(iii) Discuss qualitatively how the photons generated as described in **(ii)** would differ from the photons generated in **(i)**. Illustrate your answer with a diagram.

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....[3]

[Total: 13]

71

This question is about the generation of energy from the fusion of deuterium and tritium.
Deuterium and tritium in the plasma state are raised to a high temperature inside the JET experimental fusion reactor.
A nucleus of deuterium ${}^{2}_{1}H$ fuses with a nucleus of tritium ${}^{3}_{1}H$ and a neutron ${}^{1}_{0}n$ is released. This neutron carries, on average, 80% of the energy generated in the fusion reaction.

data:	mass of ${}^{2}_{1}H$	2.0141 u
	mass of ${}^{3}_{1}H$	3.0160 u
	mass of ${}^{4}_{2}He$	4.0026 u
	mass of ${}^{1}_{0}n$	1.0086 u

(a) Write a nuclear equation for the fusion of a deuterium nucleus with a tritium nucleus.

....[1]

(b) Calculate how much energy in joule is released when a deuterium nucleus fuses with a tritium nucleus.

energy = ... J [4]

(c) Calculate the mean kinetic energy of the neutron emitted in this reaction.

kinetic energy = ... J [1]

(d) Explain why the neutron carries most, but not all of the energy released. State what happens to the remaining 20% of the energy released.

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....[4]

72

A certain carbon (C) nuclide and a certain oxygen (O) nuclide each decay to form the same nitrogen (N) nuclide. These two decay reactions are represented by the arrows on Fig. 5.1.

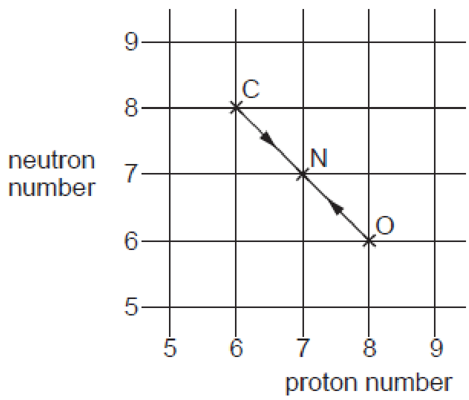

Fig. 5.1

(a) Write the symbols for the nuclei of each of these nuclides.

carbon .... oxygen .... nitrogen .... [2]

(b) Write nuclear equations for each of the decay reactions.

carbon decay ....

oxygen decay ....[2]

(c) Use your answers to **(b)** to deduce, **in their simplest form**, the quark equations which occur in these decay reactions.
Show all the steps in your deduction. Do not neglect leptons in your equations.

carbon decay

oxygen decay

[4]

(d) The axes shown in Fig. 5.2 can be used to plot a graph of the variation of nuclear mass with proton number. The nuclear mass scale does **not** start from zero.

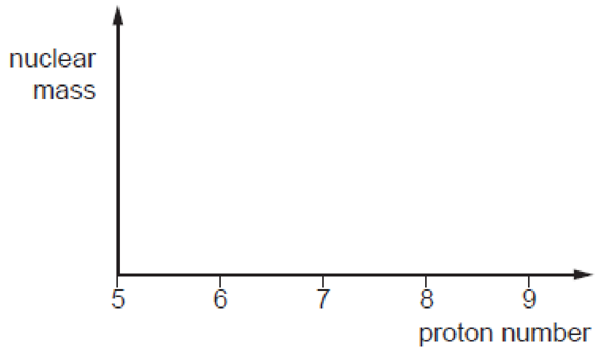

Fig. 5.2

Mark points showing possible positions for the carbon, oxygen and nitrogen nuclei, shown in Fig. 5.1, on this graph. Label your points **C**, **O** and **N** respectively.
Explain how you arrived at your answer.
Assume that the mass of the electron is negligible.

....

....

....

....[2]

[Total: 10]

73

Describe the process of uranium fission inside a nuclear power station.
Your account should include

- a description of a self-sustaining fission reaction
- the meaning and significance of thermal neutrons
- a description of the distribution of nuclides among the fission products
- the principles of the extraction of useful energy from a fission reactor.

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[12]

[Total: 12]

74

(a) In a short period at the end of the nineteenth century four radiations emitted by solid matter were discovered, namely α, β, γ and X-rays.

State and explain **two differences** between

(i) α and β-radiation

1. ....

....

....

2. ....

....

.... [4]

(ii) γ and X-radiation.

1. ....

....

....

2. ....

....

.... [4]

(b) Fig. 6.1 shows a gamma-ray detector placed 1.0 m from a pin-head source which emits uniformly in all directions. The detector registers a count of $40\,s^{-1}$. The background count is negligible.

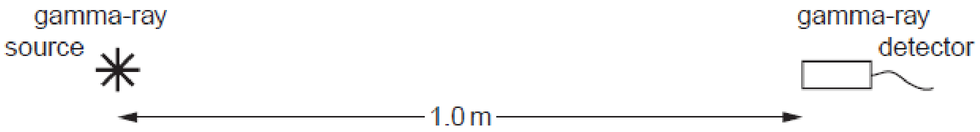

Fig. 6.1

(i) Use the inverse square law to explain why the count rate rises to $640\,s^{-1}$ when the detector is moved to 0.25 m from the source.

....

....

.... [2]

(ii) A thin lead sheet is now placed just in front of the source halving the count rate to $320\,s^{-1}$. The detector is moved from its position at 0.25 m towards the source until the count returns to $640\,s^{-1}$.

1 State the value of the count rate if the sheet is now removed.

count rate = ... s^{-1} [1]

2 Calculate the final distance of the detector from the source.

distance = ... m [2]

[Total: 13]

75

This question is about the *nuclear* and *atomic* densities of aluminium and gold.

(a) **(i)** Calculate the mass of the aluminium-27 nucleus $^{27}_{13}Al$.

You may assume that the proton and neutron each have a mass of 1.67×10^{-27} kg.

mass = ... kg [1]

(ii) Using the equation

$$r = A^{1/3} r_0$$

calculate the volume of a $^{27}_{13}Al$ nucleus.

$r_0 = 1.40 \times 10^{-15}$ m

volume = ...m^3 [3]

(iii) Show that the density of the $^{27}_{13}Al$ nucleus is about 1.5×10^{17} kg m^{-3}.

[1]

(b) State the density of the gold-197 nucleus $^{197}_{79}Au$.
Explain in terms of nuclear structure how you arrived at this value.

density = ... $kg\,m^{-3}$

....

....

....

.... [2]

(c) **(i)** The densities of aluminium and gold **metals** are:

aluminium $2.70 \times 10^3\,kg\,m^{-3}$
gold $19.3 \times 10^3\,kg\,m^{-3}$.

Show that the ratio

$$\frac{\text{mass of gold atom}}{\text{mass of aluminium atom}} \approx \frac{\text{density of gold metal}}{\text{density of aluminium metal}}.$$

State any assumption you have made.

....

....

....

.... [2]

(ii) Suggest what can be deduced from the relationship in **(i)**.

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.... [1]

[Total: 10]

76

This question is about the products of nuclear fission.

(a) Explain how *nuclear fission* differs from *radioactive nuclear decay*.

....

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.... [2]

(b) When a uranium-235 nucleus, ${}^{235}_{92}U$, is exposed to neutrons it may absorb a neutron and then undergoes fission. The percentage mass yield of the fission products varies with nucleon number as shown in Fig. 2.1.

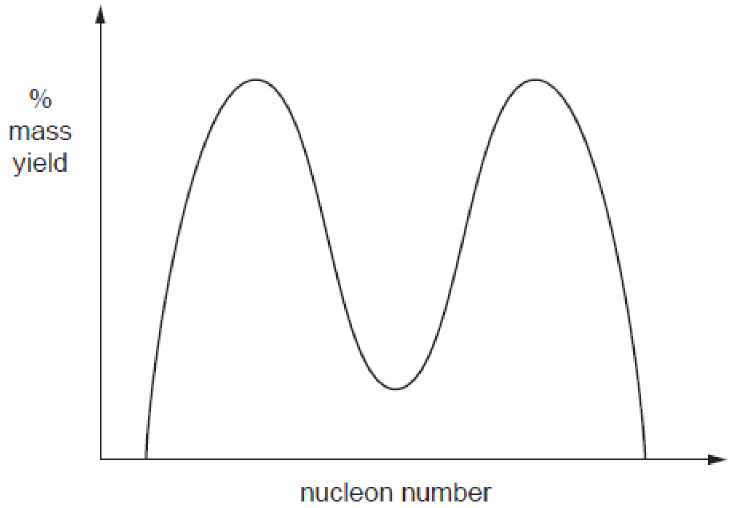

Fig. 2.1

(i) Explain why this graph is symmetrical.

....

....

....

....

.... [2]

(ii) In a few cases the fission results in the formation of two **identical** fission products.

State the proton number and nucleon number of **one** of these fission products.

Assume that no neutrons are produced in this fission reaction.

proton number = ... nucleon number = ... [1]

(c) In a particular fission reaction one of the fission products is iodine-140, $^{140}_{53}\text{I}$.

State the proton number and nucleon number of the other product of this reaction.
Assume that two neutrons are produced in this fission reaction.

proton number = ... nucleon number = ... [1]

(d) A student suggests that the iodine-140 nucleus could decay by emitting **either** a neutron **or** a β^- particle.

The following are some relevant data:

mass of	$^{140}_{53}\text{I}$	139.9019 u
mass of	$^{139}_{53}\text{I}$	138.8969 u
mass of	$^{140}_{54}\text{Xe}$	139.8919 u
mass of	$^{1}_{0}\text{n}$	1.0087 u
mass of	$^{0}_{-1}\text{e}$	0.0006 u

(i) Write a nuclear equation for each of the suggested decay reactions.

neutron emission ....

beta emission .... [3]

(ii) Explain, **without** using numerical data, why the student might expect iodine-140 to decay in these two ways.

....

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.... [2]

The relevant data given on page 7 is repeated here for your convenience:

mass of	$^{140}_{53}\mathrm{I}$	139.9019 u
mass of	$^{139}_{53}\mathrm{I}$	138.8969 u
mass of	$^{140}_{54}\mathrm{Xe}$	139.8919 u
mass of	$^{1}_{0}\mathrm{n}$	1.0087 u
mass of	$^{0}_{-1}\mathrm{e}$	0.0006 u

(iii) Use the numerical data to show whether the suggested decay reactions can actually occur.

neutron emission:

conclusion ....

....

beta emission:

conclusion ....

....

[4]

[Total: 15]

77

This question is about the possibility of fusion between two hydrogen nuclei, ${}^1_1H$, inside the Sun. Two ${}^1_1H$ nuclei approach each other along the same line, with equal kinetic energies. They will fuse if their separation becomes equal to or less than 2.0×10^{-15} m.

Fig. 3.1

(a) **(i)** Show that the potential energy E_p of two ${}^1_1H$ nuclei at a separation of 2.0×10^{-15} m is about 1×10^{-13} J. You may assume that the potential energy of two charges Q_1 and Q_2 at a separation of r is equal to

$$\frac{Q_1 Q_2}{4 \pi \varepsilon_0 r}.$$

ε_0 = permittivity of free space

[2]

(ii) The initial kinetic energy of each ${}^1_1H$ nucleus is E_k. They both come to rest at a separation of 2.0×10^{-15} m.

State the relationship between E_k and E_p.

relationship .... [1]

(iii) The mean kinetic energy, in joule, of the hydrogen nuclei in the Sun is $2.1 \times 10^{-23}\ T$, where T is the temperature of the Sun's interior.

Show that, for the mean kinetic energy to be equal to E_k, T must be more than 2.5×10^9 K.

[2]

(iv) The Sun's interior is actually at a temperature of about 1.5×10^7 K.

Explain why ${}^1_1H$ nuclei do fuse inside the Sun, even though its interior is at a much lower temperature than was deduced in **(iii)**.

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.... [2]

Fig. 3.2 shows the binding energy per nucleon of the ${}^1_1H$ and the ${}^4_2He$ nuclei, plotted on a graph grid.

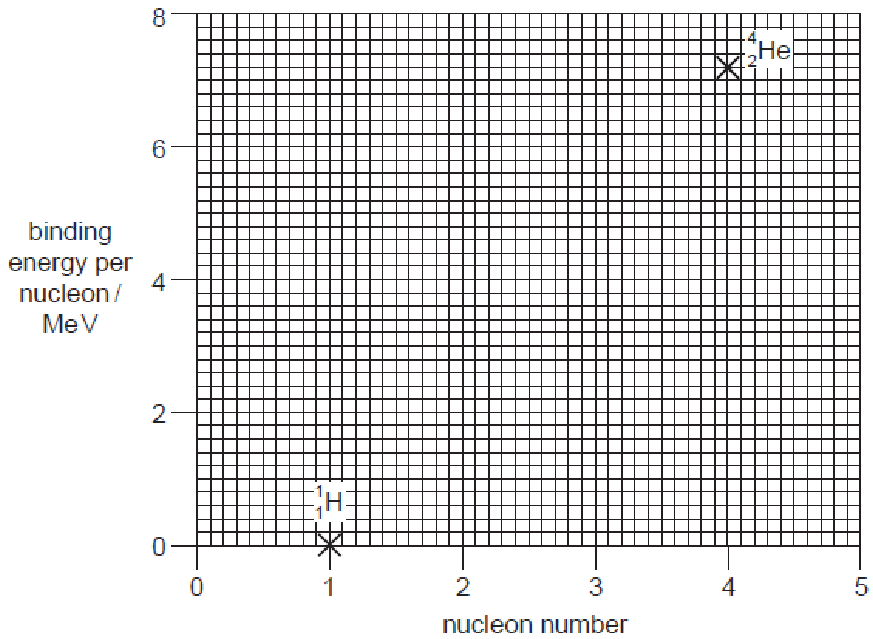

Fig. 3.2

(b) Explain why the binding energy per nucleon of the ${}^1_1H$ nucleus is zero.

....

.... [1]

(c) In the hydrogen cycle of reactions which take place inside the Sun, four $^{1}_{1}H$ nuclei fuse to form a $^{4}_{2}He$ nucleus and two positrons.

(i) Write a nuclear equation which summarises this series of reactions.

.... [1]

(ii) Calculate how much energy in joule is released when one $^{4}_{2}He$ nucleus is created by fusion.

energy = ... J [2]

[Total: 11]

78

Name and describe fully the **three** forces which act between nucleons inside a nucleus.
Your account should

- list the forces which act
- state which are long-range and which are short-range forces
- describe the way in which each force varies with particle separation
- state the relative size and importance of each force inside the nucleus
- state which type of particle experiences each type of force.

Illustrate your answer by sketching any relevant graph.

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[10]

[Total: 10]

79

(a) State the name of a group of particles which includes both the proton and the neutron.

name .... [1]

(b) Describe the stability of the proton

(i) when it is part of a nucleus

.... [1]

(ii) when it is free.

.... [1]

(c) A group of 500 neutrons are emitted simultaneously in a nuclear reaction and travel through space. Calculate how many of these neutrons will **not** have decayed after 200 s.

data: half-life of a free neutron = 613 s

number = ... [3]

(d) (i) Complete the table of Fig. 6.1 to show the charge and baryon numbers for the down quark and the neutron.

	charge	baryon number
up quark	$\frac{2}{3}$	$\frac{1}{3}$
down quark		
neutron		

[1]

Fig. 6.1

(ii) By considering the quark composition of the neutron, write **two** numerical equations to show how the charge and baryon number of the neutron are related to the charge and baryon number of its constituent quarks.

charge ....

baryon number .... [2]

[Total: 9]

80

(a) Define the terms *nuclide* and *nucleon*.

[2]

(b) Fig. 6.1 shows a small region of the chart of nucleon number against proton number. A radioactive nuclide $^{212}_{83}\mathrm{Bi}$ decays by either α or β-emission. The nucleon and proton numbers for this nuclide are plotted on the chart at the dot marked with the letter **X**.

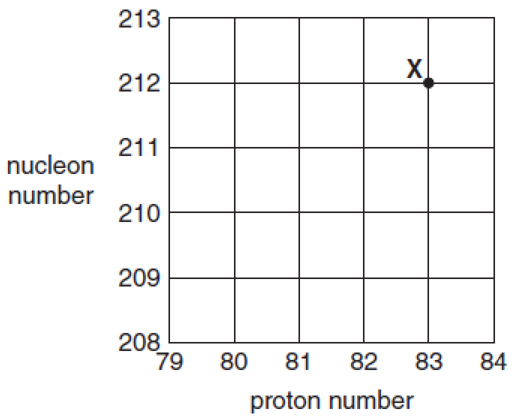

Fig. 6.1

(i) Mark with a dot and the letter **A** the position on the chart for the daughter nuclide created when $^{212}_{83}\mathrm{Bi}$ emits an α-particle. **[2]**

(ii) Mark with a dot and the letter **B** the position on the chart for the daughter nuclide created when $^{212}_{83}\mathrm{Bi}$ emits a β-particle. **[1]**

(iii) Explain why it is not possible to represent a γ-decay on this chart.

[1]

(c) **(i)** Complete the table below for the three types of ionising radiation.

radiation	range in air	range in a solid
α		0.2 mm paper
β		
γ	several km	

[2]

(ii) Describe briefly with the aid of a sketch an absorption experiment to distinguish between the three radiations listed in **(i)**.

....

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.... **[3]**

[Total: 11]

81 The radius r of a nucleus is related to the nucleon number A of the nucleus by the equation

$$r = r_0 A^{1/3}.$$

(a) Fig. 1.1 shows this relationship as a graph.

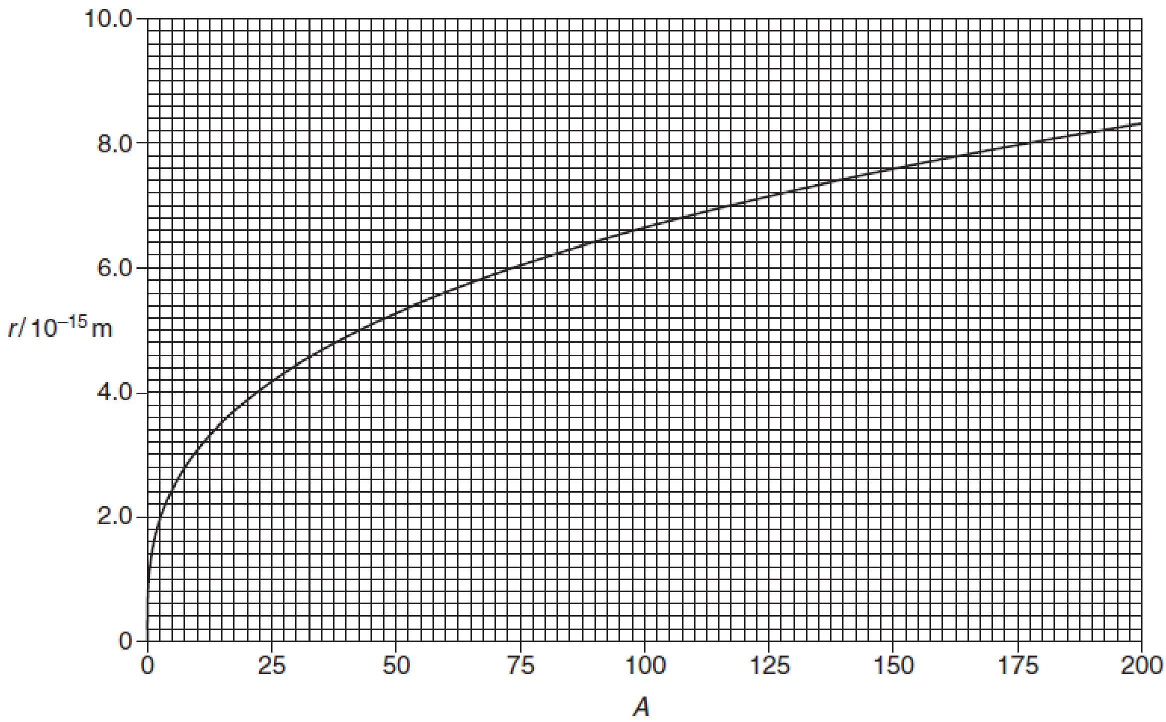

Fig. 1.1

Use information from Fig. 1.1 to calculate the value of r_0.

r_0 = ... m [2]

(b) **(i)** Show that the radius of a $^{235}_{92}U$ nucleus is about 9×10^{-15} m.

[1]

(ii) Show that the mass of a $^{235}_{92}U$ nucleus is about 4×10^{-25} kg.

Assume that proton mass = neutron mass = 1.67×10^{-27} kg.

[1]

(iii) Calculate the density of a $^{235}_{92}U$ nucleus.

density = ... $kg\,m^{-3}$ [3]

(iv) A nucleus of uranium-235 $^{235}_{92}U$ can absorb a neutron and undergo fission.

The products of a particular fission reaction are selenium-83 $^{83}_{34}Se$ and a cerium nuclide $^{X}_{Y}Ce$. A single neutron is emitted during this fission.

State the values of X and Y.

X = ... Y = ... [2]

(v) Calculate the ratio $\dfrac{\text{radius of cerium nucleus}}{\text{radius of selenium nucleus}}$.

ratio = ... [2]

(vi) Explain in words why both the selenium and the cerium nuclei have the same density as the $^{235}_{92}U$ nucleus.

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.... **[2]**

[Total: 13]

82

This question is about neutron-induced fission reactions inside a nuclear reactor and a nuclear bomb.

In a **nuclear reactor**, uranium-235 nuclei undergo fission releasing neutrons having kinetic energy of about 2 MeV. In order to be absorbed by other uranium-235 nuclei these neutrons must have as little kinetic energy as possible and are then known as *thermal neutrons*.

(a) Why is it not possible for the neutrons to lose all their energy?

....

.... **[1]**

(b) The nuclei of uranium-238 which are also present can absorb neutrons which have more than 1 MeV of energy.

(i) Describe what happens after a uranium-238 nucleus has absorbed a neutron. Your description should state any processes that occur and name any nuclides that are formed.

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.... **[2]**

(ii) Explain why it is important in nuclear reactors that the 2 MeV neutrons lose their energy **quickly**.

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.... **[2]**

(c) 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]**

(d) A **nuclear bomb** can be created by pushing together several small masses of uranium-235 to make a larger mass. The uranium-235 then becomes very unstable and an explosion occurs.

Suggest why a larger mass of uranium-235 may explode even though a smaller mass does not.

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.... **[2]**

[Total: 13]

83

This question is about choosing the most appropriate fusion reaction for generating useful energy.

(a) Use the ideas of kinetic energy and electric potential energy to explain why high temperatures are needed for fusion.

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.... **[4]**

(b) The physicists designing the JET experimental reactor had to choose the best fusion reaction.

Two fusion reactions which could be used are:

$${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} \qquad \textbf{reaction 1}$$

$${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} \qquad \textbf{reaction 2}$$

data:

nuclide	atomic mass / u
${}^{2}_{1}\mathrm{H}$	2.01410
${}^{3}_{1}\mathrm{H}$	3.01605
${}^{3}_{2}\mathrm{He}$	3.01603
${}^{4}_{2}\mathrm{He}$	4.00260
${}^{1}_{0}\mathrm{n}$	1.00866

Fig. 3.1

(i) In reaction 1 the mass defect is 0.00351 u.

Calculate the mass defect in reaction 2.

Hence explain which is the more suitable reaction for generating useful energy in the JET reactor.

mass defect = ... u

....

.... [3]

(ii) Fig. 3.1 states the masses of the **atoms** of these isotopes. Reaction 1 and reaction 2 are **nuclear** reactions.

Explain whether a more accurate answer in **(i)** could be obtained by allowing for the mass of the electrons in each atom.

....

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.... [1]

(iii) Suggest why both fusion reactions occur at about the same temperature.

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.... [2]

[Total: 10]