Name: ____

Topic 11: Nuclear Radiation Part 2

Date:

Time:

Total marks available:

Total marks achieved: ______

Questions

Q1.

An old type of camping lamp used a 'gas mantle'. The gas mantle is heated by the gas flame on the lamp and emits a bright white light. Gas mantles used to contain thorium-230.

Thorium-230 decays by alpha emission to form an isotope of radium. A student keeps a radioactive gas mantle in a sealed polythene bag. The student suggests that over a period of a year a significant volume of helium gas will be collected, since an alpha particle is a helium nucleus.

A particular gas mantle contains 5.18×10^{-5} g of thorium-230.

(i) Show that the activity of the thorium-230 in the mantle is about 4.0×10^4 Bq.

230 g of thorium-230 contains 6.02×10^{23} atoms

half-life of thorium-230 = 75 400 years

number of seconds in 1 year = 3.15×10^7

(4)

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(ii) Determine the volume of helium gas that could be collected in a year as a result of alpha emission.

Assume that the temperature is 22.0 °C and the pressure is 1.00×10^5 Pa.

(4)

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Volume = ...

(iii) Calculate the root mean square speed of the atoms in the helium gas at a temperature of 22.0 °C.

(3)

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Root mean square speed = ...

(Total for question = 11 marks)

Q2.

When a photographic film that is not exposed to light is placed near to a source of ionising radiation the film darkens.

(a) (i) State what is meant by ionising radiation.

(1)

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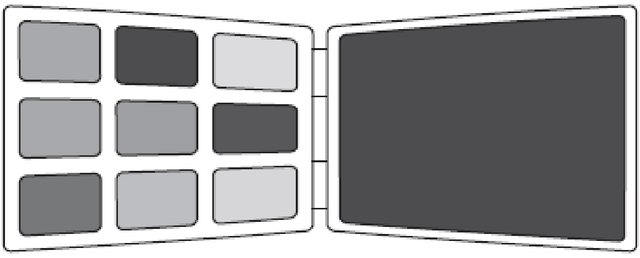
(ii) Complete the table to show α, β, and γ radiations in order of increasing ionising power.

(1)

Least ionising	⟶	Most ionising

(b) In a physics lesson some students are learning about the use of a film badge to monitor exposure to ionising radiation.

Each absorber window is made from a different material and the type of radiation can be determined from the extent to which the film is darkened.



The students are asked to predict what would happen if α, β, and γ radiations were incident upon absorber windows made from paper, aluminium and lead.

(i) Complete the table to show the penetration of α, β, and γ radiations through each material.

Use the words "passes through" or "stopped".

(3)

	Paper	**0.5 cm aluminium**	**0.5 cm lead**
α radiation		stopped	
β radiation			stopped
γ radiation	passes through		

(ii) In a nuclear power plant there may be other radiation present which would **not** be detected by a film badge.

Suggest what type of radiation this is and why it would not be detected by a film badge.

(2)

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(Total for question = 7 marks)

Q3.

The ionising properties of radiations determine their penetrating power.

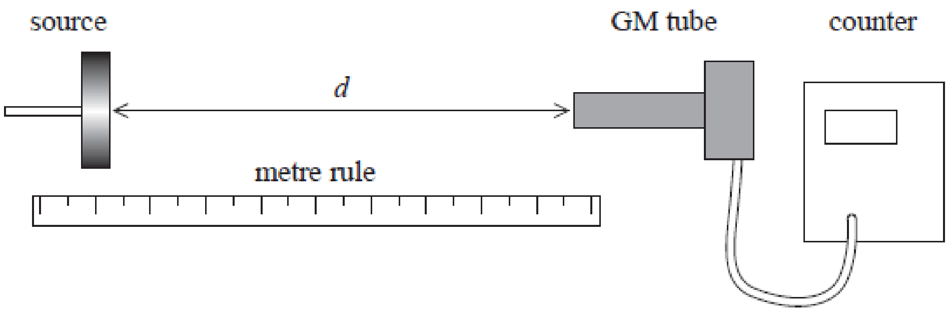
Which of the following statements is correct?

- ☒ **A** α-particles are not very ionising so they are stopped by thin paper.
- ☒ **B** α-particles are very ionising so can only travel a few centimetres in air
- ☒ **C** γ-radiation is very penetrating because it is very ionising
- ☒ **D** γ-radiation is not very penetrating because it is very ionising

(Total for question = 1 marks)

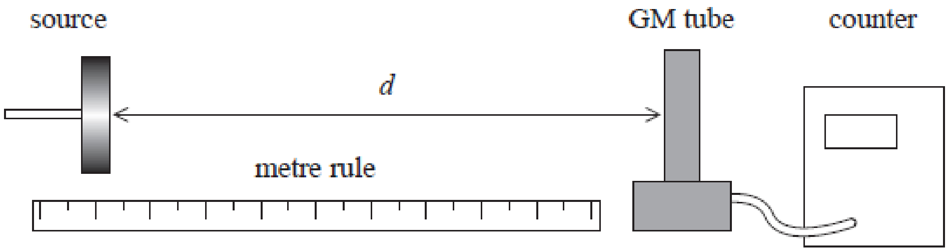
Q4.

A student investigated the way in which gamma radiation spreads out from a source.
He placed a cobalt-60 source in a source holder and set up a Geiger-Müller (GM) tube a short distance *d* away. He connected the GM tube to a counter as shown.



The student recorded the count for 2 minutes.

His teacher turned the GM tube through 90° so that the side of the tube faced the source as shown below.



(i) Explain why this arrangement could lead to more accurate data.

(2)

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(ii) Explain another modification to the experimental method which would improve the accuracy of the data.

(2)

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(Total for question = 4 marks)

Q5.

State what is meant by binding energy.

(2)

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(Total for question = 2 marks)

Q6.

The radium isotope $^{226}_{88}\text{Ra}$ is unstable and undergoes a series of α and β^- emissions until a stable isotope of lead $^{206}_{82}\text{Pb}$ is formed.

Which of the following nuclear equations correctly shows the number of α and β^- emissions?

☒ **A** 226 88Ra → 206 82Pb + 3α + 8β⁻

☒ **B** 226 88Ra → 206 82Pb + 4α + 5β⁻

☒ **C** 226 88Ra → 206 82Pb + 5α + $4\beta^-$

☒ **D** 226 88Ra → 206 82Pb + 5α + $6\beta^-$

(Total for question = 1 mark)

Q7. 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)

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Activity = ...

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

(3)

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Fraction decayed = ...

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

(2)

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(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)

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

(2)

Spontaneous

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Random

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

(2)

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(Total for Question = 16 marks)

Q8.

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)

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(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)

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Energy = ... J

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

(2)

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(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)

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Activity of the sample = ...

(Total for Question = 13 marks)

Q9.

The fuel used in a nuclear fission reactor is uranium.
Which of the following is required for fission to proceed?

☒ **A** Neutrons must be removed from the reactor core.

☒ **B** The reactor core must be very hot.

☒ **C** The uranium nuclei must absorb neutrons.

☒ **D** The uranium nuclei must absorb protons.

(Total for question = 1 mark)

Q10.

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)

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

(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)

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(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

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

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)

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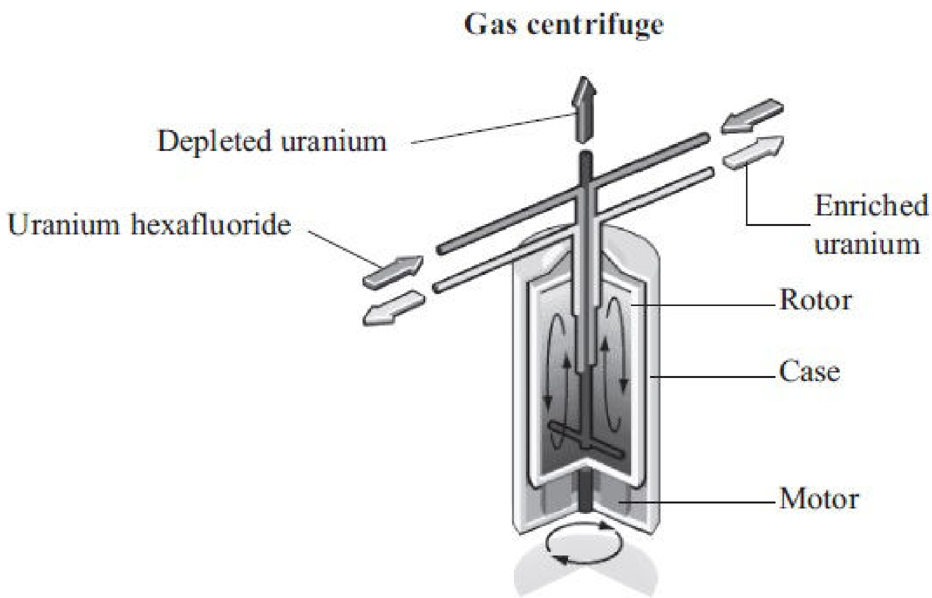
(c) Naturally occurring uranium is more than 99% uranium-238. Fuel for a fission reactor requires at least 3% of the uranium to be uranium-235.

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 center of the cylinder.



(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 motor.

(2)

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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 transfered 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)

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Efficiency = ...

(Total for question = 16 marks)

Q11.

* The energy radiated by stars is released by nuclear fusion.

Explain the conditions required to bring about and maintain nuclear fusion in stars.

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(Total for question = 6 marks)

Q12.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

A nucleus of protactinium, $^{231}_{91}Pa$, decays by emitting an α particle.

The nucleus formed is

☐ **A** $^{233}_{95}Am$

☐ **B** $^{235}_{93}Np$

☐ **C** $^{227}_{89}Ac$

☐ **D** $^{229}_{87}Fr$

(Total for question = 1 mark)

Q13.

Pions (π^+, π^-, π^0) are created in the upper atmosphere when cosmic rays collide with protons. Pions are unstable and decay rapidly.

(a) Pions are the lightest of the hadrons. Charged pions (π^+ and π^-) decay to produce muons which then decay to positrons or electrons.

(i) A positive pion π^+ has a quark composition $u\bar{d}$.

State with a justification the possible quark compositions of a neutral pion π^0.

(2)

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(ii) Muons are examples of leptons whereas pions are examples of mesons.
State a structural difference between leptons and mesons.

(1)

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....

(b) Muons with a speed of 0.99*c* travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

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(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.

half-life of muon = 2.2 μs

(4)

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Fraction = ...

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

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(Total for question = 11 marks)

Q14.

Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

(i) In a sample of 1.0 g of phosphogypsum, the activity of radium-226 is 1.3 Bq.

Calculate the number of nuclei of radium-226 in this sample.

(3)

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Number of nuclei = ...

(ii) Calculate the time in years it would take before this sample reached the permitted level of decay rate.

(3)

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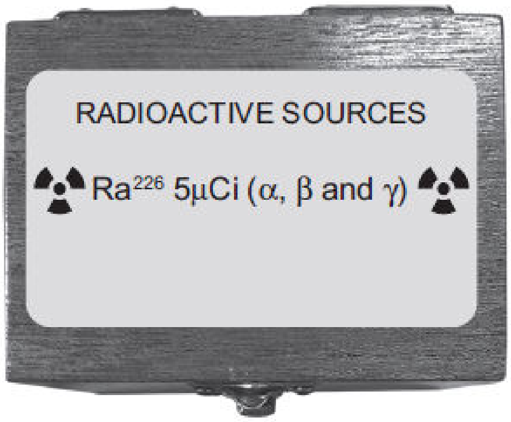
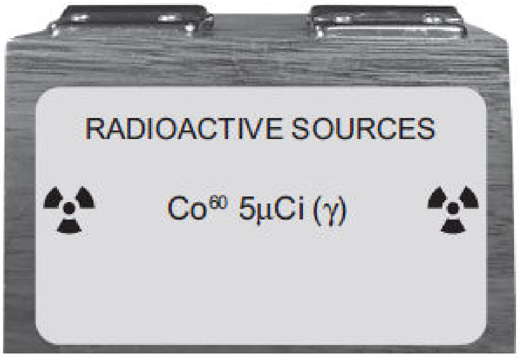
Time = ... years

(Total for question = 6 marks)

Q15.

The photograph shows the containers of two radioactive sources kept in a school.





The school is required to make a safety inspection of the sources every year.

(i) Explain how the sources can be tested to ensure that each source is in the correct container.

(4)

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(ii) Explain a safety precaution that must be applied during this procedure.

(2)

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Q16.

In 2012, building commenced on the International Thermonuclear Experimental Reactor (ITER) in France. The aim is for this fusion reactor to be working by 2020.

(a) (i) Describe the process of nuclear fusion.

(2)

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(ii) Explain why it is difficult to maintain the conditions needed for nuclear fusion in a reactor.

(2)

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(b) Explain why the fusion of hydrogen nuclei should release energy.

(2)

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(Total for question = 6 marks)

Q17.

A radioactive source is placed a few cm away from a detector. There is no change in the count rate when a thin aluminium foil is placed between the source and the detector, but the count rate is reduced to the background rate when a 0.5 cm aluminium plate is introduced.

These observations show that the source must be emitting

☒ **A** alpha and beta radiation.

☒ **B** beta and gamma radiation.

☒ **C** beta radiation only.

☒ **D** gamma radiation only.

(Total for Question = 1 mark)

Q18.

In a famous thought experiment, Schrödinger imagined that a cat is locked in a box, along with a radioactive atom that is connected to a tube containing a deadly poison. If the atom decays, it causes the tube to smash and the cat to die.

The random nature of radioactive decay means that the radioactive atom will

☒ **A** decay after one half-life.

☒ **B** probably decay after one half-life.

☒ **C** have a fixed probability of decaying in a given time interval.

☒ **D** have a number of possible decay paths.

(Total for Question = 1 mark)

Q19.

Radioactive decay is often described in textbooks as a spontaneous, random process.

* Explain why there is an exponential decrease in the rate of decay for a sample containing a large number of unstable nuclei.

(6)

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(Total for question = 6 marks)

Q20.

Radioactive isotopes are often used as markers, so that chemical substances can be traced around the body. In one medical procedure tritium is used as a means of studying protein absorption by the intestine.

A patient was given a sample containing the tritium to drink and then monitored. The initial activity of the sample was 3450 Bq.

Tritium is a beta-emitter with a half-life of 3.89×10^8 s.

(a) State what is meant by the activity of a radioactive source.

(1)

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(b) Show that the decay constant of the tritium is about 1.8×10^{-9} s^{-1} and hence calculate the number of tritium nuclei in the initial sample.

(3)

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Number of nuclei = ...

(c) (i) Show that the time taken for the activity of the sample to fall to 10% of its initial value is about 40 years.

(3)

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(ii) Comment on the time given in (c) (i).

(1)

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(Total for question = 8 marks)

Q21.

The Sun is believed to be about 4.5 billion years old. To determine this, scientists measure the ratios of the lead isotopes found in meteorites. Since uranium undergoes radioactive decay in a chain to eventually become an isotope of lead, the ratios of lead isotopes can be used to find the age of a meteorite.

(i) $^{238}_{92}U$ decays to $^{206}_{82}Pb$ via the emission of α and β^- radiation.

In the transition of U-238 to Pb-206 eight alpha decays must occur.

State the number of beta decays that must occur. Justify your answer.

(2)

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....

Number of β^- decays = ...

(ii) One isotope produced in the chain is thorium-230, which decays to an isotope of radium with a half-life of 75,000 years.

Calculate the time in years it would take for 90% of an initial sample of thorium to have decayed.

(4)

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Time taken = ... years

(Total for question = 6 marks)

Q22.

In an experiment to measure the activity of a radioactive source the measured activity should always be corrected by

☒ **A** adding the background count.

☒ **B** adding the background count rate.

☒ **C** subtracting the background count.

☒ **D** subtracting the background count rate.

(Total for question = 1 mark)

Q23.

*****Radium is a radioactive element. The most common isotope of radium has a half-life of almost two thousand years. A sample of radium can remain at a higher temperature than its surroundings for a long period of time.

Explain how a sample of radium is able to release significant amounts of energy over a long period of time.

(6)

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(Total for question = 6 marks)

Q24.

The table below gives the range and number of ion pairs per centimetre produced by β particles, compared to α particles of the same energy.

Select the row from the table which shows the correct comparison.

	Range of β particles	Number of ion pairs per centimetre
☒ **A**	greater	greater
☒ **B**	smaller	greater
☒ **C**	greater	smaller
☒ **D**	smaller	smaller

Q25.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

Select the row of the table that describes the relative ionisation and relative penetration of nuclear radiations.

	Most ionising	Most penetrating
☒ **A**	α	α
☒ **B**	α	γ
☒ **C**	γ	α
☒ **D**	γ	γ

(Total for question = 1 mark)

Q26.

Radioactive decay is often described in textbooks as a spontaneous, random process.

State what is meant by spontaneous decay.

(1)

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(Total for question = 1 mark)

Q27.

Radioactive decay is said to be a spontaneous process.

This means that

☒ **A** we cannot know when a nucleus will decay.

☒ **B** we cannot know which nucleus will decay next.

☒ **C** we cannot know how many nuclei will decay.

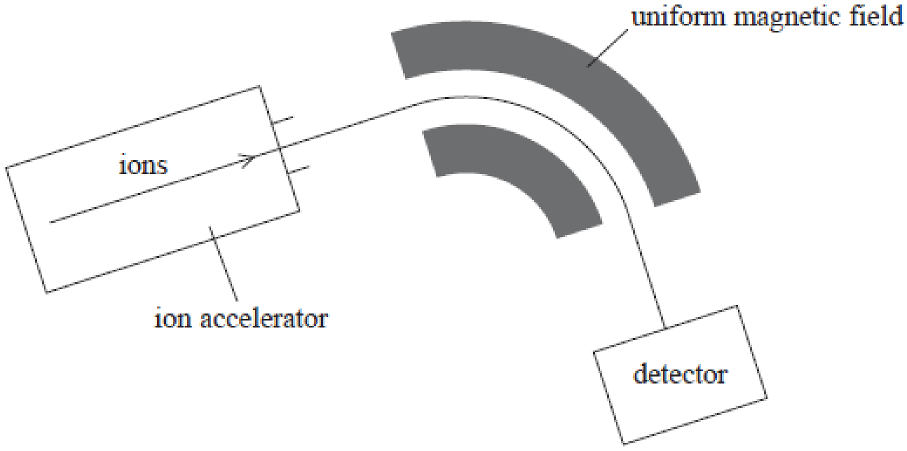
☒ **D** we cannot influence when a nucleus will decay.

(Total for question = 1 mark)

Q28.

Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam.
This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

State what is meant by isotopes.

(1)

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(Total for question = 1 mark)

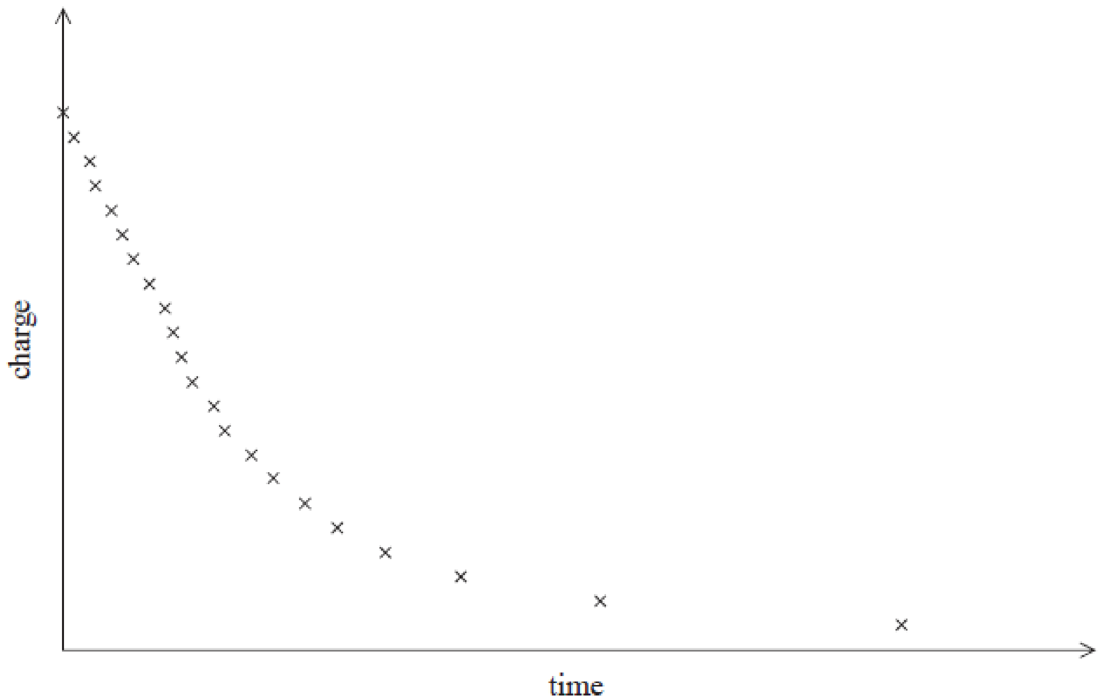
Q29.

A coulombmeter is used to measure charge.

In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

For one sheet of zinc, the charge at different times was measured.

The following graph was obtained.



A student suggests that this is an exponential decay curve.
Explain how this suggestion could be tested.

(3)

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(Total for question = 3 marks)

Q30.

In March 2011, a nuclear meltdown occurred at the Fukushima Nuclear Power Plant and radioactive materials were released into the environment.

A month later, seaweed off the coast near Long Beach, California was found to be contaminated with iodine-131, a radioisotope that decays by emitting β particles. In one sample the activity was found to be 2.5 Bq per gram of dry seaweed.

(a) State what is meant by the activity of a radioactive source.

(1)

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....

(b) A Geiger counter is used to measure the count from a sample of seaweed over a period of 10 minutes. The corrected readings obtained are shown in the table below.

Corrected count 1	Corrected count 2	Corrected count 3	Corrected count rate / Bq
3820	3830	3825	6.38

(i) State why the readings obtained from the Geiger counter have to be corrected.

(1)

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(ii) Explain why the radioactive count is repeated.

(2)

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(iii) The measurements were repeated with the same sample of seaweed 30 days later. Calculate the new corrected count rate of the sample.

half-life of iodine-131 = 8.0 days

(3)

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New corrected count rate = ...

(iv) There is a moderate risk to the public from the accumulation of iodine-131 in the seaweed. Explain why.

(2)

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(Total for question = 9 marks)

Mark Scheme

Q1.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Calculate no of nuclei • Use of ln 2 = $t_{½} \times \lambda$ • Use of $A = \lambda N$ • $A = 3.97 \times 10^4$ Bq)	(1) (1) (1) (1)	Example of calculation $N = (5.18 \times 10^{-5}$ g/230 g) $\times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7)$ s = ln 2 $\lambda = 2.92 \times 10^{-13}$ s^{-1} $A = 2.92 \times 10^{-13}$ s$^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4$ Bq	4
(ii)	• Calculates decays in one year (ecf from (b)(i)) • Use of $pV = NkT$ • uses $T = 295$ K • $V = 5.09 \times 10^{-14}$ m^3	(1) (1) (1) (1)	Example of calculation ecf λ from (a) decays in one year = 3.97×10^4 Bq $\times$ 3.15×10^7 s $= 1.25 \times 10^{12}$ 1.00×10^5 Pa $\times V = 1.25 \times 10^{12} \times 1.38$ $\times 10^{-23}$ J K^{-1} $\times$ 295 K $V = 5.09 \times 10^{-14}$ m^3	4
(iii)	• Use of ½ $m <c^2> = 3/2\ kT$ **Or** Use of $pV = \frac{1}{3}Nm < c^2 >$ (allow ecf for N, V from (b)(ii)) • uses $m = 4u$ • $\sqrt{<c^2>} = 1360$ m s^{-1}	(1) (1) (1)	Example of calculation ½ $m <c^2> = 3/2\ kT$ ½ $\times (4 \times 1.66 \times 10^{-27}$ kg) $\times <c^2> = 3/2$ $\times 1.38 \times 10^{-23}$ J K^{-1} $\times$ 295 K $<c^2> = 1\,840\,000$ m^2 s^{-2} $\sqrt{<c^2>} = 1360$ m s^{-1} Accept the use of proton/neutron mass instead of u	3

Q2.

Question Number	Answer		Mark
(a)(i)	Ionising radiation removes electrons from atoms/molecules	(1)	**1**
(a)(ii)	Least ionising ⟶ most ionising γ | β | α	(1)	**1**
(b)(i)	(see table below)	(1) (1) (1)	**3**
(b)(ii)	(There is the possibility of) exposure to neutrons Uncharged particles are not (directly) ionising	(1) (1)	**2**
	Total for question		**7**

(b)(i):

	Paper	0.5 cm aluminium	0.5 cm lead	
α radiation	**stopped**	stopped	**stopped**	(1)
β radiation	**passes through**	**stopped**	stopped	(1)
γ radiation	passes through	**passes through**	**passes through**	(1)

Q3.

Question Number	Answer	Mark
	B	1

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	**Either** • The GM-tube has a low efficiency for γ-ray detection **Or** there is an increased area exposed to γ-rays **(1)** • (So) placing the tube side on to the radiation would increase the count rate **(1)** **Or** • The γ-radiation could be detected anywhere inside the GM-tube **(1)** • So placing the tube side on to the radiation would reduce the uncertainty in the distance measurement **(1)**	For low efficiency, accept GM tube poor at detecting γ-rays.	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• Record the count (at least) twice and then determine an average count rate **Or** record the count for a much longer time **(1)** • This reduces the effect of (random) errors in the measurement of the count rate **(1)**		2

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
	• The energy equivalent to the mass deficit **(1)** • When nucleons bind together to form an atomic nucleus **(1)**		2

Q6.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is **C**: mass decrease by 20 → 5 α, which is a charge decrease of 10, but total charge decrease is 6, so 4 β A is not correct because there are too few alpha and too many beta B is not correct because there are too few alpha and too many beta D is not correct because there are too many beta	**1**

Q7.

Question Number	Answer		Mark
(a)(i)	Use of $\lambda t_{1/2} = \ln 2$ $\lambda = 5.8 \times 10^{-8}$ (s^{-1}) Use of $\frac{\Delta N}{\Delta t} = -\lambda N$ $\frac{\Delta N}{\Delta t} = (-)1.5 \times 10^{8}$ Bq [accept s^{-1} **Or** counts s^{-1}] <u>Example of calculation</u> $\lambda = \frac{0.693}{(138 \times 24 \times 3600)s} = 5.81 \times 10^{-8} s^{-1}$ $\frac{\Delta N}{\Delta t} = -5.81 \times 10^{-8} s^{-1} \times 2.54 \times 10^{15} = -1.48 \times 10^{8}$ Bq	(1) (1) (1) (1)	**4**
(a)(ii)	Use of $N = N_0 e^{-\lambda t}$ Fraction of nuclei remaining = 0.90 10% of nuclei have decayed [accept 0.1 **Or** 1/10] <u>Example of calculation</u> t = 21 × 24 × 3600 s = 1 814 400 s $\frac{N}{N_0} = e^{-5.81\times10^{-8} s^{-1} \times 1.81\times10^{6} s}$ $\frac{N}{N_0} = e^{-0.105} = 0.900$ Fraction decayed = 1- 0.9 = 0.1	(1) (1) (1)	**3**

(b)	Idea that α-particles are not able to penetrate the (dead layer of) skin (from outside the body) Damage/danger if energy is transferred to cells/DNA **Or** damage/danger to cells/DNA due to ionisation	(1) (1)	**2**
(c)(i)	${}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}\alpha$ Top line correct Bottom line correct	(1) (1)	**2**
(c)(ii)	So that momentum is conserved	(1)	**1**
(d)	Spontaneous means that the decay cannot be influenced by any external factors. Random means that we cannot identify which atom/nucleus will (be the next to) decay **Or** we cannot identify when an individual atom/nucleus will decay **Or** we cannot state exactly how many atoms/nuclei will decay in a set time **Or** we can only estimate the fraction of the total number that will decay in the next time interval	(1) (1)	**2**

(e)	Idea that traces of the isotope will be excreted from the body (and deposited in the surroundings) Idea that the half life is long enough for the activity to be detectable for a long time	(1) (1)	**2**
	Total for question		**16**

Q8.

Question Number	Answer		Mark
(a)	A radioactive atom has an unstable nucleus which emits α, β, or γ radiation [at least one of α β γ named]	(1) (1)	2
(b)	$C \rightarrow {}^{11}_{5}B + {}^{0}_{1}e^{+} + \nu_e$ Top line correct Bottom line correct	(1) (1)	2
(c)	Attempt at mass diference calculation Attempt at conversion from (M)eV to J $\Delta E = 1.4 \times 10^{-13}$ (J) <u>Example of calculation:</u> $\Delta E = 10\,253.6 - 10252.2 - 0.5 = 0.889$ MeV $\Delta E = 0.889 \text{ MeV} \times 1.6 \times 10^{-13} \text{ J MeV}^{-1} = 1.42 \times 10^{-13}$ J	(1) (1) (1)	3
(d)	The idea that the sample will not produce radiation for very long (because carbon-11 has a relatively short half-life) β particles are not very ionising **Or** positrons are not very ionising **Or** boron is safe in small amounts	(1) (1)	2
(e)	Use of $\lambda t_{1/2} = \ln 2$ ($\lambda = 5.68 \times 10^{-4}$ s^{-1}) Use of $A = A_0 e^{-\lambda t}$ Use $A = 1.58 \times 10^{6}$ Bq in $A = A_0 e^{-\lambda t}$ $A_0 = 1.2 \times 10^{7}$ Bq <u>Example of calculation:</u> $\lambda = \frac{0.693}{1220 \text{ s}} = 5.68 \times 10^{-4} \text{ s}^{-1}$ $1.58 \times 10^{6} \text{ Bq} = A_0 e^{-5.68 \times 10^{-4} \text{ s}^{-1} \times 60 \times 60 \text{ s}}$ $A_0 = 1.22 \times 10^{7}$ Bq	(1) (1) (1) (1)	4
	Total for question		**13**

Q9.

Question Number	Answer	Mark
	C	1

Q10.

Question Number	Answer		Mark
(a)(i)	$N + \alpha \rightarrow {}^{17}_{8}O + {}_{1}p$ All values correct	(1)	1
(a)(ii)	In nuclear fission a chain reaction can be set up **Or** in a chain reaction the (total) energy released can be very large **Or** heavier/larger nuclei release much more energy **Or** a very high reaction rate releases much more energy	(1)	1
(b)	Attempt at mass deficit calculation Use of $\Delta E = c^2 \Delta m$ (Allow use of 1 u = 1.66×10^{-27} kg) Use of 1 MeV = 1.6×10^{-13} J (Allow use of 1u = 931.5 MeV/c^2) ΔE = 174 MeV Example of calculation $\Delta m = (390.29989 - 233.99404 - 152.64708 - (2 \times 1.67493)) \times 10^{-27}\,\text{kg}$ $\Delta m = 3.0891 \times 10^{-28}\,\text{kg}$ $\Delta E = (3.00 \times 10^8\,\text{m s}^{-1})^2 \times 3.0891 \times 10^{-28}\,\text{kg} = 2.780 \times 10^{-11}\,\text{J}$ $\Delta E = \frac{2.780 \times 10^{-11}\,\text{J}}{1.60 \times 10^{-13}\,\text{J MeV}^{-1}} = 173.8\,\text{MeV}$	(1) (1) (1) (1)	4
(c)(i)	Same number of protons [do not accept atomic/proton number], Different numbers of neutrons [do not accept mass/nucleon/neutron number]	(1) (1)	2
(c)(ii)	Correct calculation for ω [see 6283 or 2000π or $\frac{60\,000 \times 2\pi}{60}$] a = (-) 5.9×10^6 m s^{-2} Example of calculation $a = -\left(\frac{60000 \times 2\pi}{60\,\text{s}}\right)^2 \times 15 \times 10^{-2}\,\text{m} = 5.92 \times 10^6\,\text{m s}^{-2}$	(1) (1)	2
(c)(iii)	**Max 2** Stiff/stiffness Strong/strength Low density	(1) (1) (1)	2
(d)	Use of $\Delta E = mc\Delta\theta$ Rate at which energy is removed = 3.1×10^9 (W) Use of the efficiency equation [must have 2.2×10^9 (W) on top line] Efficiency = 42% [accept 0.42] Example of calculation $\Delta E = 70000\,\text{kg} \times 3990\,\text{J kg}^{-1}\,\text{K}^{-1} \times 11\,\text{K} = 3.07 \times 10^9\,\text{J}$ $\%\,\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}} \times 100 = \frac{2.2 \times 10^9\,\text{W}}{(2.2 + 3.1) \times 10^9\,\text{W}} \times 100 = 41.5\%$	(1) (1) (1) (1)	4

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
k	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content.	The following table shows how the marks should be awarded for structure and lines of reasoning.	**6**

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

	No. of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

Indicative content:

- Requires a (very) high temperature
- Nuclei all have positive charge leading to a large repulsive force between nuclei
- At high temperature nuclei have high <u>kinetic</u> energy, sufficient to overcome repulsion
- Nuclei must get close enough to fuse (accept reference to close enough for strong force)
- Requires (very) high density
- Collision rate must be high enough to sustain fusion

Q12.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **C** emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2 A is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been increased by 2 and the proton number has been increased by 4 B is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been increased by 4 and the proton number has been increased by 2 D is not correct because emitting an alpha particle decreases the nucleon number by 4 and decreases the proton number by 2, but here the nucleon number has been decreased by 2 and the proton number has been decreased by 4		1

Q13.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• a π^0 may be $u\bar{u}$ **Or** $d\bar{d}$ (1) • it must be a quark combined with its own antiquark so that overall charge is 0 (1) <u>OR</u> it can only contain up or down quarks (as it is not a strange particle)	Allow $s\bar{s}$	**(2)**
(a)(ii)	mesons are made up of quarks, whereas leptons are fundamental particles (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	• use of v = s/t (1) • t = 5.05 × 10^{-5} s (1)	Example of calculation: $t=\frac{s}{v}=\frac{15\times10^{3}\,\text{m}}{0.99\times3\times10^{8}\,\text{m s}^{-1}}=5.05\times10^{-5}\,\text{s}$	**(2)**
(b)(ii)	• use of $\lambda t_{1/2}=0.693$ (1) • λ = 3.15 × 10^{5} s^{-1} (1) • use of $N=N_0e^{-\lambda t}$ (1) • $\frac{N}{N_0}=1.23\times10^{-7}$ (1)	Example of calculation: $\lambda=\frac{\ln 2}{t_{1/2}}=\frac{0.693}{2.2\times10^{-6}\,\text{s}}=3.15\times10^{5}\,\text{s}^{-1}$ $\frac{N}{N_0}=e^{-\lambda t}=e^{-3.15\times10^{5}\,\text{s}^{-1}\times5.05\times10^{-5}\,\text{s}}=1.23\times10^{-7}$ $\frac{N}{N_0}=1.1\times10^{-7}$ if "show that" value used	**(4)**
(b)(iii)	• This is much smaller than 10% indicating the muon lifetime is much greater than the expected value (1) • The high speed of the muon has led to relativistic effects (1)		**(2)**

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $\lambda t_{½}=\ln 2$ (1) • Use of $dN/dt=-\lambda N$ (1) • $N=9.5\times10^{10}$ (1)	$\lambda\times(1600\times365\times24\times60\times60)$ s = ln 2 $\lambda=1.37\times10^{-11}\,\text{s}^{-1}$ $1.3\,\text{Bq}=1.37\times10^{-11}\,\text{s}^{-1}\times N$ $N=9.46\times10^{10}$	3
(ii)	• Use of $A=A_0\,e^{-\lambda t}$ (1) • Use of $\ln A=\ln A_0-\lambda t$ or equivalent (1) • $t=8.58\times10^{10}$ s = 2700 years (1)	ecf λ calculated in (i) $\ln 0.4=\ln 1.3-1.37\times10^{-11}\,\text{s}^{-1}\times t$ $t=8.58\times10^{10}$ s = 2721 years	3

Q15.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	An explanation that makes reference to the following:			
	• use a GM tube and counter to measure the number of counts in a known time	(1)	Answers may refer to the use of a ratemeter instead of a counter	
	• place a piece of aluminium a few mm thick between the source and the detector	(1)		
	• α and β will not penetrate aluminium but γ will	(1)		
	• so the source that is unchanged is Co 60 and the one with a decreased count is Ra 226	(1)		
	<u>OR</u> use a GM tube and counter to measure the number of counts in a known time			
	• place a strong magnet near the source	(1)		**(4)**
	• α and β will be deviated but γ will not	(1)		
	• so the source that is unchanged is Co 60 and the one with a decreased count is Ra 226	(1)		

Question Number	Acceptable answers	Additional guidance	Mark
(ii)	An explanation that makes reference to a precaution and the reason for it • make sure the source remains at a distance of at least 30 cm from your body to minimise exposure (1) <u>OR</u> make sure the source is always pointed away from you to minimise exposure (1) <u>OR</u> only use one source at a time to minimise exposure (1) • the sources emit ionising radiation which can be harmful to your cells (1)		**(2)**

Q16.

Question Number	Answer	Mark
(a)(i)	(Small mass) nuclei come very close together **Or** strong (nuclear) force acts on nuclei (1) Nuclei join to form a more massive nucleus (1)	2
(a)(ii)	A very/extremely high temperature (plasma) is required (1) Plasma must not touch reactor walls, so strong magnetic fields are required **Or** If plasma touches the walls of the reactor its temperature falls (and fusion stops) (1)	2
(b)	Mass of fused nucleus is less than sum of masses of fusing nuclei (1) Mass difference/deficit releases energy according to $\Delta E = c^2 \Delta m$ **Or** Binding energy per nucleon is greater in the fused nucleus; **Or** Strong (nuclear) force binds the nucleons, lowering total energy of system. (1)	2
	Total for question	**6**

Q17.

Question Number	Answer	Mark
	C	1

Q18.

Question Number	Answer	Mark
	C	1

Q19.

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*</td>
<td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Indicative content:
IC1 There is a fixed probability (λ) of an individual nucleus undergoing decay (in the next second)
IC2 For a sample with large number of unstable nuclei there is a predictable pattern
IC3 The fraction of nuclei decaying in the next second is equal to the decay constant (λ)</td>
<td>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
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<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>
Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

	IC4 Hence the number of nuclei decaying (in the next second) depends on the number of (unstable) nuclei **Or** activity = λN IC5 The number of unstable nuclei decreases exponentially (with time) **Or** number of (unstable) nuclei = $N_0 e^{-\lambda t}$ IC6 So the rate of decay decreases exponentially (with time) **Or** rate of decay = $A_0 e^{-\lambda t}$		

Q20.

Question Number	Answer		Mark
(a)	Activity is the rate of decay (of radioactive nuclei) **Or** the number of decays in a second	(1)	1
(b)	Use of $\lambda t_{1/2} = 0.693$ Use of $A = -\lambda N$ $N = 1.9 \times 10^{12}$ Example of calculation: $\lambda = \frac{0.693}{3.89 \times 10^8 \text{ s}} = 1.78 \times 10^{-9} \text{ s}^{-1}$ $N = \frac{3450 \text{ s}^{-1}}{1.78 \times 10^{-9} \text{ s}^{-1}} = 1.94 \times 10^{12}$	(1) (1) (1)	3
(c)(i)	Use of $A = A_0 e^{-\lambda t}$ Conversion between seconds and years t = 41 (years) Example of calculation: $0.1 = e^{-(1.78 \times 10^{-9} s^{-1})t}$ $t = 1.29 \times 10^9$ s $t = 1.29 \times 10^9 \text{ s} / (365 \times 24 \times 3600 \text{ s y}^{-1}) = 41$ y	(1) (1) (1)	3
(c)(ii)	This is a very long time and so: The sample's activity will stay approx. constant for the procedure **Or** tritium may be in the body long enough for damage to be caused **Or** the sample can be prepared well in advance of the procedure	(1) (1) (1)	1
	Total for question		**8**

Q21.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• 8 alpha decays reduce the proton number by 16 **(1)** • proton number decreases by only 10, so there must be 6 β decays **(1)** **OR** • balanced equation written for overall decay **(1)** • explicit solution to give 6 β^- decays **(1)**	Example of calculation: ${}^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + 8 \times {}^{4}_{2}\alpha + \text{N} \times {}^{0}_{-1}\beta^-$ $92 = 82 + (8 \times 2) - \text{N}$ $92 = 82 + 16 - \text{N}$ $\text{N} = 98 - 92 = 6$ Proof must be given to obtain these marks.	2
(ii)	• use of $\lambda t_{1/2} = \ln 2$ **(1)** • use of $N = N_0 e^{-\lambda t}$ **(1)** • $N/N_0 = 0.1$ **(1)** • $t = 2.5 \times 10^5$ years **(1)**	Example of calculation: $\lambda = \frac{0.693}{75000} = 9.24 \times 10^{-6} \text{ y}^{-1}$ $\lambda t = -\ln\left(\frac{N}{N_0}\right)$ $\therefore t = \frac{-\ln(0.1)}{9.24 \times 10^{-6} \text{ y}^{-1}} = 2.49 \times 10^5 \text{ y}$	4

Q22.

Question Number	Answer	Mark
	D	1

Q23.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	See below	See below	6

Acceptable Answer

IC points	IC mark	Max linkage mark	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

Indicative content:

- IC1 The rate of decay depends upon the number of unstable nuclei in the sample ($A = -\lambda N$)
- IC2 Radium has a large half-life, so unstable nuclei are present in the sample for a long time
- IC3 When a nucleus decays there is a (small) decrease in mass Δm
- IC4 Energy is released according to $\Delta E = c^2 \Delta m$
- IC5 Δm is small but c is large, so a significant amount of energy is released
- IC6 Energy released by the decay becomes kinetic energy of the atoms in the sample (hence sample is above the temperature of the surroundings

Additional Guidance

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The table shows how the marks should be awarded for indicative content and structure and lines of reasoning.

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5–4	3
3–2	2
1	1
0	0

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

IC2: accept idea that it takes a long time to decay for "unstable nuclei are present…or a long period of time"

IC3 accept a reference to binding energy increasing

Q24.

Question Number	Answer	Mark
	C	1

Q25.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is B because alpha is the most ionising and gamma is the most penetrating A is not correct because although alpha is the most ionising, gamma and not alpha is the most penetrating C is not correct because alpha, not gamma, is the most ionising and gamma, not alpha is the most penetrating D is not correct because alpha, not gamma is the most ionising, even though gamma is the most penetrating		1

Q26.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• decay happens without any external stimulus (1) **Or** decay is unaffected by external factors (such as temperature)	Do not credit references to the randomness of the decay	1

Q27.

Question Number	Answer	Mark
	D	1

Q28.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• (isotopes are atoms/nuclides with the) same number of protons but different numbers of neutrons/nucleons (in the nucleus) **(1)**	Ignore references to the number of electrons in the atoms Do not credit mass number or atomic number	**1**

Q29.

Question Number	Acceptable answers	Additional guidance	Mark
	• would be of form $Q = Q_0 e^{-kt}$ **(1)** • plot ln charge against time **(1)** • if straight line with negative gradient it's exponential **(1)** **Or** • would be of form $Q = Q_0 e^{-kt}$ **(1)** • Calculate Q/Q_0 for pairs of values with same time interval t **Or** calculates $t_{1/2}$ at least twice **(1)** • If equal, then it's exponential **(1)**	MP3 accept some indication that gradient is negative For both MS options MP3 is dependent on MP2	**3**

Q30.

Question Number	Answer		Mark
(a)	Activity is the rate of decay of (unstable) nuclei **Or** activity is the number of (unstable) nuclei that decay in unit time	(1)	1

(b)(i)	Background radiation/count will increase the recorded count **Or** background count must be subtracted from the recorded count **Or** background radiation contributes systematic error to the count [Do not accept "to correct for background radiation"]	(1)	**1**
(b)(ii)	Radioactive decay is a random process (so count for a fixed period will vary) [Ignore references to spontaneous, accurate, reliable] Idea that repeating enables a mean/average value to be calculated	(1) (1)	**2**
(b)(iii)	Use of $\lambda = \frac{\ln 2}{t_{1/2}}$ Use of $A = A_0 e^{-\lambda t}$ [allow 2.5 Bq for A_0 here; allow use of $N = N_0 e^{-\lambda t}$] $A = 0.47$ Bq [Allow calculation of number of half lives elapsed and use of $A = A_0 \left(\frac{1}{2}\right)^{t/t_{1/2}}$ for mp1 and mp2] <u>Example of calculation:</u> $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{8.0\,\text{d}} = 0.0866\,\text{d}^{-1}$ $A = A_0 e^{-\lambda t} = 6.38 \times e^{-0.0866\,\text{d}^{-1} \times 30\,\text{d}} = 6.38\,\text{Bq} \times 0.074 = 0.47\,\text{Bq}$	(1) (1) (1)	**3**
(b)(iv)	Idea that people have to be close to or ingest seaweed for any degree of risk **Or** β particles are moderately ionising **Or** β particles can enter body through the skin The half-life is short **Or** after a month the activity has decayed to negligible levels **Or** the radioisotope doesn't remain in the seaweed for very long	(1) (1)	**2**
	Total for Question		**9**