Radiation QP1

1 Radioisotopes are often used for medical applications. ^{131}I is a β^--emitter, and can be used to treat an overactive thyroid gland. When a small dose of ^{131}I is swallowed, it is absorbed into the bloodstream. It is then concentrated in the thyroid gland, where it begins destroying the gland's cells.

(a) Patients are advised that radiation detection devices used at airports may detect increased radiation levels up to 3 months after the treatment. Explain how it is possible for the activity of the ^{131}I to be detected outside the body.

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(b) (i) The half-life of ^{131}I is 8 days. What fraction of the original number of iodine atoms will have decayed after a period of 24 days?

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Fraction = ...

(ii) Doctors wish to prescribe a sample of ^{131}I of activity 1.5 MBq. The sample is prepared exactly 24 hours before it is due to be swallowed by the patient. Calculate the activity that the sample should have when it is prepared.

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Activity = ... MBq

(Total for Question 1 = 7 marks)

2 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.

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

(2)

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

(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

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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.

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(Total for Question 2 = 7 marks)

3 In September 1987, two youngsters in Brazil removed a stainless steel cylinder from a machine in an abandoned clinic. Five days later they sold the cylinder to a scrap dealer who prised open a platinum capsule inside to reveal a glowing blue powder. The powder was found to contain caesium-137 and had an activity of 5.2×10^{13} Bq.

Caesium-137 is a β^--emitter with a half-life of 30 years.

*(a) Discuss the dangers to the youngsters of possessing this cylinder for 5 days.

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(b) Complete the equation to represent the decay of caesium-137 into barium.

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$$^{137}_{55}\text{Cs} \rightarrow \,^{\cdots}_{\cdots}\text{Ba} + \,^{\cdots}_{\cdots}\beta^-$$

(c) (i) The decay of caesium into barium is a random process. Why is the decay process described as random?

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(ii) Show that the decay constant for the caesium-137 is about 7×10^{-10} s^{-1}.

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(d) In September 2007, 20 years after the cylinder was removed from the machine, the substance was still highly radioactive. Calculate the number of caesium-137 atoms remaining in the powder.

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Number = ...

(e) Caesium-137 is one of the products from the nuclear fission of uranium-235 in a nuclear reactor.

(i) Complete the equation for this reaction and show the number of neutrons released.

(1)

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{137}_{55}\mathrm{Cs} + ^{95}_{\dots}\mathrm{Rb} + \dots ^{1}_{0}\mathrm{n}$$

(ii) Explain the significance to the operation of the reactor of the number of neutrons emitted in each fission.

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(Total for Question 3 = 15 marks)

4 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)**

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

(2)

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

(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

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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.

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

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

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.

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(Total for Question 4 = 16 marks)

5 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.

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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 5 = 13 marks)

6 In a demonstration to her class, a teacher pours popcorn kernels onto a hot surface and waits for them to pop. The kernels pop one by one. There is a large rate of popping at first and this rate decreases as time goes on. However, the order in which the kernels pop cannot be predicted.

*(a) How realistic is this demonstration as an analogy to radioactive decay? Consider aspects of the demonstration that are similar to radioactive decay and aspects that are different.

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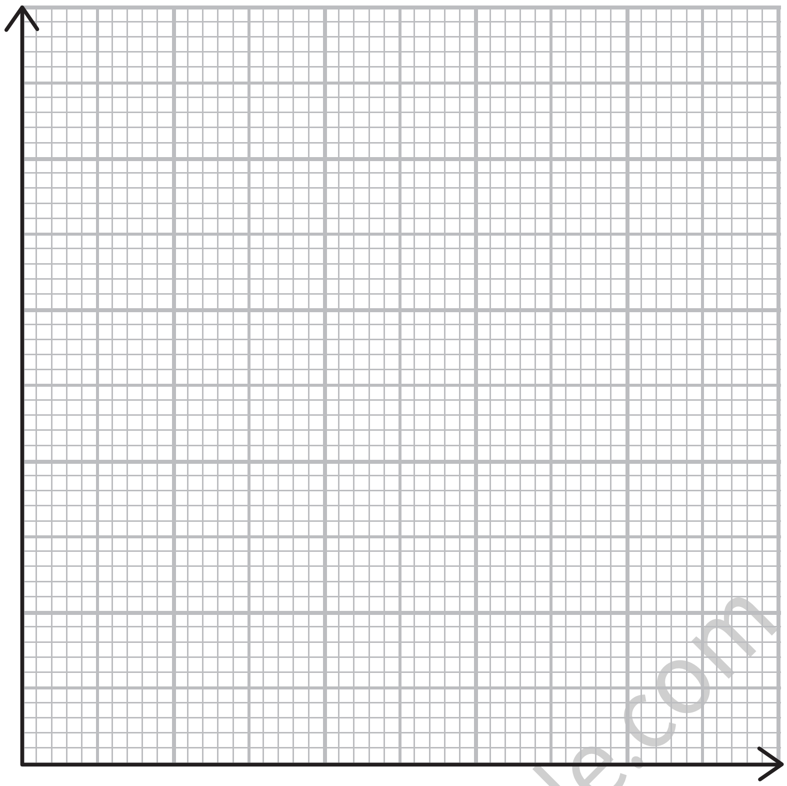
(b) In another demonstration, bags of popcorn are placed in a microwave oven for different lengths of time. Initially, each bag contains the same number of kernels. Once the bags are removed from the oven they are opened and the number of unpopped kernels counted. Assume that the popcorn obeys a similar rule to radioactive decay.

The results from the demonstration are shown in the table:

Time in oven / s	**Number of unpopped kernels, *N***	**ln (*N*)**
0	100	4.61
30	78	4.36
60	61	4.11
90	47	3.85
120	37	3.61
150	29	3.37

(i) Use the data to draw a graph to show that the half-life of this process is about 80 s.

(6)



Half-life of popcorn = ...

(ii) A bag of popcorn is placed in the microwave oven until three quarters of the kernels have popped.

Determine the time for which the bag is in the oven.

(1)

Time = ...

(Total for Question 6 = 11 marks)

7 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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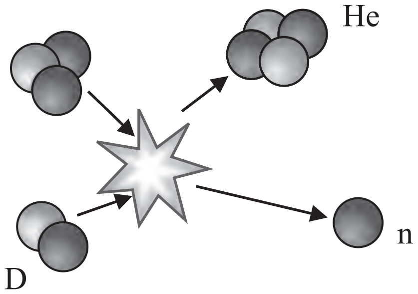
(c) The diagram represents the fusion of deuterium, D, and tritium, T, to form helium, He.



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

(2)

$$\underset{\dots}{\overset{\dots}{}}D + \underset{\dots}{\overset{\dots}{}}T \rightarrow \underset{\dots}{\overset{\dots}{}}He + \underset{\dots}{\overset{\dots}{}}n$$

(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

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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.

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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.

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(Total for Question 7 = 17 marks)