1. (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)

2. (a) (i) Complete the equation below to represent the emission of an α particle by a $^{238}_{92}U$ isotope.

$^{238}_{92}U \quad \rightarrow$

(ii) Calculate the energy released when this $^{238}_{92}U$ isotope nucleus emits an α particle

....

....

....

....

....

(5)

(b) $^{238}_{92}U$ decays sequentially by emitting α particles and β^- particles, eventually forming $^{206}_{82}Pb$, a stable isotope of lead.

(i) There are eight α particles in the sequence.
Calculate the number of β^- particles in the sequence.

....

....

....

(ii) State the nuclear change that occurs during positron emission. Hence, explain why no positrons are emitted in this sequence.

....

....

....

....

....

....

(6)
(Total 11 marks)

3. (a) Show that the kinetic energy of an α particle travelling at 2.00×10^7 ms^{-1} is 1.33×10^{-12} J when relativistic effects are ignored.

....

....

....

(2)

(b) Calculate the closest distance of approach for a head-on collision between the α particle referred to in part (a) and a gold nucleus for which the proton number is 79.
Assume that the gold nucleus remains stationary during the collision.

....

....

....

....

....

....

....

(4)

(c) State **one** reason why methods other than α particle scattering are used to determine nuclear radii.

....

....

(1)
(Total 7 marks)

4. (a) Nuclear fission can occur when a neutron is absorbed by a nucleus of uranium-235. An incomplete equation for a typical fission reaction is given below.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + \text{X} + 3\,^{1}_{0}\text{n}$$

(i) State the nuclear composition of X.

proton number ....

neutron number ....

(ii) Name the element of which X is an isotope.

....

(3)

(b) In a small nuclear power plant one fifth of the fission energy is converted into a useful output power of 10 MW. If the average energy released per fission is 3.2×10^{-11} J, calculate the number of uranium-235 nuclei which will undergo fission per day.

....

....

....

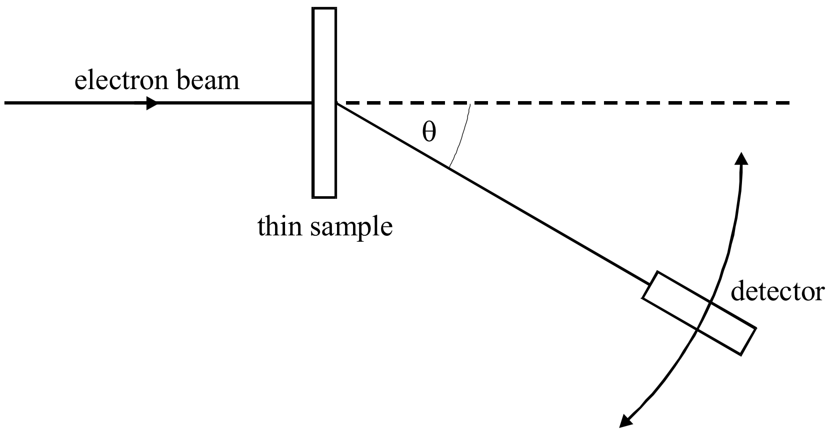
....

....

....

(3)
(Total 6 marks)

5. Nuclear radii can be determined by observing the diffraction of high energy electrons, as shown in the diagram.



(a) On the axes below, sketch a graph of the results expected from such an electron diffraction experiment.

(2)

(b) State why high energy electrons are used in determining nuclear size.

....

....

....

(1)

(c) Electron diffraction experiments have been performed on a range of different nuclei to give information about nuclear density and average separation of particles in the nucleus. Give the main conclusion in each case.

nuclear density ....

....

average separation of particles ....

....

(2)

(d) On the axes below, sketch the relationship between the radius of a nucleus and its nucleon number.

(1)

(e) Given that the radius of the $^{12}_{6}C$ nucleus is 3.04×10^{-15}m, calculate the radius of the $^{16}_{8}O$ nucleus.

....

....

....

....

....

(3)
(Total 9 marks)

6. 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 30s, *C*	60	42	35	23	18	14	10
In *C*							

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

....

.... **(1)**

(b) Complete the table. **(1)**

(c) On the grid below

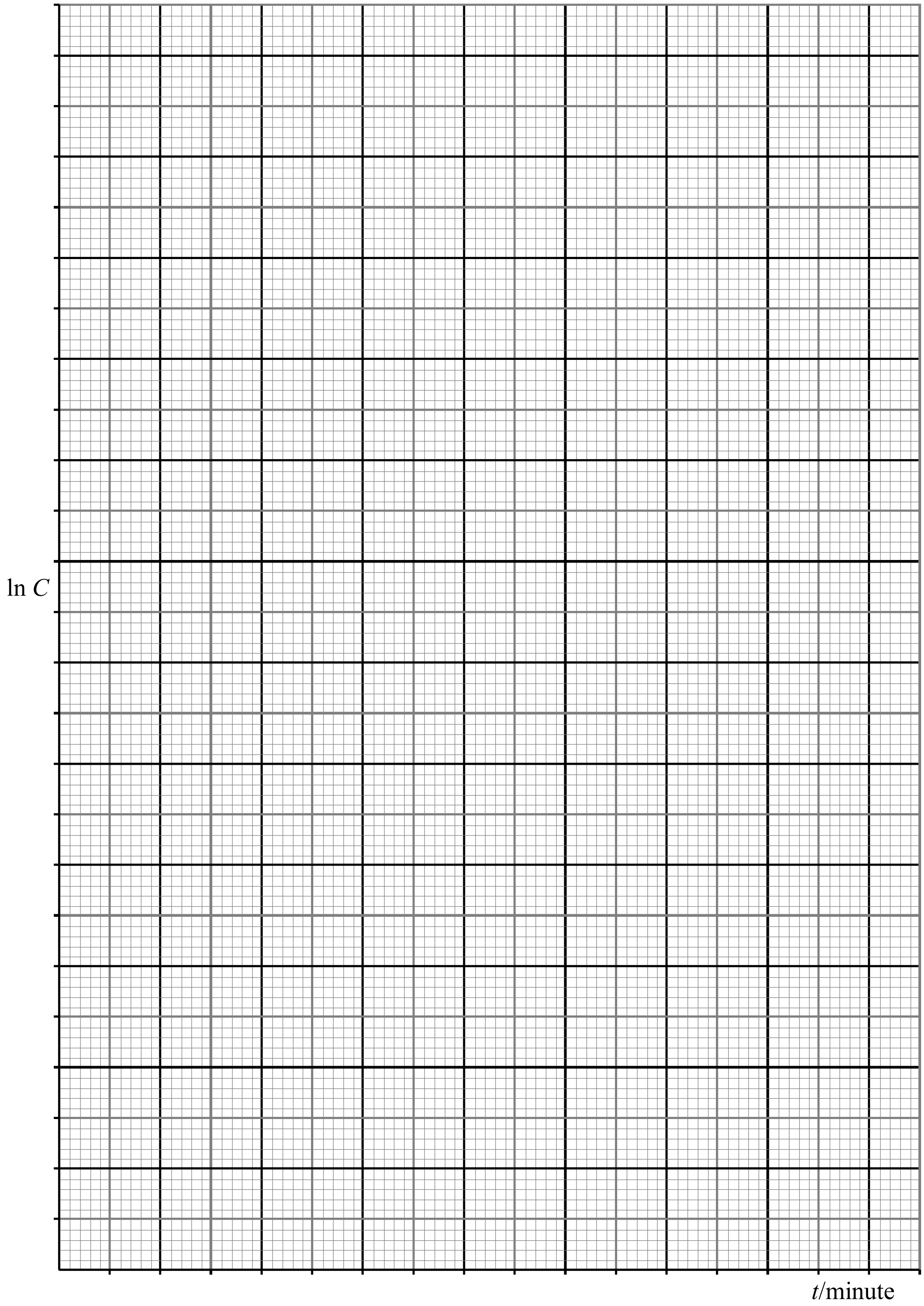
(i) plot ln C against *t,*

(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)

7. (a) Ancient rocks can be dated by measuring the proportion of trapped argon gas to the radioactive isotope potassium –40. Potassium –40 produces argon as a result of electron capture. The gas is trapped in the molten rock when the rock solidifies.

(i) Write down an equation to represent the process of electron capture by a potassium nucleus.

....

....

(ii) The atomic masses of potassium –40 and argon –40 are 39.96401 u and 39.96238 u, respectively. Calculate the energy released, in MeV, when the process given in part (a)(i) occurs.

....

....

....

....

(iii) An argon atom formed in this way subsequently releases an X-ray photon. Explain how this occurs.

....

....

....

(5)

(b) Potassium –40 also decays by beta emission to form calcium –40.

(i) Write down an equation to represent this beta decay.

....

....

(ii) This process is eight times more probable than electron capture. A rock sample is found to contain 1 atom of argon –40 for every 5 atoms of potassium –40. The half-life of potassium –40 is 1250 million years. Calculate the age of this rock.

....

....

....

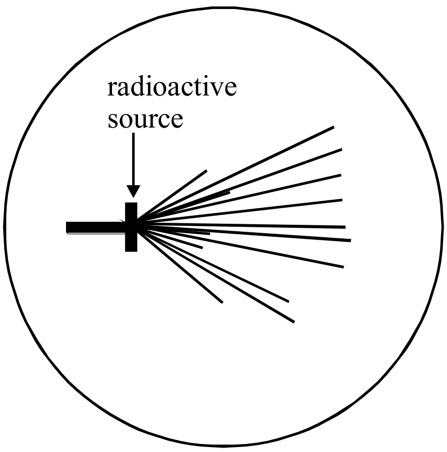
....

....

....

(4)
(Total 9 marks)

8. (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.

....

....

....

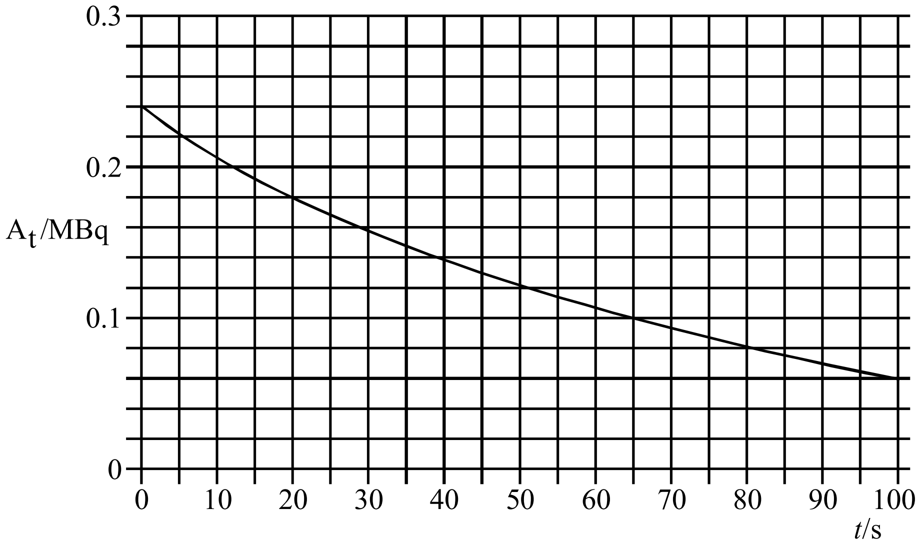
....

....

....

(5)
(Total 9 marks)

9. A radioactive nuclide decays by emitting α particles. The graph shows how the rate of decay *A* 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)

10. (a) Sketch a graph to show how the number of neutrons, *N,* varies with the number of protons, ***Z*****,** for stable nuclei over the range Z = 0 to Z = 80. Draw a scale on the *N* axis.

(2)

(b) On the same graph, enclosing each region by a line, indicate the region in which nuclides are likely to decay, by

(i) α emission, labelling the region A,

(ii) β^- emission, labelling the region B,

(iii) β^+ emission, labelling the region C.

(3)

(c) Complete the table.

mode of decay	change in proton number Z	change in neutron number *N*
α emission	–2	
β^- emission		
β^+ emission		
e capture		
p emission		0
n emission	0	

(3)
(Total 8 marks)

11. The radius of a nucleus, *R,* is related to its nucleon number, *A,* by

$$R = r\ A^{1/3}, \text{ where } r \text{ is a constant.}$$

The table lists values of nuclear radius for various isotopes.

Element	$R/10^{-15}$m	A	
carbon	2.66	12	
silicon	3.43	28	
iron	4.35	56	
tin	5.49	120	
lead	6.66	208	

(a) Use the data to plot a straight line graph and use it to estimate the value of *r*.

....

....

....

....

....

....

....

....

(Allow one sheet of graph paper)

(8)

(b) Assuming that the mass of a nucleon is 1.67×10^{-27} kg, calculate the approximate density of nuclear matter, stating **one** assumption you have made.

....

....

....

....

....

....

(4)
(Total 12 marks)

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

$$^{203}_{83}\text{Bi} + {}^{0}_{-1}\text{e}^{-} \rightarrow {}^{203}_{82}\text{Pb} + \nu_e + \text{Q}.$$

(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.

$^{203}_{83}\text{Bi} \rightarrow$

(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 counts s^{-1}. After an interval of 24 hours the corrected rate falls to 290 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 $1.6 \times 10^{-5}\ s^{-1}$.

....

....

....

....

....

(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 counts s^{-1}.

....

....

....

....

(5)
(Total 10 marks)

13. (a) In the reactor at a nuclear power station, uranium nuclei undergo *induced fission* with *thermal neutrons.* Explain what is meant by each of the terms in italics.

....

....

....

....

....

(3)

(b) A typical fission reaction in the reactor is represented by

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

(i) Calculate *N*.

....

(ii) How do the neutrons produced by this reaction differ from the initial neutron that goes into the reaction?

....

....

(iii) Calculate the energy released in MeV when one uranium nucleus undergoes fission in this reaction. Use the following data.

mass of neutron	=	1.00867 u
mass of ^{235}U nucleus	=	234.99333 u
mass of ^{92}Kr nucleus	=	91.90645 u
mass of ^{141}Ba nucleus	=	140.88354 u

1 u is equivalent to 931 MeV

....

....

....

....

....

(5)
(Total 8 marks)

14. (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.

....

....

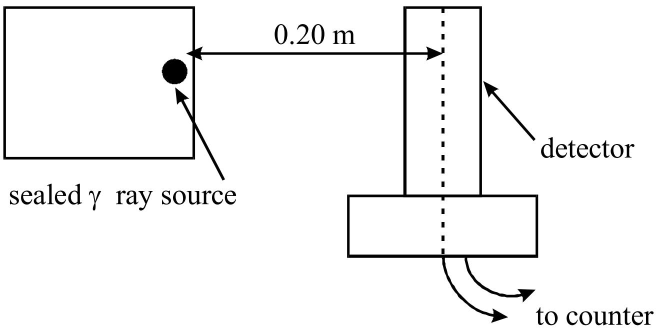
(iii) State why the source should **not** have a very long half-life.

....

....

(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)

15. (a) (i) State **two** physical features or properties required of the shielding to be placed around the reactor at a nuclear power station.

....

....

(ii) Which material is usually used for this purpose?

....

(3)

(b) Describe the effect of the shielding on the γ rays, neutrons and neutrinos that reach it from the core of the reactor. Also explain why the shielding material becomes radioactive as the reactor ages. You may be awarded marks for the quality of written communication provided in your answer.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(4)
(Total 7 marks)

16. The radioactive isotope of sodium $^{22}_{11}\text{Na}$ has a half life of 2.6 years. A particular sample of this isotope has an initial activity of 5.5×10^5 Bq (disintegrations per second).

(a) Explain what is meant by the *random nature* of radioactive decay.

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

....

....

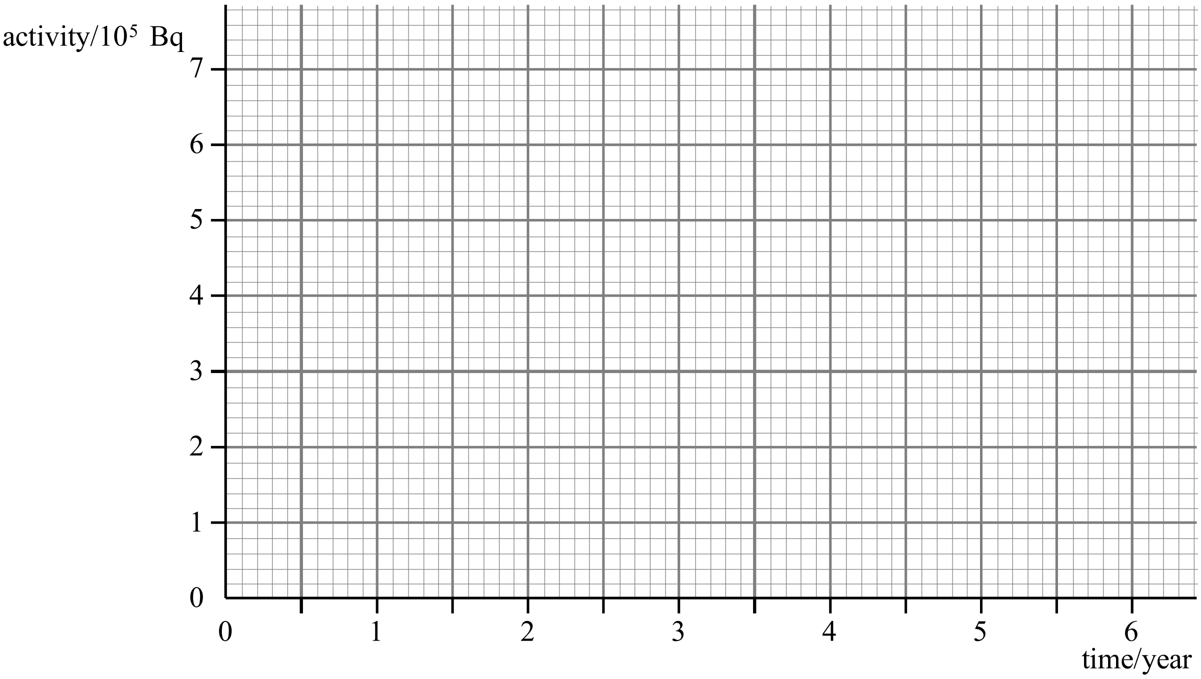
....

....

....

(2)

(b) Use the axes to sketch a graph of the activity of the sample of sodium over a period of 6 years.



(2)

(c) Calculate

(i) the decay constant, in s^{-1}, of $^{22}_{11}Na$,
1 year = 3.15×10^{7} s

....

....

....

....

(ii) the number of atoms of $^{22}_{11}Na$ in the sample initially,

....

....

....

....

(iii) the time taken, in s, for the activity of the sample to fall from 1.0×10^{5} Bq to 0.75×10^{5} Bq.

....

....

....

....

(6)
(Total 10 marks)

17. **Figure 1** shows a grid of neutron number against proton number. A nucleus ${}^{A}_{Z}X$ is marked.

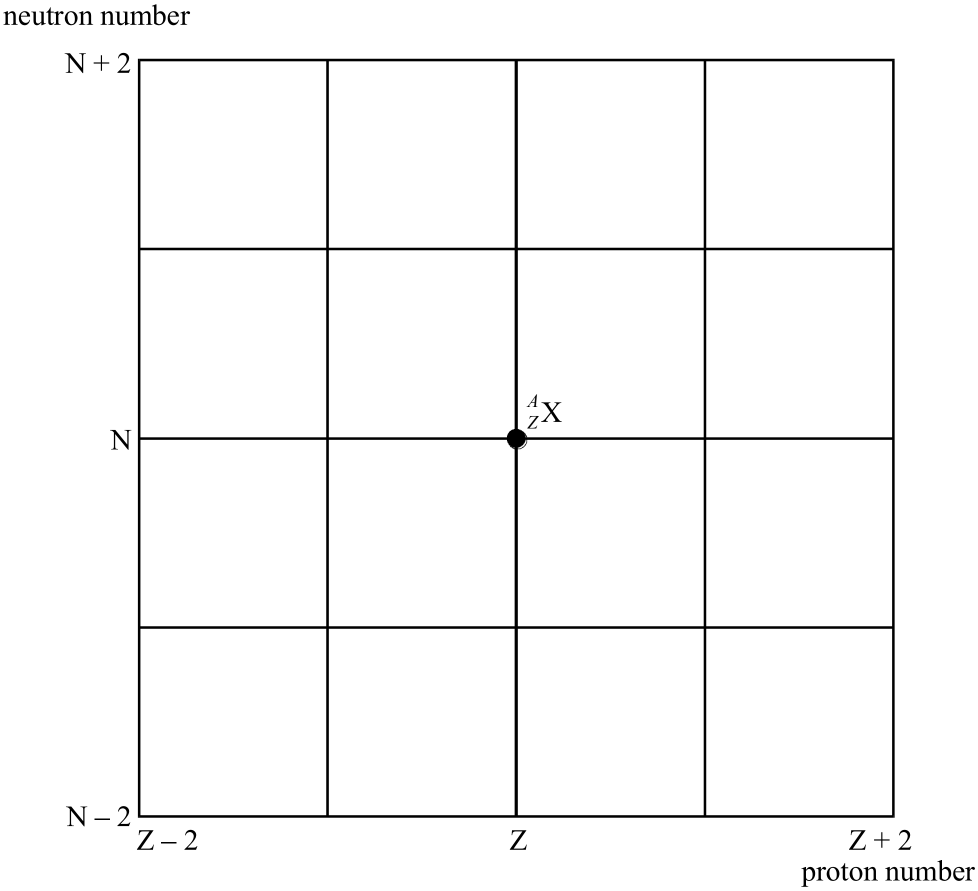


Figure 1

(a) Draw arrows on **Figure 1**, each starting on ${}^{A}_{Z}X$ and ending on a daughter nucleus after the following transitions:

(i) β^{-} emission (label this arrow A)
neutron emission (label this arrow B)
electron capture (label this arrow C).

(ii) Give the equation for electron capture by the nucleus ${}^{A}_{Z}X$.

....

(4)

(b) When $^{27}_{12}Mg$ decays to $^{27}_{13}Al$ by β^- decay, the daughter nucleus is produced in one of two possible excited states. These two states are shown in **Figure 2** together with their corresponding energies.

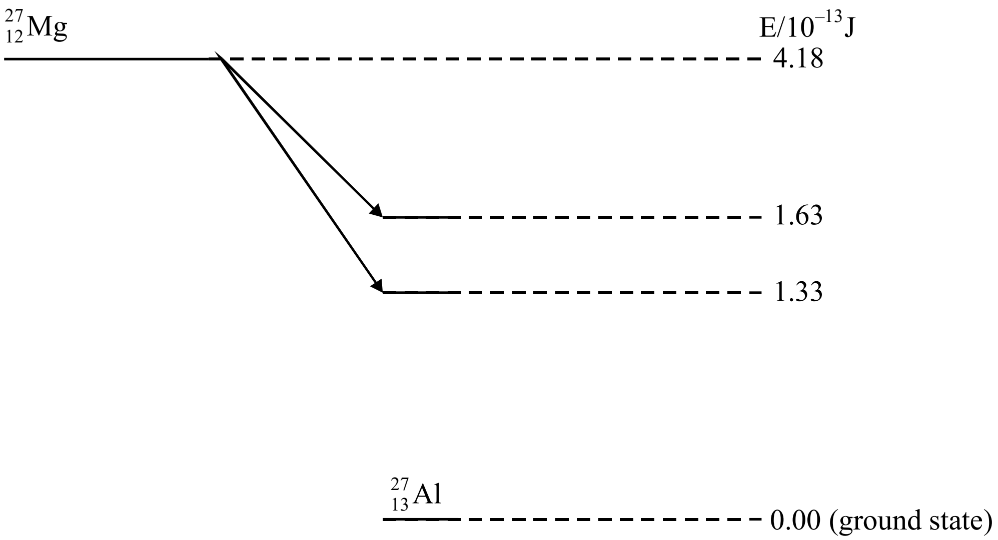


Figure 2

(i) Calculate the maximum possible kinetic energy, in J, which an emitted β^- particle can have.

....

....

(ii) The excited aluminium nuclei emit γ photons. Calculate each of the three possible γ photon energies in J.

....

....

....

(iii) Calculate the frequency of the most energetic γ photon emitted.

....

....

....

(3)

(c) (i) State and explain **two** precautions that should be taken when working with a sample of ${}^{27}_{12}Mg$ in a school laboratory.

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

....

....

....

....

....

....

(ii) Discuss which of the two types of radiation, β^- or γ, emitted from a sample of ${}^{27}_{12}Mg$ would be the more hazardous.

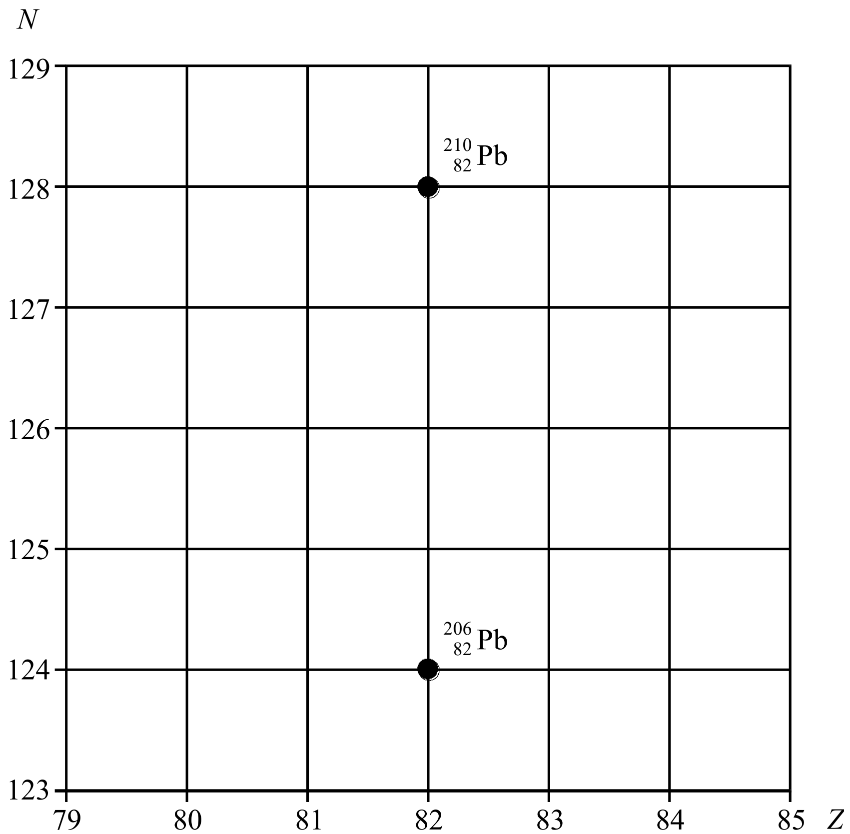
....

....

....

(3)
(Total 10 marks)

18. (a) The lead nuclide $^{210}_{82}Pb$ is unstable and decays in three stages through α and β emissions to a different lead nuclide $^{206}_{82}Pb$. The position of these lead nuclides on a grid of neutron number, *N*, against proton number, *Z*, is shown below.



On the grid draw **three** arrows to represent one possible decay route.
Label each arrow with the decay taking place.

(3)

(b) The copper nuclide $^{64}_{29}Cu$ may decay by positron emission or by electron capture to form a nickel (Ni) nuclide.
Complete the two equations that represent these two possible modes of decay.

positron emission $^{64}_{29}Cu$

electron capture $^{64}_{29}Cu$

(4)

(c) The nucleus of an atom may be investigated by scattering experiments in which radiation or particles bombard the nucleus.

Name **one** type of radiation or particle that may be used in this investigation and describe the main physical principle of the scattering process.

State the information which can be obtained from the results of this scattering.

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

....

....

....

....

....

(3)
(Total 10 marks)

19. (a) A radioactive source gives an initial count rate of 110 counts per second. After 10 minutes the count rate is 84 counts per second.

background radiation = 3 counts per second

(i) Give **three** origins of the radiation that contributes to this background radiation.

1 ....

2 ....

3 ....

(ii) Calculate the decay constant of the radioactive source in s^{-1}.

....

....

....

....

....

....

(iii) Calculate the number of radioactive nuclei in the initial sample assuming that the detector counts all the radiation emitted from the source.

....

....

....

....

(7)

(b) Discuss the dangers of exposing the human body to a source of α radiation. In particular compare the dangers when the α source is held outside, but in contact with the body, with those when the source is placed inside the body.

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

....

....

....

....

....

....

....

....

....

(3)
(Total 10 marks)

20. The high energy electron diffraction apparatus represented in **Figure 1** can be used to determine nuclear radii. The intensity of the electron beam received by the detector is measured at various diffraction angles, θ.

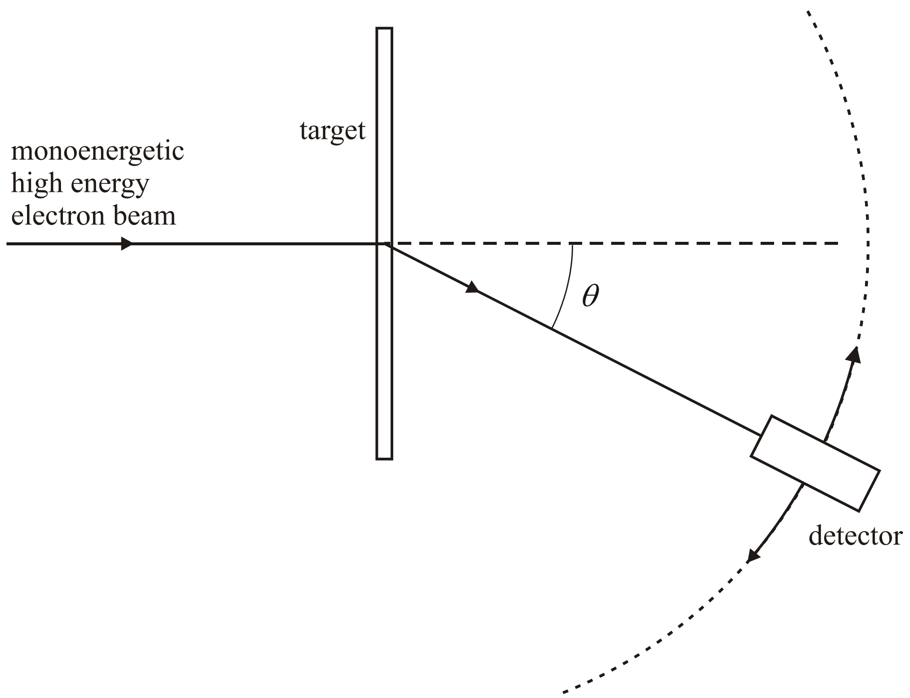
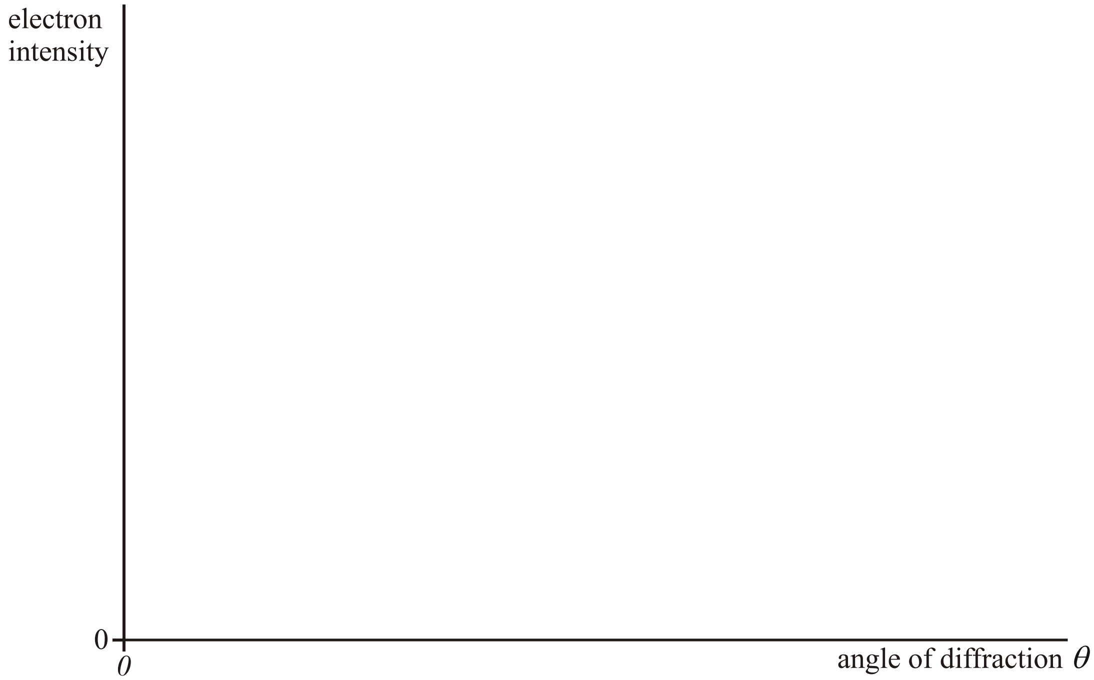


Figure 1

(a) Sketch on the axes below a graph of the results expected from such an electron diffraction experiment.



(2)

(b) (i) Use the data in the table to plot a straight line graph that confirms the relationship $R = r_0 A^{\frac{1}{3}}$.

element	**radius of nucleus, *R* 10^{-15}m**	**nucleon number; *A***	
lead	6.66	208	
tin	5.49	120	
iron	4.35	56	
silicon	3.43	28	
carbon	2.66	12	

(ii) Estimate the value of r_0 from the graph.

....

....

....

....

....

(5)

(c) Discuss the merits of using high energy electrons to determine nuclear radii rather than using α particles.

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

....

....

....

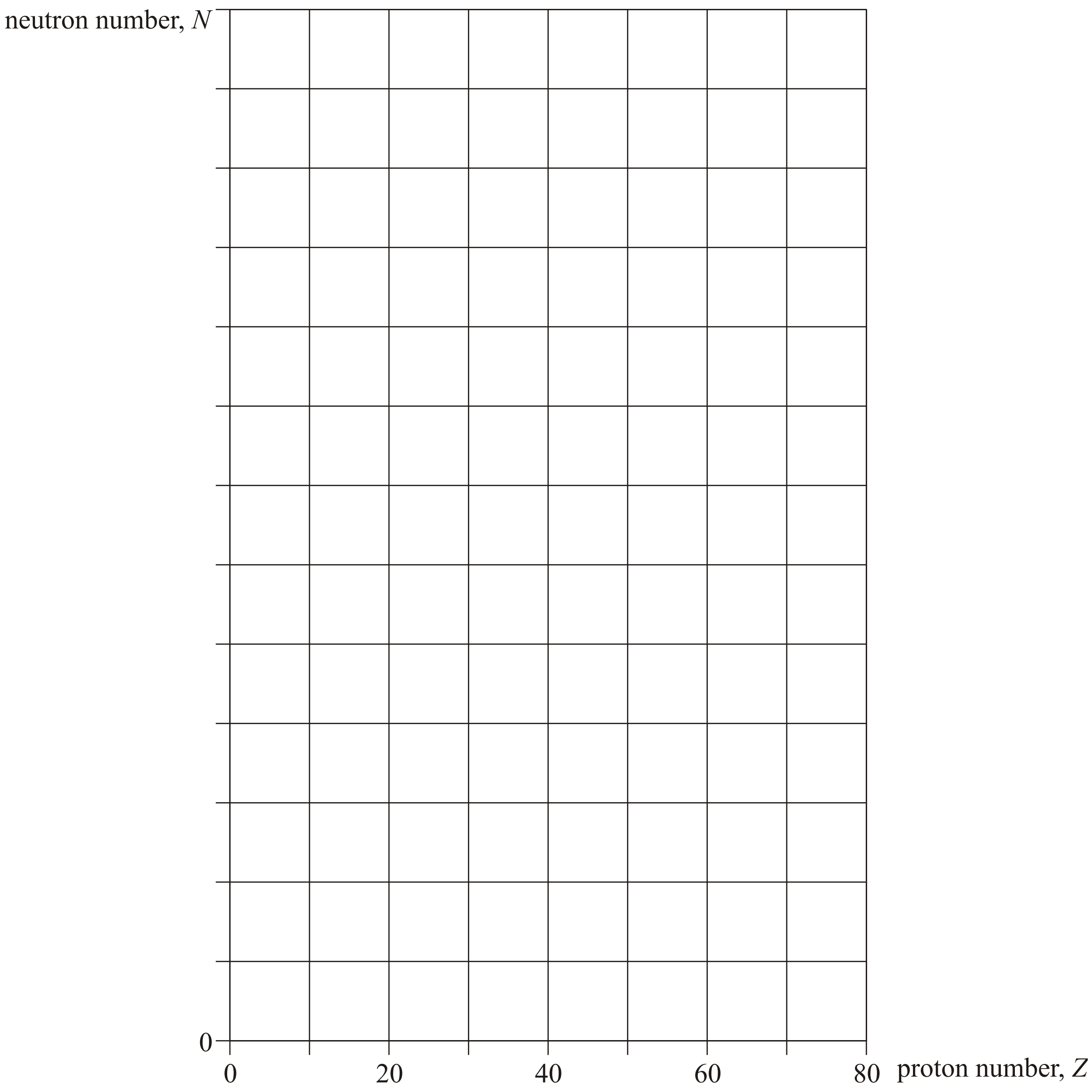
....

....

....

(3)
(Total 10 marks)

21. (a) Sketch, using the axes provided, a graph of neutron number, N, against proton number, Z, for stable nuclei over the range $Z = 0$ to $Z = 80$. Show suitable numerical values on the N axis.



(2)

(b) On the graph indicate, for each of the following, a possible position of a nuclide that may decay by

(i) α emission, labelling the position with **W**,

(ii) β^- emission, labelling the position with **X**,

(iii) β^+ emission, labelling the position with **Y**.

(3)

(c) The isotope $^{222}_{86}\text{Rn}$ decays sequentially by emitting α particles and β^- particles, eventually forming the isotope $^{206}_{82}\text{Pb}$. Four α particles are emitted in the sequence.

Calculate the number of β^- particles in the sequence.

....

....

....

....

(2)

(d) A particular nuclide is described as proton-rich. Discuss **two** ways in which the nuclide may decay. You may be awarded marks for the quality of written communication in your answer.

....

....

....

....

....

....

....

(3)
(Total 10 marks)

22. (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 Me V. 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 J kg^{-1} K^{-1}

....

....

....

....

(5)
(Total 7 marks)

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

$r_0 = 1.3 \times 10^{-15}$ 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 β 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, $^{99}Tc_{m}$, 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.

....

....

....

....

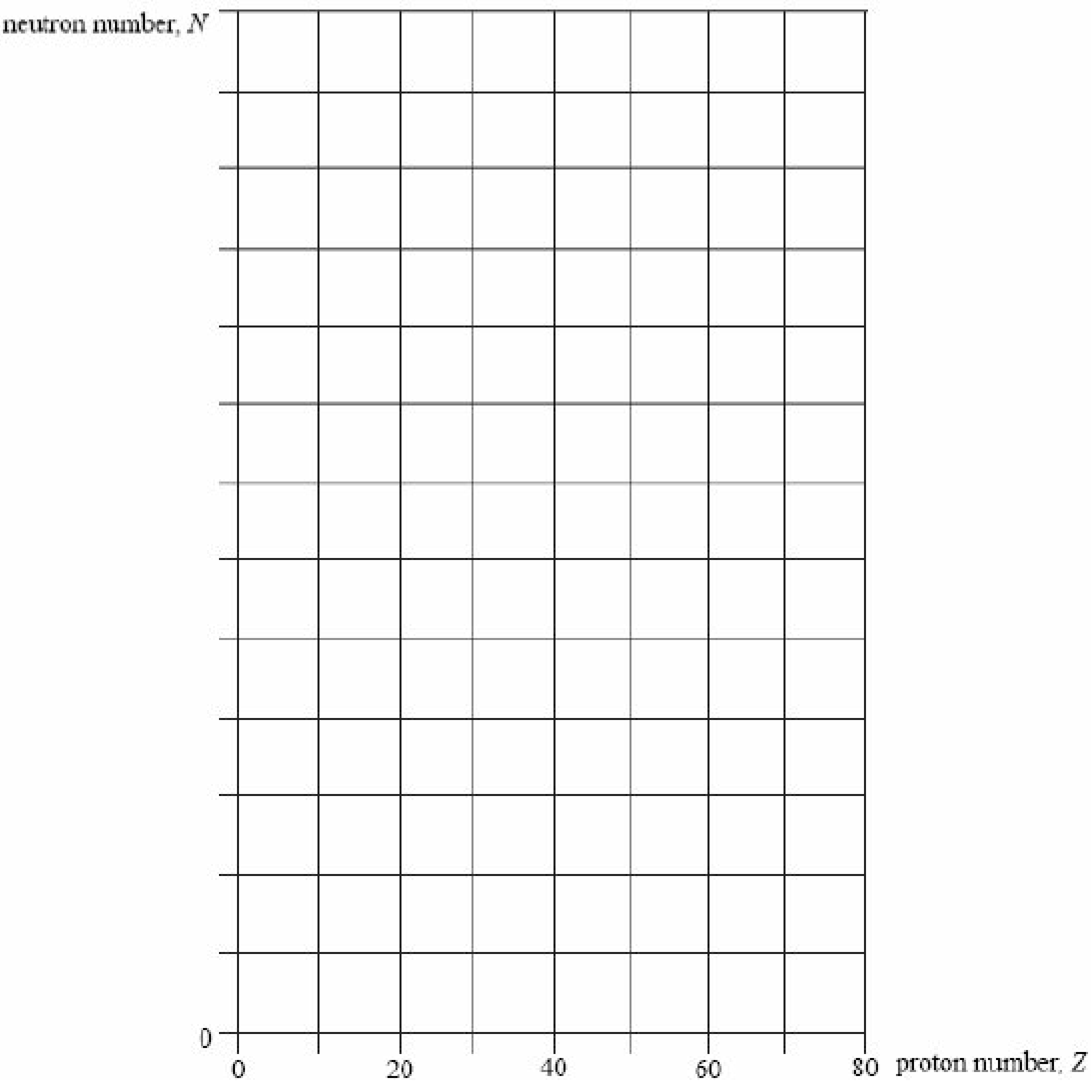
....

....

....

(3)
(Total 10 marks)

24. (a) Sketch, using the axes provided, a graph of neutron number, N, against proton number, Z, for stable nuclei over the range $Z = 0$ to $Z = 80$. Show suitable numerical values on the N axis.



(2)

(b) On the graph indicate, for each of the following, a possible position of a nuclide that might decay by

(i) α emission, labelling the position with **W**,

(ii) β^- emission, labelling the position with **X**,

(iii) β^+ emission, labelling the position with **Y**.

(3)

(c) Used fuel rods from a nuclear reactor emit β^- particles from radioactive isotopes that were not present before the fuel rod was inserted in the reactor. Explain why β^- emitting isotopes are produced when the fuel roads are in the reactor.

....

....

....

....

(3)

(d) A nuclear power station is a reliable source of electricity that does not produce greenhouse gases but it does produce radioactive waste. Discuss the relative importance of these features in deciding whether or not new nuclear power stations are needed.

The quality of your written answer will be assessed in this question.

....

....

....

....

....

....

....

....

....

....

(6)
(Total 14 marks)

25. Potassium-42 decays with a half-life of 12 hours. When potassium-42 decays, it emits β^- particles and gamma rays. One freshly prepared source has an activity of 3.0×10^7 Bq.

(a) To determine the radiation dose absorbed by the scientist working with the source, the number of gamma rays photons incident on each cm^2 of the body has to be known.

One in every five of the decaying nuclei produces a gamma ray photon. A scientist is initially working 1.50 m from the fresh source with no shielding. Show that at this time approximately 21 gamma photons per second are incident on each cm2 of the scientist's body.

(3)

(b) The scientist returns 6 hours later and works at the same distance from the source.

(i) Calculate the new number of gamma ray photons incident per second on each cm^2 of the scientist's body.

number of gamma photons per second per cm^2 = ...

(ii) Explain why it is not necessary to consider the beta particle emissions when determining the radiation dose the scientist receives.

....

....

....

(5)
(Total 8 marks)