Radioactivity

1.

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.

[1 mark]

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

(a) (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.

[3 marks]

age ..... yr

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

[2 marks]

(b) (i) less than 200 years old,

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(b) (ii) more than 60 000 years old.

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2.

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 mark)

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

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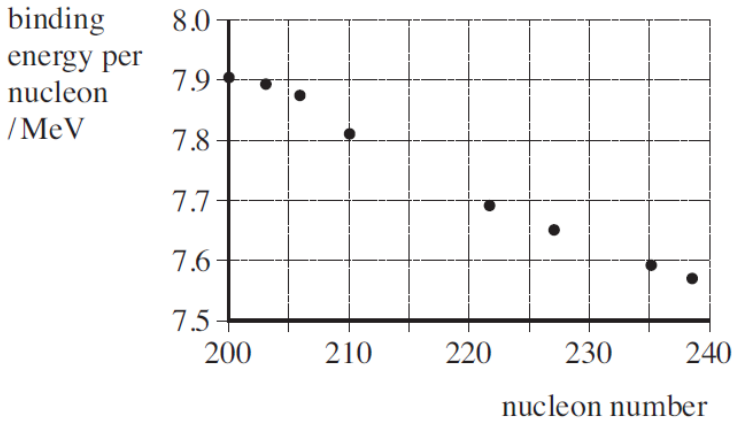
(2 marks)

(b) (ii) **Figure 2** shows the binding energy per nucleon for some stable nuclides.

Figure 2



Use **Figure 2** to estimate the binding energy, in MeV, of the $^{206}_{82}Pb$ nucleus.

answer = ... MeV

(1 mark)

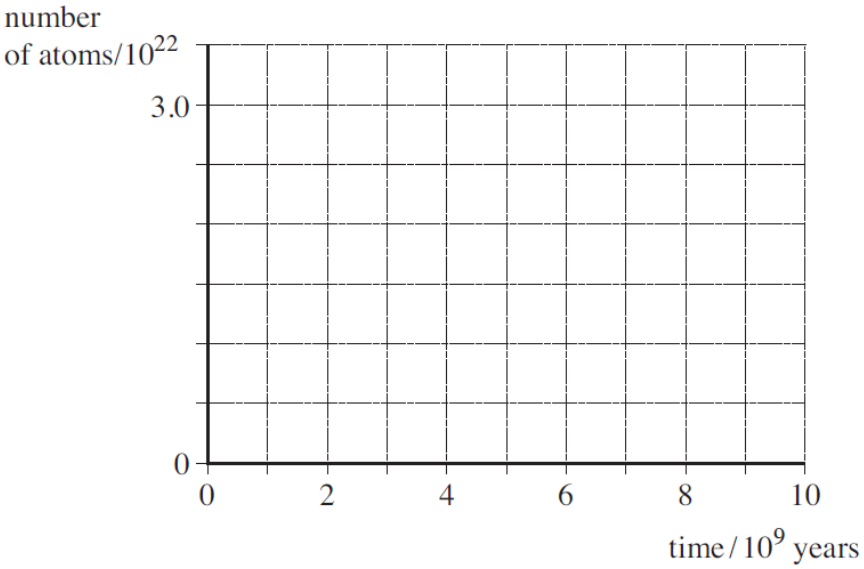
(c) The half-life of $^{238}_{92}U$ is 4.5×10^9 years, which is much larger than all the other half-lives of the decays in the series.

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.

(c) (i) Sketch on **Figure 3** 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 3



(2 marks)

(c) (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 mark)

(c) (iii) Calculate t in years.

answer = ... years
(3 marks)

3.

The radioactive radium nuclide $^{226}_{88}Ra$ decays by alpha-particle emission to an isotope of radon Rn with a half-life of 1600 years.

(a) State the number of

(i) neutrons in a radium nucleus .....[1]

(ii) protons in the radon nucleus resulting from the decay .....[1]

(b) The historic unit of radioactivity is called the curie and is defined as the number of disintegrations per second from 1.0 g of $^{226}_{88}Ra$. Show that

(i) the decay constant of the radium nuclide is $1.4 \times 10^{-11}\,s^{-1}$

1 year = 3.16×10^{7} s

[1]

(ii) 1 curie equals 3.7×10^{10} Bq.

[3]

(c) Use the data below to show that the energy release in the decay of a single nucleus of $^{226}_{88}Ra$ by alpha-particle emission is 7.9×10^{-13} J.

nuclear mass of Ra-226 = 226.0254 u
nuclear mass of Rn-222 = 222.0175 u
nuclear mass of He = 4.0026 u

[3]

(d) Estimate the time it would take a freshly made sample of radium of mass 1.0 g to increase its temperature by 1.0 °C. Assume that 80% of the energy of the alpha-particles is absorbed within the sample so that this is the energy which is heating the sample. Use data from **(b)** and **(c)**.

specific heat capacity of radium = 110 J kg^{-1} K^{-1}

time = ... s [4]

4.

(a)

The nuclei of carbon-14 are produced naturally in the upper atmosphere from the reactions of slow-moving neutrons with nitrogen nuclei.

(i) The reaction below shows a nuclear reaction between a neutron and a nitrogen nucleus.

$$^{1}_{0}n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + \mathbf{X}$$

Identify the particle **X**.

..... **[1]**

(ii) Carbon-14 has a half-life of 5700 years. The molar mass of carbon-14 is $0.014\,kg\,mol^{-1}$. The total activity from all the carbon-14 nuclei found on the Earth is estimated to be 1.1×10^{19} Bq. Estimate the total mass of carbon-14 on the Earth.

mass = ... kg **[3]**

(b)

Energy in the core of a nuclear reactor is produced by induced nuclear fission of uranium-235 nuclei. Explain what is meant by *induced nuclear fission*.

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..... **[2]**

(c)

Many nuclear reactors use uranium-235 as fuel. Some of these reactors use water as both coolant and moderator. The control rods contain boron-10. Fig. 6.2 shows part of the inside of the core of a nuclear reactor.

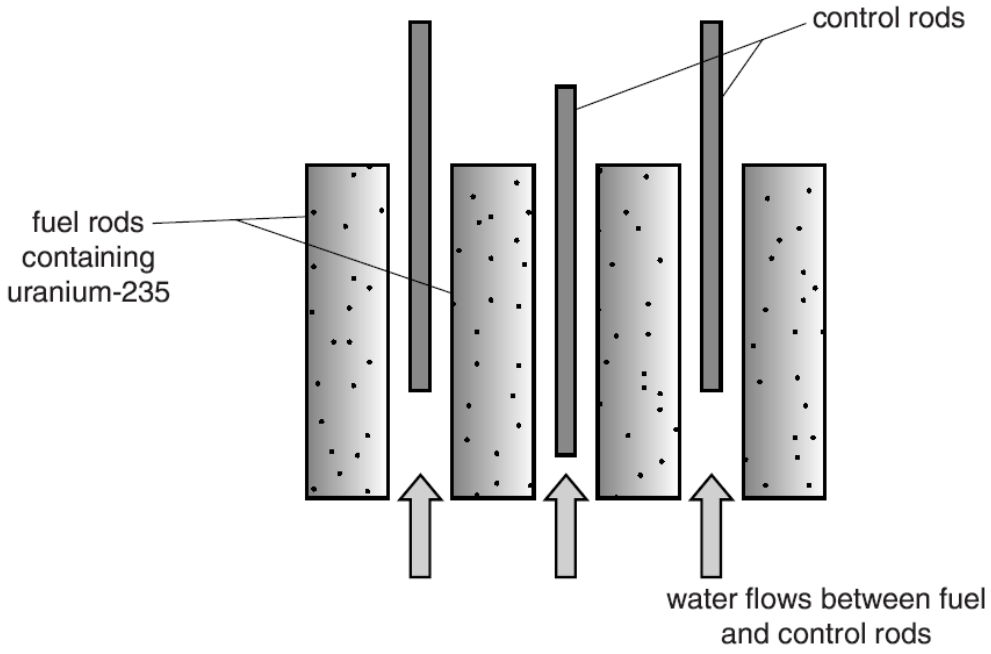

Fig. 6.2

Explain the purpose of using a moderator and control rods in the core of a nuclear reactor.

In your answer you should make clear how a moderator works at a microscopic level.

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..... **[4]**