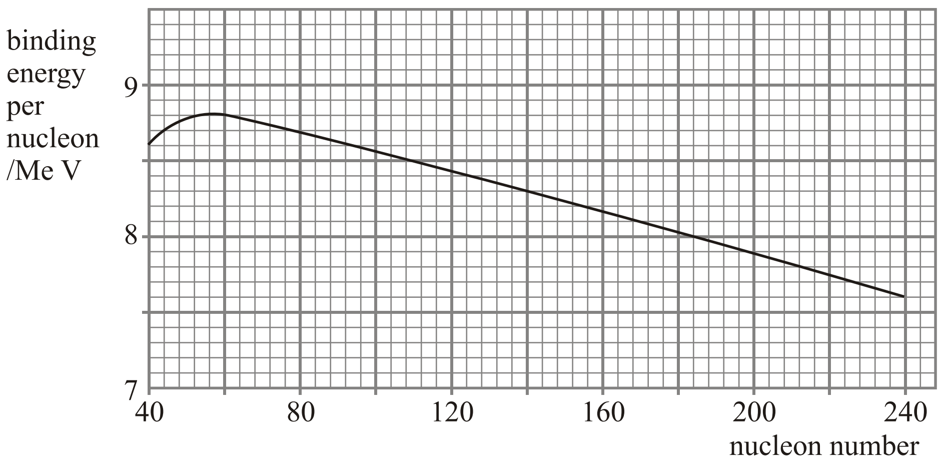
1. (a) The mass of a nucleus ${}^{A}_{Z}X$ is M.

(i) If the mass of a proton is m_p, and the mass of a neutron is m_n, give an expression for the mass difference Δm of this nucleus.

(ii) Give an expression for the binding energy per nucleon of this nucleus, taking the speed of light to be c.

(2)

(b) The figure below shows an enlarged portion of a graph indicating how the binding energy per nucleon of various nuclides varies with their nucleon number.



(i) State the value of the nucleon number for the nuclides that are most likely to be stable. Give your reasoning.

(ii) When a fission of uranium 235 takes place so that the nucleus splits into two roughly equal parts and approximately 200 MeV of energy is released. Use information from the figure above to justify this figure, explaining how you arrive at your answer.

(5)
(Total 7 marks)

2. (a) When a nucleus of uranium-235 fissions into barium-141 and krypton-92, the change in mass is 3.1×10^{-28} kg. Calculate how many nuclei must undergo fission in order to release 1.0 J of energy by this reaction.

(2)

(b) A nuclear power station produces an electrical output power of 600 MW. If the overall efficiency of the station is 35%, calculate the decrease in the mass of the fuel rods, because of the release of energy, during one week of continuous operation.

(4)
(Total 6 marks)

3. (a) Explain why, after a period of use, the fuel rods in a nuclear reactor become

(i) less effective for power production,

(ii) more dangerous.

(3)

(b) Describe the stages in the handling and processing of spent fuel rods after they have been removed from a reactor, indicating how the active wastes are dealt with.

(5)
(Total 8 marks)

4. (a) (i) State the function of the moderator in a thermal nuclear reactor.

(ii) By considering the free neutrons in a thermal nuclear reactor to behave like the atoms of an ideal gas, estimate the speed of free neutrons in the core of a thermal nuclear reactor when the core temperature is 700 K.

(4)

(b) In the core of a nuclear reactor, a fission neutron moving at a speed of 3.9×10^6 m s^{-1} collides with a carbon 12 nucleus which is initially at rest. Immediately after the collision, the carbon nucleus has a velocity of 6.0×10^5 m s^{-1} in the same direction as the initial direction of the neutron.

molar mass of carbon 12 = 0.012 kg

(i) Show that the neutron rebounds with a speed of 3.3×10^6 m s^{-1}.

(ii) Show that the collision is an elastic collision.

(iii) Calculate the percentage of the initial kinetic energy of the neutron that is transferred to the carbon nucleus.

(7)
(Total 11 marks)

5. In a nuclear reactor, uranium nuclei undergo *induced fission* by *thermal neutrons*. The reaction is a *self-sustaining chain reaction* which requires *moderation* and has to be *controlled*.

(a) Explain the meaning of

(i) induced fission,
(ii) thermal neutrons,
(iii) self-sustaining chain reaction.

(5)

(b) (i) Explain what is involved in the process of moderation.
(ii) Describe how the rate of fission is controlled in a nuclear reactor.

(7)
(Total 12 marks)

6. (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.*

(ii) Explain, using the charged liquid drop model, the energy changes in the fission of a uranium–235 nucleus.

(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.

(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%.

(5)
(Total 13 marks)

7. (a) When ^{235}U undergoes fission, the average number of neutrons produced per fission is about 2.5. Describe what happens to these neutrons in a thermal reactor which is producing power at a constant rate.

(5)

(b) Write brief notes on the safety aspects of the following in the use of nuclear reactors for power production.

(i) use of control rods in normal operation and in emergency shut down
(ii) shielding
(iii) treatment of spent fuel rods

(8)

(c) Explain how artificial isotopes are produced

(2)
(Total 15 marks)

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

(i) Complete the equation which shows the formation of $^{236}_{92}$ U.

$$+ \qquad \rightarrow \; ^{236}_{92}U$$

(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 $^{145}_{56}Ba$ = 144.92694u

(3)
(Total 5 marks)

9. 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.*

(ii) Why is enriched uranium rather than natural uranium used in many nuclear reactors?

(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.

(ii) Explain why all the fuel in a nuclear reactor is **not** placed in a single fuel rod.

(5)
(Total 7 marks)

10. (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.

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

State the nuclear composition of X (proton number and neutron number).

(2)

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

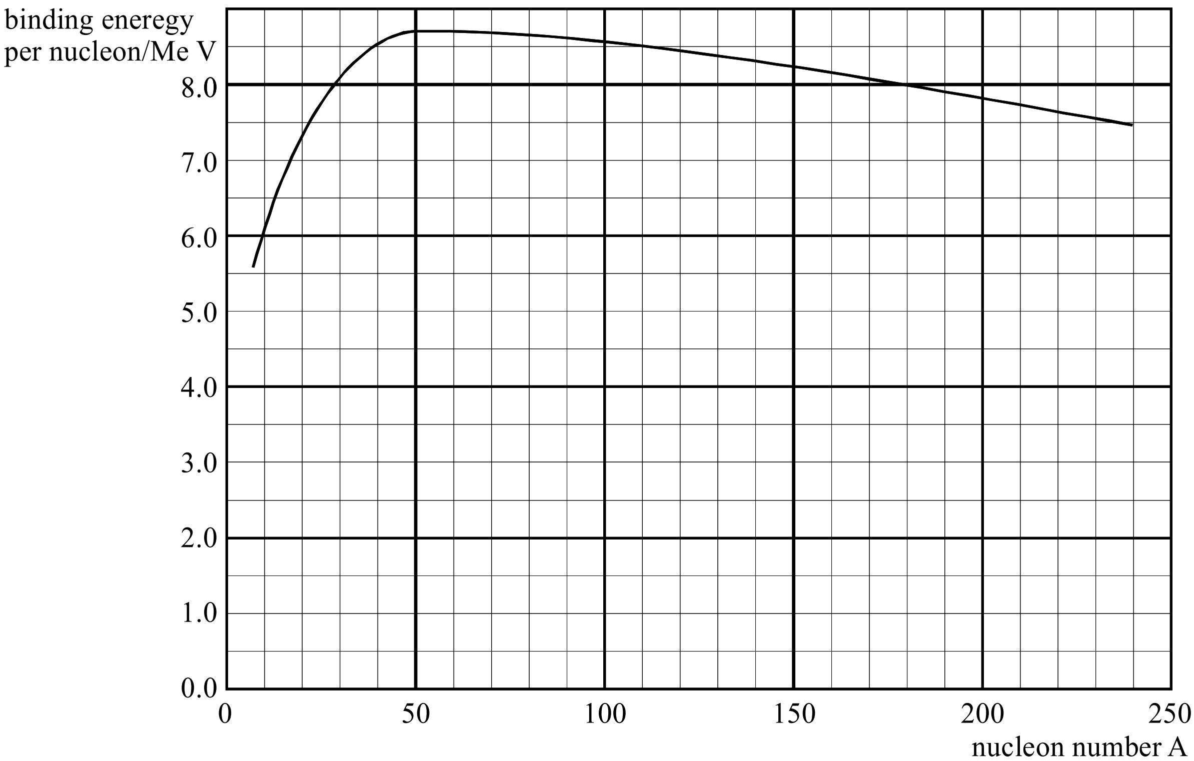
(3)
(Total 5 marks)

11. (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.

(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.

(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.

(6)
(Total 12 marks)

12. A space probe contains a small fission reactor, fuelled by plutonium, which is designed to produce an average of 300W 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 $^{239}_{94}Pu = 3.2 \times 10^{-11}$ J

the Avogadro constant = 6.0 × 10^{23} mol^{-1}

(Total 7 marks)