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

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[1]

The variation of the binding energy per nucleon with nucleon number of all the different nuclei is shown in Fig. 9.1.

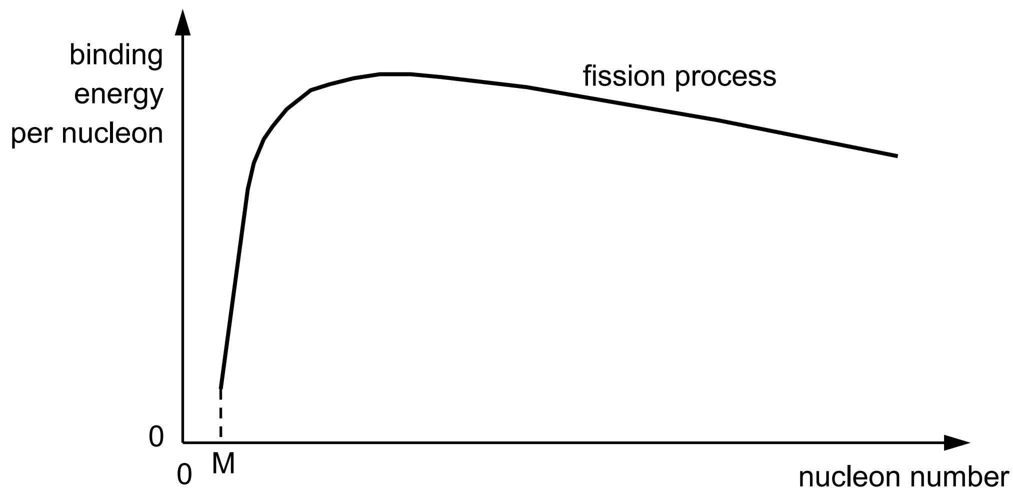

Fig. 9.1

(ii) State the value of M and explain your answer clearly.

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.... [2]

(b) In a fission process, a neutron with speed of 2.00 × 10^3 m s^{-1} collides with a Uranium-235 nucleus and causes a nuclear reaction summarised in the following equation:

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{143}_{53}Xe + ^{90}_{38}Sr + 3\,^{1}_{0}n + \text{energy}$$

(i) Using the data from Fig. 9.2, show that the binding energy per nucleon for Strontium-90 is 8.73 MeV.

	rest mass
Strontium, $^{90}_{38}Sr$	89.9077 u
Proton, $^{1}_{1}p$	1.0078 u
Neutron, $^{1}_{0}n$	1.0087 u

Fig. 9.2

[3]

(ii) Data for binding energies per nucleon are shown in Fig. 9.3. Hence calculate the total energy released during the nuclear fission reaction.

Isotope	binding energy per nucleon / MeV

Uranium-235	7.59
Xenon-143	8.41

Fig. 9.3

energy released = ... J [2]

(iii) Explain quantitatively why the kinetic energy of the neutron directed at Uranium-235 is neglected.

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[1]

(c) Fig. 9.4 shows the possible directions of Strontium-90, Xenon-143, and neutrons when nuclear fission takes place. Assume that this is an isolated system.

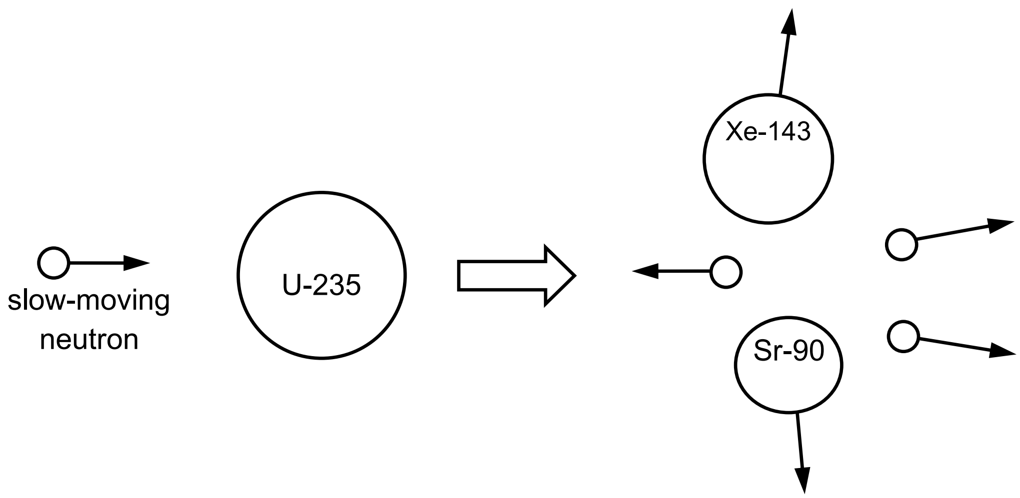

Fig. 9.4

(i) Explain why it is unlikely for the two fission products to move in the same direction after the fission process.

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[1]

(ii) The total momentum of two fission products and neutrons after reaction is not zero even though the total momentum of Uranium-235 and slow moving neutron may be taken to be zero. Explain why this may be so.

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[2]

(d) Neutrons emitted from a nuclear fission may hit another Uranium-235 nucleus, causing a chain reaction.

(i) To control the reaction, neutrons emitted from a fission reaction may be slowed down by Carbon-12 nuclei, $^{12}_{6}C$. Show that when a neutron undergoes an elastic head-on collision with a Carbon-12 nucleus as shown in Fig. 9.5, the speed is reduced by about 15%.

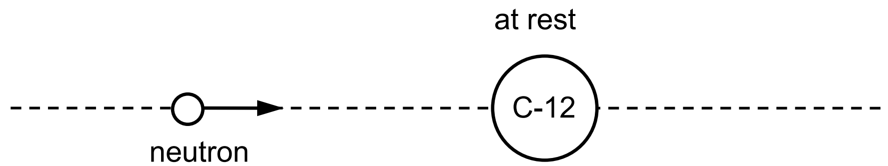

Fig. 9.5

[3]

(ii) On average, the neutron speed after each collision is 0.93 of its speed before the collision.

Suggest why this speed reduction is different from what is stated in **(ii)** for a nuclear reactor.

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[1]

(iii) Suggest why a slow neutron has a higher chance of being captured by Uranium-235 to cause a fission reaction compared to a fast neutron.

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[1]

(e) The fission products are usually radioactive and give rise to a series of radioactive decay products. Each decay product has its own half life, but eventually a stable nuclide is reached.

One such fission product and its decay products is shown here:

$$^{143}_{54}\mathrm{Xe} \rightarrow {}^{143}_{55}\mathrm{Cs} \rightarrow {}^{143}_{56}\mathrm{Ba}$$

The half-lives of Xenon-143 and Caesium-143 are 0.511 s and 1.79 s respectively.

(i) Suggest how the number of Caesium-143 nuclei inside the nuclear reactor may remain constant even when it decays to form Barium-143.

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.... [2]

(ii) Explain why a particular Xenon-143 nucleus produced earlier in the reaction may not necessarily decay before another Xenon-143 nucleus which was produced after it.

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.... [1]

[Total: 20]

End of Paper