Q1. An ancient sealed flask contains a liquid, assumed to be water. An archaeologist asks a scientist to determine the volume of liquid in the flask without opening the flask. The scientist decides to use a radioactive isotope of sodium ($^{24}_{11}Na$) that decays with a half-life of 14.8 h.

(a) She first mixes a compound that contains 3.0×10^{-10} g of sodium-24 with 1500 cm^3 of water. She then injects 15 cm^3 of the solution into the flask through the seal. Show that initially about 7.5×10^{10} atoms of sodium-24 are injected into the flask.

(1)

(b) Show that the initial activity of the solution that is injected into the flask is about 1×10^6 Bq.

activity = _____Bq

(3)

(c) She waits for 3.5 h to allow the injected solution to mix thoroughly with the liquid in the flask. She then extracts 15 cm^3 of the liquid from the flask and measures its activity which is found to be 3600 Bq.

Calculate the total activity of the sodium-24 in the flask after 3.5 h and hence determine the volume of liquid in the flask.

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(3)

(d) The archaeologist obtained an estimate of the volume knowing that similar empty flasks have an average mass of 1.5 kg and that mass of the flask and liquid was 5.2 kg. Compare the estimate that the archaeologist could obtain from these masses with the volume calculated in part 4.3 and account for any difference.

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(2)
(Total 9 marks)

Q2. Which of the following best describes the decay constant for a radioisotope?

A The reciprocal of the half-life of the radioisotope. ⬭

B The rate of decay of the radioisotope. ⬭

C The constant of proportionality which links half-life to the rate of decay of nuclei. ⬭

D The constant of proportionality which links rate of decay to the number of undecayed nuclei. ⬭

(Total 1 mark)

Q3. After 64 days the activity of a radioactive nuclide has fallen to one sixteenth of its original value. The half-life of the radioactive nuclide is

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A 2 days. ⬭

B 4 days. ⬭

C 8 days. ⬭

D 16 days. ⬭

(Total 1 mark)

Q4. The carbon content of living trees includes a small proportion of carbon-14, which is a radioactive isotope. After a tree dies, the proportion of carbon-14 in it decreases due to radioactive decay.

(a) (i) The half-life of carbon-14 is 5740 years.
Calculate the radioactive decay constant in yr^{-1} of carbon-14.

decay constant ..... yr^{-1}

(1)

(ii) A piece of wood taken from an axe handle found on an archaeological site has 0.375 times as many carbon-14 atoms as an equal mass of living wood.
Calculate the age of the axe handle in years.

age ..... yr

(3)

(b) Suggest why the method of carbon dating is likely to be unreliable if a sample is:

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(i) less than 200 years old,

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(ii) more than 60 000 years old.

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(2)
(Total 6 marks)

Q5. The isotope of uranium, $^{238}_{92}U$, decays into a stable isotope of lead, $^{206}_{82}Pb$, by means of a series of α and β^- decays.

(a) In this series of decays, α decay occurs 8 times and β^- decay occurs *n* times. Calculate *n*.

answer = ...

(1)

(b) (i) Explain what is meant by the binding energy of a nucleus.

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(2)

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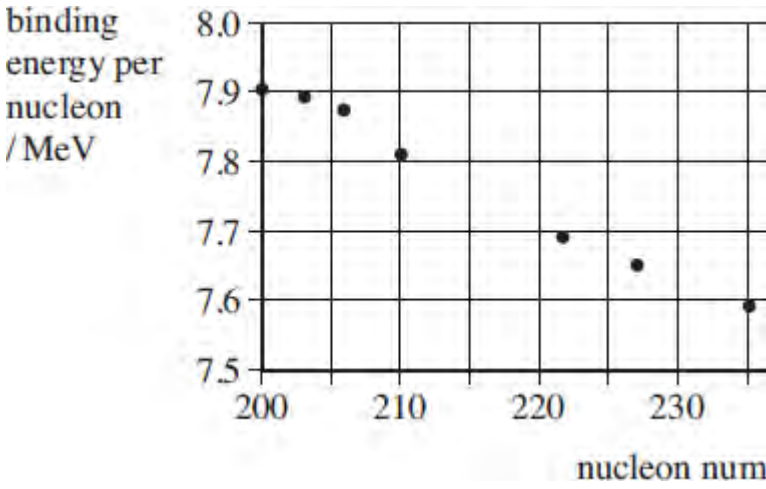
(ii) **Figure 1** shows the binding energy per nucleon for some stable nuclides.

Figure 1



Use **Figure 1** to estimate the binding energy, in MeV, of the $^{206}_{82}Pb$ nucleus.

answer = ... MeV

(1)

(c) The half-life of $^{238}_{92}U$ is 4.5×10^{9} years, which is much larger than all the other half-lives of the decays in the series.

A rock sample when formed originally contained 3.0×10^{22} atoms of $^{238}_{92}U$ and no $^{206}_{82}Pb$ atoms.

At any given time most of the atoms are either $^{238}_{92}U$ or $^{206}_{82}Pb$ with a negligible number of atoms in other forms in the decay series.

(i) Sketch on **Figure 2** graphs to show how the number of $^{238}_{92}U$ atoms and the number of $^{206}_{82}Pb$ atoms in the rock sample vary over a period of 1.0×10^{10} years from its formation.
Label your graphs U and Pb.

Figure 2

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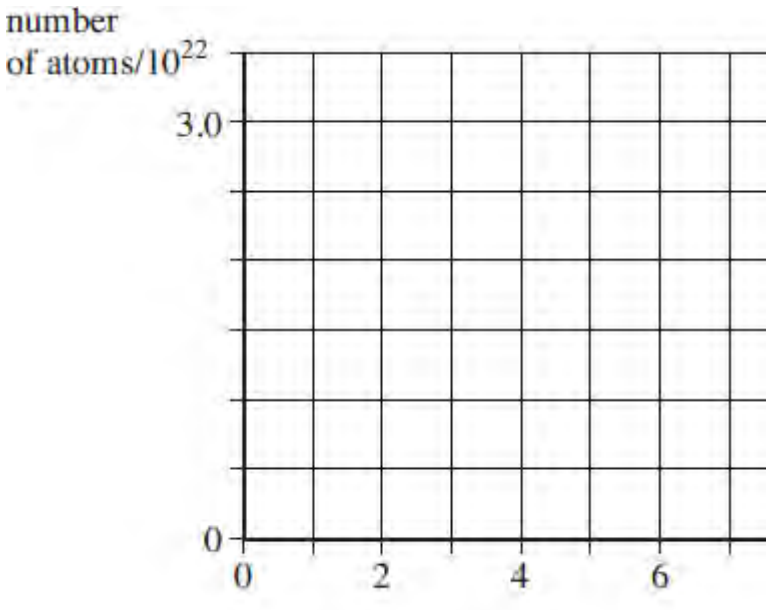

(2)

(ii) A certain time, *t*, after its formation the sample contained twice as many $^{238}_{92}U$ atoms as $^{206}_{82}Pb$ atoms.

Show that the number of $^{238}_{92}U$ atoms in the rock sample at time *t* was 2.0×10^{22}.

(1)

(ii) Calculate *t* in years.

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answer = ... years

(3)

(Total 10 marks)

Q6. Complete the following equation showing the β^+ decay of carbon-11.

$$^{11}_{6}\mathrm{C} \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{B} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{+} + {}^{\cdots\cdots}_{\cdots\cdots}\ \cdots\cdots$$

(Total 3 marks)

Q7. A nuclide of manganese $(^{52}_{25}\mathrm{Mn})$ undergoes beta$^+$ decay to form a nuclide of chromium (Cr).

(a) Complete the equation for this decay process.

$$^{52}_{25}\mathrm{Mn} \rightarrow {}^{\cdots\cdots}_{24}\mathrm{Cr} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{+} + {}^{\cdots\cdots}_{\cdots\cdots}$$

(2)

(b) State the name of the exchange particle involved in this beta$^+$ decay.

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(1)

(Total 3 marks)

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Q8. Radioisotope thermoelectric generators (RTGs) are electrical generators powered by radioactive decay. As a radioisotope decays some of the energy released is converted into electricity by means of devices called thermocouples. In this way RTGs have been used as power sources in satellites, space probes and heart pacemakers.

The Cassini space probe was launched in 1997. It carried three RTGs each containing 11 kg of a nuclear fuel, plutonium oxide (a compound having two oxygen atoms combined with every plutonium-238 atom). In 1997, when the probe was launched, the power released from one gram of plutonium oxide was 500 mW.

Plutonium-238 $^{238}_{94}Pu$ is an alpha emitter, decaying into uranium(U).
The half-life of the decay is 87.7 years.

mass of one mol of plutonium-238 = 238 g
mass of one mol of oxygen atoms = 16 g

(a) State and explain why environmentalists might have been concerned by the use of such a large quantity of plutonium-238.

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(2)

(b) State and explain whether the activity of a given number of atoms of plutonium is affected when they are in the form of plutonium oxide.

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(2)

(c) (i) Calculate the decay constant, in s^{-1}, for plutonium-238.

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decay constant ..... s^{-1}

(2)

(ii) Calculate the number of plutonium-238 atoms in the total mass of the plutonium oxide in the Cassini probe at the beginning of its mission.

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number of plutonium-238 atoms .....

(5)

(iii) Calculate the initial activity of the plutonium-238 in the Cassini probe. Give a suitable unit for your answer.

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initial activity of plutonium-238 ..... unit .....

(3)

(d) (i) Write a nuclear equation for the $\left({}^{238}_{94}\mathrm{Pu}\right)$ decay.

.....

(2)

(ii) Assume the power released by the RTGs' fuel originated as the kinetic energy

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of the alpha particles emitted in the decay of $\left({}^{238}_{94}\mathrm{Pu}\right)$.

Calculate the maximum kinetic energy of each alpha particle.

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kinetic energy of alpha particle ..... J

(4)
(Total 20 marks)

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