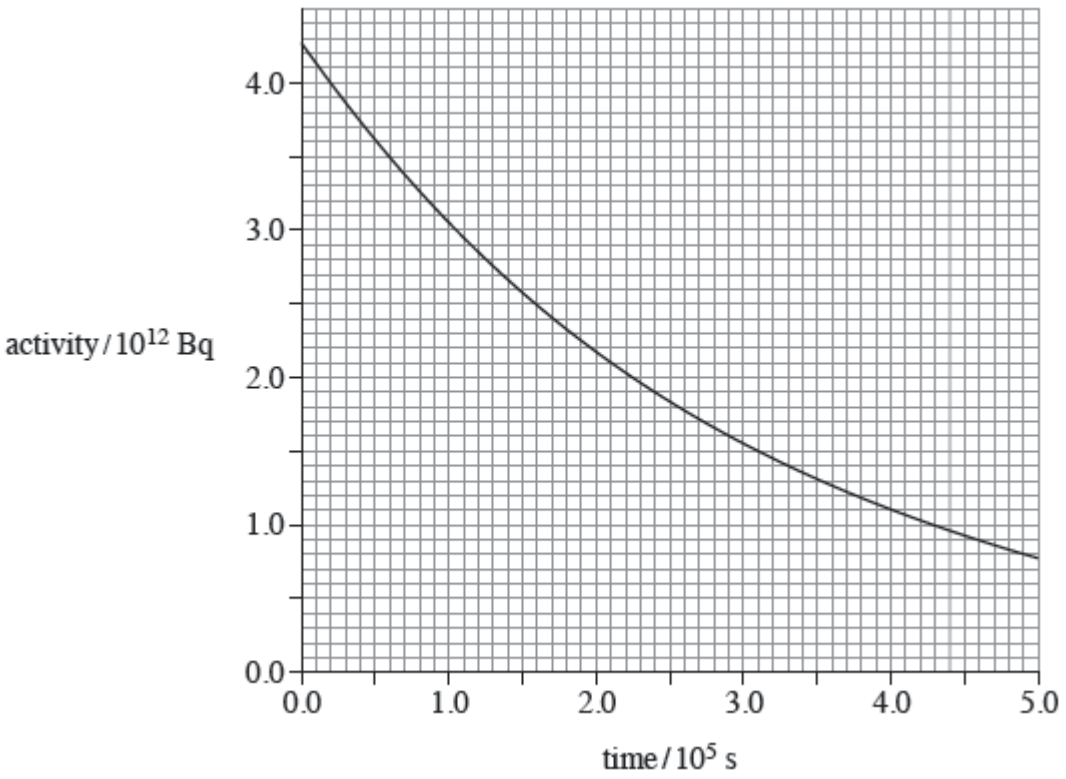
Q1. A rod made from uranium−238 ($^{238}_{92}\mathrm{U}$) is placed in the core of a nuclear reactor where it absorbs free neutrons.
When a nucleus of uranium−238 absorbs a neutron it becomes unstable and decays to neptunium−239 ($^{239}_{93}\mathrm{Np}$), which in turn decays to plutonium−239 ($^{239}_{94}\mathrm{Pu}$).

(a) Write down the nuclear equation that represents the decay of neptunium−239 into plutonium−239.

(2)

(b) A sample of the rod is removed from the core and its radiation is monitored from time t = 0 s.
The variation of the activity with time is shown in the graph.



(i) Show that the decay constant of the sample is about 3.4×10^{-6} s^{-1}.

(2)

(ii) Assume that the activity shown in the graph comes only from the decay of neptunium.

Estimate the number of neptunium nuclei present in the sample at time $t = 5.0 \times 10^5$ s.

number of nuclei .....

(1)

(c) (i) A chain reaction is maintained in the core of a thermal nuclear reactor that is operating normally.

Explain what is meant by a chain reaction, naming the materials and particles involved.

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(2)

(ii) Explain the purpose of a moderator in a thermal nuclear reactor.

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(2)

(iii) Substantial shielding around the core protects nearby workers from the most hazardous radiations. Radiation from the core includes α and β particles, γ rays, X−rays, neutrons and neutrinos.

Explain why the shielding becomes radioactive.

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(2)
(Total 11 marks)

Q2.(a) State what is meant by the binding energy of a nucleus.

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(2)

(b) (i) When a $^{235}_{92}U$ nucleus absorbs a slow-moving neutron and undergoes fission

one possible pair of fission fragments is technetium $^{112}_{43}\text{Tc}$ and indium $^{122}_{49}\text{In}$.

Complete the following equation to represent this fission process.

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \rightarrow ^{112}_{43}\text{Tc} + ^{122}_{49}\text{In} + \ldots\ldots\ldots\ldots$$

(1)

(ii) Calculate the energy released, in MeV, when a single $^{235}_{92}\text{U}$ nucleus undergoes fission in this way.

binding energy per nucleon of $^{235}_{92}\text{U}$ = 7.59 MeV

binding energy per nucleon of $^{112}_{43}\text{Tc}$ = 8.36 MeV

binding energy per nucleon of $^{122}_{49}\text{In}$ = 8.51 MeV

energy released ..... MeV

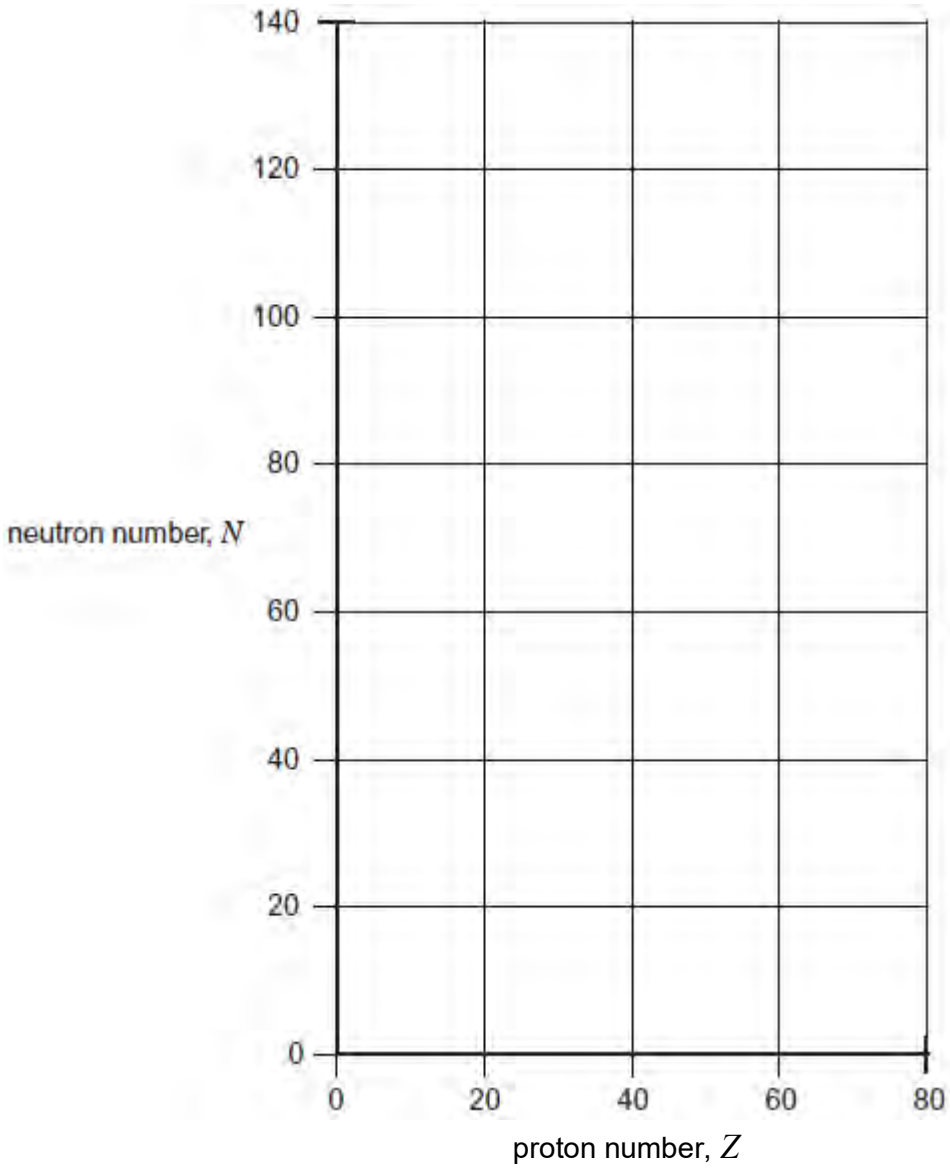
(3)

(iii) Calculate the loss of mass when a $^{235}_{92}\text{U}$ nucleus undergoes fission in this way.

loss of mass ..... kg

(2)

(c) (i) On the figure below sketch a graph of neutron number, N, against proton number, Z, for stable nuclei.



(1)

(ii) With reference to the figure, explain why fission fragments are unstable and explain what type of radiation they are likely to emit initially.

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(3)

(Total 12 marks)

Q3. The isotope of uranium, $^{238}_{92}U$, decays into a stable isotope of lead, $^{206}_{82}Pb$, by means of a series of α and β^- decays.

(a) In this series of decays, α decay occurs 8 times and β^- decay occurs *n* times. Calculate *n*.

answer = ...

(1)

(b) (i) Explain what is meant by the binding energy of a nucleus.

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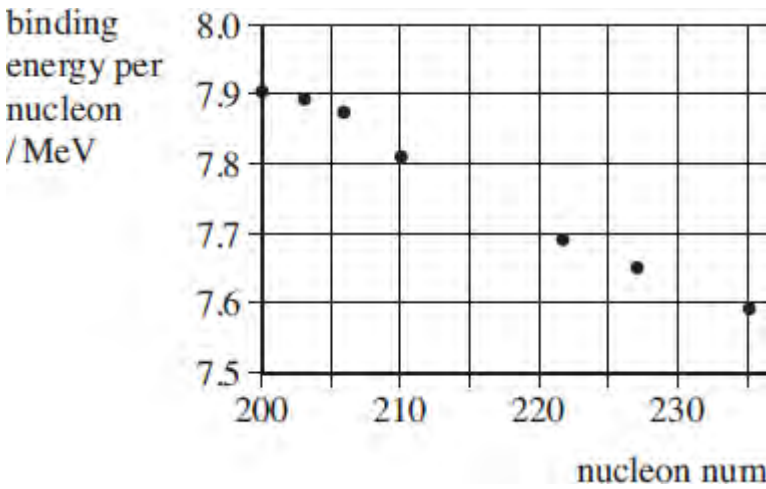
(2)

(ii) **Figure 1** shows the binding energy per nucleon for some stable nuclides.

Figure 1



Use **Figure 1** to estimate the binding energy, in MeV, of the $^{206}_{82}Pb$ nucleus.

answer = ... MeV

(1)

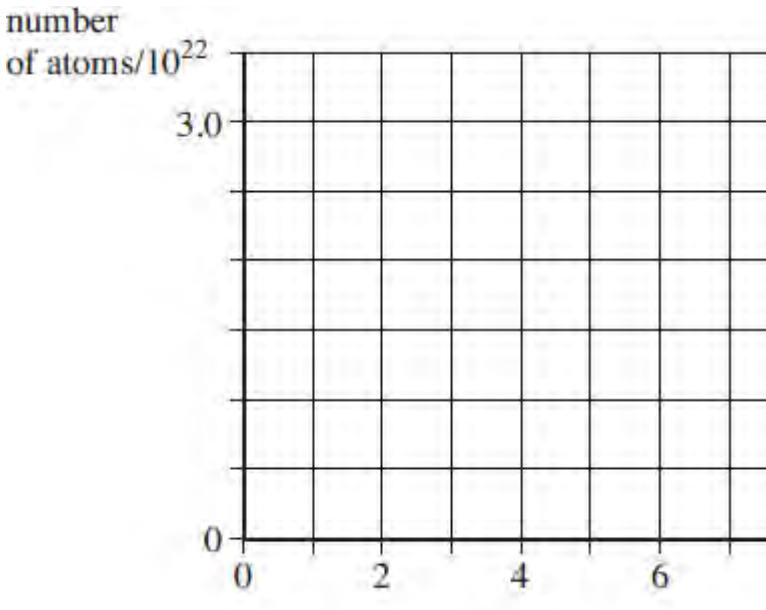
(c) The half-life of $^{238}_{92}U$ is 4.5×10^{9} years, which is much larger than all the other half-lives of the decays in the series.

A rock sample when formed originally contained 3.0×10^{22} atoms of $^{238}_{92}U$ and no $^{206}_{82}Pb$ atoms.

At any given time most of the atoms are either $^{238}_{92}U$ or $^{206}_{82}Pb$ with a negligible number of atoms in other forms in the decay series.

(i) Sketch on **Figure 2** graphs to show how the number of $^{238}_{92}U$ atoms and the number of $^{206}_{82}Pb$ atoms in the rock sample vary over a period of 1.0×10^{10} years from its formation.
Label your graphs U and Pb.

Figure 2



(2)

(ii) A certain time, *t*, after its formation the sample contained twice as many $^{238}_{92}U$ atoms as $^{206}_{82}Pb$ atoms.

Show that the number of $^{238}_{92}U$ atoms in the rock sample at time *t* was 2.0×10^{22}.

(1)

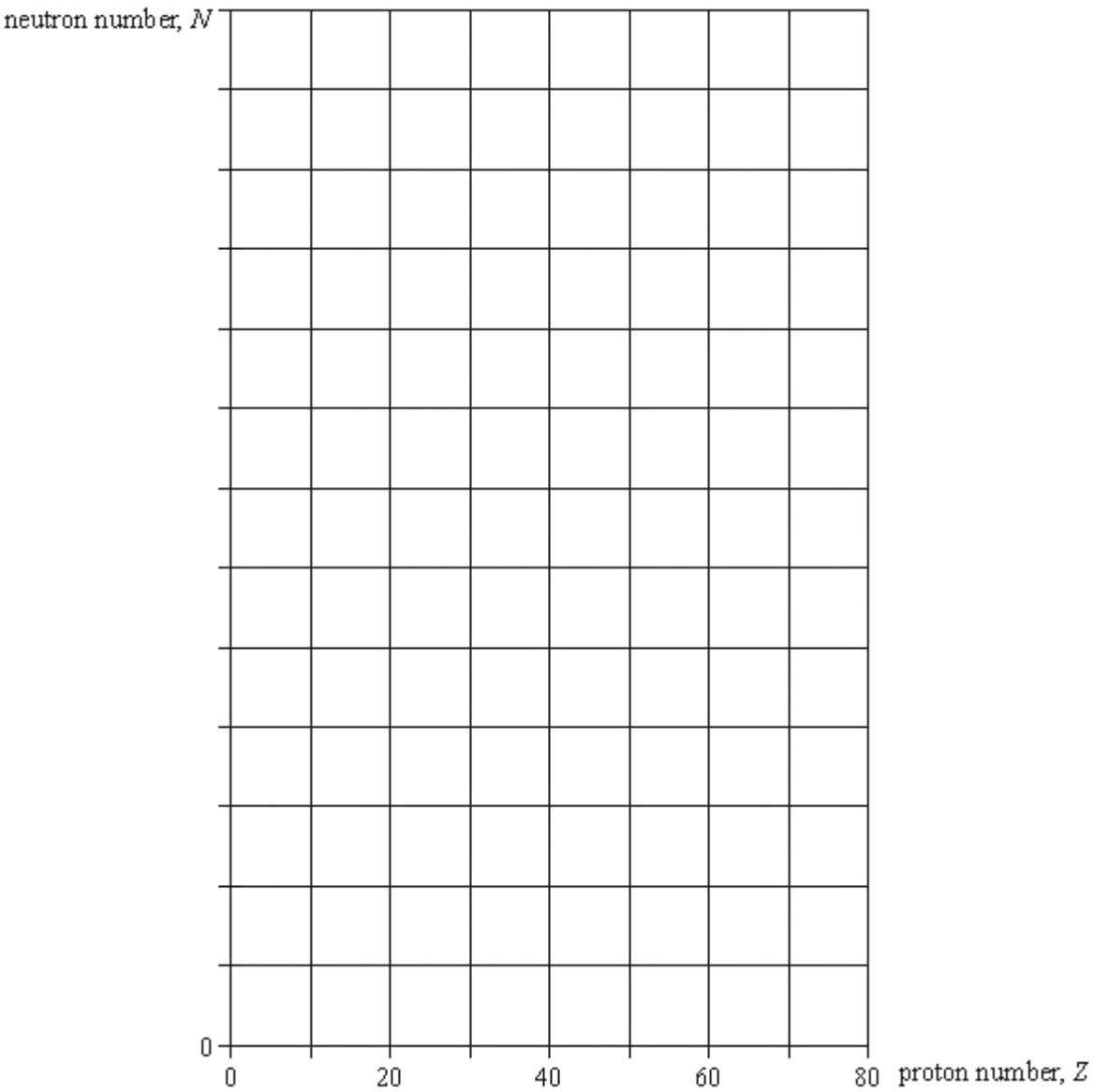
(ii) Calculate *t* in years.

answer = ... years

(3)

(Total 10 marks)

Q4. (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 $^{222}_{86}Rn$ decays sequentially by emitting α particles and β^- particles, eventually forming the isotope $^{206}_{82}Pb$. Four α particles are emitted in the sequence.

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

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(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.

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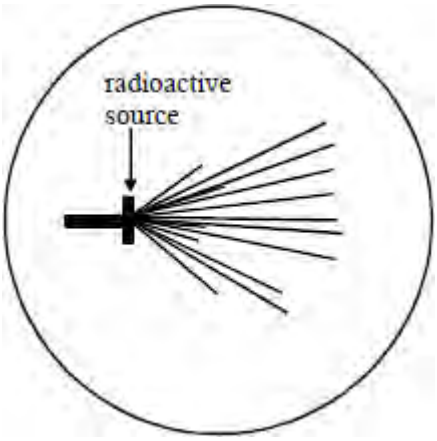
(3)
(Total 10 marks)

Q5.(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)