A-Level Physics

Induced Fission

Question Paper

Time available: 66 minutes
Marks available: 47 marks

1. A thermal nuclear reactor uses enriched uranium as its fuel.
This is fuel in which the ratio of U-235 to U-238 has been artificially increased from that found in naturally-occurring ore.

(a) Describe what happens when neutrons interact with U-235 and U-238 nuclei in a thermal nuclear reactor.

(3)

(b) The amounts of U-235 and U-238 in the ore decrease due to radioactive decay at different rates.

A sample of uranium ore today contains 993 g of U-238
The mass of U-238 in this sample was greater 2.00×10^9 years ago.

Show that the mass of U-238 in this sample at that time was about 1.4 kg.

decay constant of U-238 = 1.54×10^{-10} year^{-1}

(2)

(c) A thermal nuclear reactor requires a minimum of 3.0% of its uranium mass to be U-235

The ratio of U-235 to U-238 in the ore has changed over time.
2.00×10^9 years ago, the sample in part (b) contained 52 g of U-235

Deduce whether the sample had a high enough U-235 content to be used in a reactor 2.00×10^9 years ago.

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(1)

(Total 6 marks)

2. A thermal nuclear reactor uses a moderator to lower the kinetic energy of fast-moving neutrons.

(a) Explain why the kinetic energy of neutrons must be reduced in a thermal nuclear reactor.

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(1)

(b) As a result of a collision with an atom of a particular moderator, a neutron loses 63% of its kinetic energy.

A neutron has an initial kinetic energy of 2.0 MeV.

Calculate the kinetic energy of the neutron after five collisions.

kinetic energy = _____ eV

(2)

(c) The kinetic energy of a neutron in a thermal nuclear reactor is reduced from about 2 MeV to about 1 eV.

Explain why the number of collisions needed to do this depends on the nucleon number of the moderator atoms.

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(2)

(d) One fission process which can occur in a thermal nuclear reactor is represented by the equation

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} = {}^{142}_{54}\mathrm{Xe} + {}^{90}_{38}\mathrm{Sr} + 4\,{}^{1}_{0}\mathrm{n}$$

Calculate in MeV the energy released in this fission process.

mass of $^{235}_{92}\mathrm{U}$ = 235.044 u

mass of $^{142}_{54}\mathrm{Xe}$ = 141.930 u

mass of $^{90}_{38}\mathrm{Sr}$ = 89.908 u

mass of $^{1}_{0}\mathrm{n}$ = 1.0087 u

energy released = _____ MeV

(3)

(e) Many magazine and newspaper articles focus on the risks of using nuclear power.

State **three benefits** of using nuclear power.

1 _____

_____

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2 _____

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3 _____

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(3)

(Total 11 marks)

3. The core of a thermal nuclear reactor contains a number of components that are exposed to moving neutrons.

(a) State what happens to a neutron that is incident on the moderator.

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(1)

(b) State what happens to a neutron that is incident on a control rod.

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(1)

(c) A slow-moving neutron is in collision with a nucleus of an atom of the fuel which causes fission.

Describe what happens in the process.

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(3)

(d) A thermal nuclear reactor produces radioactive waste.

State the source of this waste and discuss some of the problems faced in dealing with the waste at various stages of its treatment.

Your answer should include:

- the main source of the most dangerous waste
- a brief outline of how waste is treated
- problems faced in dealing with the waste, with suggestions for overcoming these problems.

(6)

(Total 11 marks)

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

(2)

(b) (i) When a $^{235}_{92}\mathrm{U}$ nucleus absorbs a slow-moving neutron and undergoes fission one possible pair of fission fragments is technetium $^{112}_{43}\mathrm{Tc}$ and indium $^{122}_{49}\mathrm{In}$.

Complete the following equation to represent this fission process.

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

(1)

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

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

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

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

energy released _____ MeV

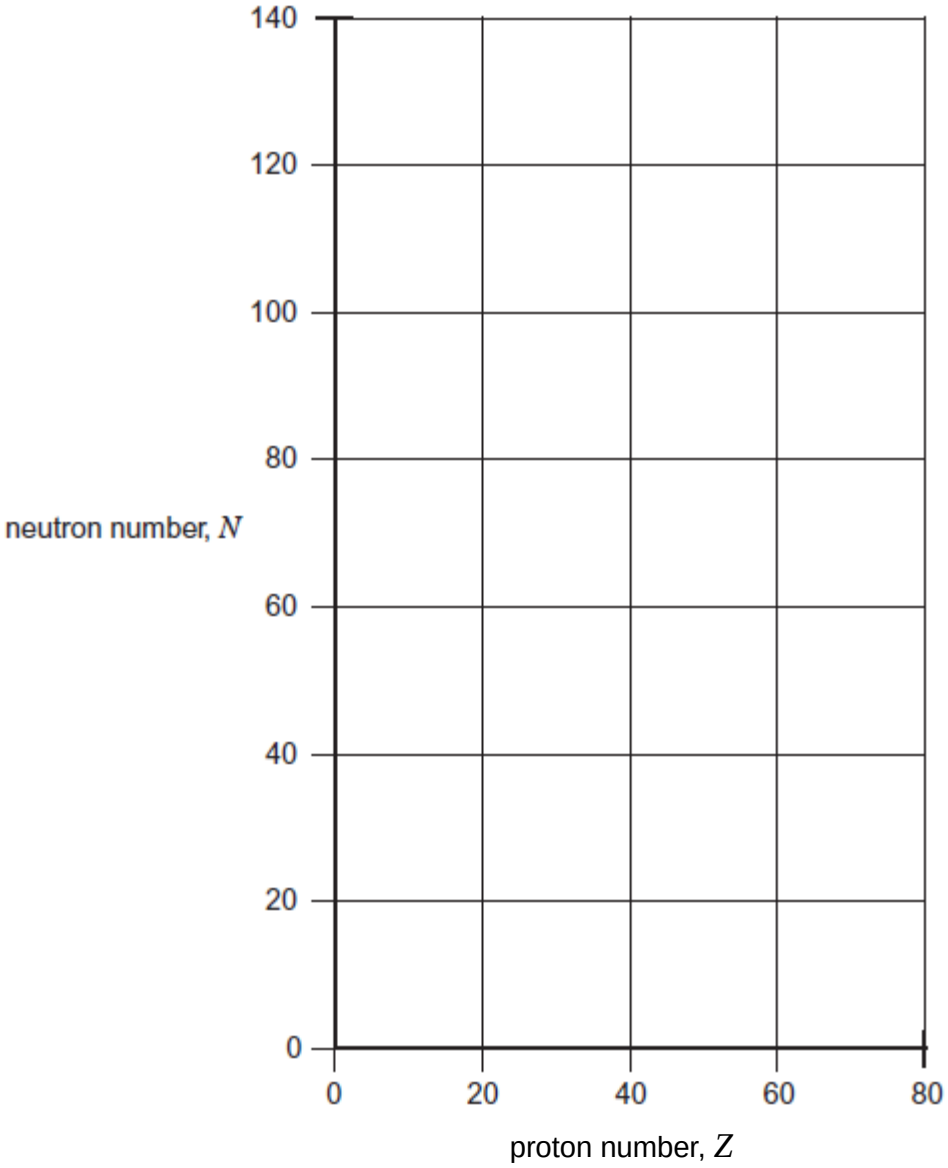
(3)

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

(3)

(Total 12 marks)

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

(2)

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

(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.

(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)