8 While the first nuclear explosion occurred on July 1945, when a plutonium implosion device was tested in New Mexico, it relied on nuclear fission in order to produce the explosive energy. Nuclear fusion on the other hand, is something that laboratories all around the world are still working on for the last few decades. Scientists have managed to produce working nuclear reactors which managed to combine deuterium and tritium for a short period of time. However, they have not yet succeeded in having a working nuclear reactor that is self-sustaining.

Our Sun is the nearest nuclear fusion reactor. To fuse on our Sun, nuclei need to collide with each other at very high temperatures and pressures within the core.

One of two known sets of nuclear fusion reactions by which stars convert hydrogen to helium is the proton-proton chain. It starts with the fusion of two protons into a deuteron which then goes through further reactions as shown in Fig. 8.1.

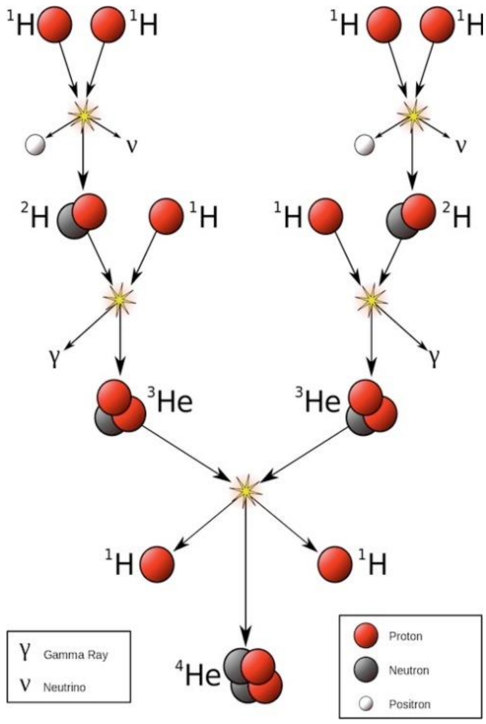

Fig. 8.1

The overall equation is as follows.

$$4{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2{}^{\;0}_{+1}\text{e}$$

Our Sun will continue to fuse hydrogen into helium via the proton-proton chain and other reactions until the amount of hydrogen in the core is depleted. Scientists have calculated that based on our Sun's luminosity of about 3.8×10^{26} W and its mass of 2.0×10^{30} kg, it has a predicted lifetime of 10 billion years. When our Sun nears the end of its lifetime, our Sun will grow into in size to become a red giant where it will be become 100 times as large in radius and 1000 times as bright in luminosity.

When our Sun becomes a red giant, it will be able to fuse helium into carbon in its core. Stars that are even more massive will be able to fuse carbon into neon, and into other heavier elements. However even the most massive stars stop fusion when they have an iron core.

(a) **(i)** State one similarity and one difference between nuclear fusion and fission.

Similarity: ……………………………………………………………………………....

……………………………………………………………………………… [1]

Difference: ……………………………………………………………………......

……………………………………………………………………………… [1]

(ii) Explain what is meant by the term self-sustaining.

…………..…………………………………………………………………………....

……………………………………………………………………………… [1]

(iii) Suggest one benefit of nuclear fusion over nuclear fission in terms of power generation.

…………..…………………………………………………………………………....

……………………………………………………………………………… [1]

(b) The passage states that nuclei need to collide with each other at very high temperatures and pressure.

Explain why the following are necessary.

(i) High temperatures

……………………………………………………………………………………....

……………………………………………………………………………………....

……………………………………………………………………………… [2]

(ii) High pressures

……………………………………………………………………………………....

……………………………………………………………………………………....

……………………………………………………………………………… [1]

(c) Given that the masses of the atomic particles involved are

m_H = 1.007825 u
m_{He} = 4.002604 u
m_e = 0.000549 u

(i) Determine the difference in mass between the reactants and products in the fusion reaction stated in the passage.

mass = ... kg [2]

(ii) Hence, determine the net energy released in the fusion of four hydrogen nuclei into one helium nuclei.

energy released = ... MeV [1]

(iii) Determine the percentage loss in mass during the fusion.

percentage loss = ... [1]

(iv) Using the mass of the Sun and its luminosity as well as your answers in part **(c)(iii)**, determine the lifespan of our Sun.

Assume that the Sun contained 100% hydrogen at the start and that its core contains 10 % of its mass. Leave your answers to the relevant number of significant figures.

lifespan = ... years [3]

(d) **(i)** In Fig. 8.2, sketch a graph for variation of binding energy per nucleon with nucleon number *A*.

State an approximate value, in MeV for the maximum binding energy per nucleon as well as the corresponding nucleon number.

Fig. 8.2

[3]

(ii) With reference to Fig. 8.2, explain why is it that even the most massive stars stop fusion when they have an iron core.

…………………………………………………………………………………………....

…………………………………………………………………………………………....

…………………………………………………………………………………………....

………………………………………………………………………………… [2]

(iii) However in our universe, it is still possible to find elements with nucleon number higher than iron. Suggest how this is possible.

…………………………………………………………………………………………....

…………………………………………………………………………………………....

………………………………………………………………………………… [1]

END OF PAPER