**1.** Nuclei of $^{218}_{84}Po$ decay by the emission of an $\alpha$ particle to form a stable isotope of an element X. You may assume that no $\gamma$ 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 $8.6 \times 10^{-13}$ 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 $^{218}_{84}Po$ atom and the combined mass of an atom of X and an $\alpha$ particle.

speed of light in vacuum = $3.0 \times 10^{8}$ 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 $^{239}_{94}\text{Pu} = 3.2 \times 10^{-11}$ J

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

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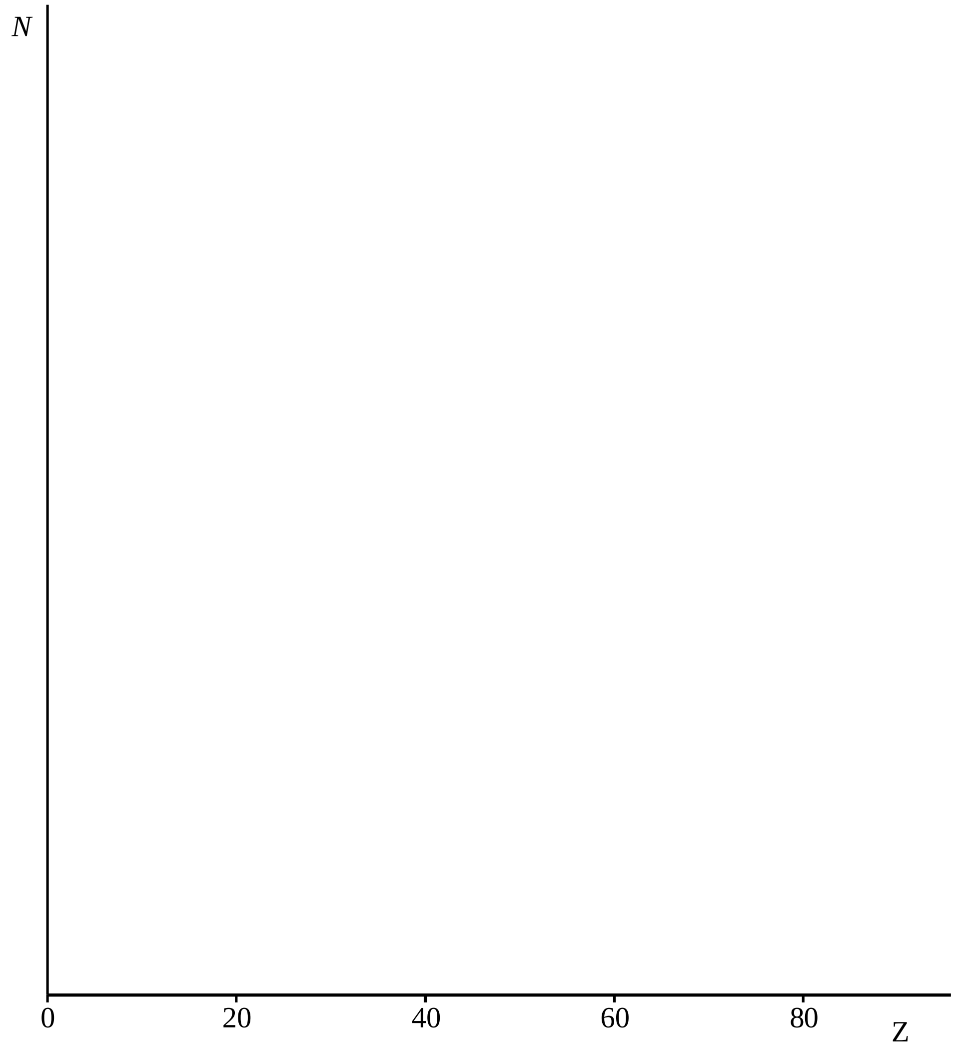
**(Total 7 marks)**

**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) $\alpha$ emission, labelling the region A,

(ii) $\beta^-$ emission, labelling the region B,

(iii) $\beta^+$ 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 | |
| $\beta^-$ emission | | |
| $\beta^+$ 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 $^{56}_{26}Fe$ has a very high binding energy per nucleon. Calculate its value in MeV.

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(ii) If the isotope $^{56}_{26}Fe$ 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 $\alpha$-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 $5.0 \times 10^4$ 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 $5.4 \times 10^4$ disintegrations $s^{-1}$ to $5.0 \times 10^4$ disintegrations $s^{-1}$.

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**(6)**
**(Total 12 marks)**

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

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

(i) Explain what is meant by electron capture.

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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.

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

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

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

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

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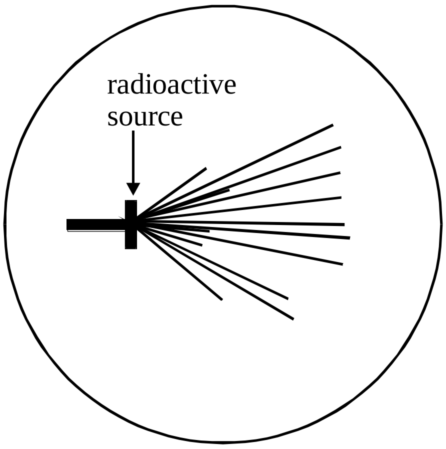
**(5)**

**(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 $\alpha$ 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 $\beta^-$ 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 | $R/10^{-15}$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 $1.67 \times 10^{-27}$ kg, calculate the approximate density of nuclear matter, stating **one** assumption you have made.

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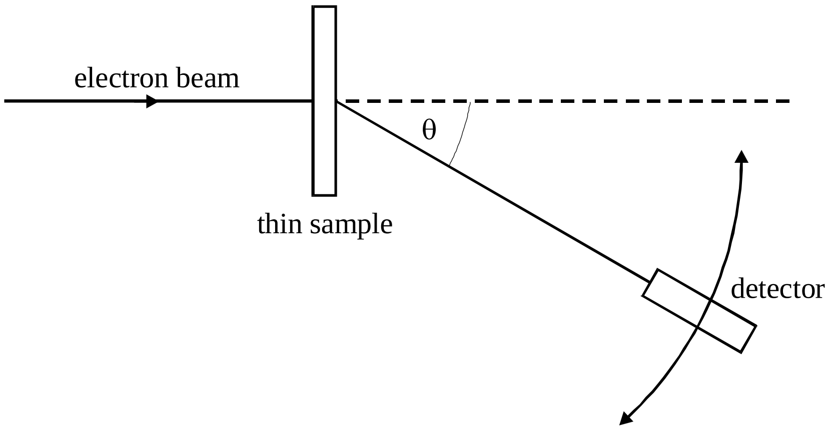
**(4)**
**(Total 12 marks)**

**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 $^{12}_{6}C$ nucleus is $3.04 \times 10^{-15}$m, calculate the radius of the $^{16}_{8}O$ nucleus.

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**(3)**
**(Total 9 marks)**

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

(i) Complete the equation which shows the formation of U.

$$+ \quad \rightarrow \ ^{236}_{92}U$$

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

$$^{236}_{92}U \rightarrow \ ^{145}_{56}Ba \ + \qquad + \ 4\,^{1}_{0}n$$

**(2)**

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

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

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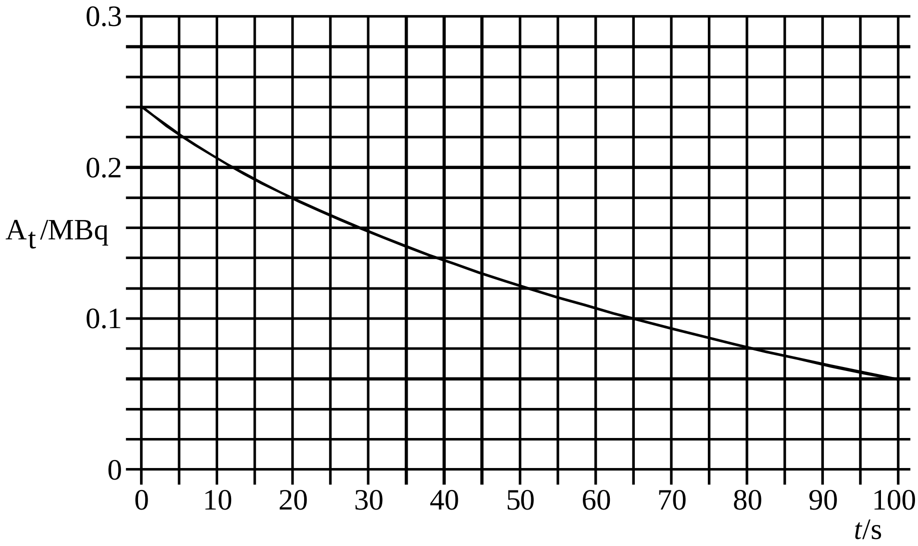
**(3)**
**(Total 5 marks)**

**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 x $10^{-12}$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 $^{238}_{92}U$ isotope.

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

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

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**(5)**

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

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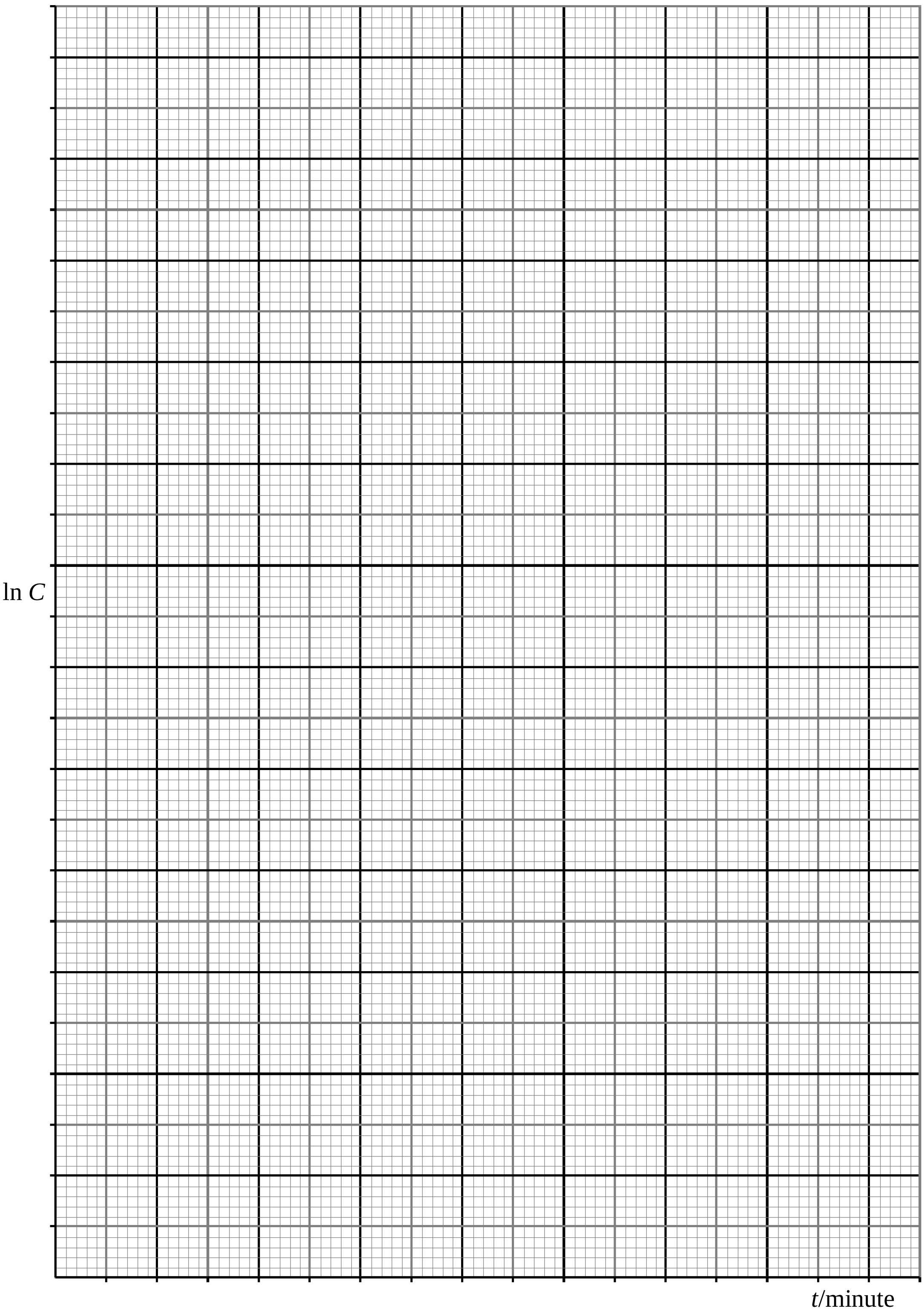


**(5)**

(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 $^{14}C$ = 5730 years

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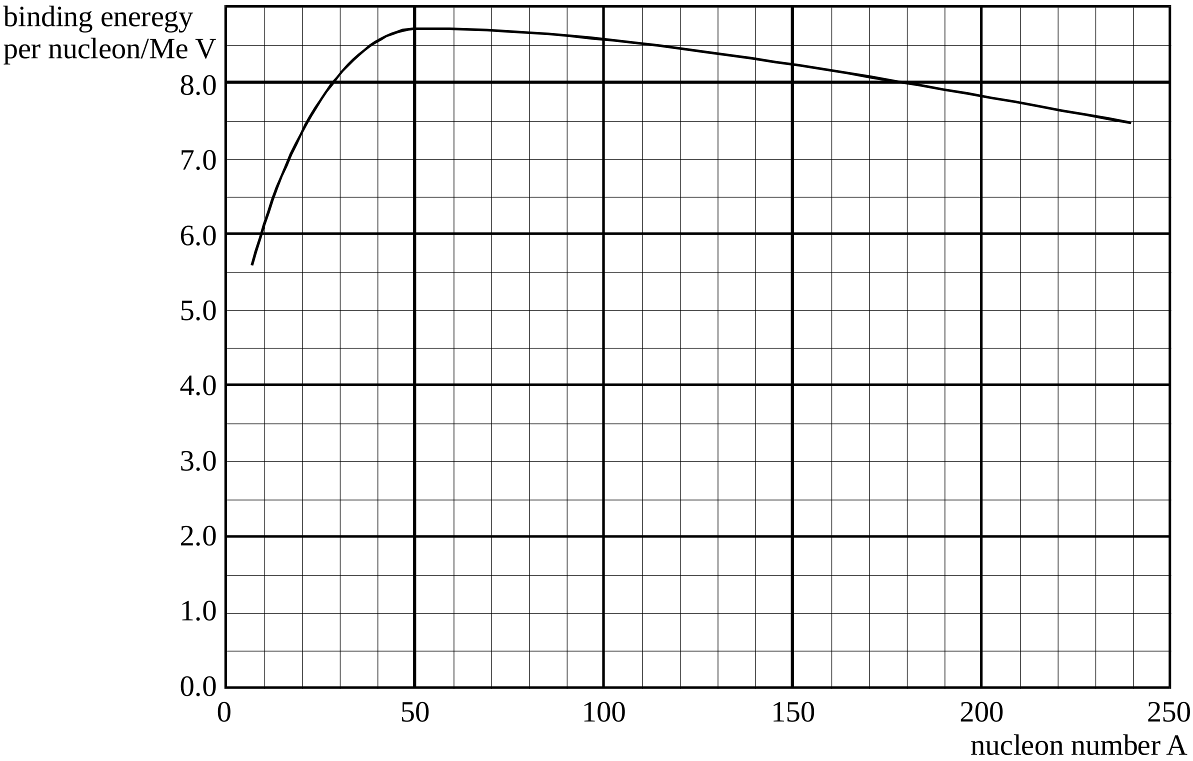
**(4)**
**(Total 16 marks)**

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

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{98}_{38}Sr + {}_{54}Xe + {}^{1}_{0}n$$

(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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**(6)**

(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 $^{235}_{92}U$, 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 $2.00 \times 10^7$ ms$^{-1}$ is $1.33 \times 10^{-12}$ 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% $^{238}_{92}U$ and 0.7% $^{235}_{92}U$. 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, $\alpha$ particles were aimed at thin gold foil in a vacuum. A detector was used to determine the number of $\alpha$ particles deflected through different angles.

(a) State **two** observations about the $\alpha$ 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.

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

(i) State the nuclear composition of X.

proton number ...........................................................................................

neutron number ..........................................................................................

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

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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 $3.2 \times 10^{-11}$ J, calculate the number of uranium-235 nuclei which will undergo fission per day.

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**(3)**

**(Total 6 marks)**