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

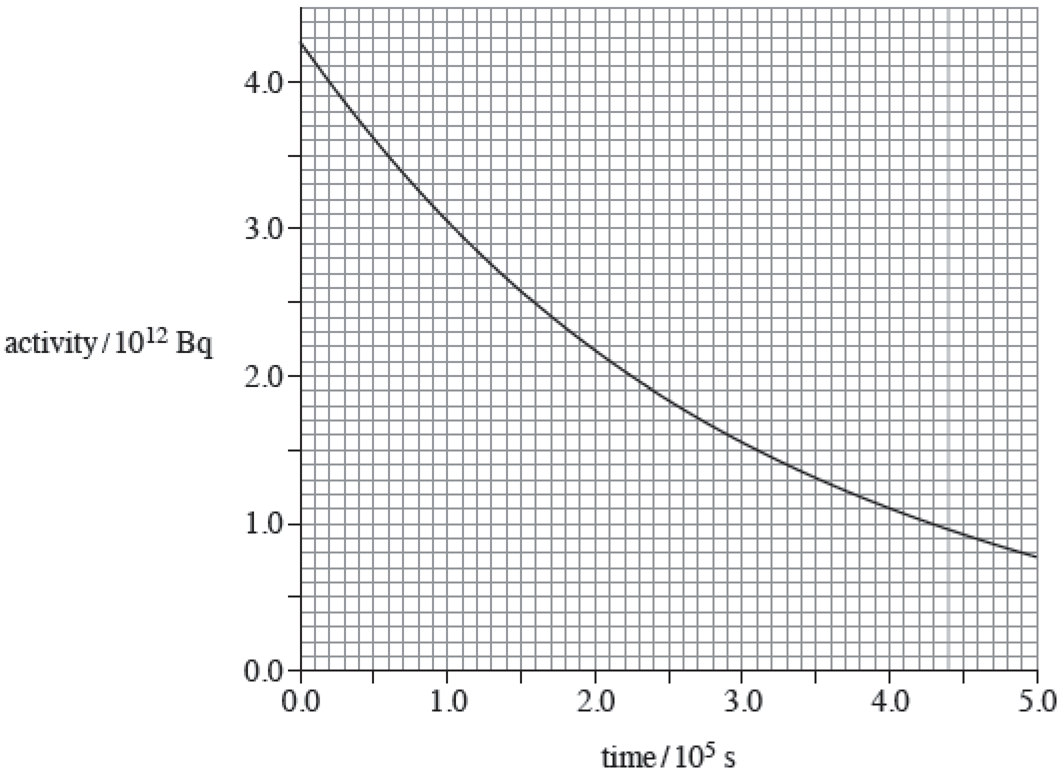
When a nucleus of uranium−238 absorbs a neutron it becomes unstable and decays to neptunium−239 ($^{239}_{93}Np$), which in turn decays to plutonium−239 ($^{239}_{93}Pu$).

(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 × 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) Explain what is meant by a **thermal** neutron.

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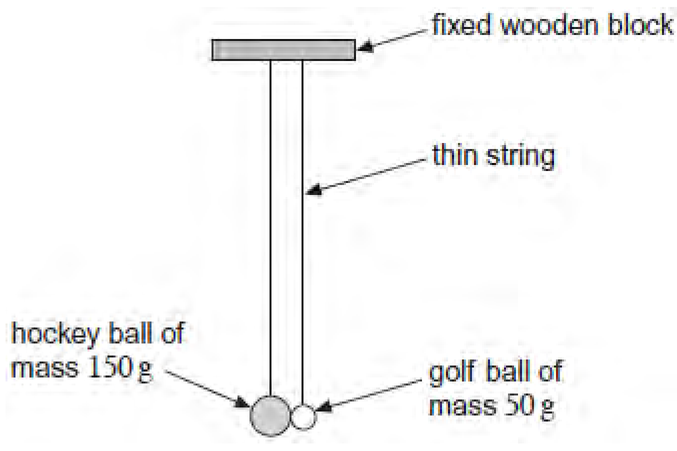
(2)

(b) A student sets up the arrangement, shown in the diagram below, to demonstrate the principle of moderation in a nuclear reactor.



A golf ball of mass 50 g is initially hanging vertically and just touching a hockey ball of mass 150 g. The golf ball is pulled up to the side and released. It has a speed of 1.3 m s^{-1} when it collides head-on with the hockey ball. After the collision the balls move in opposite directions with equal speeds of 0.65 m s^{-1}.

(i) Calculate the height above its initial position from which the golf ball is released. Assume that there is no air resistance.

height .... m

(2)

(ii) Show that momentum is conserved in the collision and that the collision is perfectly elastic.

(4)

(iii) Calculate the percentage of the kinetic energy of the golf ball transferred to the hockey ball during the collision.

percentage transferred .... %

(2)

(iv) Explain how this demonstration relates to the moderation process in a reactor and state **one** way in which the collisions in a reactor differ from the collision in the demonstration.

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(2)

(v) Name the substance used as the moderator in a pressurised water reactor (PWR).

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(1)
(Total 13 marks)

Q3.(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 $^{112}_{43}Tc$ and indium $^{122}_{49}In$.

Complete the following equation to represent this fission process.

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

(1)

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

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

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

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

energy released .... MeV

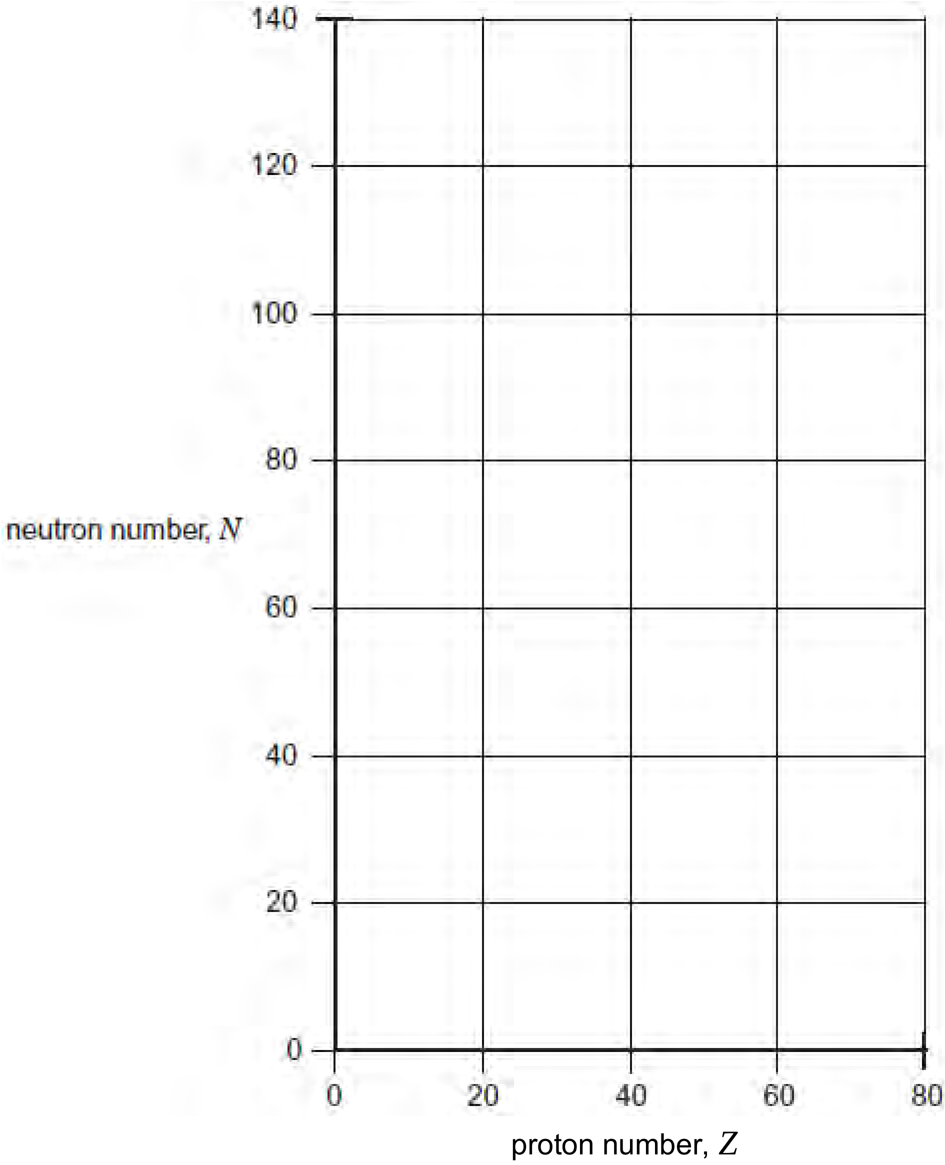
(3)

(iii) Calculate the loss of mass when a $^{235}_{92}U$ 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)

Q4.(a) Describe the changes made inside a nuclear reactor to reduce its power output and explain the process involved.

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(2)

(b) State the main source of the highly radioactive waste from a nuclear reactor.

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(1)

(c) In a nuclear reactor, neutrons are released with high energies. The first few collisions of a neutron with the moderator transfer sufficient energy to excite nuclei of the moderator.

(i) Describe and explain the nature of the radiation that may be emitted from an excited nucleus of the moderator.

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(2)

(ii) The subsequent collisions of a neutron with the moderator are elastic.

Describe what happens to the neutrons as a result of these subsequent collisions with the moderator.

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(2)
(Total 7 marks)