

1. Nuclei of ${}_{84}^{218}\text{Po}$ decay by the emission of an α particle to form a stable isotope of an element X. You may assume that no γ emission accompanies the decay.

(a) (i) State the proton number and the nucleon number of X.

proton number

nucleon number

(ii) Identify the element X.

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(2)

(b) Each decaying nucleus of Po releases 8.6×10^{-13} J of energy.

(i) State the form in which this energy *initially* appears.

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(ii) Using **only** the information provided in the question, calculate the difference in mass between the original ${}_{84}^{218}\text{Po}$ atom and the combined mass of an atom of X and an α particle.

speed of light in vacuum = 3.0×10^8 m s⁻¹

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(3)

(Total 5 marks)

2. A space probe contains a small fission reactor, fuelled by plutonium, which is designed to produce an average of 300 W of useful power for 100 years. If the overall efficiency of the reactor is 10%, calculate the minimum mass of plutonium required.

energy released by the fission of one nucleus of ${}_{94}^{239}\text{Pu} = 3.2 \times 10^{-11} \text{ J}$

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

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(Total 7 marks)

3. (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)

4. (a) State what is meant by the *binding energy* of a nucleus.

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(2)

(b) (i) The iron isotope ${}^{56}_{26}\text{Fe}$ has a very high binding energy per nucleon. Calculate its value in MeV.

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- (ii) If the isotope ${}_{26}^{56}\text{Fe}$ were assembled from its constituent particles, what would be the mass change, in kg, during its formation?

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(6)
(Total 8 marks)

- 5. (a) An α particle source of half-life 3420 years has a rate of decay of 450 kBq. Calculate

- (i) the decay constant, in s^{-1} ,

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- (ii) the number of radioactive atoms in the source.

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(4)

- (b) A narrow beam of α particles is directed at a thin gold foil target in an evacuated vessel. Only a very small proportion of the α particles scatter backwards at an angle greater than 90° to the direction from which they came

- (i) Describe what happens to the majority of the α particles incident on the gold foil.

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- (ii) Several deductions may be made about the structure of gold atoms from the results of α -particle scattering. Write down **two** of these deductions.

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(3)
(Total 7 marks)

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

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

isotopes

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radioactive half-life

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radioactive decay constant

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(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 ,

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- (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),

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- (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} .

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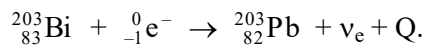
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(6)
(Total 12 marks)

7. (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.

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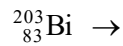
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- (ii) Give **one** reason why electromagnetic radiation is emitted following this process.

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- (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 $1.6 \times 10^{-5} \text{ s}^{-1}$.

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

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

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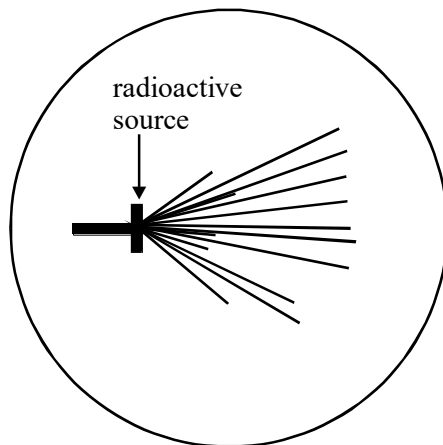
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(5)
(Total 10 marks)

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?

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- (ii) State and explain what can be deduced about the energy of the particles emitted by the source.

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(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.

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

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

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

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(5)
(Total 9 marks)

9. 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	$R/10^{-15} \text{ m}$	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 .

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(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.

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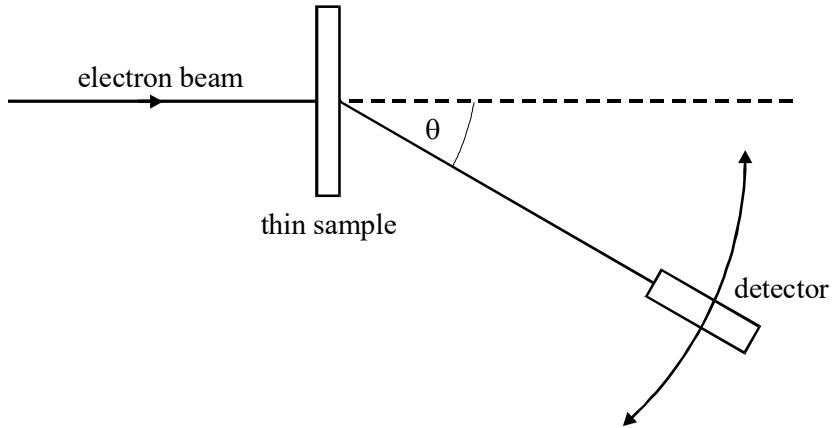
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(4)

(Total 12 marks)

10. 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.

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(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

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average separation of particles

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(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 $^{12}_6\text{C}$ nucleus is $3.04 \times 10^{-15}\text{m}$, calculate the radius of the $^{16}_8\text{O}$ nucleus.

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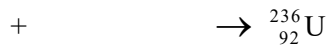
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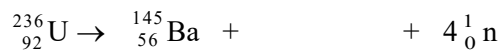
(3)
(Total 9 marks)

11. (a) The unstable uranium nucleus $^{236}_{92}\text{U}$ is produced in a nuclear reactor.

- (i) Complete the equation which shows the formation of $^{236}_{92}\text{U}$.



- (ii) $^{236}_{92}\text{U}$ can decay by nuclear fission in many different ways. Complete the equation which shows one possible decay channel.



(2)

- (b) Calculate the energy released, in MeV, in the fission reaction.

atomic mass of ${}_{56}^{145}\text{Ba} = 144.92694\text{u}$

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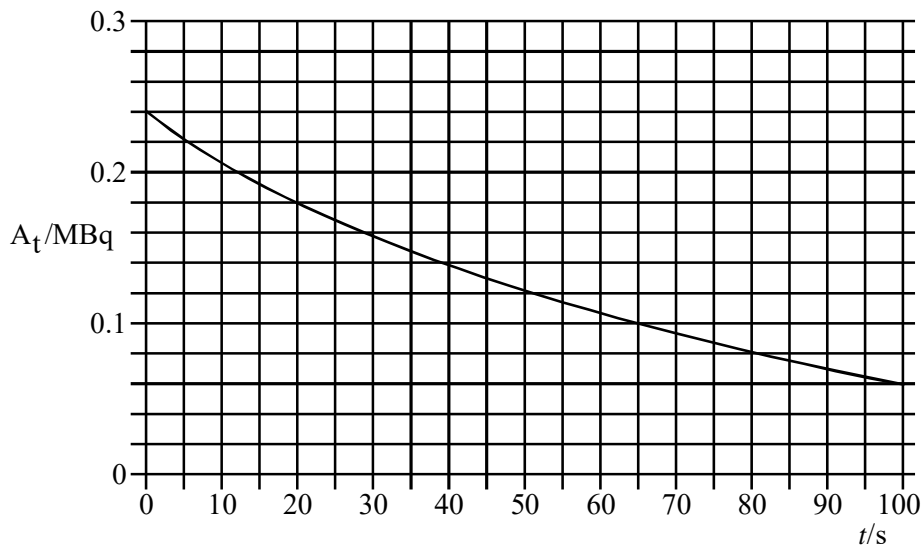
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(3)
(Total 5 marks)

12. 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,

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(ii) the decay constant,

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

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(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,

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(ii) the energy released.

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(4)

(Total 9 marks)

13. (a) In a nuclear reactor, energy is released as a result of *induced fission* of uranium -235 nuclei.

(i) Explain what is meant by *induced fission*.

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(ii) Explain, using the charged liquid drop model, the energy changes in the fission of a

uranium –235 nucleus.

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(iii) Describe and explain how the fission of the uranium –235 nuclei in a fuel rod causes the fuel rods and the moderator to become very hot.

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(8)

- (b) When a uranium –235 nucleus undergoes fission, approximately 200 MeV of energy is released. Estimate the total mass of original fuel required per year in a 1600 MW nuclear reactor that uses enriched fuel containing 3% uranium-235 and 97% uranium-238 and operates at an efficiency of 25%.

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(5)
(Total 13 marks)

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



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

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(5)

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

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

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

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(6)
(Total 11 marks)

15. 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*.

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(1)

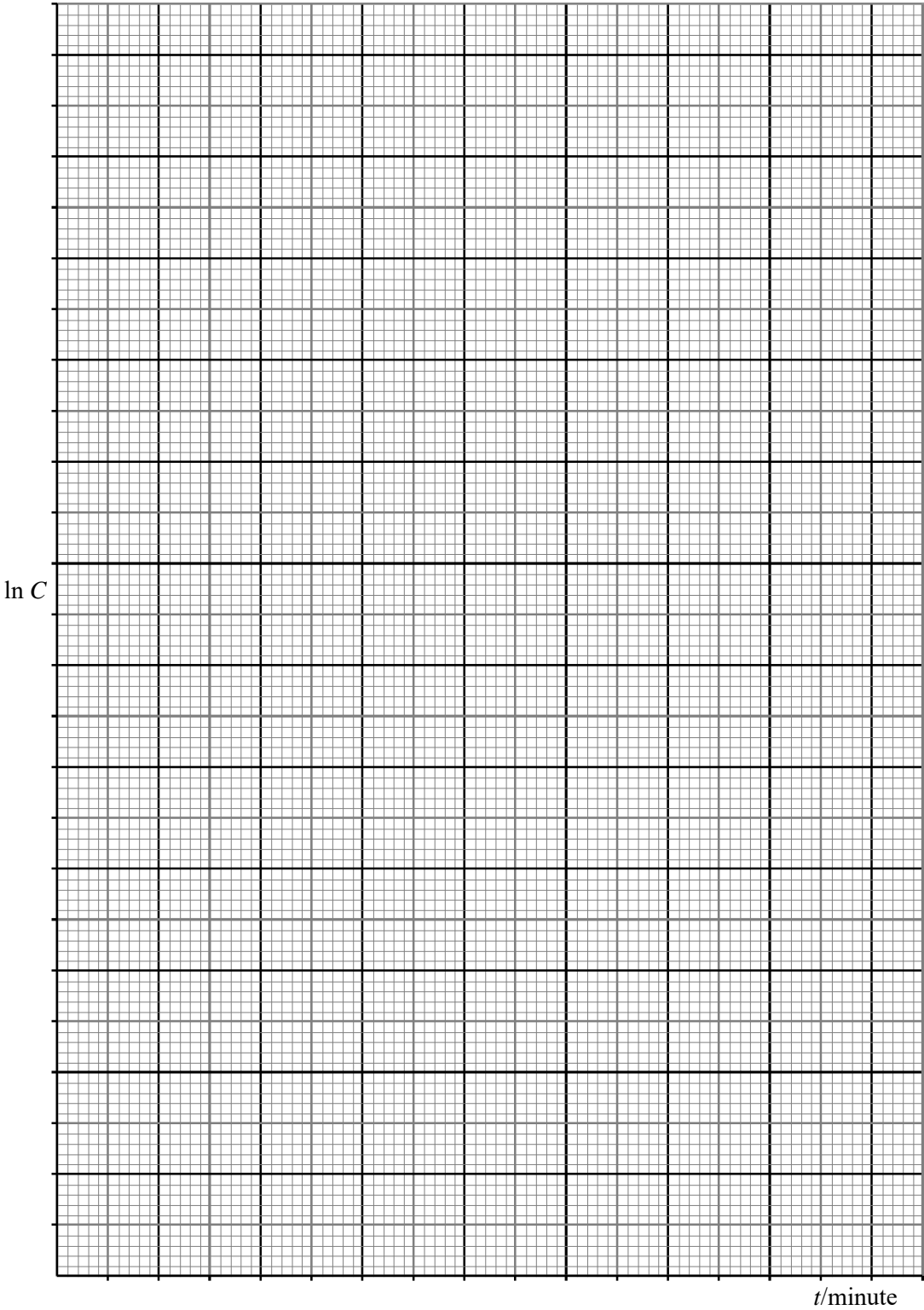
(b) Complete the table.

(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.

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

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

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(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.

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(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 $^{14}\text{C} = 5730$ years

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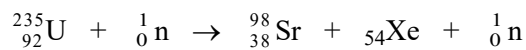
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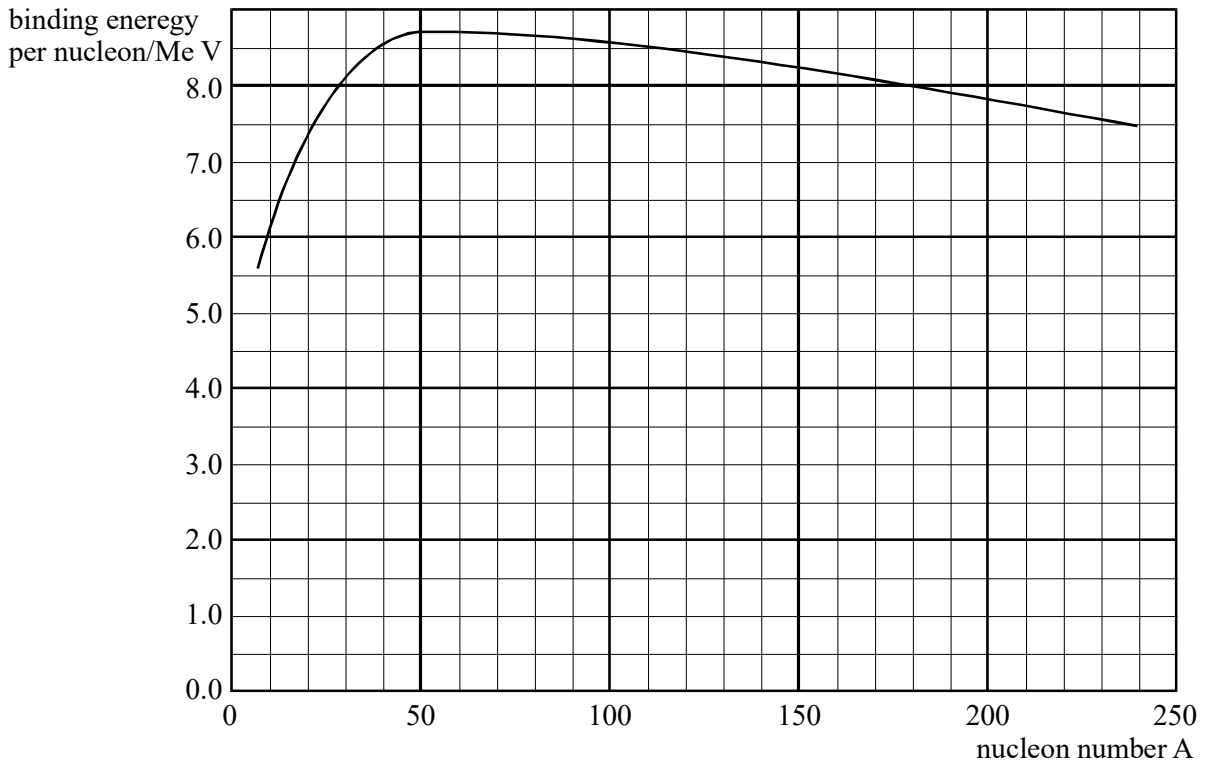
(4)
(Total 16 marks)

16. (a) (i) Complete the equation below which represents the induced fission of a nucleus of uranium $^{235}_{92}\text{U}$.



- (ii) The graph shows the binding energy per nucleon plotted against nucleon number A.

Mark on the graph the position of each of the three nuclei in the equation.



- (iii) Hence determine the energy released in the fission process represented by the equation.

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- (b) (i) Use your answer to part (a)(iii) to estimate the energy released when 1.0 kg of uranium, containing 3% by mass of ${}_{92}^{235}\text{U}$, undergoes fission.

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- (ii) Oil releases approximately 50 MJ of heat per kg when it is burned in air. State and explain **one** advantage and **one** disadvantage of using nuclear fuel to produce electricity.

advantage

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disadvantage

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(6)
(Total 12 marks)

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

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(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.

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(4)

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

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(1)

(Total 7 marks)

18. Natural uranium consists of 99.3% ${}_{92}^{238}\text{U}$ and 0.7% ${}_{92}^{235}\text{U}$. In many nuclear reactors, the fuel consists of enriched uranium enclosed in sealed metal containers.

- (a) (i) Explain what is meant by *enriched uranium*.

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- (ii) Why is enriched uranium rather than natural uranium used in many nuclear reactors?

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(2)

- (b) (i) By considering the neutrons involved in the fission process, explain how the rate of production of heat in a nuclear reactor is controlled.

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- (ii) Explain why all the fuel in a nuclear reactor is **not** placed in a single fuel rod.

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(5)
(Total 7 marks)

19. In an experiment to investigate the structure of the atom, α particles were aimed at thin gold foil in a vacuum. A detector was used to determine the number of α particles deflected through different angles.

- (a) State **two** observations about the α particles detected coming from the foil.

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(2)

- (b) State **two** features of the structure of the atom which can be deduced from these observations.

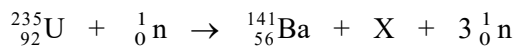
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(2)
(Total 4 marks)

20. (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.



- (i) State the nuclear composition of X.

proton number

neutron number

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

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(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.

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(3)
(Total 6 marks)