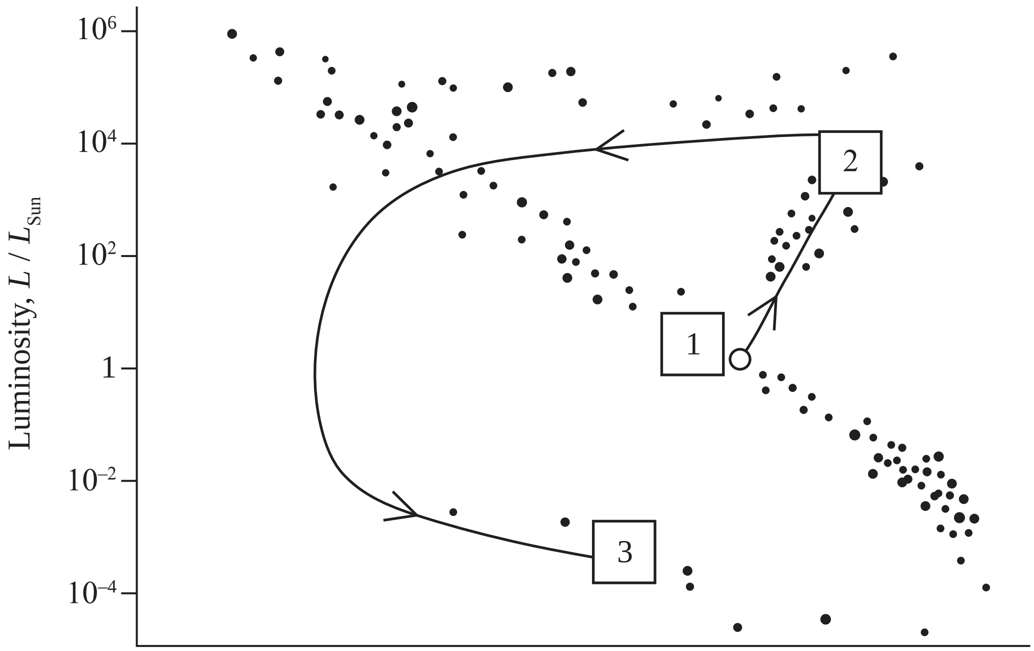
1 The Sun has a surface temperature of 5800 K and is approximately 4.5 billion years old.

The Hertzsprung-Russell diagram maps the future evolution of the Sun, from its current position in area 1 of the diagram, through to its final position in area 3 of the diagram.



(a) (i) Complete a suitable temperature scale on the x-axis.

(2)

*(ii) Use the diagram to describe the lifecycle of the Sun starting from its present position in area 1 and concluding in area 3.

(6)

(b) The energy source for the Sun is the fusion of light nuclei to heavy nuclei. In its present stage of evolution hydrogen is being converted into helium in the core of the Sun.

(i) State and explain the conditions necessary for fusion to occur in a star.

(3)

(ii) In a star the fusion of hydrogen into helium takes place in a number of stages. The final stage is:

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2 \times ^{1}_{1}H$$

Calculate the energy released in MeV when one nucleus of the normal isotope of helium is produced.

(4)

Isotope	**Mass / 10^{-27} kg**
^{3}He	5.008238
^{4}He	6.646483
^{1}H	1.673534

Energy released = MeV

(Total for Question = 15 marks)

2 In 2010 The National Ignition Facility (NIF) in California began experiments to produce viable fusion. They used an extremely powerful laser to fuse hydrogen nuclei.

The following "recipe for a small star" was found on the NIF website:

- Take a hollow, spherical, plastic capsule about 2 mm in diameter.
- Fill it with 150 μg of a mixture of deuterium and tritium, the two heavy isotopes of hydrogen.
- Take a laser that for about 15 ns can generate 500×10^{12} W.
- Focus all this laser power onto the surface of the capsule.
- Wait at least 10 ns.

Result: one miniature star.

(a) Give one similarity and one difference between the nuclei of deuterium and tritium.

(2)

Similarity ....

Difference ....

(b) Show that the energy supplied by the laser in a time period of 15 ns is about 8 MJ.

(2)

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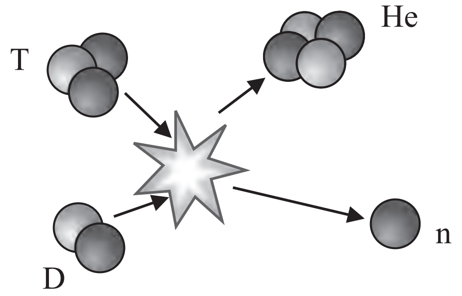
(c) The diagram represents the fusion of deuterium, D, and tritium, T, to form helium, He.



(i) Complete the nuclear equation to represent the fusion of deuterium and tritium to form helium.

(2)

$$^{\cdots}_{\cdots}\mathrm{D} + {}^{\cdots}_{\cdots}\mathrm{T} \rightarrow {}^{\cdots}_{\cdots}\mathrm{He} + {}^{\cdots}_{\cdots}\mathrm{n}$$

(ii) Use the data in the following table to show that about 20 MeV of energy is released when this fusion reaction takes place.

	Mass / MeV/c²
Neutron	939.6
Deuterium	1875.6
Tritium	2808.9
Helium	3727.4

(2)

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(iii) Estimate the number of fusions that need to take place in 15 ns if the “miniature star” is to produce the same amount of energy as the laser supplies.

(2)

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Number of fusions ....

(iv) Calculate the kinetic energy, in MeV, of the neutron released by the fusion of deuterium and tritium nuclei. Assume that the net momentum of the nuclei before fusion is zero.

(4)

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Neutron kinetic energy .... MeV

(d) Nuclear power stations currently use the process of fission to release energy. Outline the process of fission.

(3)

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(Total for Question 17 marks)

3 Fission and fusion are both nuclear processes that release energy. About 20% of the UK's energy need is currently provided by the controlled fission of uranium. Intensive research continues to harness the energy released from the fusion of hydrogen.

(a) (i) Fission of uranium-235 takes place after the absorption of a thermal neutron. Assume such neutrons behave as an ideal gas at a temperature of 310 K.

Show that the square root of the mean square speed of the neutrons is about 3000 m s^{-1}.

mass of neutron = 1.0087u

(3)

(ii) Complete the equation for the fission of uranium-235.

(2)

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{\cdots\cdots}_{92}\text{U} \rightarrow ^{138}_{\cdots\cdots}\text{Cs} + ^{96}_{37}\text{Rb} + \cdots\cdots\ ^{1}_{0}\text{n}$$

(iii) Calculate the energy released in a single fission. Hence determine the rate of fission necessary to maintain a power output of 2.5 GW.

Mass / u	
^{235}U	235.0439
^{138}Cs	137.9110
^{96}Rb	95.9343

(4)

Fission rate =

(b) *(i) State the conditions for fusion and hence explain why it has proved difficult to maintain a sustainable reaction in a practical fusion reactor.

(4)

(ii) The nuclear reaction below represents the fusion of two deuterium nuclei. Complete the equation and identify particle X.

(1)

$$ {}^{2}_{1}\mathrm{D} + {}^{2}_{1}\mathrm{D} \rightarrow {}^{3}_{1}\mathrm{H} + {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{X} $$

Particle X is a

(iii) Despite the difficulties, the quest for a practical fusion reactor continues.

State **two** advantages fusion power might have over fission power.

(2)

1

2

(Total for Question = 16 marks)

4 Ionisation smoke detectors contain a small amount of the radioactive isotope americium. ^{241}Am is an α-emitter. It has a half-life of 432 years, and the activity from the source in a new smoke detector is about 3.5×10^4 Bq.

(a) Explain why the radiation produced by a smoke detector does not pose a health hazard.

(1)

(b) (i) Complete the nuclear equation for the decay of americium.

(2)

$$^{241}\text{Am} \rightarrow {}_{93}\text{Np} + \alpha$$

(ii) Using data from the table, calculate the energy, in MeV, of α-particles released when a nucleus of americium-241 undergoes alpha decay.

(3)

Nuclide	**Mass/u**
Am	241.056 822
Np	237.048 166
α-particle	4.002 603

Energy = MeV

(c) An ionisation smoke detector is sold with the guarantee that it "lasts a lifetime". Comment on the appropriateness of this guarantee, based on its use of americium-241.

(1)

(Total for Question = 7 marks)