

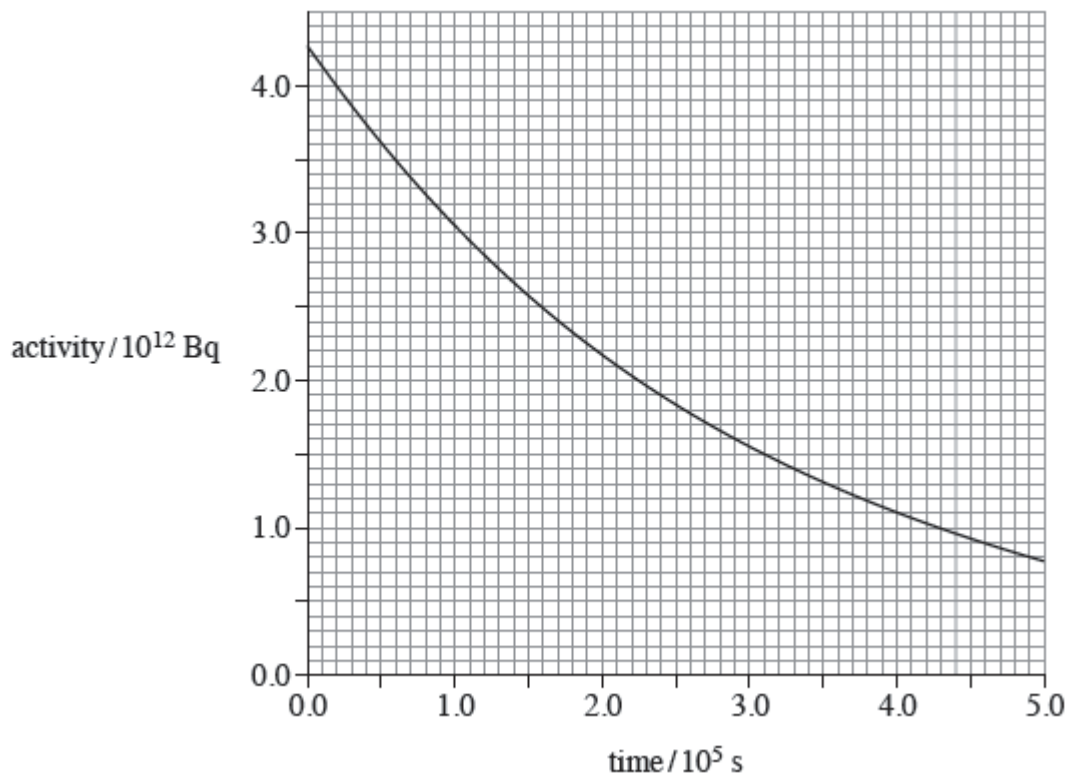
**Q1.** A rod made from uranium-238 ( $^{238}_{92}\text{U}$ ) is placed in the core of a nuclear reactor where it absorbs free neutrons.

When a nucleus of uranium-238 absorbs a neutron it becomes unstable and decays to neptunium-239 ( $^{239}_{93}\text{Np}$ ), which in turn decays to plutonium-239 ( $^{239}_{94}\text{Pu}$ ).

- (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  $3.4 \times 10^{-6} \text{ s}^{-1}$ .

(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  $t = 5.0 \times 10^5 \text{ s}$ .

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  $\alpha$  and  $\beta$  particles,  $\gamma$  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.

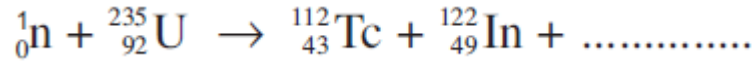
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(2)

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

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

Complete the following equation to represent this fission process.



(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  ${}^{235}_{92}\text{U} = 7.59 \text{ MeV}$

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

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

energy released ..... MeV

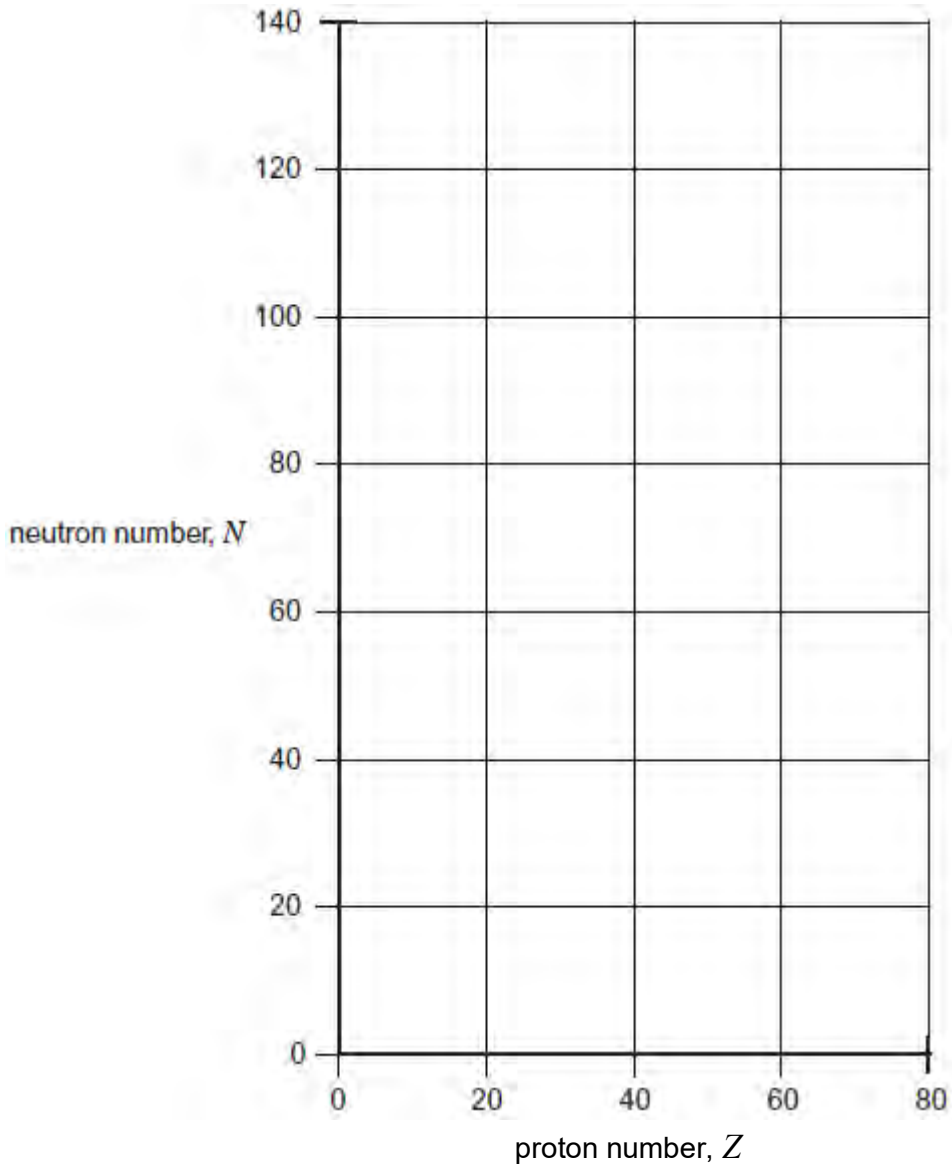
(3)

- (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)

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

- (a) In this series of decays,  $\alpha$  decay occurs 8 times and  $\beta^-$  decay occurs  $n$  times. Calculate  $n$ .

answer = .....

(1)

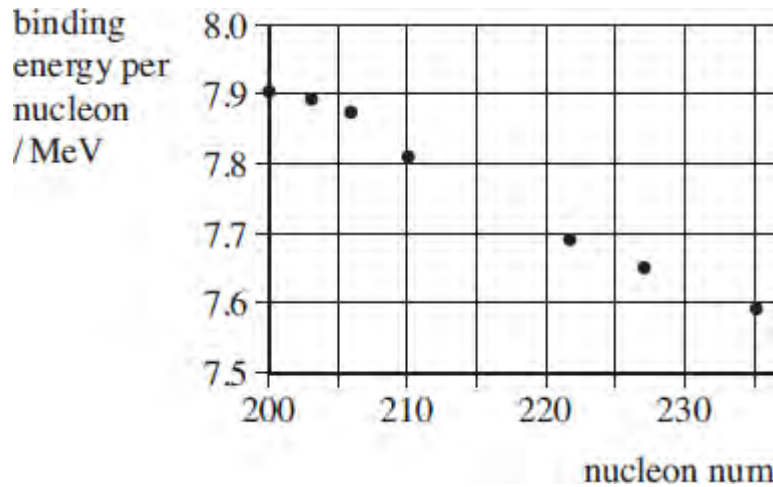
- (b) (i) Explain what is meant by the binding energy of a nucleus.

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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  $^{206}_{82}\text{Pb}$  nucleus.

answer = ..... MeV

(1)

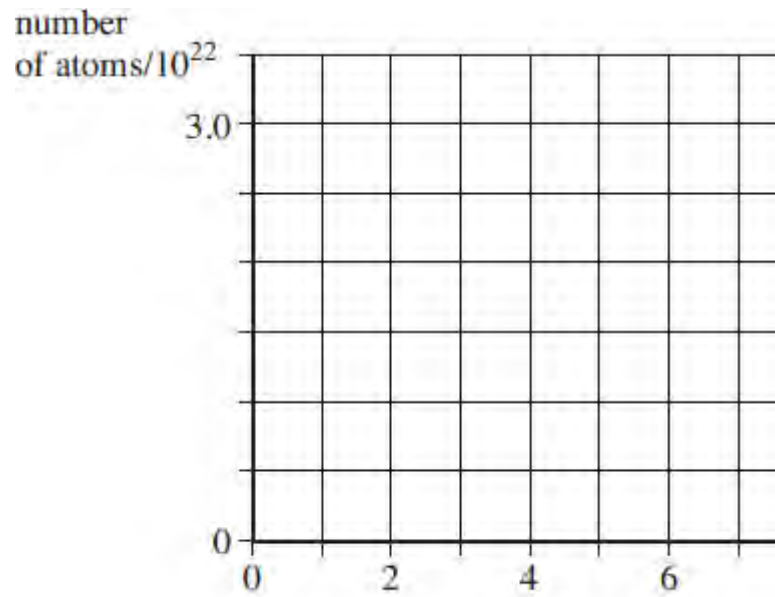
- (c) The half-life of  $^{238}_{92}\text{U}$  is  $4.5 \times 10^9$  years, which is much larger than all the other half-lives of the decays in the series.

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

At any given time most of the atoms are either  $^{238}_{92}\text{U}$  or  $^{206}_{82}\text{Pb}$  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  $^{238}_{92}\text{U}$  atoms and the number of  $^{206}_{82}\text{Pb}$  atoms in the rock sample vary over a period of  $1.0 \times 10^{10}$  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  $^{238}_{92}\text{U}$  atoms as  $^{206}_{82}\text{Pb}$  atoms.

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

(1)

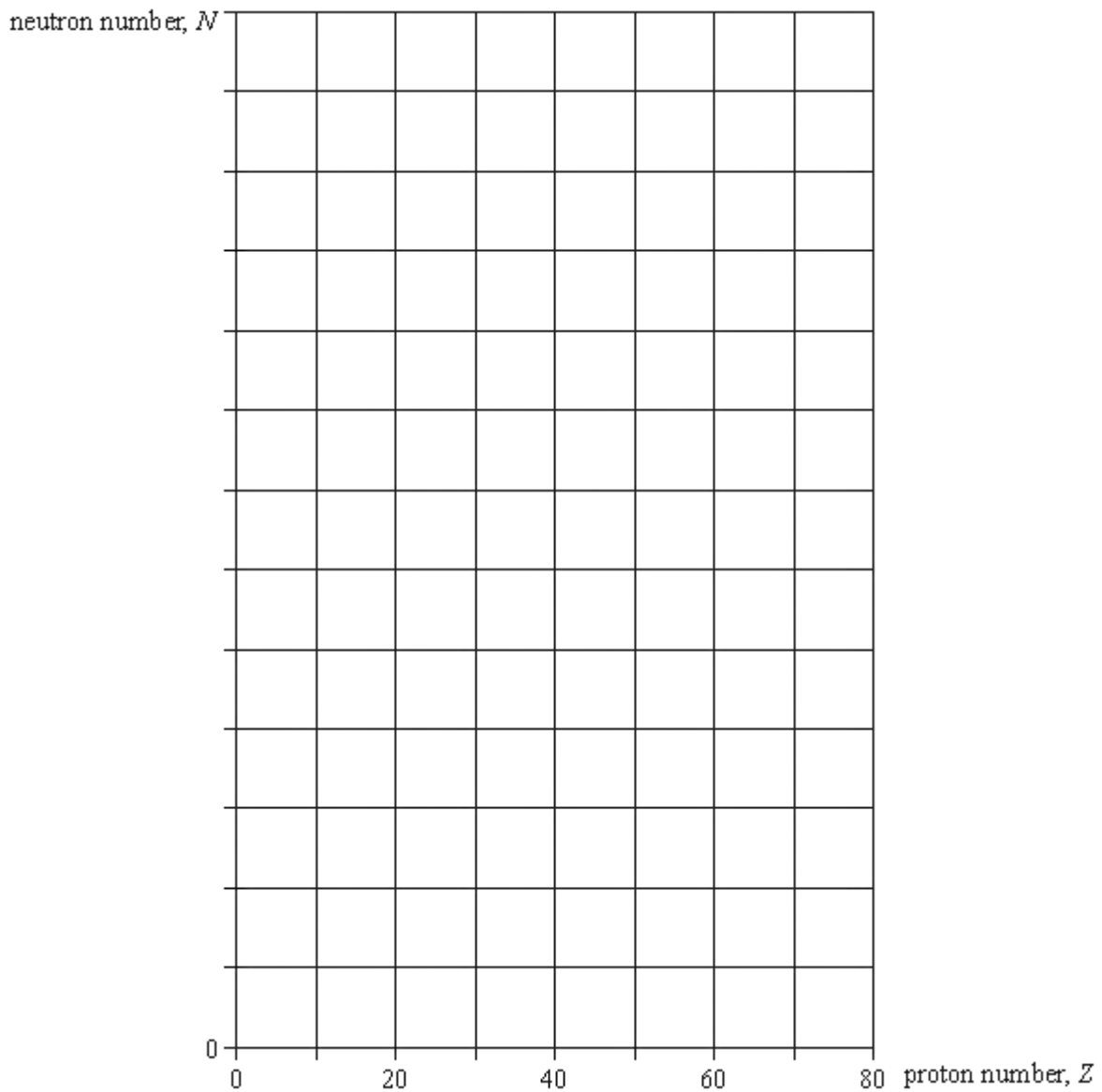
- (ii) Calculate  $t$  in years.



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)  $\alpha$  emission, labelling the position with **W**,
  - (ii)  $\beta^-$  emission, labelling the position with **X**,
  - (iii)  $\beta^+$  emission, labelling the position with **Y**.

(3)

- (c) The isotope  ${}^{222}_{86}\text{Rn}$  decays sequentially by emitting  $\alpha$  particles and  $\beta^-$  particles, eventually forming the isotope  ${}^{206}_{82}\text{Pb}$ . Four  $\alpha$  particles are emitted in the sequence. Calculate the number of  $\beta^-$  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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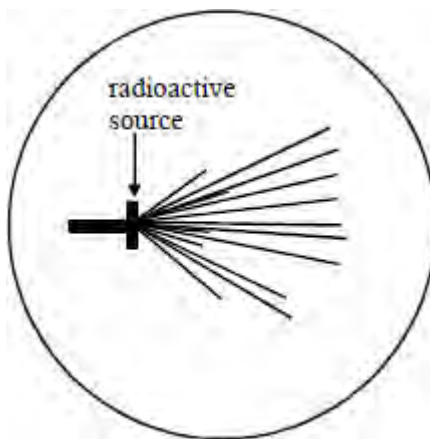
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(3)

(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  $\alpha$  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)