Radiation QP2

1 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 1 = 6 marks)

2 Electrical power generated by nuclear fission makes an important contribution to world energy needs. However Rutherford, who is credited with the discovery and first splitting of the nuclear atom, later said:

"The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine."

Rutherford carried out experiments that involved firing alpha particles at nitrogen atoms.

(a) (i) Complete the equation for the interaction between nitrogen and alpha particles. **(1)**

$$^{14}_{7}N + ^{4}_{2}\alpha \rightarrow ^{\dots}_{\dots}O + ^{1}_{\dots}p$$

(ii) This interaction requires a small energy input. Other similar nuclear reactions may give an energy output of no more than 20 MeV, giving some justification to Rutherford's statement. Suggest why Rutherford's statement eventually turned out to be very inaccurate.

(1)

....

....

....

(b) Uranium-235 is able to undergo fission when it absorbs a neutron to become uranium-236. The equation below shows a possible fission reaction.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3 \times ^{1}_{0}n$$

Use the data in the table to show that the energy released by the fission of one uranium nucleus is about 170 MeV.

Isotope	**Mass / 10^{-27} kg**
^{235}U	390.29989
^{141}Ba	233.99404
^{92}Kr	152.64708
^{1}n	1.67493

(4)

....

....

....

....

....

....

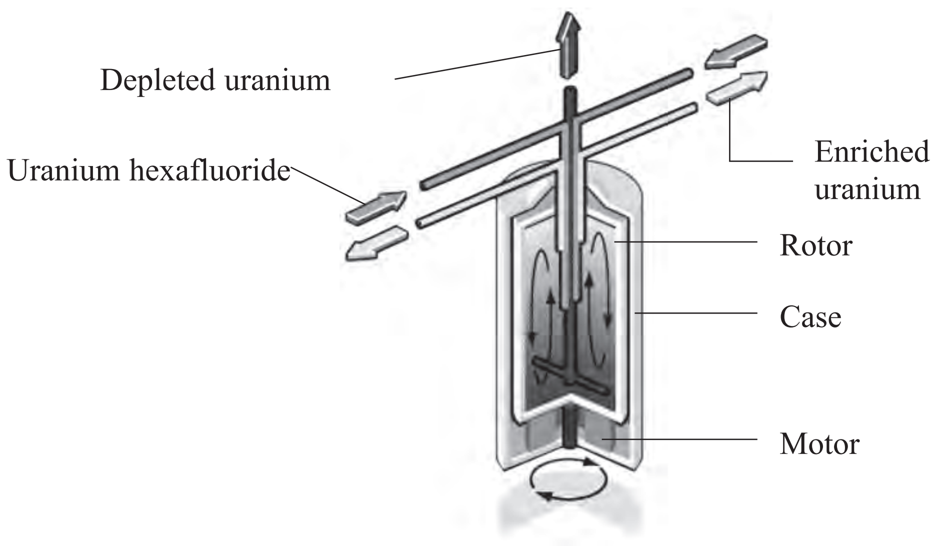
....

....

(c) Naturally occurring uranium is more than 99% uranium-238. Fuel for a fission reactor requires at least 3% of the uranium to be uranium-235.

Uranium hexafluoride gas is used during the uranium enrichment process. It is fed into a centrifuge, and a rotating cylinder (rotor) sends the uranium-238 to the outside of the cylinder, where it can be drawn off, while the uranium-235 diffuses to the centre of the cylinder.

Gas centrifuge



(i) Give **one** similarity and **one** difference between the nuclei of uranium-238 and uranium-235.

(2)

Similarity ....

Difference ....

(ii) The rotor has a diameter of 30 cm and spins at a rate of 60,000 revolutions per minute.

Calculate the centripetal acceleration at the rim of the rotor.

(2)

....

....

....

....

Centripetal acceleration = ...

(iii) The rotor is subjected to huge forces because of the high spin rate.

Give **two** mechanical properties essential for the material from which the rotor is made.

(2)

Property 1 ....

Property 2 ....

(d) The waste heat from some power stations is transferred to water.

The San Onofre Nuclear Generating Station in California has reactors with a total output power of 2200 MW. These reactors circulate sea water at an average mass flow rate of 7.0×10^4 kg s^{-1}. The water is heated to approximately 11 K above the input temperature as it flows through condensers, before being discharged back into the ocean.

Show that the rate at which energy is removed from the reactors is about 3000 MW, and hence estimate a value for the efficiency of the electrical power generation process.

specific heat capacity of the sea water = 3990 J kg^{-1} K^{-1}

(4)

....

....

....

....

....

....

....

....

....

....

Efficiency = ...

(Total for Question 2 = 16 marks)

3 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)

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

(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 3 = 16 marks)

4 Positron emission tomography (PET) is a nuclear medicine imaging technique. Pairs of gamma rays, produced when positrons from a radioisotope annihilate with electrons, are detected to form the image.

Radioisotopes used in PET scanning are typically isotopes with short half-lives such as carbon-11. Carbon-11 has a half-life of 1220 s and decays by positron emission to stable boron-11. Positrons are the antiparticles to electrons.

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

(2)

....

....

....

....

(b) Complete the equation for the decay of carbon-11.

$$^{11}_{6}\text{C} \rightarrow \;^{\dots}_{\dots}\text{B} + \;^{\dots}_{\dots}\text{e}^{+} + \;^{0}_{0}\nu_{e}$$

(2)

(c) Calculate the energy in joules released in a positron decay of carbon-11.

	Mass / MeV/c^2
positron	0.511
carbon	10 253.6
boron	10 252.2

(3)

....

....

....

....

....

Energy = ... J

(d) Explain why carbon-11 is a relatively safe radioisotope to use within the body.

(2)

....

....

....

....

(e) A patient was injected intravenously with a radioactive compound containing carbon-11 with an activity of 1.58×10^6 Bq.

The sample was prepared 3600 s before it was administered to the patient.

Calculate the activity of the sample when it was prepared.

(4)

....

....

....

....

....

....

....

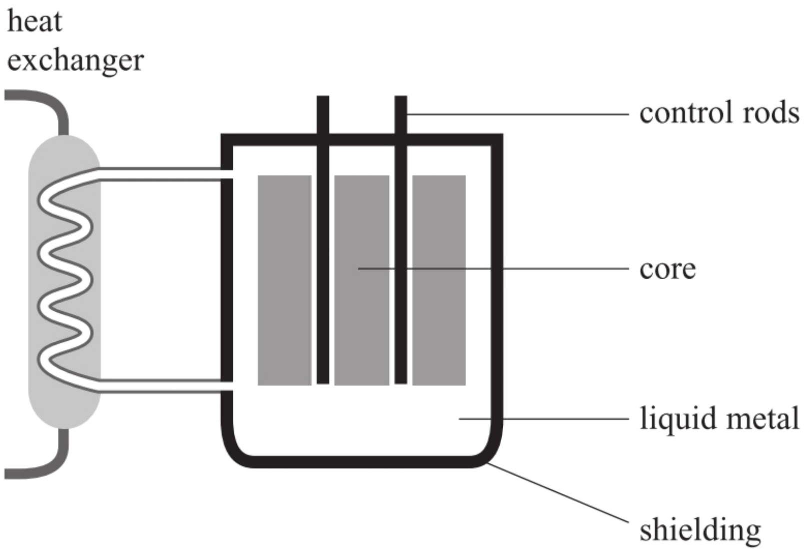
....

....

Activity of the sample = ...

(Total for Question 4 = 13 marks)

5 In one type of fission reactor the coolant is a liquid metal alloy of sodium and potassium. The sodium absorbs neutrons from the reactor core and becomes the isotope sodium-24. Sodium-24 emits both beta and gamma radiation.



*(a) State what is meant by nuclear fission and explain why energy is released during the fission of a nucleus such as uranium.

(3)

....

....

....

....

....

....

....

....

....

(b) A sample of coolant from the reactor contains 1.2×10^{13} nuclei of sodium-24.

Calculate the activity of this sample when it is first removed from the reactor.

decay constant of sodium-24 = $1.3 \times 10^{-5}\ s^{-1}$

(2)

....

....

....

....

Activity = ...

(c) Shielding is placed around the core of the reactor.

State **one** physical property this shielding must have and name the material that is usually used.

(2)

Property..

Material..

(d) Many governments are funding research into replacing fission reactors with fusion reactors. Suggest why.

(2)

....

....

....

....

(Total for Question = 9 marks)

6 The element polonium was discovered by Marie and Pierre Curie in 1898 whilst they were investigating the radioactive substance pitchblende. Polonium is an unstable element and decays by alpha emission.

(a) The decay of polonium is said to be random and spontaneous.

Explain what is meant by a decay that is

(i) random

(1)

....

....

(ii) spontaneous.

(1)

....

....

(b) A particular isotope of polonium decays to lead.

(i) Complete the nuclear equation representing this decay.

(2)

$$^{\cdots}_{84}\text{Po} \rightarrow {}^{206}_{\cdots}\text{Pb} + {}^{4}_{\cdots}\alpha$$

(ii) In this decay the α-particle is emitted with a kinetic energy of 8.50×10^{-13} J.

Show that the initial speed of the α-particle is about 2×10^{7} m s^{-1}.

alpha particle mass = 6.64×10^{-27} kg

(2)

....

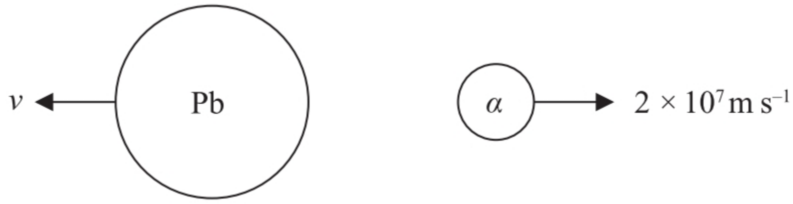
....

....

....

....

(iii) The diagram shows the products of this decay.



(1) Explain why the lead nucleus recoils during the decay.

(2)

....

....

....

....

....

(2) Calculate the speed at which the lead nucleus begins to recoil.

(2)

....

....

....

....

....

Speed = ...

(iv) Explain why most of the energy released in this decay is transferred to the alpha particle.

(2)

....

....

....

....

(c) Polonium has been used as an energy source for thermoelectric cells.

This isotope of polonium has a decay constant of 5.0×10^{-3} day^{-1}. A sample of polonium, with mass 0.50 g, releases energy at a rate of about 70 W.

(i) The activity of the sample is 8.1×10^{7} MBq and the α-particle is emitted with a kinetic energy of 8.50×10^{-13} J.

Show that this sample releases energy at a rate of about 70 W.

(2)

....

....

....

....

(ii) This sample of polonium would **not** be suitable to provide energy for a period of several years.

Explain why, using a calculation in your answer.

(3)

....

....

....

....

....

(Total for Question = 17 marks)