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.

....

....

.... **[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]**

[Total: 6]

2 A proton travelling at a high velocity is fired at a stationary proton. It stops momentarily at a distance of 2.0×10^{-15} m from the stationary proton.

(a) Calculate the electrostatic force acting on each proton when separated by 2.0×10^{-15} m.

force = ... N **[2]**

(b) The two protons fuse together. Explain how the protons are able to remain together.

....

.... **[1]**

(c) Explain why the proton must have a very large velocity for the fusion to occur and the protons to remain together.

....

....

....

.... **[2]**

[Total: 5]

3 **(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.

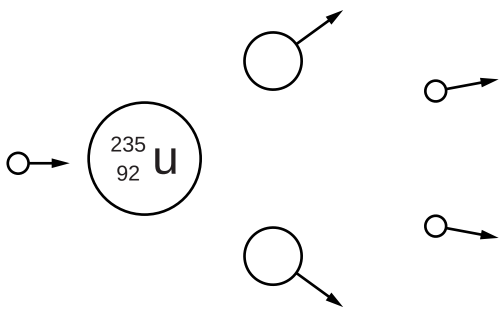

Fig. 4.1

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.

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

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.

....

....

.... **[1]**

[Total: 10]

4 The isotopes of carbon-14 ($^{14}_{6}C$) and carbon-15 ($^{15}_{6}C$) are beta-minus emitters. The table in Fig. 5.1 shows the maximum kinetic energy of each electron emitted and the half-life of the isotope.

isotope	maximum kinetic energy / MeV	half-life
$^{14}_{6}C$	0.16	5560 years
$^{15}_{6}C$	9.8	2.3 s

Fig. 5.1

(a) State one property common to all isotopes of an element.

....

.... **[1]**

(b) The neutrons and protons inside each isotope experience fundamental forces. Name the two fundamental forces experienced by both neutrons and protons.

1. ....

2. .... **[2]**

(c) An isotope of carbon-15 decays into an isotope of nitrogen (N).

(i) Complete the nuclear reaction below.

$$^{15}_{6}C \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}N + \,^{0}_{-1}e + \bar{\nu}$$

[1]

(ii) Use the quark model to state the changes taking place within the nucleus of the carbon-15 atom.

....

.... **[1]**

(d) **(i)** Estimate the maximum speed of an electron from the nucleus of carbon-14.

speed = ... $m\,s^{-1}$ **[2]**

(ii) Suggest why the actual speed of the electron is much less than your answer in **(i)**.

....

.... **[1]**

(e) **(i)** Calculate the decay constant λ in s^{-1} of carbon-14.

λ = ... s^{-1} **[2]**

(ii) The molar mass of carbon-14 is $14\,g\,mol^{-1}$. Show that 1.0 mg of carbon-14 has 4.3×10^{19} nuclei.

[1]

(iii) Calculate the activity of the 1.0 mg mass of carbon-14.

activity = ... Bq **[2]**

(f) The isotope of carbon-14 is very useful in determining the age of a relic (e.g. ancient wooden axe) using a technique known as carbon-dating.
Describe carbon-dating and explain one of its major limitations.

....

....

....

....

....

....

....

....

....

....

.... **[4]**

[Total: 17]

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

....

....

.... **[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.

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(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]**

[Total: 8]

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