Nuclear fission and fusion

Questions

Name: ______________________

Class: ______________________

Date: ______________________

Time: **84 minutes**

Marks: **84 marks**

Comments:

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1 The first commercial nuclear power station in the world was built at Calder Hall in Cumbria.

The atoms produced by the fission of uranium are also radioactive. The used fuel is sent to a reprocessing plant where it can be safely treated.

(i) Calder Hall power station is next to the Sellafield reprocessing plant. Suggest an advantage of having the two plants close together.

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(1)

(ii) One of the radioactive products is iodine-138. This has a half-life of 6 seconds.
A sample of radioactive material contains 2000 atoms of iodine-138.
How long will it take for the number of iodine-131 atoms to decrease to 125?

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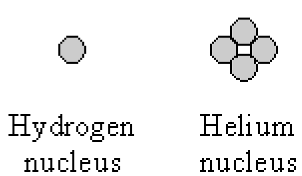
Answer = ________________ seconds

(3)

(Total 4 marks)

2 At the very high temperatures in the sun, hydrogen is converted into helium. It takes four hydrogen nuclei to produce one helium nucleus.

The table shows the relative masses of hydrogen and helium nuclei.



Nucleus	Relative Mass
hydrogen	1.007825
helium	4.0037

(a) Use these figures to calculate what happens to the mass of the sun as hydrogen is converted to helium.

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(3)

(b) Use your answer to part (a) to explain how the sun has been able to radiate huge amounts of energy for billions of years.

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(2)

(Total 5 marks)

3 Many countries use nuclear power stations to generate electricity.
Nuclear power stations use the process of nuclear fission to release energy.

(a) (i) What is nuclear fission?

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(1)

(ii) Plutonium-239 is one substance used as a fuel in a nuclear reactor. For nuclear fission to happen, the nucleus must absorb a particle.

What type of particle must be absorbed?

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(1)

(b) Nuclear **fusion** also releases energy.
Nuclear fusion happens at very high temperatures. A high temperature is needed to overcome the repulsion force between the nuclei.

(i) Why is there a repulsion force between the nuclei of atoms?

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(1)

(ii) Where does nuclear fusion happen naturally?

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(1)

(c) In 1991, scientists produced the first controlled release of energy from an experimental nuclear **fusion** reactor. This was achieved by fusing the hydrogen isotopes, deuterium and tritium.

Deuterium is naturally occurring and can easily be extracted from seawater. Tritium can be produced from lithium. Lithium is also found in seawater.

The table gives the energy released from 1 kg of fusion fuel and from 1 kg of fission fuel.

Type of fuel	**Energy released from 1 kg of fuel in joules**
Fusion fuel	3.4×10^{14}
Fission fuel	8.8×10^{13}

(i) Suggest **two** advantages of the fuel used in a fusion reactor compared with plutonium and the other substances used as fuel in a fission reactor.

1. ____

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2. ____

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(2)

(ii) Some scientists think that by the year 2050 a nuclear fusion power station capable of generating electricity on a large scale will have been developed.

Suggest **one** important consequence of developing nuclear fusion power stations to generate electricity.

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(1)

(d) Tritium is radioactive.

After 36 years, only 10 g of tritium remains from an original sample of 80 g.

Calculate the half-life of tritium.

Show clearly how you work out your answer.

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Half-life = __________________ years

(2)

(Total 9 marks)

4 (a) Nuclear power stations use the energy released by *nuclear fission* to generate electricity.

(i) Explain what is meant by *nuclear fission*.

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(2)

(ii) How does nuclear fission lead to a chain reaction?

You may give your answer as a labelled diagram.

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(1)

(b) Although nuclear fuels are relatively cheap the total cost of generating electricity using nuclear fuels is expensive. Why?

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(1)

(c) The table compares the energy released from 1 kg of coal and 1 kg of uranium.

Coal	29 MJ
Uranium	580 000 MJ

1 MJ = 1 000 000 joules

State **one** benefit to the environment of using a concentrated fuel like uranium to generate electricity rather than using the energy from coal.

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(1)

(Total 5 marks)

5 (a) Uranium atoms do not always have the same number of neutrons.
What are atoms of the same element that have different numbers of neutrons called?

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(1)

(b) By emitting an alpha particle, an atom of uranium-235 decays into an atom of thorium.

An alpha particle, which is the same as a helium nucleus, is represented by the symbol $^{4}_{2}He$.

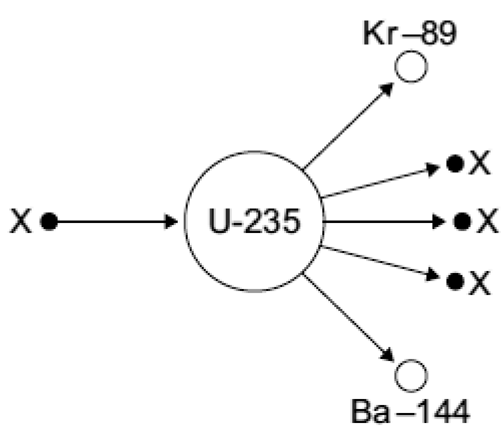
The decay can be represented by the equation below.

Complete the equation by writing the correct number in each of the two boxes.

$$^{235}_{92}U \longrightarrow ^{\square}_{\square}Th + ^{4}_{2}He$$

(2)

(c) The diagram shows an atom of uranium-235 being split into several pieces.



(i) Name the process shown in the diagram.

____

(1)

(ii) Name the particles labelled **X**.

____

(1)

(d) Uranium-235 is used as a fuel in some nuclear reactors.
Name another substance used as a fuel in some nuclear reactors.

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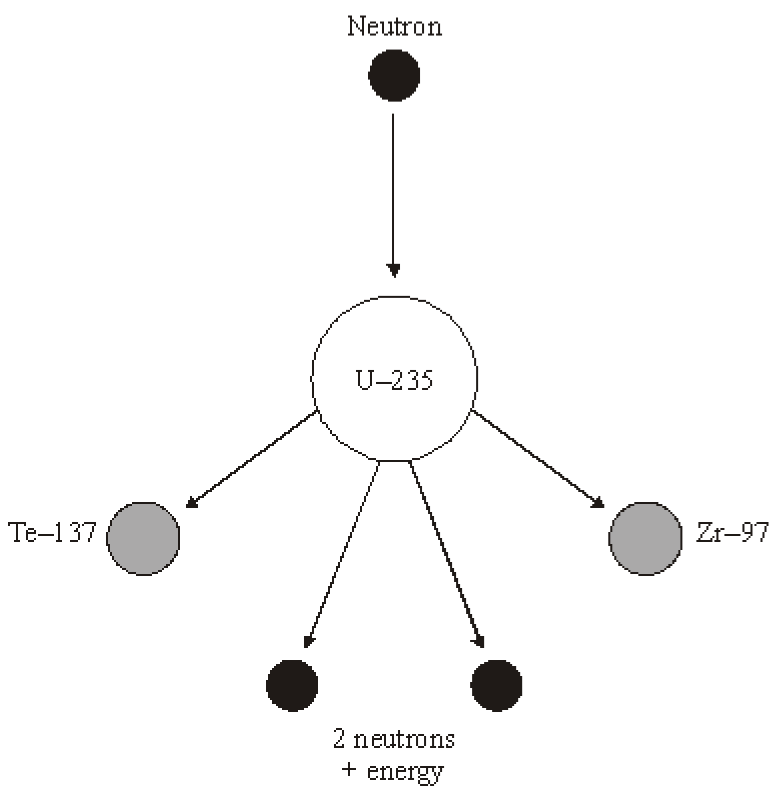
(1)

(Total 6 marks)

6 (a) The diagram shows what can happen when the nucleus of a uranium atom absorbs a neutron.



(i) What name is given to the process shown in the diagram?

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(1)

(ii) Explain how this process could lead to a chain reaction.

You may wish to add further detail to the diagram to help your answer.

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(2)

(iii) How does the mass number of an atom change when its nucleus absorbs a neutron?

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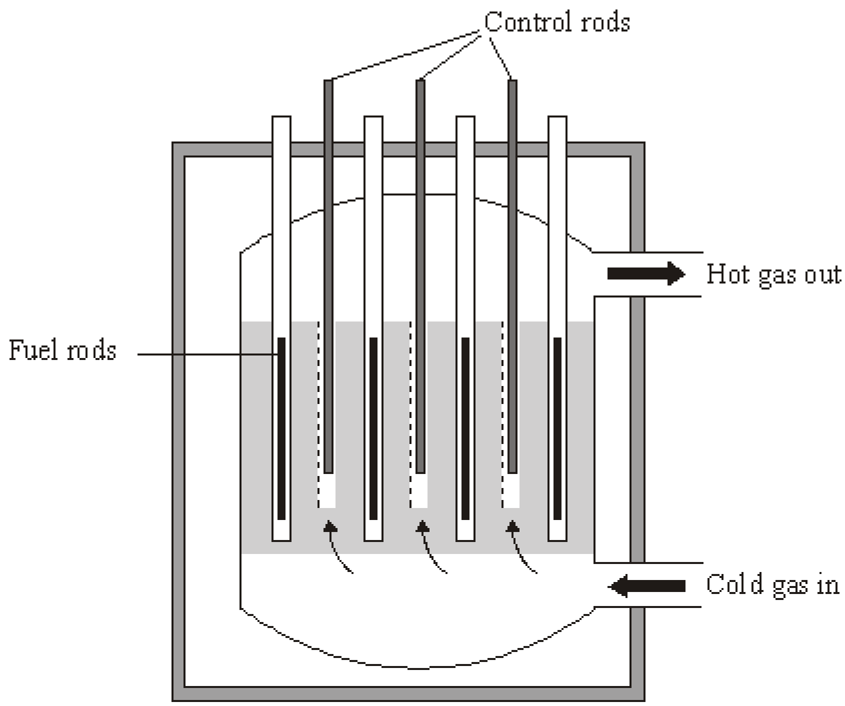
(1)

(b) Uranium-235 is used as a fuel in some nuclear reactors.



Source: adapted from 'Physics Matters', by Nick England. Published by Hodder and Stoughton, 1989. Reproduced by permission of Hodder and Stoughton Ltd.

The reactor contains control rods used to absorb neutrons.

Suggest what happens when the control rods are lowered into the reactor.

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(2)
(Total 6 marks)

7 The first commercial nuclear power station in the world was built at Calder Hall in Cumbria.

(a) The fuel used at the Calder Hall power station is uranium. Natural uranium consists mainly of two isotopes: uranium-235 $\left(^{235}_{92}U\right)$ and uranium-238 $\left(^{238}_{92}U\right)$. The nucleus of a uranium-235 atom is different to that of a uranium-238 atom.

(i) Where is the nucleus in an atom?

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(1)

(ii) Name the **two** types of particle found in the nucleus.

_______________ and _______________

(2)

(iii) How is the nucleus of a uranium-238 atom different to the nucleus of a uranium-235 atom?

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(2)

(b) In the nuclear reactor fission of uranium atoms takes place in reactions such as the one shown below.

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{138}_{53}I + {}^{95}_{39}Y + 3({}^{1}_{0}n)$$

The nuclear reactions are carefully controlled in the power station so that a chain reaction takes place.

Explain, as fully as you can:

(i) how fission of uranium atoms takes place in a nuclear reactor;

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(ii) how this leads to a chain reaction;

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(iii) why it can be used to generate electricity.

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(4)

(Total 9 marks)

8 The energy radiated by a **main sequence** star like the Sun is released by a nuclear fusion reaction in its core.

Read the following information about this reaction then use it to answer the questions below.

- The net result of the nuclear fusion reaction is that four hydrogen nuclei produce one helium nucleus. There is a loss of mass of 0.7%.
- For nuclear fusion to occur nuclei must collide at very high speeds.
- The energy released during the reaction can be calculated as shown:

energy released [J] = loss of mass [kg] × (speed of light [m/s²])

(The speed of light is 3×10^8 m/s)

(a) Calculate the energy released when 1g of hydrogen fuses to form helium.

(*Show your working*.)

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(4)

(b) The table shows the lifetimes and surface temperatures of main sequence stars with different masses.

MASS OF STAR [SUN = 1]	LIFETIME ON MAIN SEQUENCE [MILLION OF YEARS]	SURFACE TEMPERATURE * [KELVIN]
0.5	200 000	4000
1	10 000	6000
3	500	11 000
15	15	30 000

[* The higher the surface temperature of a star, the higher the temperature and pressure in its core.]

(i) Describe the relationship between the lifetime of a main sequence star and its mass.

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(2)

(ii) Suggest an explanation for this relationship.

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(3)

(Total 9 marks)

9 Atoms are different sizes.

One of the heaviest naturally occurring stable elements is lead.

Two of its isotopes are lead-206 ($^{206}_{82}Pb$) and lead-208 ($^{208}_{82}Pb$).

(a) (i) What is meant by 'isotopes'?

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(2)

(ii) How many protons are in the nucleus of a $^{206}_{82}Pb$ atom?

___

(1)

(iii) How many neutrons are in the nucleus of a $^{206}_{82}Pb$ atom?

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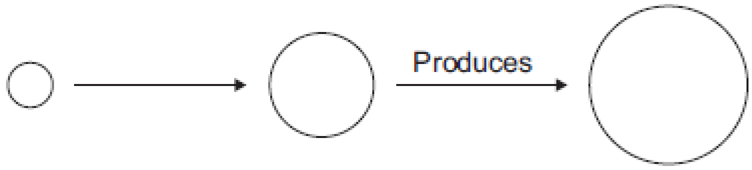
(1)

(b) A nucleus can be accelerated in a particle accelerator and directed at a large nucleus. This produces a heavy nucleus that will decay after a short time.

This is shown in **Figure 1**.

Figure 1



(i) In 1984, nuclei of iron (Fe) were directed at nuclei of lead (Pb). This produced nuclei of hassium (Hs).

Complete the equation for this reaction by writing numbers in the empty boxes.

$$^{58}_{\square}\text{Fe} + ^{\square}_{\square}\text{Pb} = ^{265}_{108}\text{Hs} + ^{1}_{0}\text{X}$$

(3)

(ii) Use the correct answer from the box to complete the sentence.

an electron	**a proton**	**a neutron**

The particle **X** in part (b)(i) is ________________________________ .

(1)

(iii) After acceleration the iron nuclei travel at a steady speed of one-tenth of the speed of light.

The speed of light is 3.00×10^8 m/s.

Calculate the time taken for the iron nuclei to travel a distance of 12 000 m.

____

____

Time taken = ______________________ s

(2)

(iv) Linear accelerators, in which particles are accelerated in a straight line, are **not** used for these experiments. Circular particle accelerators are used.

Suggest why.

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(3)

(c) Hassium-265 ($^{265}_{108}\text{Hs}$) decays by alpha emission with a half-life of 0.002 seconds.

(i) What is meant by 'half-life'?

Tick (✓) **two** boxes.

	Tick (✓)
The average time for the number of nuclei to halve	
The time for count rate to be equal to background count	
The time for background count to halve	
The time for count rate to halve	

(2)

(ii) Complete the equation for the decay of Hs-265 by writing numbers in the empty boxes.

$$^{265}_{108}\text{Hs} = {}^{\square}_{\square}\text{Sg} + {}^{\square}_{\square}\alpha$$

(2)

(d) The table below shows how the atomic radius of some atoms varies with atomic number.

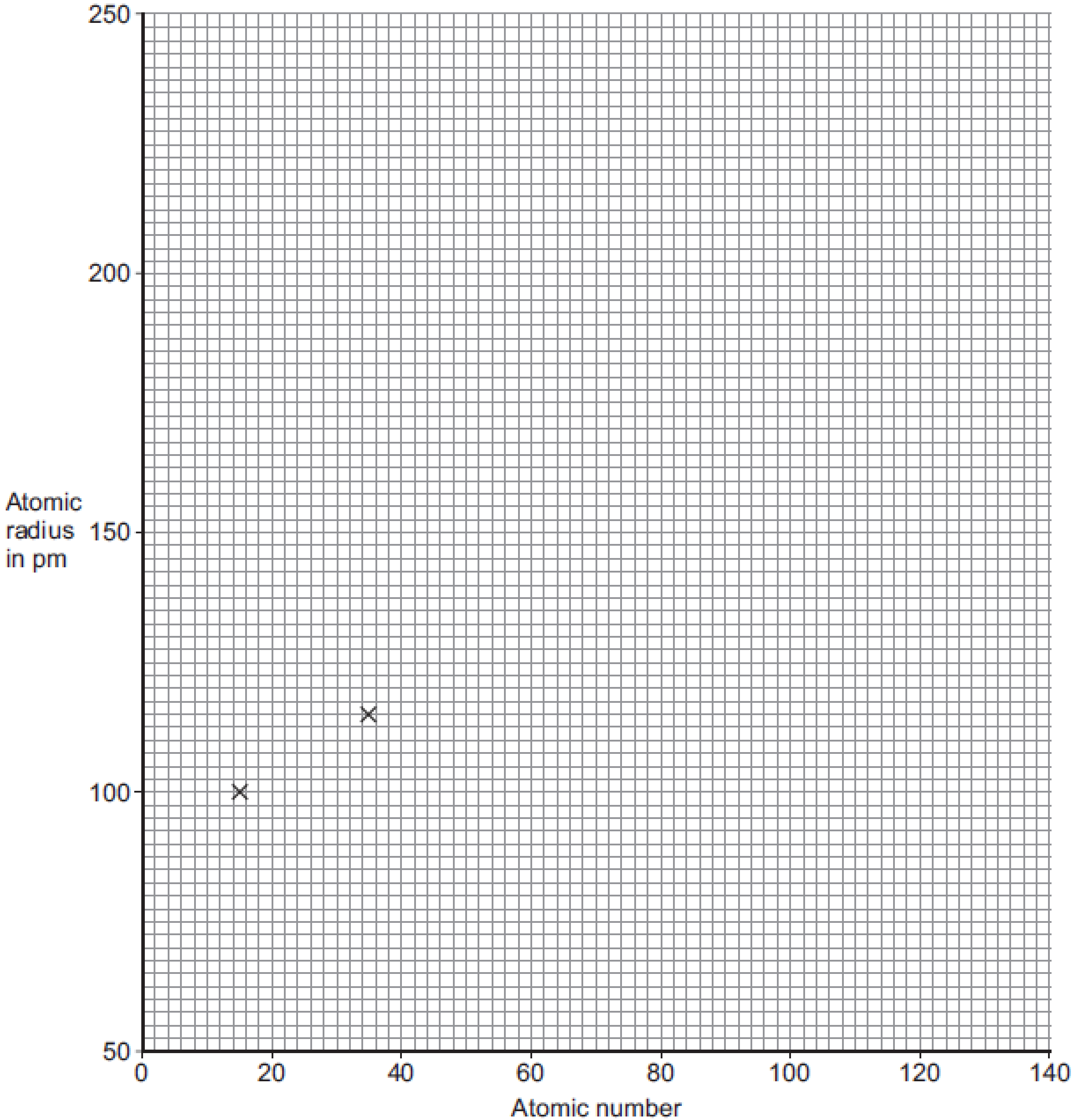
Atomic number	**Atomic radius in picometres (pm)**
15	100
35	115
50	130
70	150
95	170

$1 \text{ pm} = 10^{-12} \text{ m}$

(i) On **Figure 2**, use the data from the table above to plot a graph of atomic radius against atomic number and draw a line of best fit.

Two points have been plotted for you.

Figure 2



(2)

(ii) Scientists believe that the element with atomic number 126 can be produced and that it will be stable.

Use your graph in **Figure 2** to predict the atomic radius of an atom with atomic number 126.

Atomic radius = ____________________ pm

(1)

(Total 20 marks)

10 (a) There are many isotopes of the element molybdenum (Mo).

What do the nuclei of different molybdenum isotopes have in common?

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(1)

(b) The isotope molybdenum-99 is produced inside some nuclear power stations from the nuclear fission of uranium-235.

(i) What happens during the process of nuclear fission?

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(1)

(ii) Inside which part of a nuclear power station would molybdenum be produced?

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(1)

(c) When the nucleus of a molybdenum-99 atom decays, it emits radiation and changes into a nucleus of technetium-99.

$$^{99}_{42}\text{Mo} \longrightarrow {}^{99}_{43}\text{Tc} + \text{Radiation}$$

What type of radiation is emitted by molybdenum-99?

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Give a reason for your answer.

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(2)

(d) Technetium-99 has a short half-life and emits gamma radiation.

What is meant by the term 'half-life'?

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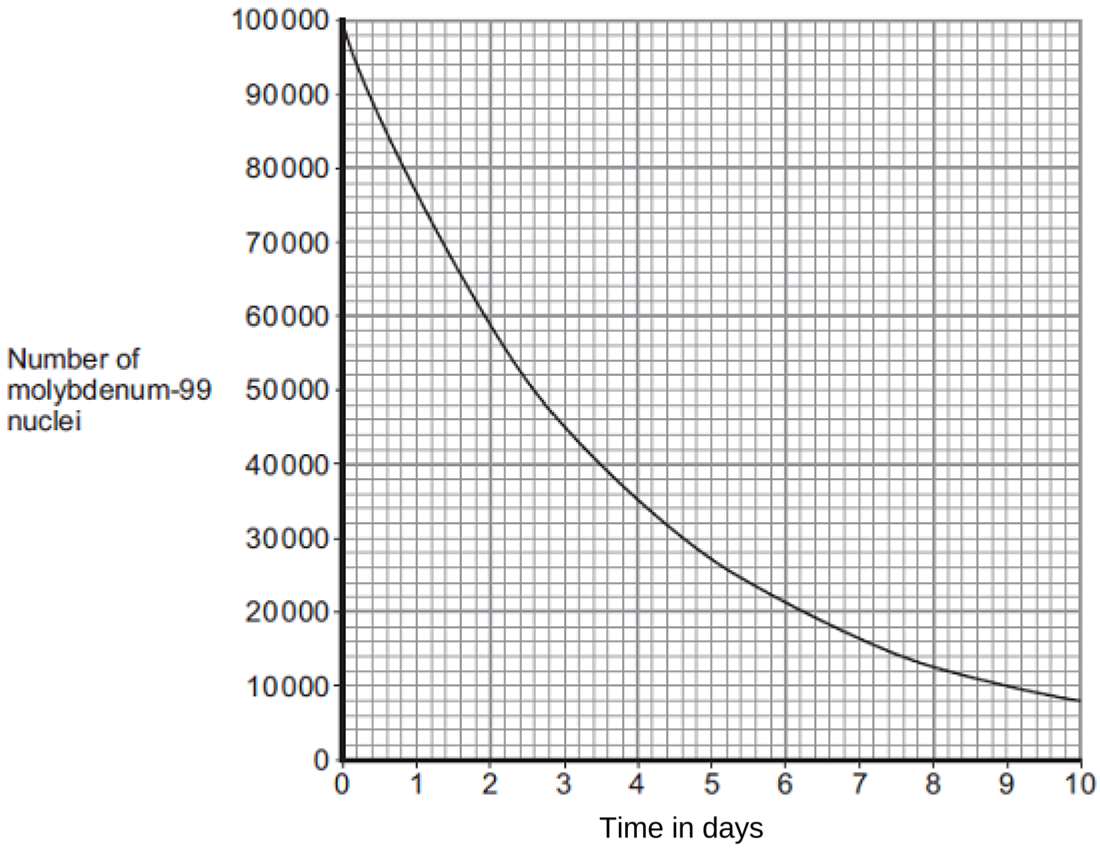
(1)

(e) Technetium-99 is used by doctors as a medical tracer. In hospitals it is produced inside a technetium generator by the decay of molybdenum-99 nuclei.

(i) The figure below shows how the number of nuclei in a sample of molybdenum-99 changes with time as the nuclei decay.



A technetium generator will continue to produce sufficient technetium-99 until 80% of the original molybdenum nuclei have decayed.

After how many days will a source of molybdenum-99 inside a technetium-99 generator need replacing?

Show clearly your calculation and how you use the graph to obtain your answer.

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Number of days = ________________________

(2)

(ii) Medical tracers are injected into a patient's body; this involves some risk to the patient's health.

Explain the risk to the patient of using a radioactive substance as a medical tracer.

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(2)

(iii) Even though there may be a risk, doctors frequently use radioactive substances for medical diagnosis and treatments.

Suggest why.

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(1)

(Total 11 marks)