1 On 1st November 2006, the former Russian spy Alexander Litvinenko fell ill. Twenty one days later he died from the radiation effects of polonium-210. Experts suggest that as little as 0.89 μg of polonium-210 would be enough to kill, although Mr Litvinenko's death was linked to a much larger dose of the radioactive isotope. Traces of the isotope were later found in washrooms at five locations around London visited by the Russian.

Polonium-210 has a half life of 138 days.

(a) (i) In a 0.89 μg sample of polonium-210 there are 2.54×10^{15} atoms of polonium. Show that the decay constant for polonium-210 is about 6×10^{-8} s^{-1}, and hence calculate the activity of a sample of this size.

(4)

Activity =

(ii) Calculate the fraction of polonium-210 nuclei that have decayed after a time of 21 days.

(3)

Fraction decayed =

(b) Polonium-210 emits alpha particles. Explain why polonium-210 is virtually harmless unless it is taken into the body.

(2)

(c) (i) Complete the equation below for the decay of polonium.

(2)

$$^{210}_{84}\text{Po} \rightarrow \quad \text{Pb} + \quad \alpha$$

(ii) State why the Pb nuclei would recoil from the alpha particles emitted during the decay.

(1)

(d) Radioactive decay is said to occur spontaneously and randomly. Explain what is meant by spontaneous and random in this context.

(2)

Spontaneous

Random

(e) Suggest why traces of the isotope were found in locations visited by the Russian.

(2)

(Total for Question = 16 marks)

2 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.

(4)

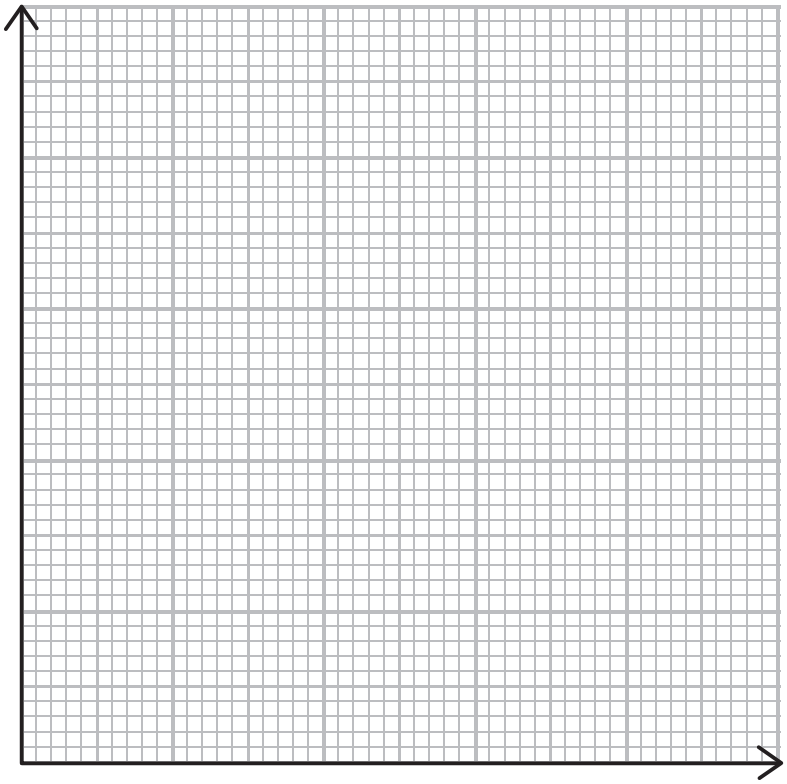
(b) In another demonstration, bags of popcorn are placed in a microwave oven for different lengths of time. Initially, each bag contains the same number of kernels. Once the bags are removed from the oven they are opened and the number of unpopped kernels counted. Assume that the popcorn obeys a similar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



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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 11 marks)

3 Polonium-210 is an alpha-emitter with a half-life of 138 days. It emits alpha particles of energy 5.3 MeV as it decays to a stable isotope of lead.

One small pellet of polonium-210 contains 1.3×10^{21} atoms.

(a) (i) Show that the initial activity of this polonium pellet is about 8×10^{13} Bq.

(3)

(ii) Hence show that the rate of energy release by the pellet is more than 60 W.

(3)

(b) The radius of the pellet is 2.25 mm and its equilibrium temperature would be about 1000 K.

(i) Assuming that 5% of the energy released is radiated away, show that this approximate value of temperature is correct.

(3)

(ii) Calculate the wavelength at which peak energy radiation occurs.

(2)

Wavelength of peak energy radiation =

(iii) State the region of the electromagnetic spectrum in which this wavelength of radiation would be found.

(1)

(c) Explain why very small quantities of polonium-210 are a health hazard only if taken into the body.

(2)

(Total for Question = 14 marks)

4 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.

(2)

(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?

(2)

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.

(3)

Activity = MBq

(Total for Question = 7 marks)

5 All living organisms contain ^{12}C and radioactive ^{14}C. The concentration of ^{14}C in the organism is maintained whilst the organism is alive, but starts to fall once death has occurred.

(a) The count rate obtained from wood from an old Viking ship is 14.7 min^{-1} per gram of wood, after being corrected for background radiation. The corrected count rate from similar living wood is 16.5 min^{-1} per gram of wood.

Calculate the age of the ship in years.

^{14}C has a half life of 5700 years.

(4)

Age of ship ..... years

(b) The concentration of ^{14}C in living organisms might have been greater in the past.

Explain how this would affect the age that you have calculated.

(2)

(Total for Question 6 marks)