Binding Energy

1.

(a) The following nuclear reaction occurs when a slow-moving neutron is absorbed by an isotope of uranium-235.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

(i) Explain how this reaction is able to produce energy.

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....

.... **[2]**

(ii) State in what form the energy is released in such a reaction.

.... **[1]**

(b) The binding energy per nucleon of each isotope in **(a)** is given in Fig. 8.1.

isotope	binding energy per nucleon / MeV
$^{235}_{92}U$	7.6
$^{141}_{56}Ba$	8.3
$^{92}_{36}Kr$	8.7

Fig. 8.1

(i) Explain why the neutron $^{1}_{0}n$ does not appear in the table above.

....

.... **[1]**

(ii) Calculate the energy released in the reaction shown in **(a)**.

energy = ... MeV **[2]**

2.

(a) Explain the term *binding energy* of a nucleus.

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.... **[2]**

(b) Nuclear fusion takes place in the core of the Sun. One of the simplest fusion reactions is shown below.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He$$

(i) The binding energy per nucleon of $^{2}_{1}H$ is 1.8×10^{-13} J and the binding energy per nucleon of $^{4}_{2}He$ is 1.1×10^{-12} J. Show that the energy released in the reaction is 3.7×10^{-12} J.

[2]

(ii) The Sun radiates its energy uniformly through space. The mean intensity of the Sun's radiation reaching the Earth's atmosphere is about $1400\,W\,m^{-2}$. The mean radius of the Earth's orbit round the Sun is 1.5×10^{11} m.

1 Show that the mean power radiated from the surface of the Sun is 4.0×10^{26} W.

[2]

2 Assume all the radiated energy from the Sun comes from the fusion reaction shown in **(b)**. Estimate the number of helium-4 nuclei produced every second by the Sun.

number = ... s^{-1} **[2]**

3.

(a) Explain what is meant by the statement below.

Radioactivity is a random process.

....

.... **[1]**

(b) Uranium-235 was present during the formation of the Solar System, including the Earth. The percentage of the original quantity of $^{235}_{92}U$ found in rocks today is 1.1%. The half-life of $^{235}_{92}U$ is 7.1×10^8 years. Calculate the age, in years, of the Earth.

age = ... y **[3]**

(c) Fig. 6.1 shows the variation of binding energy per nucleon against nucleon number *A*.

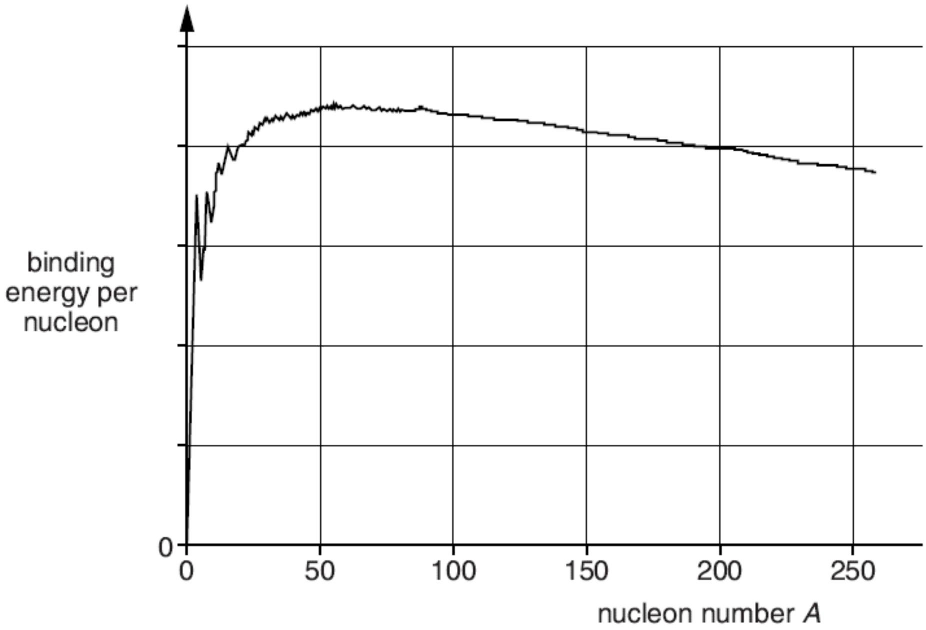

Fig. 6.1

(i) Use Fig. 6.1 to estimate the value of the nucleon number of the most stable isotope.

.... **[1]**

(ii) Use Fig. 6.1 to explain why nuclei of $^{100}_{42}Mo$ cannot produce energy by **fusion**.

....

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.... **[1]**

(iii) The mass of a $^{8}_{4}Be$ nucleus is 1.329×10^{-26} kg. Use data provided on the second page of the Data, Formulae and Relationships Booklet to determine the binding energy per nucleon for this nucleus.

binding energy per nucleon = ... J **[4]**

4.

The nuclear reaction represented by the equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{39}Y + ^{139}_{53}I + 3\,^{1}_{0}n$$

takes place in the core of a nuclear reactor at a power station.

(a) Describe how this reaction can lead to a chain reaction.

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.... **[1]**

(b) Explain the role of fuel rods, control rods and a moderator in a nuclear reactor.

In your answer you should make clear how chain reactions are controlled in the reactor.

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.... **[5]**

(c) In the nuclear reactor of a power station, each fission reaction of uranium produces 3.2×10^{-11} J of energy. The electrical power output of the power station is 3.0 GW. The efficiency of the system that transforms nuclear energy into electrical energy is 22%. Calculate

(i) the total power output of the reactor core

power output = ... W **[1]**

(ii) the total energy output of the reactor core in one day

1 day = 8.64×10^4 s

energy output = ... J **[1]**

(iii) the mass of uranium-235 converted in one day. The mass of a uranium-235 nucleus is 3.9×10^{-25} kg.

mass = ... kg **[2]**

(d) Discuss the physical properties of nuclear waste that makes it dangerous.

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.... **[2]**

5.

(a) In the core of a nuclear reactor, one of the many fission reactions of the uranium-235 nucleus is shown below.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n$$

(i) State **one** quantity that is conserved in this fission reaction.

.... **[1]**

(ii) Fig. 4.1 illustrates this fission reaction.

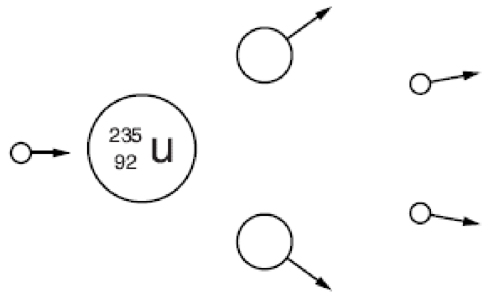

Fig. 4.1

Label all the particles in Fig. 4.1 and extend the diagram to show how a chain reaction might develop. **[2]**

(b) Fusion of hydrogen nuclei is the source of energy in most stars. A typical reaction is shown below.

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n$$

The $^{2}_{1}H$ nuclei repel each other. Fusion requires the $^{2}_{1}H$ nuclei to get very close and this usually occurs at very high temperatures, typically 10^9 K.

(i) Use the data below to calculate the energy released in the fusion reaction above.

mass of $^{2}_{1}H$ nucleus = 3.343×10^{-27} kg

mass of $^{3}_{2}He$ nucleus = 5.006×10^{-27} kg

mass of $^{1}_{0}n$ = 1.675×10^{-27} kg

energy = ... J **[3]**

(ii) State in what form the energy in **(b)(i)** is released.

.... **[1]**

(iii) The $^{2}_{1}H$ nuclei in stars can be modelled as an ideal gas. Calculate the mean kinetic energy of the $^{2}_{1}H$ nuclei at 10^9 K.

energy = ... J **[2]**

(iv) Suggest why some fusion can occur at a temperature as low as 10^7 K.

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.... **[1]**

6.

In a particular fission reaction a uranium-235 nucleus absorbs a neutron and undergoes fission to a barium-141 nucleus and a krypton-92 nucleus. The reaction is as follows:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

data: binding energies per nucleon for these nuclei are:

$^{235}_{92}U$ 7.6 MeV ; $^{141}_{56}Ba$ 8.4 MeV ; $^{92}_{36}Kr$ 8.6 MeV

(i) Show that the energy released when one $^{235}_{92}U$ nucleus undergoes fission in this way is about 200 MeV.

[3]

(ii) Calculate how much energy is released when 1.00 kg of uranium-235 undergoes fission. Assume that every fission generates the same amount of energy as the reaction stated above.

energy = ... J **[3]**