1)

(a) Deuterium (^2_1H) and tritium (^3_1H) are isotopes of hydrogen.

(i) State **two** features common to all isotopes of hydrogen.

....

....

....

.... **[1]**

(ii) Explain why the total mass of the individual nucleons of a deuterium nucleus is different from the mass of the deuterium nucleus.

....

....

....

....

....

....

.... **[3]**

(b) A fusion reaction between two nuclei is shown below.

$$^2_1H + ^3_1H \rightarrow ^4_2He + ^1_0n$$

A neutron inside a nucleus is stable. However, a 'free' neutron, when outside the nucleus, undergoes beta decay with a half-life of about 11 minutes.

(i) Complete the decay equation below for a free neutron.

$^1_0n \rightarrow$ .... $+ \; ^{0}_{-1}e \; +$ .... **[2]**

(ii) Explain what is meant by the *half-life* of a free neutron.

....

....

....

.... **[1]**

(c) For the fusion reaction to occur the separation between the deuterium and tritium nuclei must be less than 10^{-14} m. This means that the average kinetic energy of these hydrogen nuclei needs to be about 70 keV. The energy released by the fusion reaction is 18 MeV.

(i) Calculate the repulsive electrical force between the deuterium and tritium nuclei at a separation of 10^{-14} m.

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

(ii) Assume that a mixture of these hydrogen nuclei behaves as an ideal gas.

Estimate the temperature of the mixture of nuclei required for this fusion reaction.

temperature = ... K **[3]**

(iii) In practice, fusion occurs at a much lower temperature. Suggest a reason why.

....

....

....

.... **[1]**

(iv) Calculate the change in mass in a single fusion reaction.

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

(v) Fig. 3.1 shows the variation of probability of fusion reaction with temperature *T* for deuterium and tritium and for deuterium and helium.

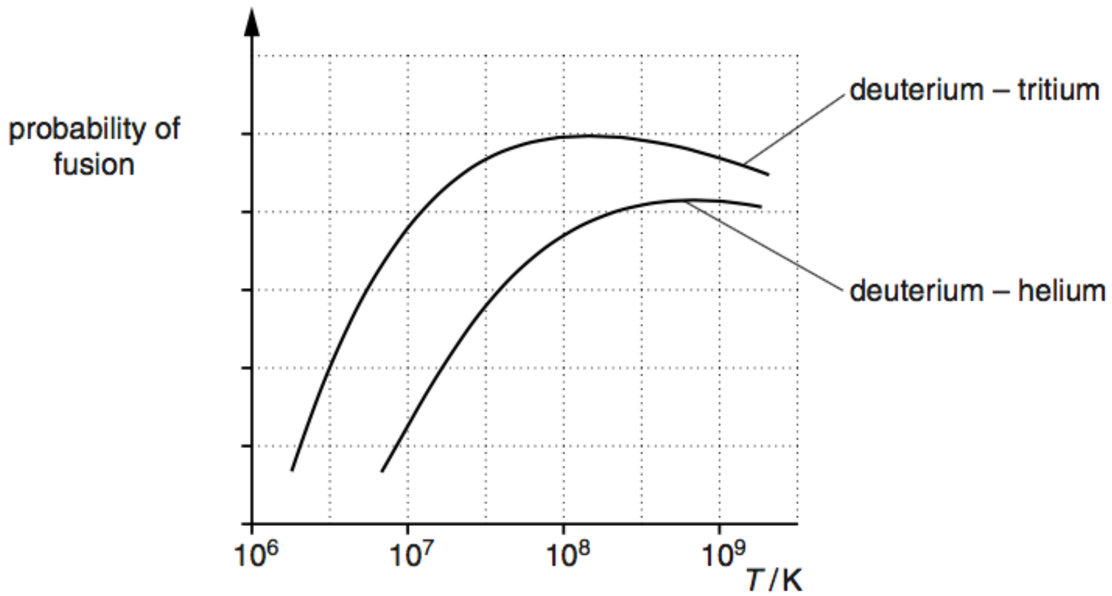

Fig. 3.1

Suggest why the probability of reaction at a given temperature is smaller for deuterium and helium.

....

....

....

....

....

.... **[2]**

[Total: 17]

2)

(a) Fig. 6.1 shows the quark composition of some particles.

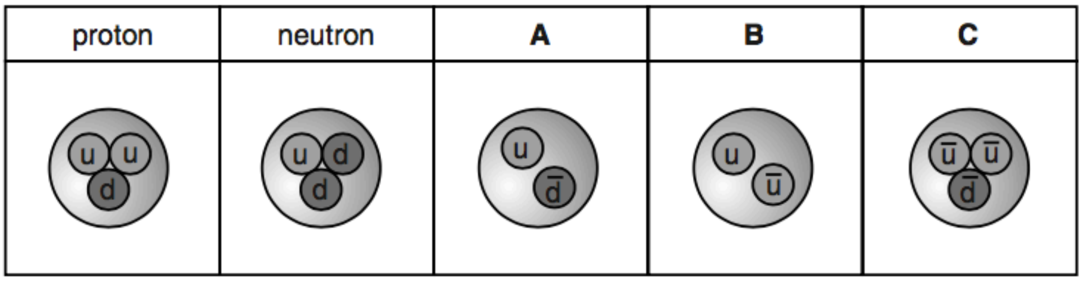

Fig. 6.1

(i) Identify the anti-proton from the table of particles shown in Fig. 6.1.

.... **[1]**

(ii) State the value of the charge of particle **B**.

.... **[1]**

(b) The nuclei of carbon-14 are produced naturally in the upper atmosphere from the reactions of slow-moving neutrons with nitrogen nuclei.

(i) The reaction below shows a nuclear reaction between a neutron and a nitrogen nucleus.

$$^{1}_{0}\text{n} + ^{14}_{7}\text{N} \rightarrow ^{14}_{6}\text{C} + \mathbf{X}$$

Identify the particle **X**.

.... **[1]**

(ii) Carbon-14 has a half-life of 5700 years. The molar mass of carbon-14 is 0.014 kg mol^{-1}. The total activity from all the carbon-14 nuclei found on the Earth is estimated to be 1.1×10^{19} Bq. Estimate the total mass of carbon-14 on the Earth.

mass = ... kg **[3]**

(c) Energy in the core of a nuclear reactor is produced by induced nuclear fission of uranium-235 nuclei. Explain what is meant by *induced nuclear fission*.

....

....

.... **[2]**

(d) Many nuclear reactors use uranium-235 as fuel. Some of these reactors use water as both coolant and moderator. The control rods contain boron-10. Fig. 6.2 shows part of the inside of the core of a nuclear reactor.

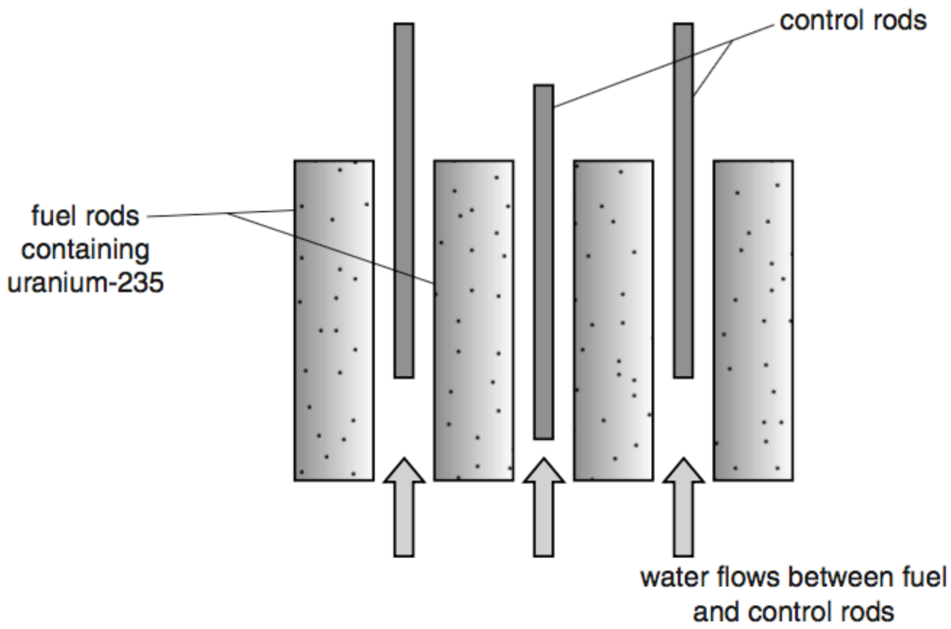

Fig. 6.2

Explain the purpose of using a moderator and control rods in the core of a nuclear reactor.

In your answer you should make clear how a moderator works at a microscopic level.

....

....

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....

....

....

....

.... **[4]**

[Total: 12]

3)

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

....

.... **[1]**

(b) The fusion of protons occurs in a star when the temperature within the core is greater than about 10^7 K. It takes the fusion of 4 protons to form a helium-4 (^4_2He) nucleus. In this process, known as the proton–proton cycle, energy is released.

The net energy released in producing a single helium-4 nucleus is 4.53×10^{-12} J.
Calculate the binding energy per nucleon of the helium-4 nucleus.

binding energy per nucleon = ... J **[1]**

(c) The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Explain why fusion of helium requires higher temperatures than the fusion of hydrogen (protons).

....

....

.... **[2]**

(d) Estimate the mean speed of helium nuclei at a temperature of 10^8 K.

mass of helium nucleus = 6.6×10^{-27} kg

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

4)

(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*.

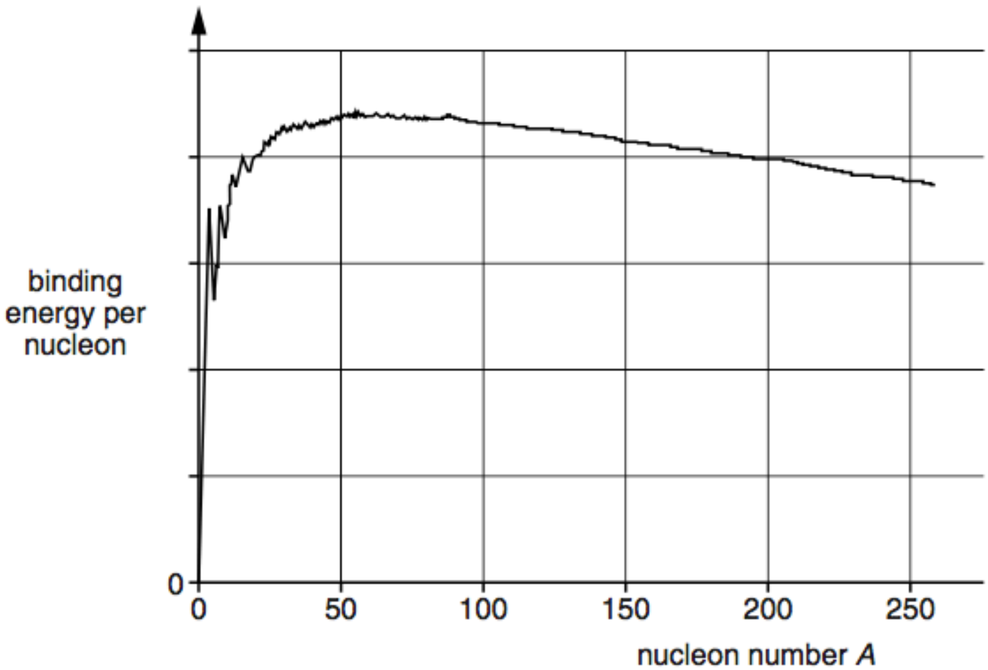

Fig. 6.1

(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**.

....

....

.... **[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]**

[Total: 10]

(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.

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

(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]**

[Total: 8]

5)

(a) Describe the process of induced nuclear fission.

....

....

....

....

.... **[2]**

(b) Explain how nuclear fission can provide energy.

....

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.... **[2]**

(c) Suggest a suitable material which can be used as a moderator in a fission reactor and explain its role.

....

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....

....

....

.... **[3]**

[Total: 7]

6)

(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]

7)

(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.

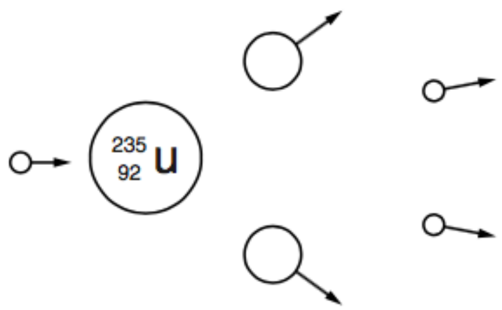

Fig. 4.1

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]