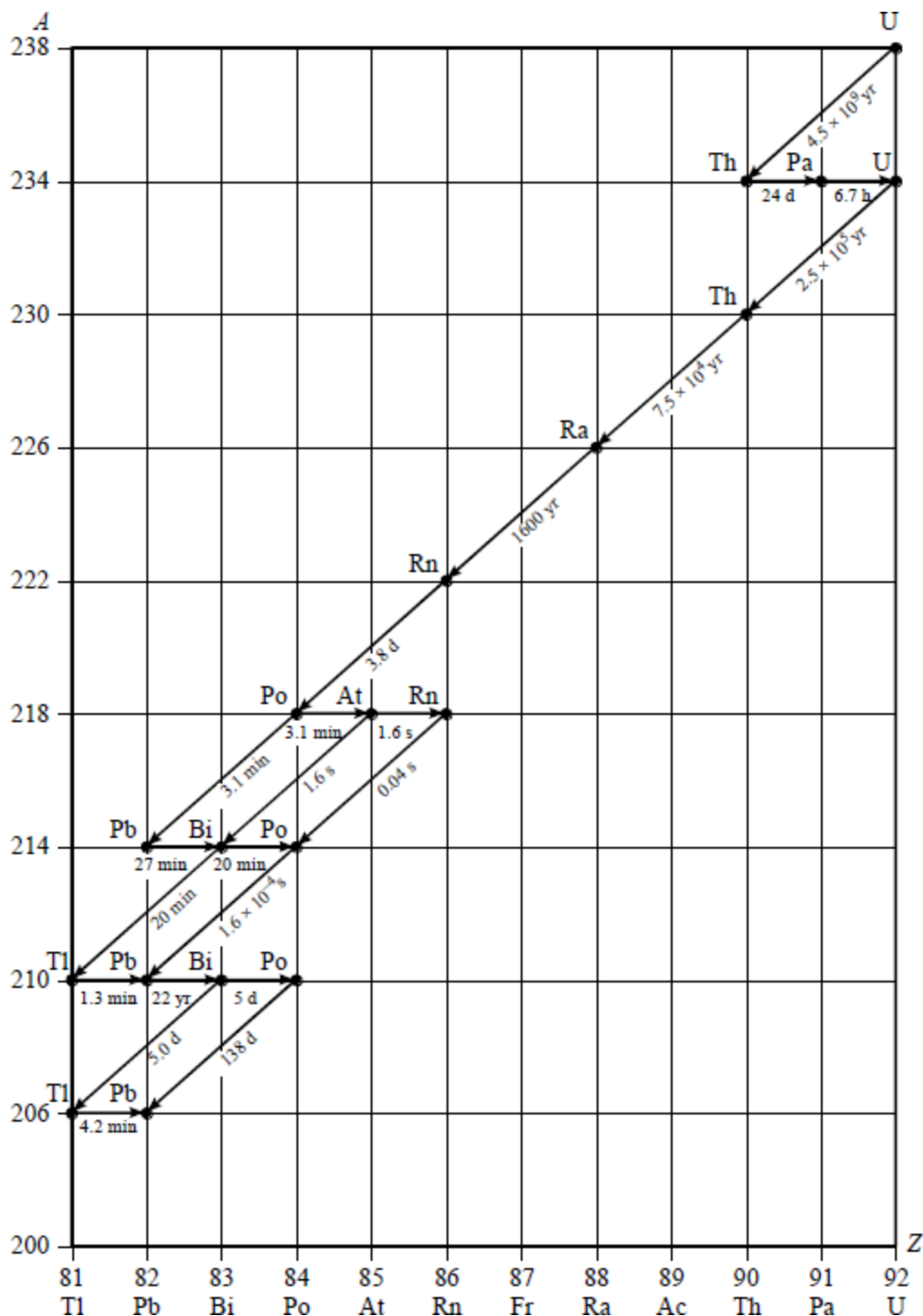
State and explain **two** reasons why the measured count rate is lower than the activity of the source.

(2)

(Total 12 marks)

7

The graph below shows how the nucleon number A changes with proton number Z for the decay series that starts with uranium-238. The half-lives of each decay are also shown.



- (a) How many alpha particles and beta particles are emitted when a uranium-238 nucleus decays to radon-222 (^{222}Rn)?

Number of alpha particles _____

Number of beta particles _____

(2)

(b) How many neutrons are there in a nucleus of polonium-210 (^{210}Po)?

(1)

(c) Identify the stable isotope that results from this decay chain.

(1)

(d) 214 g of bismuth-214 (^{214}Bi) contains 6.0×10^{23} atoms. A sample containing only bismuth-214 has an initial mass of 0.60 g.

(i) After what period of time will the mass of bismuth-214 present in the sample be 0.15 g?

(2)

(ii) Determine the number of bismuth-214 atoms present after this time.

(1)

(iii) Calculate the activity of the bismuth-214 in the sample after this time.

(4)

(iv) Explain how the total activity of the sample will be different from the value calculated in (iii).

(2)

(v) The bismuth-214 decays into polonium-214. Explain why you would find very little polonium-214 if you were to analyse the sample.

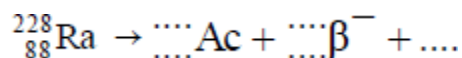
(2)

(Total 15 marks)

8

A radium-288 nuclide ($^{228}_{88}\text{Ra}$) is radioactive and decays by the emission of a β^- particle to form an isotope of actinium (Ac).

(a) Complete the equation for this decay.



(3)

- (b) β^- decay is the result of a neutron within a nucleus decaying into a proton. Describe the change in the quark sub-structure that occurs during the decay.

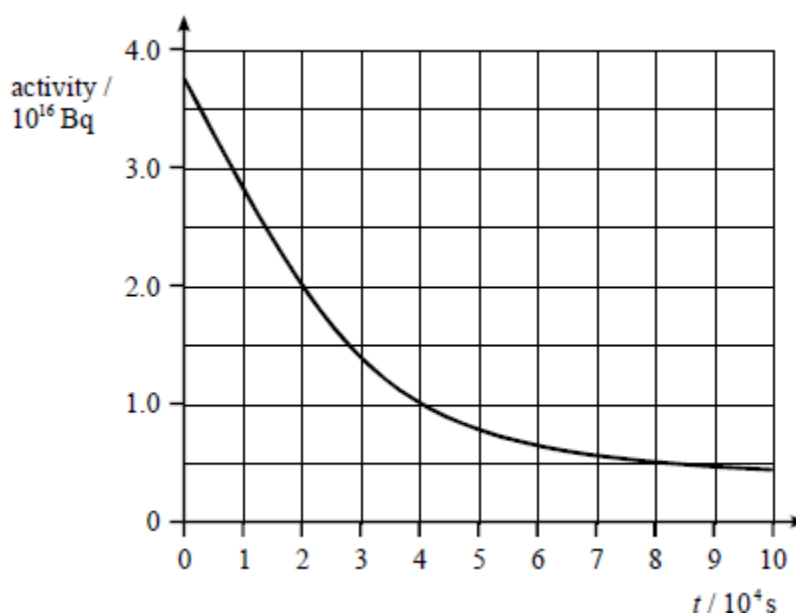
(1)

(Total 4 marks)

9

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)

10

$^{238}_{92}\text{U}$ is an isotope of uranium which decays through a decay chain to the isotope of lead, $^{208}_{82}\text{Pb}$, which is stable. During the sequence of decays, both alpha particles and beta particles are emitted.

- (a) (i) $^A_Z\alpha$ represents an alpha particle.

State the values of:

A _____

Z _____

(1)

- (ii) $^A_Z\beta$ 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)

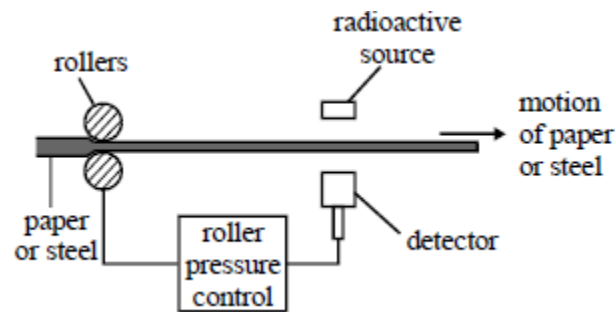
- (v) State reasons why the measurement of the amount of uranium in a rock sample would be inaccurate when performed by a radiation counting technique.

(2)

(Total 17 marks)

11

The diagram below shows an arrangement used to maintain a constant thickness of sheet paper or steel as it is being rolled. A radioactive source and detector are used to monitor the thickness.



- (a) Explain briefly how this arrangement works.

(3)

- (b) Alpha, beta or gamma sources could be selected for use in such an arrangement.

State which source should be selected in each case and explain briefly why the others would not be suitable.

Paper:

Source selected _____

Reasons why the others are unsuitable _____

Steel:

Source selected _____

Reasons why the others are unsuitable _____

(4)

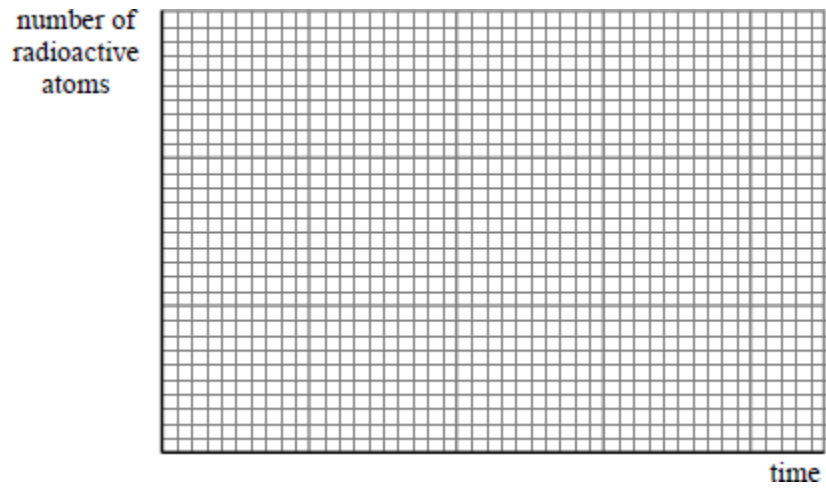
- (c) Cobalt-60 is commonly used as a source in such applications. This has a half-life of 5.3 years. When fresh the source contains 5.0×10^{20} radioactive atoms.

For it to be useful the source has to have an activity of at least 1.5×10^{12} Bq.

- (i) What is meant by an activity of 1 Bq?

(1)

- (ii) Draw a graph showing the number of radioactive atoms in the source over a period of 3 half-lives. Include suitable scales on the axes.



(2)

- (iii) Determine the decay constant of cobalt-60 in s^{-1} .

(2)

- (iv) After what time will it be necessary to replace the source?

(3)

(Total 15 marks)

Mark schemes

1

- (a) nuclear fallout / testing / weapons / nuclear accidents / Chernobyl / nuclear waste / nuclear medicine / X-rays / specific uses of radioactive sources eg medical tracers CT scan etc. / cosmic rays as a result of air travel ✓
(Any source of radiation that an individual may encounter which would not have existed 100 years ago)

No mark for general answers such as 'medical' or Nuclear Power / nuclear plant.

If a list is given all must be correct but ignore generalisations such as medical or nuclear power.

1

- (b) (i) $I_{15\text{CCR}} = 2050 - 40 = 2010$ ✓

Use of inverse square law eg $I_{\text{CCR}90} = I_{\text{CCR}15} \left(\frac{d_{15}}{d_{90}} \right)^2$ ✓ $= 2010 \times (0.15 / 0.90)^2 = 55.8$

$$I_{90\text{CR}} = 55.8 + 40$$

$$I_{90\text{CR}} = 96 \text{ counts min}^{-1} \text{ ✓}$$

regardless of order:

1st mark subtraction of background in original data

2nd mark is for using inverse square function

3rd mark is for the answer

3

- (ii) (reduce impact of) random error / decrease the (percentage) uncertainty / improve the statistics (because the percentage error is proportional to the inverse square-root of the count) ✓ (owtte)

The answer must be an uncertainty related statement and not increases reliability / accuracy or increased chance of a reading (although these ideas can accompany a correct answer) Ignore comparisons with the background count.

1

- (iii) use (sensible) absorber between source and detector ✓ (sensible absorber means it must have a noticeable effect e.g. 1mm of metal / aluminium sheet / 5mm perspex but do not allow metal foil / paper sheets. Also its effect must not be so great that it reduces the gamma rays noticeably)

(These two marks are independent)

β shown by count rate falling when sheet of aluminium absorber is used ✓ Or (using the existing apparatus)

Compare the results (at various distances) in air with the expected inverse square law ✓

Below the range of beta law does not work but above range it does. ✓

2nd mark no mark given if count rate falls to zero as γ is still present

(magnetic deflection is not common but if seen.

Use of magnetic deflection ✓ correct deflection of beta from the beam ✓)

(If a cloud chamber is suggested. Observe the tracks in a cloud chamber ✓ beta tracks have varying lengths or they are curly / not straight ✓)

(The value of the range of beta is not a marking point so accept 15 – 80 cm if a number is given)

2

[7]

2

(a) (i) α (radiation) **(1)**

(ii) γ (radiation) **(1)**

2

(b) (i) the radiation needs to pass through the body (to be detected) **(1)**

(ii) (otherwise) the activity of the source becomes too weak
(during measurements) **(1)**

(iii) the decaying source may remain in the body for a long time
and could cause damage **(1)**

[or the activity of the source will be low unless a large
quantity is used ($T_{1/2} \propto 1 / \lambda$)]

3

- (c) corrected count rate at 0.2 m (= 2550 - 50) = 2500 (c min⁻¹) **(1)**
 corrected count rate at least distance (= 6000 - 50) = 5950 (c min⁻¹) **(1)**

use of $I = k \frac{I_0}{x^2}$ (or in the form $\frac{I_1}{I_2} = \left(\frac{x_2}{x_1}\right)^2$) **(1)**

(allow C.E. for using uncorrected count rate)

gives least distance = $0.20 \times \left(\frac{2500}{5950}\right)^{1/2}$ **(1)**

least distance = 0.13 m **(1)**

5

[10]

3

- (a) (proton) down 2/-2

B1

(nucleon) down 4/-4

B1

2

- (b) gamma greater, *must express comparison*,

don't allow simple list

B1

1

- (c) use of inverse-square law

C1

$\frac{1}{9} / 0.11$

A1

2

[5]

4	Anti-neutrino indicated appropriately		B1		
	Beta 0, and -1		B1		
	Tl 81 Pb 208		B1		
					[3]
5	(a) place a sheet of aluminium/metal between source and detector Sheet thickness stated 2 to 10 mm thick or several/a few mm thick plus		M1		
	only gamma radiation can pass through such a sheet or alpha and beta will be absorbed/stopped by the sheet		A1	2	
	(b) count rate $\propto 1/r^2$ or evidence of $C_1/C_2 = r_2^2/r_1^2$		C1		
	25 counts per second (allow cps or s ⁻¹) (Bq is a up)		A1	2	
	(c) their value calculated in (b) plotted correctly and reasonable attempt to draw correct curvature		C1		
	Correct point (25 cps) plotted with correct curvature (mark quality: must not flatten out or rise at end of their line for large distances)		A1	2	
					[6]

6

- (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]

7

(a) number of alpha particles = 4

B1

number of beta particles = 2

B1

(2)

(b) 126

B1

(1)

(c) Pb-206

B1

(1)

(d) (i) number of half lives = 2
or half life = 20 minutes

C1

40 minutes

A1

(2)

(ii) 4.2×10^{20}

B1

(1)

(iii) decay constant = $0.69 / \text{half life}$ (allow e.c.f. from (i))

or $N_0/2 = N_0 e^{-\lambda t_{1/2}}$

C1

$5.75 \times 10^{-4} \text{ s}^{-1}$ or $5.78 \times 10^{-4} \text{ s}^{-1}$ or 0.0345 min^{-1}
(allow if calculation is done in (ii))

C1

$A = \lambda N$

C1

$2.4 (2.42) \times 10^{17} \text{ Bq}$ (or decays per s)

or $1.5 (1.45) \times 10^{19} \text{ decays per minute}$

A1

(4)

(iv) the (daughter) products are also decaying [or are radioactive]

M1

activity will be greater

A1

(2)

(v) any 2 of:

polonium-214 has a half life of $1.6 \times 10^{-4} \text{ s}$

B1

decays almost as soon as it is formed or decays very quickly

B1

only some of the bismuth-214 decays via polonium-214

B1

max 2

[15]

8

(a) ${}_{89}^{228}\text{Ac}$

B1

${}_{-1}^0\beta$

B1

suitable anti - neutrino indication (anti - neutrino not required)

B1

(b) Down quark changes to up quark

B1

[4]

9

- (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

B1

to cell / cell nucleus / body tissue / DNA

B1

(2)

[9]**10**

- (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

[17]

11

- (a) thicker material absorbs more particles

B1

count rate (number detected) falls if material is thicker

B1

fall in count rate produces change to adjust process to produce thinner material /
restore to original thickness

allow 1 mark for

'change in thickness changes count rate and rollers adjust to compensate'

B1**(3)**

- (b) use a beta source

M0

alphas would be absorbed by paper

A1

gammas would not be affected

A1

use a gamma source

M0

beta would be absorbed completely

A1

alphas would be absorbed completely

allow beta if candidate includes statement about the steel sheet being thin

A1**(4)**

- (c) (i) 1 disintegration / decay / particle emitted per second (per unit time)
not one count per second

B1**(1)**

- (ii) correct curvature starting at 5×10^{20} ;
time scale inserted up to 15 (unit not necessary)
or labelled $T_{1/2}$, $2T_{1/2}$, $3T_{1/2}$

M1

sensible scales (not multiples of 3);
correct number of atoms at each half-life;
reasonable curve and unit for time

A1**(2)**

- (iii) half-life = $0.69 / \text{decay constant}$

C1

$$4.1 - 4.2 \times 10^{-9} \text{ (s}^{-1}\text{)}$$

A1**(2)**

(iv) $A = (-)\lambda N$

C1

number of R / A atoms when activity is 1.5×10^{12} Bq = 3.6×10^{20}

C1

correct time read from graph

A1

(2.5 y / 920 days / 8.0×10^7 s)

or

determines original activity or final number of atoms

2.1×10^{12} Bq or 3.6×10^{20}

allow ecf from (iii)

C1

$N = N_0 e^{-\lambda t}$ **or** $A = A_0 e^{-\lambda t}$

C1

940 d or 2.6 y (answer depends on where rounding off has been done)

A1

(3)

[15]