1 The radioactive isotope carbon-14 undergoes decay with a half-life of 5730 years. While an organism is living, it takes in carbon from the atmosphere and the ratio of carbon-14 to the stable isotope carbon-12 in the organism is constant. After death the ratio changes, as the carbon-14 continues to decay but no more carbon is taken in. This is the basis of radiocarbon dating.

Archaeologists have used radiocarbon dating to pinpoint the date of construction of Stonehenge, an ancient stone circle in south west England. The archaeologists unearthed dead organic material from under the stones and sent a sample of it to Oxford University for analysis. Scientists at the university determined that the ratio of carbon-14 to carbon-12 in the sample was only 60% of that found in living organisms.

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

(2)

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(b) Radioactive decay is a random process. Explain what this means.

(2)

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(c) Calculate the decay constant of carbon-14 and hence the time since Stonehenge was constructed.

(6)

Time .....

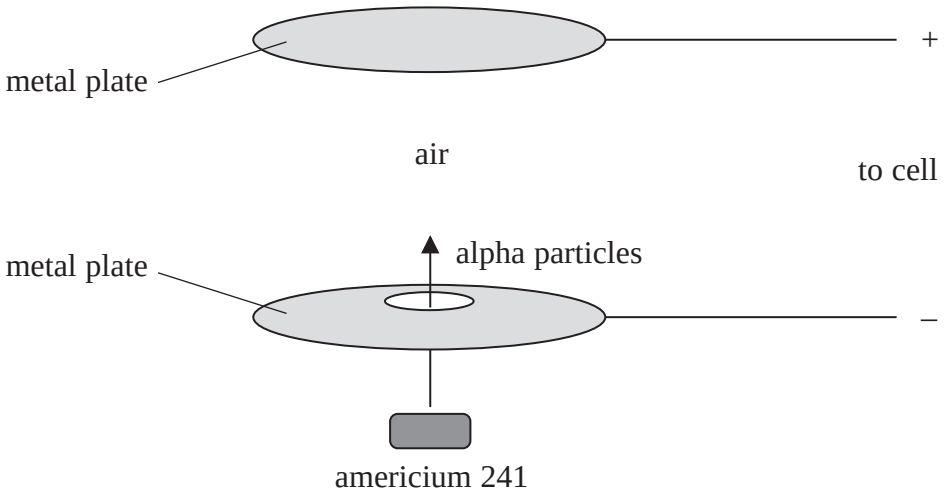
(d) The rate of production of carbon-14 in the atmosphere has decreased since Stonehenge was constructed. Explain how this would affect the scientists' calculations of when Stonehenge was constructed.

(3)

(Total for Question 13 marks)

2 Some types of smoke detector contain a radioactive isotope of americium, ^{241}Am. The nuclei of ^{241}Am decay by emitting an alpha particle.

The diagram shows part of a smoke detector.
The detectors use a small amount of ^{241}Am to make the air between two metal plates conduct charge.



(a) (i) Explain why a stream of alpha particles will cause charge to flow between the metal plates.

(2)

(ii) Suggest how smoke particles entering the space between the plates will cause the current to decrease.

(1)

(b) (i) The decay of ^{241}Am is said to be random and spontaneous.
State what is meant by random and spontaneous.

(2)

Random

Spontaneous

(ii) Complete the equation for the decay of ^{241}Am.

(2)

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

(Total for Question = 7 marks)

3 Radioactive isotopes are often used as markers, so that chemical substances can be traced around the body. In one medical procedure tritium is used as a means of studying protein absorption by the intestine.

A patient was given a sample containing the tritium to drink and then monitored. The initial activity of the sample was 3450 Bq.

Tritium is a beta-emitter with a half-life of 3.89×10^8 s.

(a) State what is meant by the activity of a radioactive source.

(1)

(b) Show that the decay constant of the tritium is about 1.8×10^{-9} s^{-1} and hence calculate the number of tritium nuclei in the initial sample.

(3)

Number of nuclei =

(c) (i) Show that the time taken for the activity of the sample to fall to 10% of its initial value is about 40 years.

(3)

(ii) Comment on the time given in (c) (i).

(1)

(Total for Question = 8 marks)

4 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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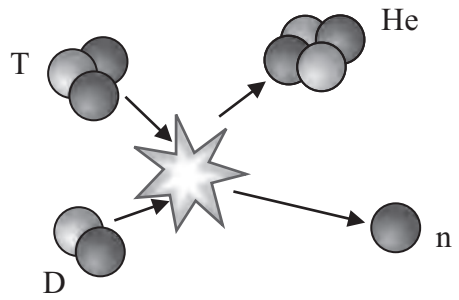
(c) The diagram represents the fusion of deuterium, D, and tritium, T, to form helium, He.



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

(2)

$$\_\_D + \_\_T \rightarrow \_\_He + \_\_n$$

(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/c^2
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)

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)

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)