1 Positron emission tomography (PET) is a nuclear medicine imaging technique. Pairs of gamma rays, produced when positrons from a radioisotope annihilate with electrons, are detected to form the image.

Radioisotopes used in PET scanning are typically isotopes with short half-lives such as carbon-11. Carbon-11 has a half-life of 1220 s and decays by positron emission to stable boron-11. Positrons are the antiparticles to electrons.

(a) Explain what is meant by a radioactive atom.

(2)

(b) Complete the equation for the decay of carbon-11.

$$^{11}_{6}\mathrm{C} \longrightarrow \quad \mathrm{B} + \quad \mathrm{e}^{+} + {}^{0}_{0}\nu_{\mathrm{e}}$$

(2)

(c) Calculate the energy in joules released in a positron decay of carbon-11.

	Mass / MeV/c^2
positron	0.511
carbon	10 253.6
boron	10 252.2

(3)

Energy = J

(d) Explain why carbon-11 is a relatively safe radioisotope to use within the body.

(2)

(e) A patient was injected intravenously with a radioactive compound containing carbon-11 with an activity of 1.58×10^6 Bq.

The sample was prepared 3600 s before it was administered to the patient.

Calculate the activity of the sample when it was prepared.

(4)

Activity of the sample =

(Total for Question = 13 marks)

2 Tritium is an isotope of hydrogen which can be produced in the upper atmosphere by the bombardment of nitrogen with neutrons produced from cosmic rays.

(a) Complete the nuclear equation for the production of tritium

(2)

$$^{14}\text{N} + \quad \text{n} \rightarrow \quad {}_{6}\text{C} + {}^{3}_{1}\text{H}$$

(b) Tritium can be used to date water samples that are less than about 75 years old, as tritium is radioactive with a half-life of 12.3 years. 1 m^3 of water collected in 2015 from an underground pool of water was measured to have a corrected activity of 1.08 Bq.

(i) State why the activity must be corrected.

(1)

(ii) State how the accuracy of the activity obtained for 1 m^3 of water could be improved.

(1)

(iii) Calculate what the corrected activity of 1 m^3 of water from the same pool would have been in 1950. No further water has been added to the pool since 1950.

(4)

Corrected activity =

(c) Tritium is used in nuclear fusion experiments. A large amount of energy is released in its reaction with deuterium.

$$^{3}H + ^{2}H \rightarrow ^{4}He + n$$

Nucleus	Mass / u
n	1.0087
^{2}H	2.0136
^{3}H	3.0155
^{4}He	4.0015

(i) Calculate the energy, in J, released when a tritium nucleus undergoes fusion with a deuterium nucleus.

(4)

Energy released = J

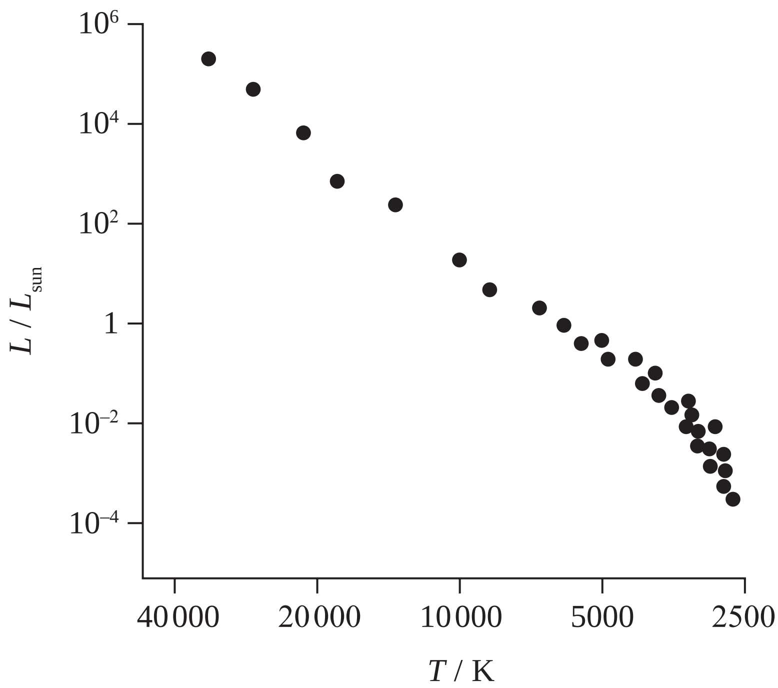
(ii) Explain the conditions necessary for a nuclear fusion experiment to maintain a continuous power output.

(2)

(Total for Question = 14 marks)

3 The Hertzsprung-Russell (H-R) diagram is a plot of luminosity against temperature for a range of stars.

(a) The H-R diagram below shows a number of main sequence stars.



(i) Label the position of our Sun on the diagram.

(1)

(ii) Label on the diagram the regions in which white dwarf and red giant stars would be located.

(2)

*(iii) Stars known as white dwarf stars have small surface areas. Explain how astronomers have deduced this.

(3)

(b) Most stars lie on the main sequence. In the early 20th century, it was thought that the main sequence represented different evolutionary stages of stars. According to this model, stars form with a high temperature and luminosity and so are located in the top left of the main sequence. As stars radiated energy they would move down the main sequence over time.

Scientists were unaware of fusion in the core of stars providing the energy for the star to shine.

Using this obsolete model explain why, in the absence of fusion, the luminosity of the star would decrease over time.

(3)

(c) In 1939 Hans Bethe published a paper describing the fusion processes in stars.

In the proton-proton cycle, hydrogen is converted to helium in stages. The nuclear equation below represents one of the stages.

$$^{7}_{3}\text{Li} + \quad \text{X} \rightarrow 2 \times {}^{4}_{2}\text{He}$$

(i) Complete the equation and identify X.

(2)

X is

(ii) Calculate, in joules, the energy emitted in this stage of the cycle.

(3)

	Mass / MeV/c^2
Proton	938.3
Neutron	939.6
Helium	3727.4
Lithium	6533.8

Energy = J

(d) In 1967 Bethe received a Nobel Prize in Physics for his work on understanding the fusion processes in stars.

Explain why sustainable fusion has not yet been achieved for the generation of electrical power.

(4)

(Total for Question = 18 marks)