My Question Paper

1.

A class of students were using dice to model radioactive decay.

- There were 8 groups of students.
- Each group of students had 50 dice.
- The 50 dice were rolled.
- Any that landed with a 6 facing upwards were removed.
- The remaining dice were counted.
- The remaining dice were rolled again and again, taking away the 6's each time.
- The table shows the results from one group and from the whole class.

Roll number	Number of dice remaining	
	One group's results	Class results
0	50	400
1	42	330
2	37	280
3	28	230
4	26	190
5	22	160
6	18	130
7	13	110
8	5	90

(a) Each group's results were added together to give the class results. Give **one** reason why the bigger sample size makes the data more repeatable. [1]

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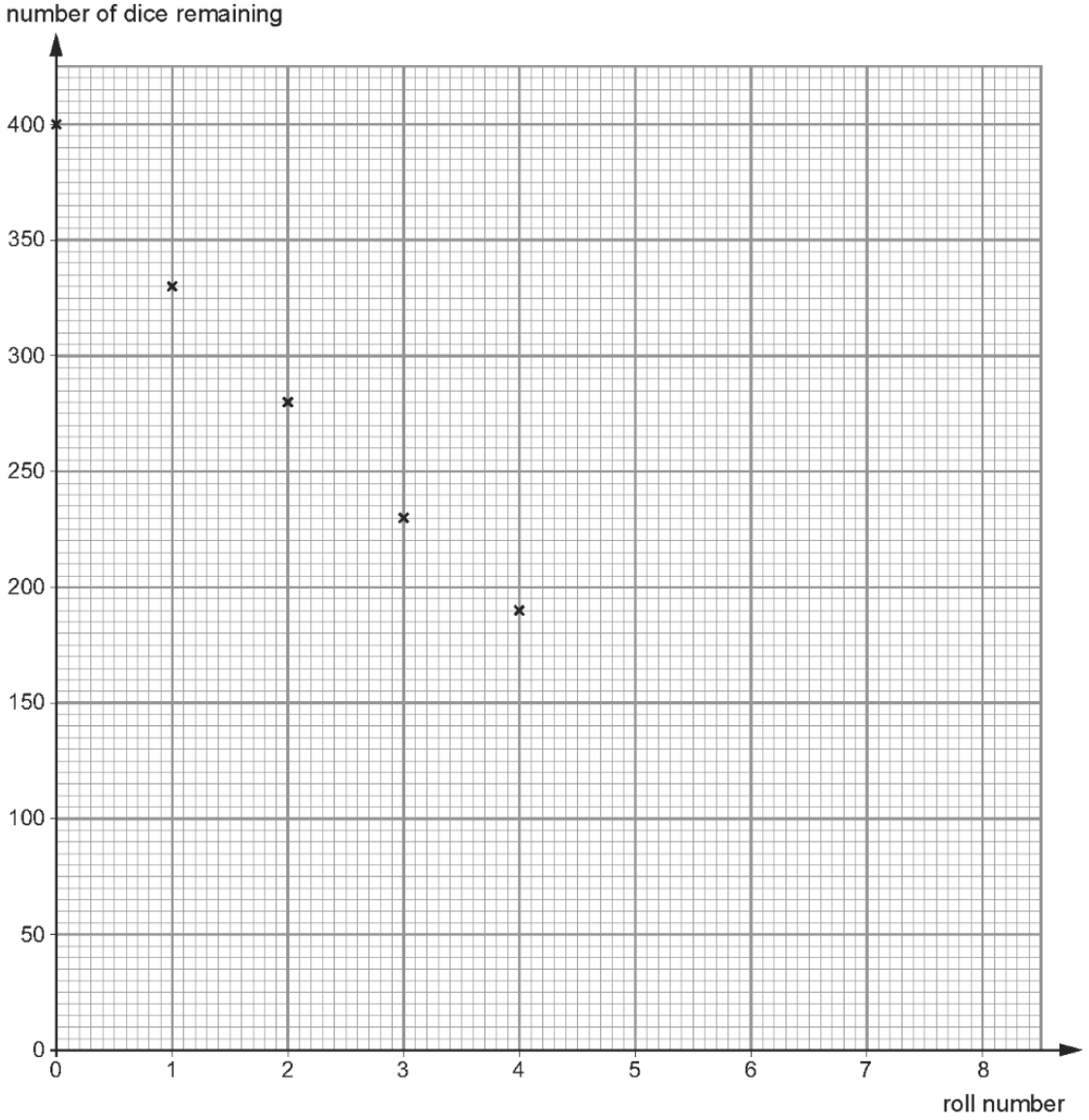
(b) The graph shows part of the data from the whole class.
Plot the remaining data and draw a suitable line. [3]



(c) The "half-life" for this modelled decay is the number of rolls needed for the number of dice to halve. *(The number of rolls will include fractions.)*

(i) Use the class results in the table on page 4 to estimate the half-life. [1]

half-life = ... rolls

(ii) Now use the graph to find the half-life. Show the method you use on the graph. [2]

half-life = ... rolls

(iii) Suggest why it is better to use the graph than the table to estimate the half-life. [1]

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(iv) Use the graph to find how many rolls it took for the number of dice to fall to $\frac{1}{4}$ of the original value. Comment on your answer. [2]

number of rolls = ...

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(d) An experiment was carried out to obtain similar data using the radioactive isotope, protactinium 234, which is a beta emitter. The **initial count** rate was measured to be 80 counts per second. After 210 s the count rate had dropped to 10 counts per second.

(i) Find the half-life of protactinium 234. [2]

half-life = ... s

(ii) Calculate how long it would take for the count rate to drop from 80 to 2.5 counts per second. [2]

time taken = ... s

(iii) State the unit of activity of a radioactive source. [1]

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2.

All living material takes in carbon-14 (C-14) which is radioactive and decays by beta emission. It has a half-life of 6000 years and is used in carbon dating which tells us the age of some old fossils. The age of things that died more than **10 half-lives** in the past cannot be accurately measured as the amount of C-14 present is too small.

(a) (i) State what you understand by the statement "the half-life of carbon-14 is 6000 years". [1]

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(ii) Explain how carbon-14 decays by beta emission. [2]

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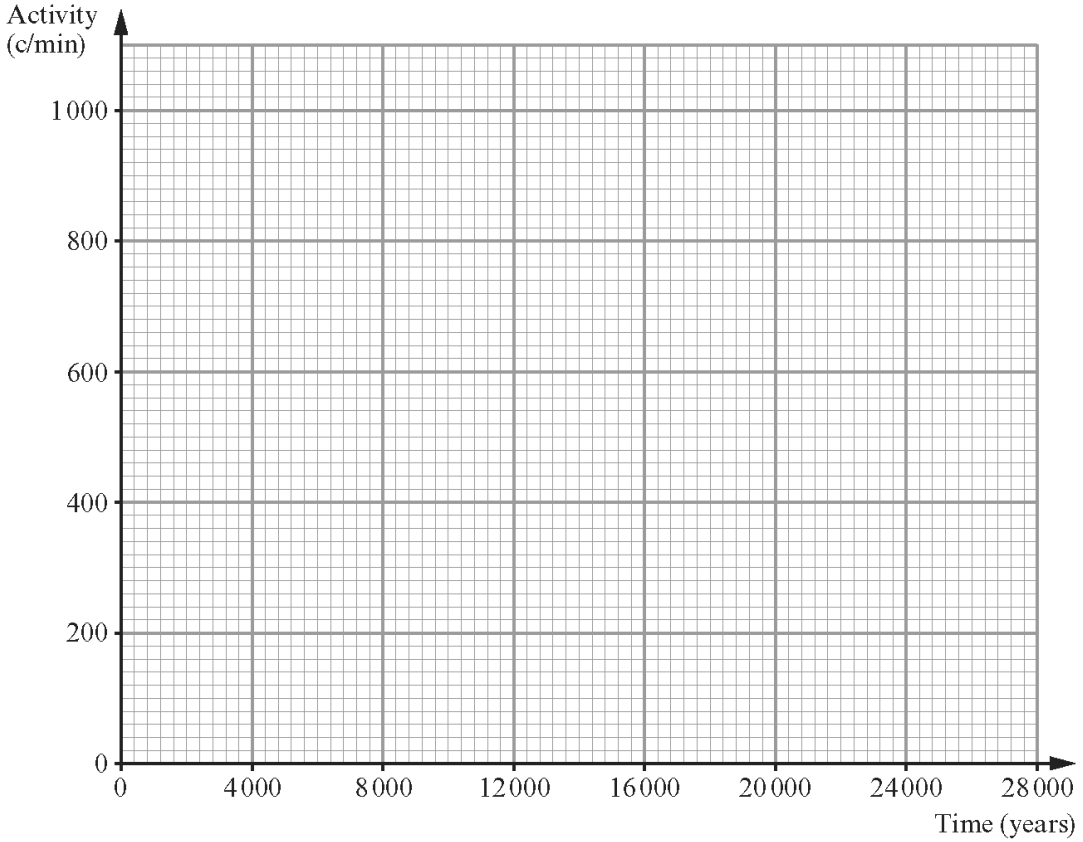
(b) The activity of an amount of carbon-14 reduces with time in the way shown in the table below. (All values have been adjusted for background radiation.)

Time (years)	0	6000	12000	18000	24000
Activity (c/min)	800	400	200	100	50

(i) Use the information in the table to **plot a graph** on the grid below. [3]



(ii) Use the graph to give the activity from the carbon at 16000 years. [1]

Activity = ... c/min

(iii) Calculate the number of years after which carbon dating proves to be impossible. [2]

Number of years = ...

(c) (i) A sample of bone taken from a skeleton at an archaeological site gave a reading of 32 c/min. An identical mass of bone in a living animal gives a reading of 80 c/min. Use the graph to find the age of the skeleton. [1]

Age = ... years

(ii) State the method you used to arrive at your answer and show it on the graph. [2]

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12

3. A smoke detector works as follows:

- It uses a radioactive source that emits alpha particles.
- The alpha particles ionise the air inside the detector causing an electric current.
- Any smoke getting into the detector absorbs the alpha particles and changes the current.
- The change in current sets off the alarm.

(a) (i) What is an alpha particle? ..... [1]

(ii) Explain why the detector would not work if the radioactive source emitted gamma rays only. [2]

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(iii) Explain why, in normal use, the radioactive source in the detector is not a risk to human health. [2]

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(b) Americium-241 has a half-life of 432 years. Curium-242 has a half-life of 160 days. Both isotopes are alpha emitters.

(i) Explain why Americium-241 is more suitable for use in the smoke detector than Curium-242. [2]

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(ii) An average smoke detector contains about 0.4 micrograms (μg) of Americium-241 which has an initial activity of 52 000 units.

(I) Name the unit of activity. ..... [1]

(II) Calculate how long it will take for the activity to drop to 26 000 units. [2]

Time = ... years

(III) Calculate the mass of Americium-241 remaining after 864 years. [2]

Mass remaining = ... μg

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4.

Isotopes of iodine can be used to study the thyroid gland in the body.

A small amount of the radioactive isotope is injected into a patient and the radiation is detected outside the body. Two isotopes that could be used are $^{123}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$.

(a) Answer the following questions in terms of the numbers of particles.

(i) State **one** similarity between the nuclei of $^{123}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$. [1]

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.....

(ii) State **one** difference between the nuclei of $^{123}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$. [1]

.....

.....

(b) The nucleus of $^{131}_{53}\mathrm{I}$ decays into xenon (Xe) by giving out beta (β) and gamma (γ) radiation.

(i) What is beta radiation? [1]

.....

(ii) Complete the equation below to show the decay of Iodine-131 (I-131). [2]

$$^{131}_{53}\mathrm{I} \longrightarrow {}^{\ldots\ldots}_{54}\mathrm{Xe} + {}^{0}_{\ldots\ldots}\beta + \gamma$$

(c) The isotope $^{123}_{53}\mathrm{I}$ decays by gamma emission. Explain why it is better to use $^{123}_{53}\mathrm{I}$ than $^{131}_{53}\mathrm{I}$ as a medical tracer. [2]

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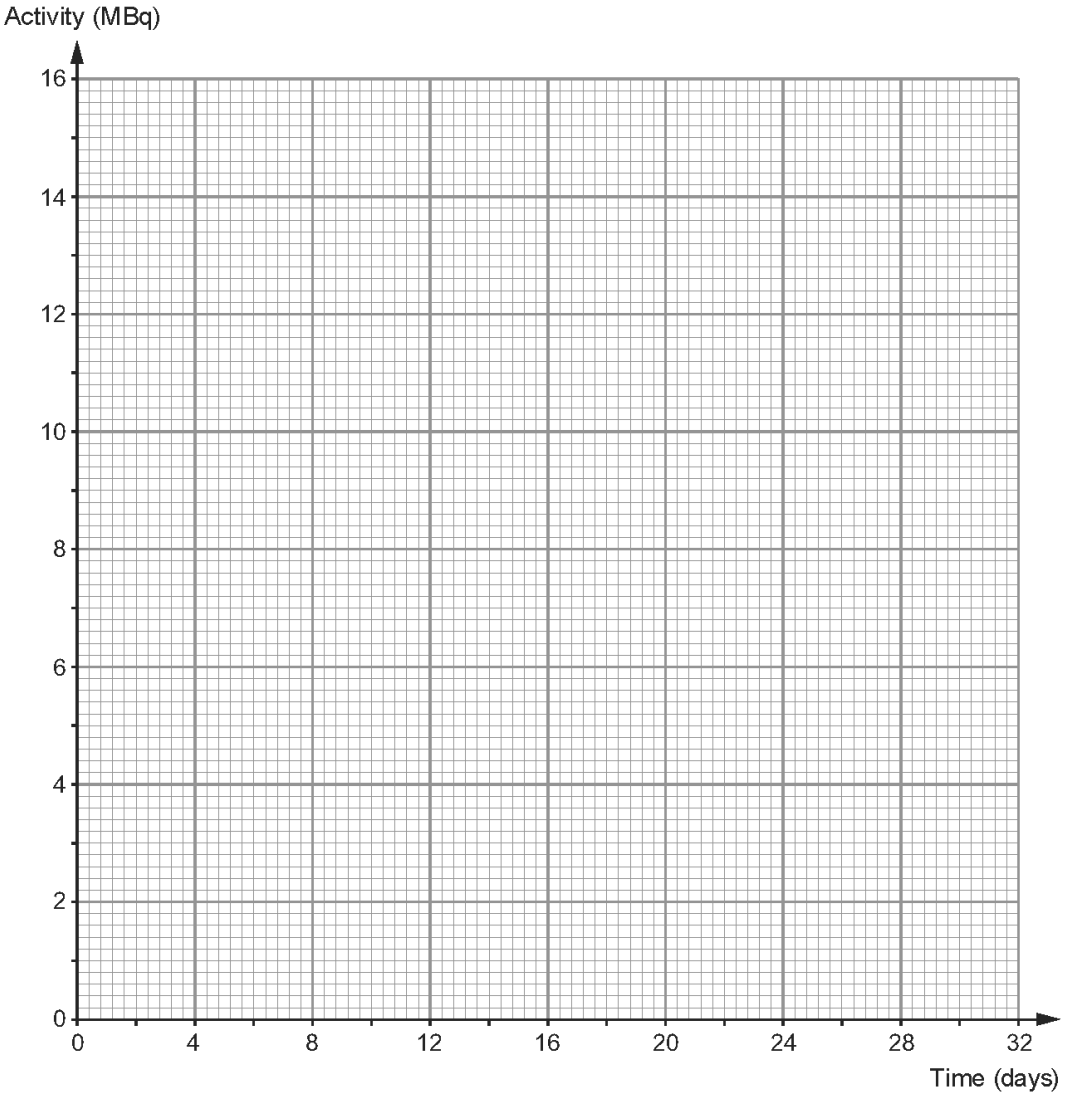
(d) (i) Iodine-131 has a half-life of 8 days. A sample has an initial activity of 16 MBq. Plot the data on the grid and draw a suitable line to show how the activity changes over 32 days. [3]

Time (days)	0	8	16	24	32
Activity (MBq)	16	8	4	2	1



(ii) **Draw lines** on the graph to find the time it takes for the activity to fall from 12 MBq to 3 MBq. Comment on your answer. [2]

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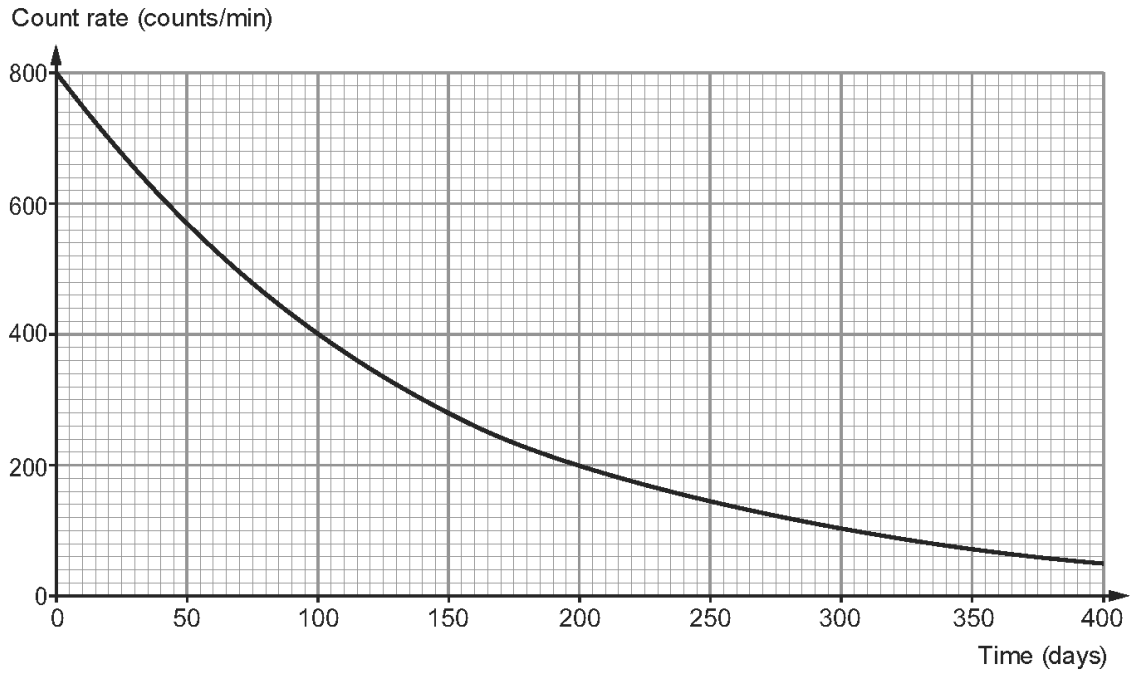
5.

(a) Put ticks (✓) in the boxes that correctly give the meaning of the **half-life** of a radioactive substance. [2]

The time taken for the radioactivity to halve.	
The time taken for the atoms to split in half.	
The time taken for the number of undecayed particles to halve.	
The time taken for the count rate to halve.	
The time taken for half of the alpha particles to decay.	

(b) The following graph shows the decay curve for a radioactive substance.



(i) Use information from the graph on page 6 to write down the count rate after 100 days. [1]

count rate = ... counts/min

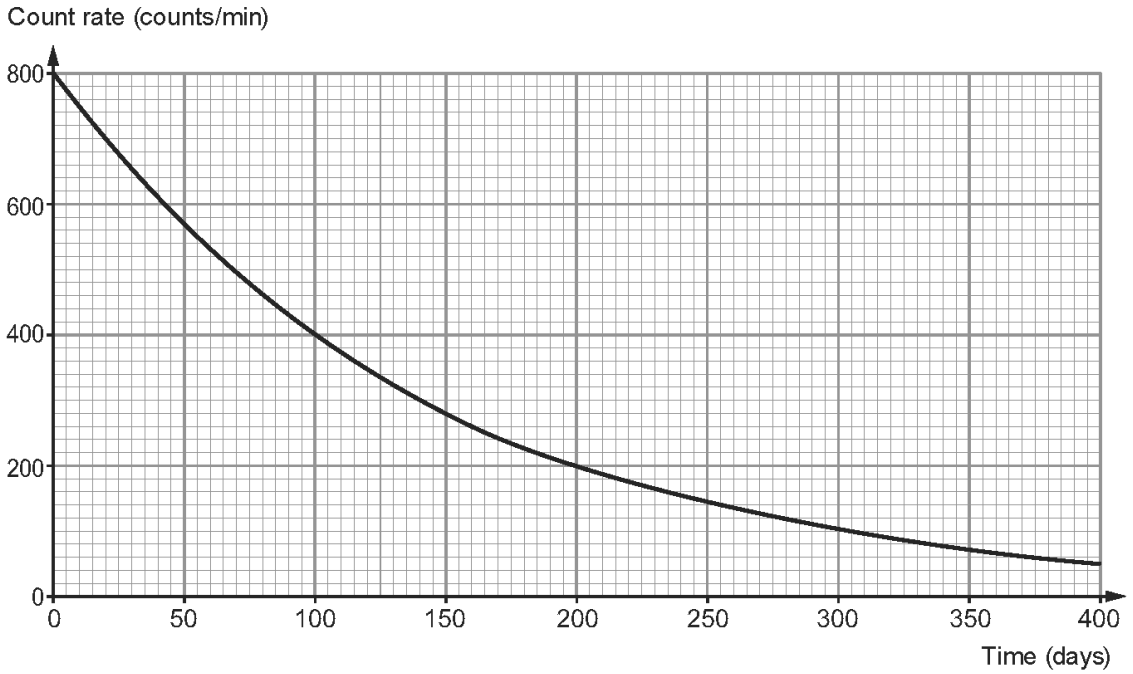
(ii) Write down the half-life of this radioactive substance. [1]

half-life = ... days

(iii) Write down the time it would take for the count rate to fall from 50 to 25 counts/min. [1]

time = ... days

(iv) Draw a decay curve on the grid **below** for a radioactive substance that has a starting count rate of 800 counts/min and a shorter half-life than the one shown. [1]



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6. The table below shows information about some radioisotopes.

Radioisotope	Half-life	Method of decay
Tellurium-133	12 minutes	beta
Astatine-211	7.2 hours	alpha
Cobalt-60	5 years	beta and gamma
Caesium-137	30 years	beta
Americium-241	432 years	alpha

(a) Using the information in the table, select the most suitable radioisotope for the tasks below, and give reasons for your choice. [4]

(i) Treating cancer by injecting the radioisotope directly into the tumour.

Name of radioisotope: .....

Reasons:

I. .....

.....

II. .....

.....

(ii) To sterilise packaged surgical instruments.

Name of radioisotope: .....

Reasons:

I. .....

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II. .....

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(b) A sample of tellurium-133 has an initial activity of 288 Bq.

(i) How many half-lives occur in 1 hour? ..... [1]

(ii) Calculate the activity of the sample after 1 hour. [2]

activity = ... Bq

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7. A student does an experiment with **dice** to investigate **radioactive decay**. The dice, which represent radioactive atoms, are thrown together onto the floor. Those that show a **six** are removed. These represent the atoms whose nuclei have decayed. The remaining dice (undecayed atoms) are thrown again and the process is repeated several times.

The student starts with **600** dice.

(a) (i) Predict how many of the dice would show a "six" on the first throw. [1]

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(ii) State why the student cannot predict **which** dice will show a "six". [1]

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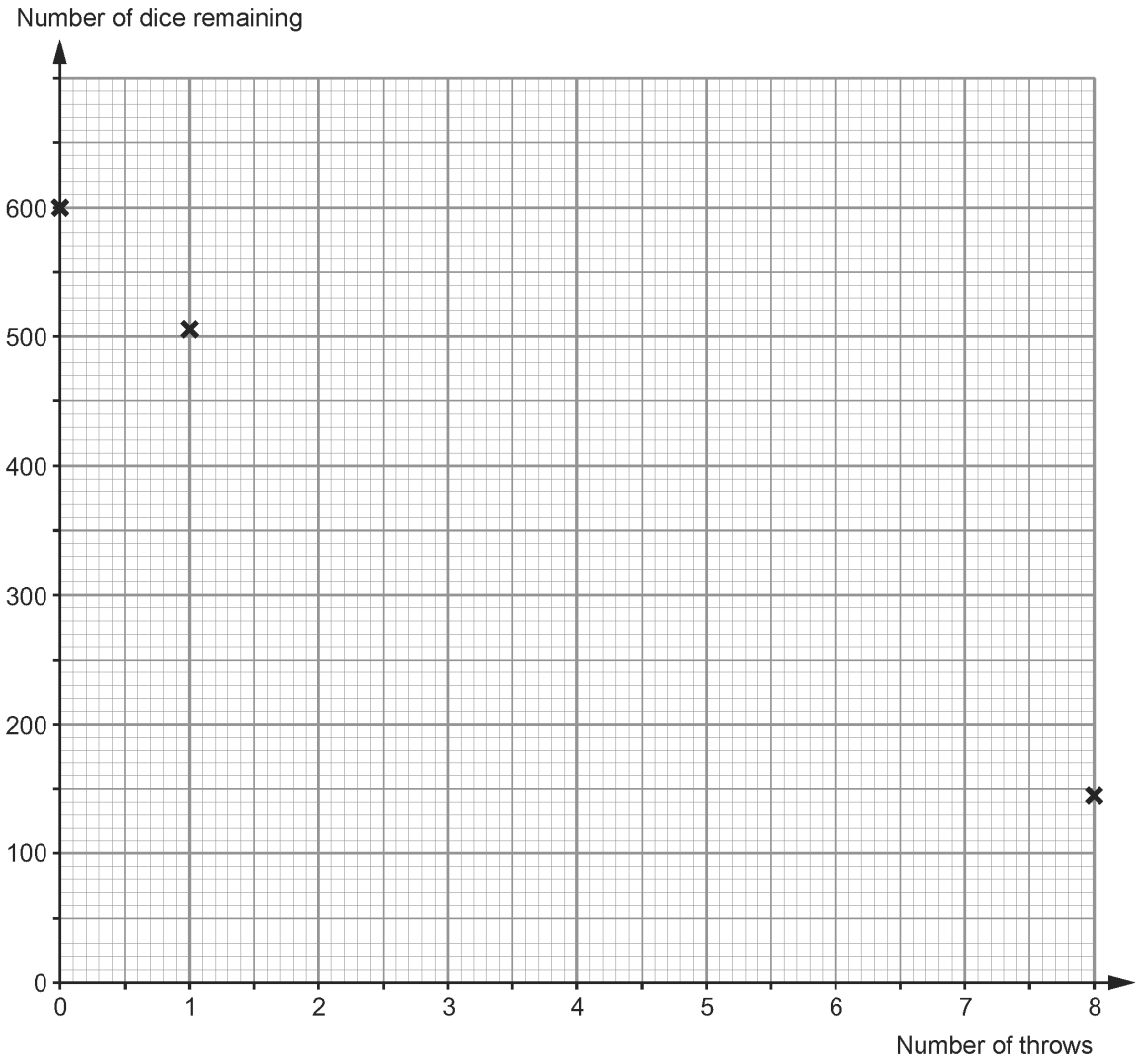
(b) The results of the experiment are shown in the table below.

Throw	Number of sixes	Number of dice remaining
0	0	600
1	95	505
2	85	420
3	.....	350
4	60	290
5	50	240
6	40	200
7	30	170
8	25	145

(i) **Fill in the gap** in the table above. [1]

(ii) Plot the results on the grid below and draw a suitable line. [3]
Three points have been plotted for you.



(iii) **Draw lines on to your graph** to enable you to find the **half-life** of the dice. [2]

half-life of dice = ... throws

(c) Americium-241 is a radioactive substance which is used in smoke alarms in houses. It decays by emitting alpha particles.

(i) State why Americium-241 is radioactive. [1]

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(ii) What is an alpha particle? [1]

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(iii) Explain why the use of Americium-241 in house smoke alarms when in normal use, does not present a significant health risk to people living in the houses. [2]

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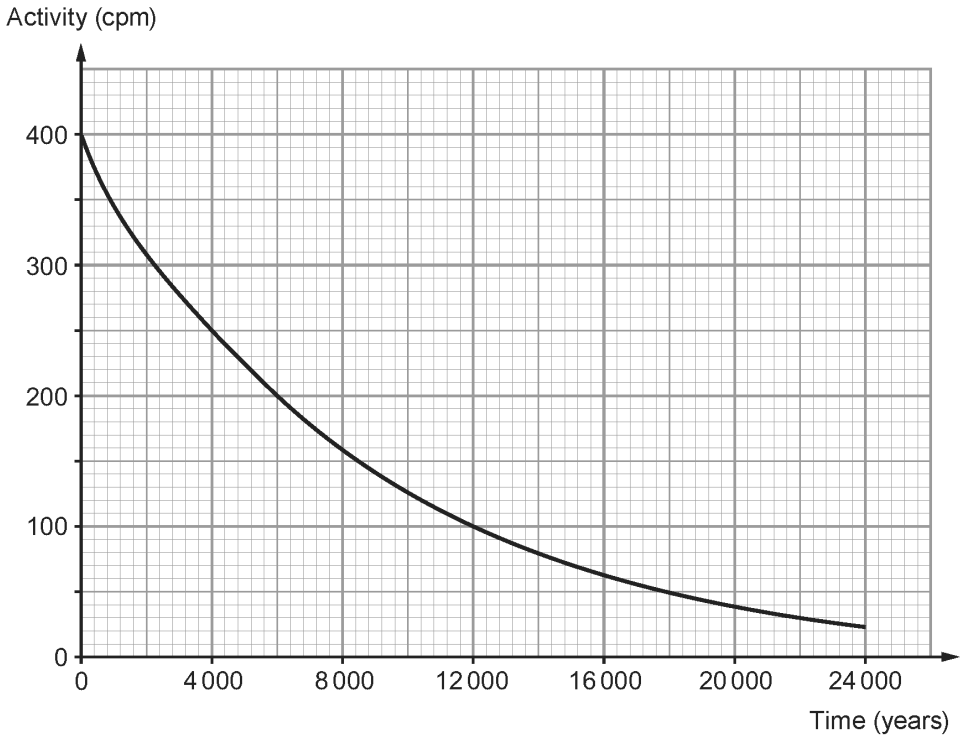
8. The graph below shows the radioactive decay in counts per minute (cpm) of a sample of carbon-14.



(a) (i) Use information from the graph to answer the following questions.

(I) State the activity after 4 000 years. [1]

activity = ... cpm

(II) State the time taken for the activity to fall from 400 cpm to 100 cpm. [1]

time = ... years

(III) State the half-life of carbon-14. [1]

half-life = ... years

(ii) State the time it would have taken for the activity to have fallen from 800 cpm to 400 cpm. [1]

time = ... years

(b) The nuclear symbol for carbon-14 is ${}^{14}_{6}\mathrm{C}$. **Complete** the following table for the nucleus of carbon-14. [3]

Nucleon number	
Number of protons in its nucleus	
Number of neutrons in its nucleus	

9. Radioactive substances are used in a wide variety of applications, which range from medical to industrial, commercial and research.

(a) The list below shows information about some radioisotopes of cobalt and iodine.

- Iodine-123 has a half-life of 13 hours and emits gamma.
- Iodine-125 has a half-life of 59 days and emits gamma.
- Iodine-127 is stable.
- Iodine-129 has a half-life of 1.6 years and emits beta.

- Cobalt-55 has a half-life of 17.3 hours and emits beta.
- Cobalt-58 has a half-life of 70 days and emits beta.
- Cobalt-59 is stable.
- Cobalt-60 has a half-life of 5.3 years and emits both beta and gamma.

Radioactive isotopes are used widely in many medical applications. In treating brain tumours, patients are exposed to an **external** cobalt source of radiation to kill cancerous cells. To check the behaviour of the thyroid gland, patients swallow a liquid containing a radioactive **tracer** of iodine.
From the list above select **one** isotope that is suitable to be used for treating brain tumours and **one** that is to be used as a radioactive tracer. Explain the reasoning for your choice of each. [6 QWC]

(b) Radioactive isotopes are also used in other applications. Americium-241 is a radioactive isotope which is used in smoke detectors. It decays into neptunium by giving out an alpha particle ($^{4}_{2}He$).

(i) Complete the decay equation below. [2]

$$^{241}_{\ldots\ldots}Am \longrightarrow {}^{\ldots\ldots}_{93}Np + {}^{4}_{2}He$$

(ii) Explain why the radiation from a smoke detector presents no danger to people living in a house. [2]

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10. A student does an experiment with **dice** to investigate **radioactive decay**. The dice, which represent radioactive atoms, are thrown together onto the floor. Those that show a **six** are removed. These represent the atoms whose nuclei have decayed. The remaining dice (undecayed atoms) are thrown again and the process is repeated several times.

The student starts with **600** dice.

(a) (i) Predict how many of the dice would show a "six" on the first throw. [1]

.....

(ii) State why the student cannot predict **which** dice will show a "six". [1]

.....

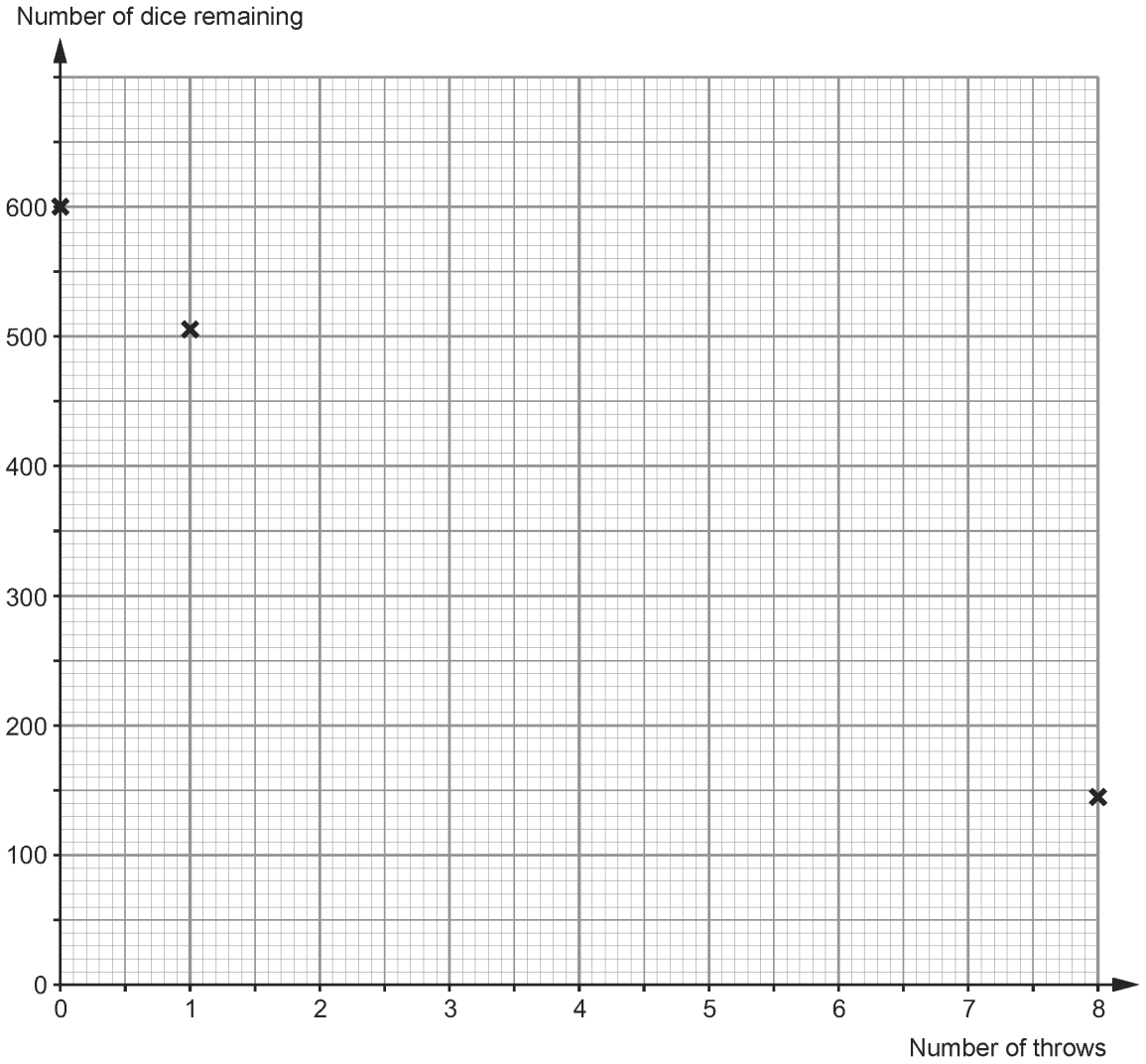
.....

(b) The results of the experiment are shown in the table below.

Throw	Number of sixes	Number of dice remaining
0	0	600
1	95	505
2	85	420
3	.....	350
4	60	290
5	50	240
6	40	200
7	30	170
8	25	145

(i) **Fill in the gap** in the table above. [1]

(ii) Plot the results on the grid below and draw a suitable line. [3]
Three points have been plotted for you.



(iii) **Draw lines on to your graph** to enable you to find the **half-life** of the dice. [2]

half-life of dice = ... throws

(c) Americium-241 is a radioactive substance which is used in smoke alarms in houses.
It decays by emitting alpha particles.

(i) State why Americium-241 is radioactive. [1]

.....

.....

(ii) What is an alpha particle? [1]

.....

(iii) Explain why the use of Americium-241 in house smoke alarms when in normal use, does not present a significant health risk to people living in the houses. [2]

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11. Nuclear medicine uses radioisotopes which emit radiation from within the body. One tracer uses iodine, which is injected into the body to treat the thyroid gland. The table shows four isotopes of iodine.

Form of iodine	Radiation emitted	Half-life
iodine-125	gamma	59.4 days
iodine-128	beta	25 minutes
iodine-129	beta and gamma	15 000 000 years
iodine-131	beta and gamma	8.4 days

(a) Iodine-129 emits both beta and gamma radiation. Describe the nature of these types of radiation. [2]

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(b) The table shows that the half-life of iodine-125 is 59.4 days. State what this means. [2]

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(c) (i) Use the data to explain why iodine-131 is the most suitable form of iodine for treating thyroid cancer. [2]

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(ii) Patients are advised that after treatment with iodine-131, the radiation they are exposed to will not drop to the background value until 12 weeks after treatment. Calculate the fraction of radioactivity due to iodine-131 remaining after 12 weeks. [3]

fraction remaining = ...

12. *(a)* State what the term "half-life of a radioactive substance" means. [2]

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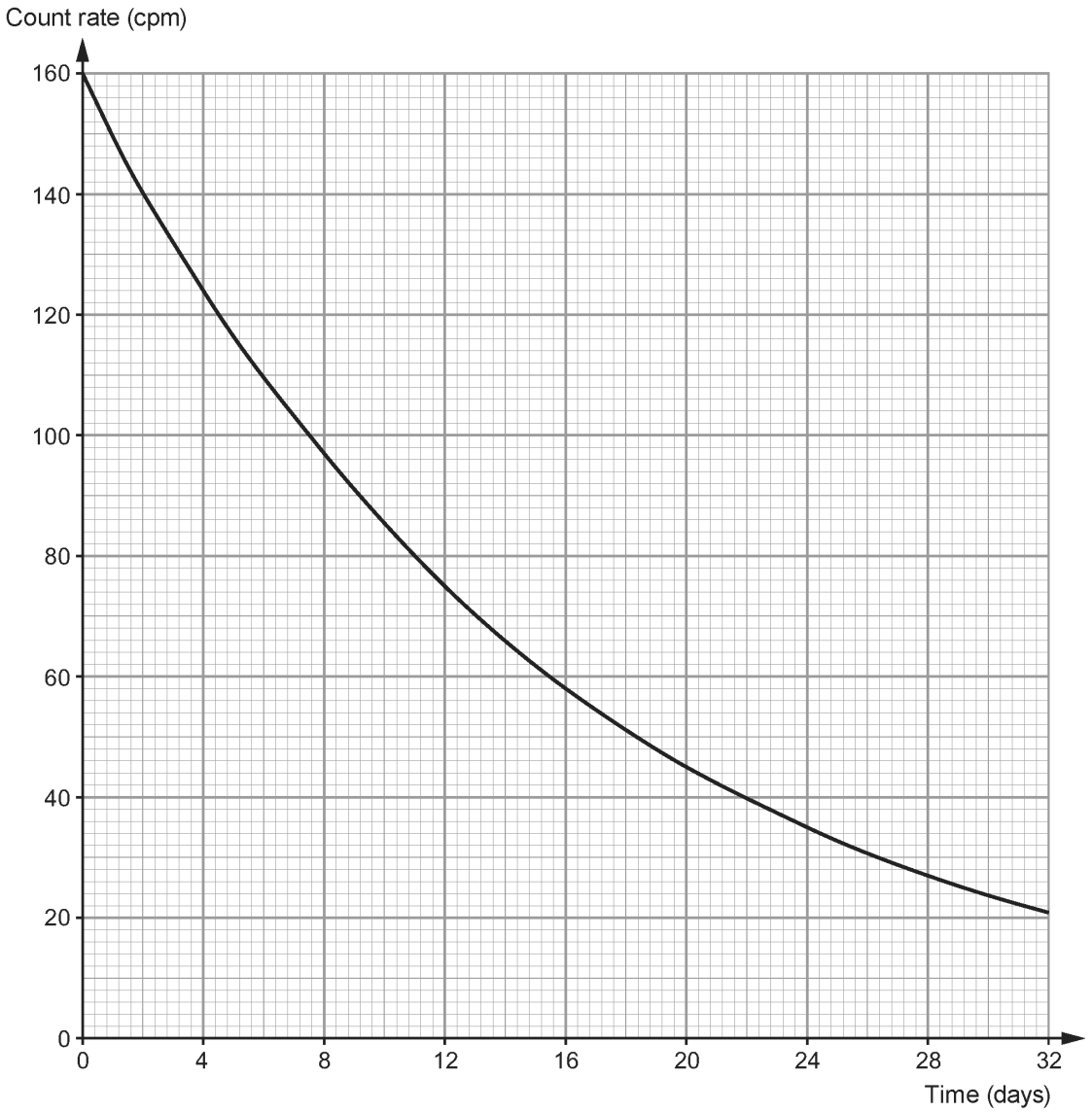
The graph below shows how the count rate in counts per minute (cpm) changes with time for a sample of a radioactive substance.



(b) **Draw lines on the graph** to show how to find the half-life of this radioactive substance and write down its value. [2]

half-life = ... days

(c) Describe **how you would use this graph** to find the time taken for the activity of a different sample of the same substance to fall from 2400 cpm to 1000 cpm. [2]

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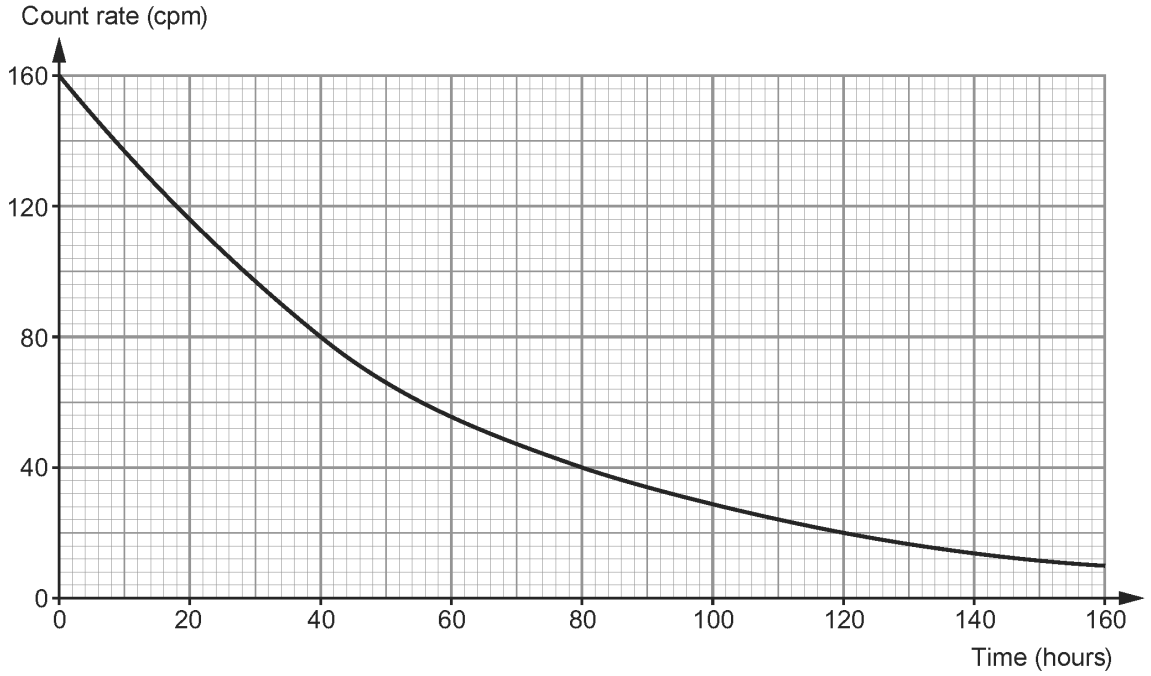
13. *(a)* Draw lines to join each statement on the left with its correct description on the right. [3]

alpha particle	slow moving neutron
beta particle	electromagnetic wave
gamma ray	fast moving electron
	helium nucleus

(b) The graph below shows the decay curve for a radioactive substance.



(i) Use information from the graph to find the count rate after 40 hours. [1]

count rate = ... cpm

(ii) State the value of the half-life. [1]

half-life = ... hours

(iii) Calculate the time it would have taken for the count rate to fall from 3200 to 800 cpm. [1]

time = ... hours

(iv) **On the grid** opposite, draw a decay curve for a substance that has a longer half-life than the one shown and with the same initial count rate. [1]

14. A smoke detector works as follows:

- It uses a radioactive source that emits alpha particles.
- The alpha particles ionise the air inside the detector causing an electric current.
- Any smoke getting into the detector absorbs the alpha particles and changes the current.
- The change in current sets off the alarm.

(a) (i) What is an alpha particle? ..... [1]

(ii) Explain why the detector would not work if the radioactive source emitted gamma rays only. [2]

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(iii) Explain why, in normal use, the radioactive source in the detector is not a risk to human health. [2]

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(b) Americium-241 has a half-life of 432 years. Curium-242 has a half-life of 160 days. Both isotopes are alpha emitters.

(i) Explain why Americium-241 is more suitable for use in the smoke detector than Curium-242. [2]

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(ii) An average smoke detector contains about 0.4 micrograms (μg) of Americium-241 which has an initial activity of 52 000 units.

(I) Name the unit of activity. ..... [1]

(II) Calculate how long it will take for the activity to drop to 26 000 units. [2]

Time = ... years

(III) Calculate the mass of Americium-241 remaining after 864 years. [2]

Mass remaining = ... μg

12

15. Isotopes of iodine can be used to study the thyroid gland in the body.

A small amount of the radioactive isotope is injected into a patient and the radiation is detected outside the body. Two isotopes that could be used are $^{123}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$.

(a) Answer the following questions in terms of the numbers of particles.

(i) State **one** similarity between the nuclei of $^{123}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$. [1]

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.....

(ii) State **one** difference between the nuclei of $^{123}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$. [1]

.....

.....

(b) The nucleus of $^{131}_{53}\mathrm{I}$ decays into xenon (Xe) by giving out beta (β) and gamma (γ) radiation.

(i) What is beta radiation? [1]

.....

(ii) Complete the equation below to show the decay of Iodine-131 (I-131). [2]

$$^{131}_{53}\mathrm{I} \longrightarrow {}^{\ldots\ldots}_{54}\mathrm{Xe} + {}^{0}_{\ldots\ldots}\beta + \gamma$$

(c) The isotope $^{123}_{53}\mathrm{I}$ decays by gamma emission. Explain why it is better to use $^{123}_{53}\mathrm{I}$ than $^{131}_{53}\mathrm{I}$ as a medical tracer. [2]

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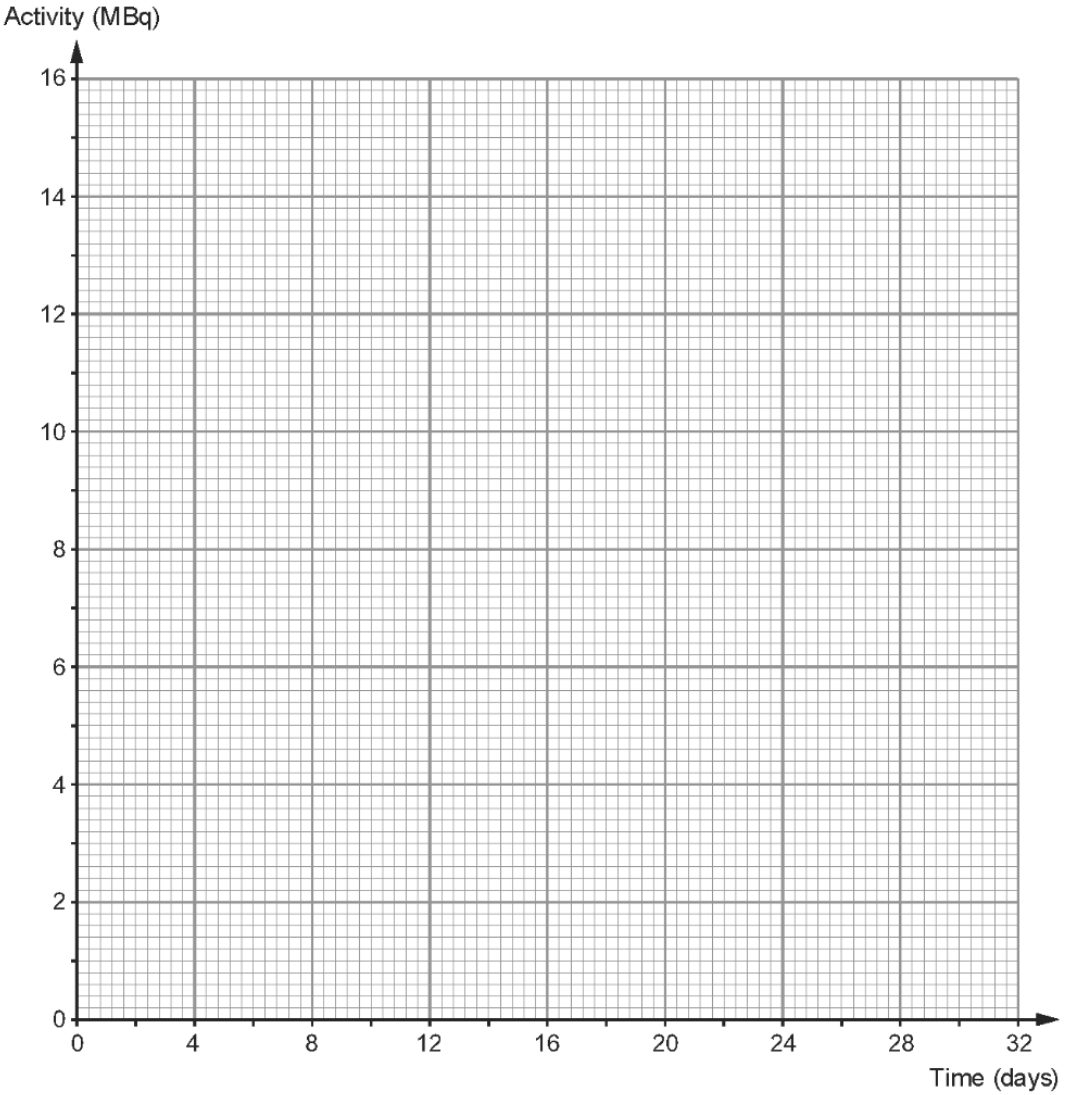
(d) (i) Iodine-131 has a half-life of 8 days. A sample has an initial activity of 16 MBq. Plot the data on the grid and draw a suitable line to show how the activity changes over 32 days. [3]

Time (days)	0	8	16	24	32
Activity (MBq)	16	8	4	2	1



(ii) **Draw lines** on the graph to find the time it takes for the activity to fall from 12 MBq to 3 MBq. Comment on your answer. [2]

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12

16. A class of students were using dice to model radioactive decay.

- There were 8 groups of students.
- Each group of students had 50 dice.
- The 50 dice were rolled.
- Any that landed with a 6 facing upwards were removed.
- The remaining dice were counted.
- The remaining dice were rolled again and again, taking away the 6's each time.
- The table shows the results from one group and from the whole class.

Roll number	Number of dice remaining	
	One group's results	Class results
0	50	400
1	42	330
2	37	280
3	28	230
4	26	190
5	22	160
6	18	130
7	13	110
8	5	90

(a) Each group's results were added together to give the class results. Give **one** reason why the bigger sample size makes the data more repeatable. [1]

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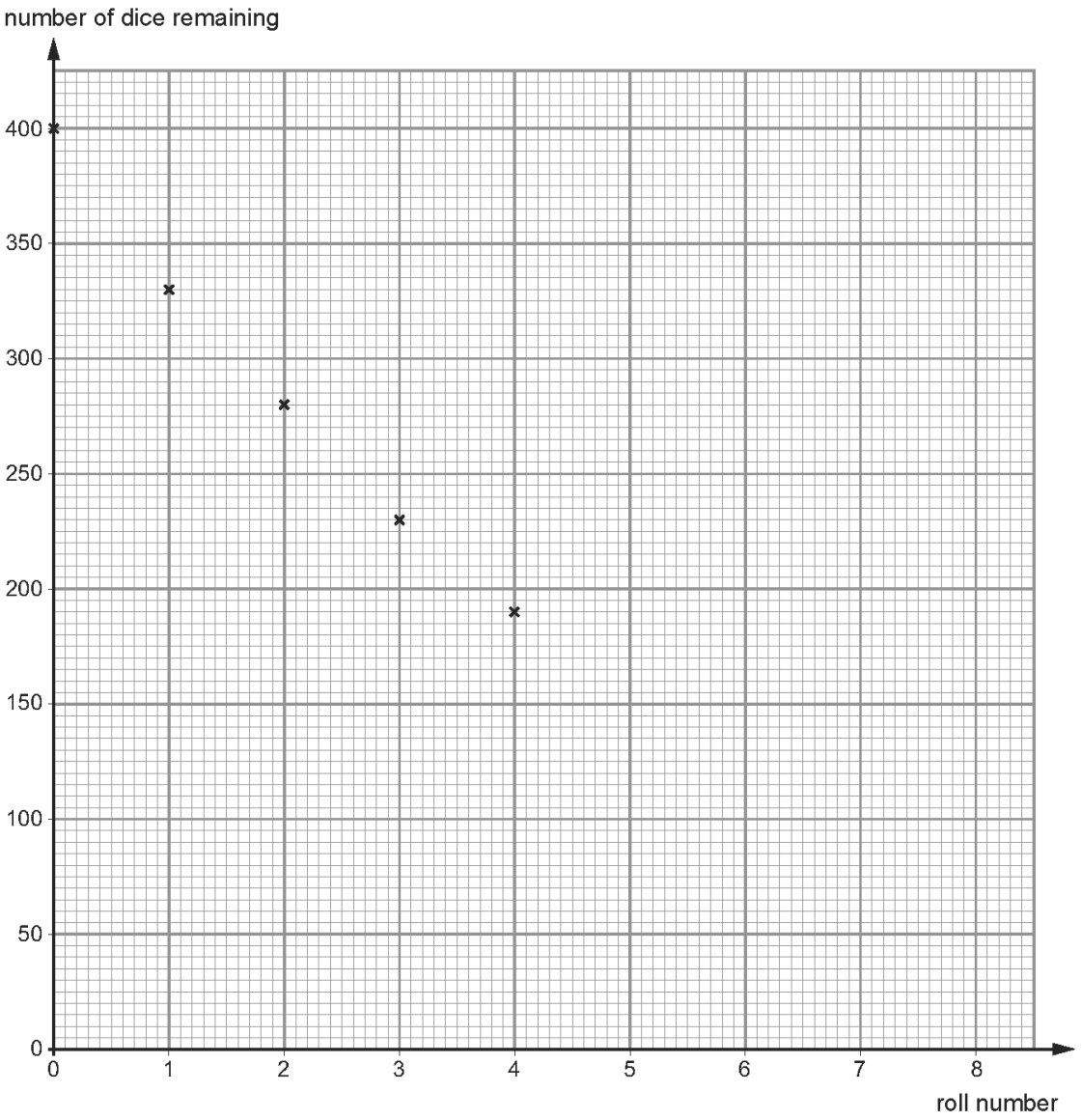
(b) The graph shows part of the data from the whole class.
Plot the remaining data and draw a suitable line. [3]



(c) The "half-life" for this modelled decay is the number of rolls needed for the number of dice to halve. *(The number of rolls will include fractions.)*

(i) Use the class results in the table on page 10 to estimate the half-life. [1]

half-life = ... rolls

(ii) Now use the graph to find the half-life. Show the method you use on the graph. [2]

half-life = ... rolls

(iii) Suggest why it is better to use the graph than the table to estimate the half-life. [1]

.....

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(iv) Use the graph to find how many rolls it took for the number of dice to fall to $\frac{1}{4}$ of the original value. Comment on your answer. [2]

number of rolls = ...

.....

.....

(d) An experiment was carried out to obtain similar data using the radioactive isotope, protactinium 234, which is a beta emitter. The **initial count** rate was measured to be 80 counts per second. After 210 s the count rate had dropped to 10 counts per second.

(i) Find the half-life of protactinium 234. [2]

half-life = ... s

(ii) Calculate how long it would take for the count rate to drop from 80 to 2.5 counts per second. [2]

time taken = ... s

(iii) State the unit of activity of a radioactive source. [1]

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17. Living animals take in small amounts of radioactive carbon-14. After death, the amount of carbon-14 in their bodies decreases, because the carbon-14 atoms decay. The amount of carbon-14 remaining in the bones of an animal's skeleton can be used to estimate its age.

Carbon-14 is a beta emitter, with a half-life of 5720 years.

(a) State what is meant by the following statements: [3]

(i) carbon-14 is a beta emitter;

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(ii) carbon-14 has a half-life of 5720 years.

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(b) Complete the decay equation for carbon-14 shown below. [3]

$$^{14}_{6}C \rightarrow \overset{\cdots\cdots}{\cdots\cdots}N + \overset{\cdots\cdots}{\cdots\cdots}e$$

(c) (i) A bone taken from a skeleton, found at an archaeological site, contains 10 units of carbon-14. An identical bone in a living animal contains 160 units of carbon-14. Use your understanding of half-life to calculate the age of the skeleton. [2]

age = ... years

(ii) Explain why this method of calculating the age of bones is unreliable for skeletons believed to be less than 100 years old. [2]

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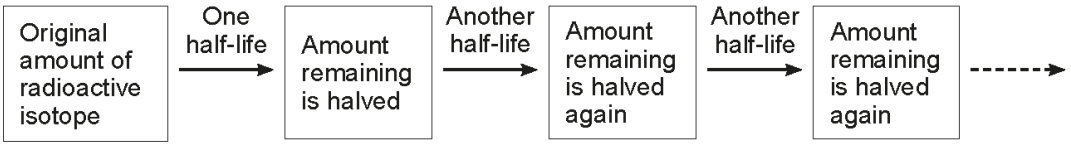
10

18.

The mass of a sample of a radioactive isotope is 64 g and it has a count rate of 800 counts per minute. It is a gamma emitter.

It has a half-life of 30 minutes.

Radioactive decay follows the pattern below:



(a) (i) Find out how many half-lives it takes for the count rate to fall to 50 counts per minute. [1]

.....

(ii) How long does it take for the count rate to fall to 50 counts per minute? [2]

time = ...

unit .....

(iii) What mass of the radioactive isotope remains at this time? [1]

mass = ... g

(b) Explain why this radioactive isotope would be suitable as a radioactive tracer in medicine. [2]

.....

.....

.....

6

19.

All living material takes in carbon-14 (C-14) which is radioactive and decays by beta emission. It has a half-life of 6000 years and is used in carbon dating which tells us the age of some old fossils. The age of things that died more than **10 half-lives** in the past cannot be accurately measured as the amount of C-14 present is too small.

(a) (i) State what you understand by the statement "the half-life of carbon-14 is 6000 years". [1]

.....

.....

(ii) Explain how carbon-14 decays by beta emission. [2]

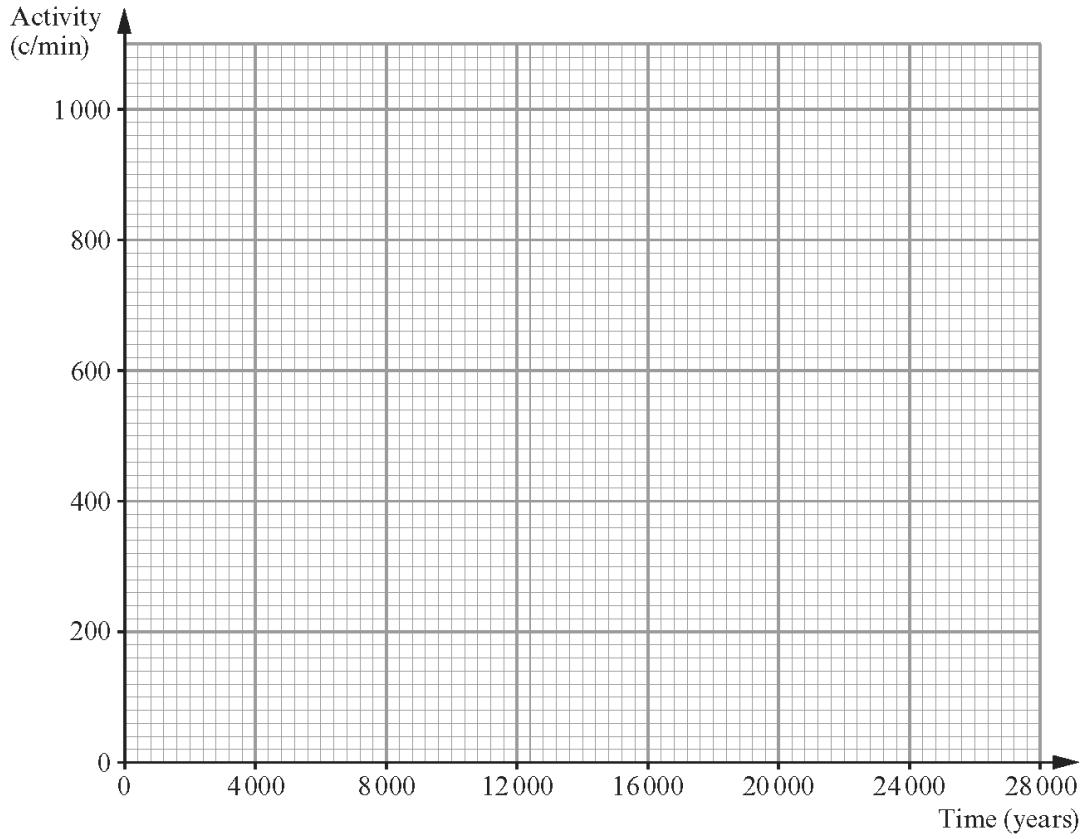
.....

.....

(b) The activity of an amount of carbon-14 reduces with time in the way shown in the table below. (All values have been adjusted for background radiation.)

Time (years)	0	6000	12000	18000	24000
Activity (c/min)	800	400	200	100	50

(i) Use the information in the table to **plot a graph** on the grid below. [3]



(ii) Use the graph to give the activity from the carbon at 16000 years. [1]

Activity = ... c/min

(iii) Calculate the number of years after which carbon dating proves to be impossible. [2]

Number of years = ...

(c) (i) A sample of bone taken from a skeleton at an archaeological site gave a reading of 32 c/min. An identical mass of bone in a living animal gives a reading of 80 c/min. Use the graph to find the age of the skeleton. [1]

Age = ... years

(ii) State the method you used to arrive at your answer and show it on the graph. [2]

.....

.....

12

20. Plutonium-238 is a radioactive isotope of plutonium that has a half-life of 88 years. Plutonium-238 emits an alpha particle as it decays into an isotope of uranium (U). It does not emit significant amounts of other radiation. This makes the plutonium-238 isotope suitable for use in radioisotope thermoelectric generators (RTG) which are used to power unmanned spacecraft. One gram (1 g) of plutonium-238 generates approximately 0.5 W of thermal power.

(a) (i) **Complete** the following decay equation for plutonium-238. [3]

$$^{238}_{94}\mathrm{Pu} \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{U} + {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{He}$$

(ii) Describe the structure of a plutonium-238 nucleus. [2]

.....

.....

.....

(iii) Describe how a RTG is different to a nuclear fission reactor. [3]

.....

.....

.....

.....

.....

(b) One spacecraft contains 5.2 kg of plutonium-238 at launch. It will function until the power produced by the RTG drops below 325 W.

(i) Calculate the maximum time the spacecraft could function normally. [4]

time = ... years

(ii) The radiation emitted by the plutonium-238 in the spacecraft will be less than background radiation after 440 years. Calculate the fraction of plutonium remaining at this time. [2]

fraction = ...

(c) Once the plutonium-238 is placed inside the RTG then the engineers working on the spacecraft do not need to take precautions to protect themselves from radiation. Explain why this is the case. [2]

.....

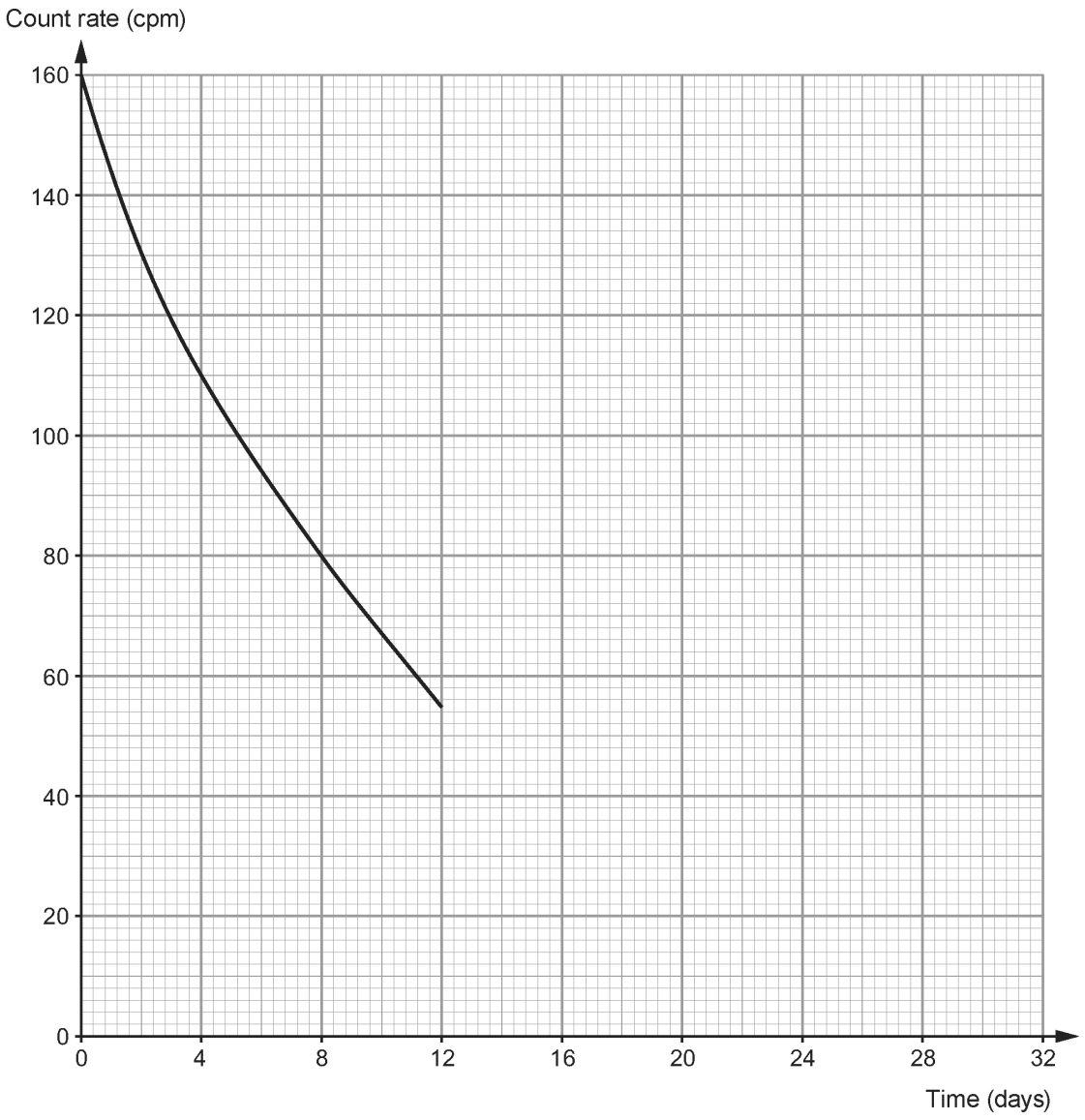
.....

.....

21. *(a)* Complete the following sentence. [1]

Half-life is the time taken for ..... to halve.

(b) The graph below shows how the count rate in counts per minute (cpm) changes with time for a sample of a radioactive substance.



(i) Use the data in the table to **complete the graph**. [2]

Time (days)	16	20	24	32
Count rate (cpm)	40	28	20	10

(ii) Use the graph to find the count rate after 4 days. [1]

count rate = ... cpm

(iii) Use the graph to find the count rate after 12 days. [1]

count rate = ... cpm

(iv) State the half-life of the radioactive substance. [1]

half-life = ... days

Marking Scheme

1.

Question			Marking details	Marks
1.	(a)		To smooth out random fluctuations in data / even out variations / reduces [the effect of] anomalies **Accept** less anomalies / odd results / closer estimate **Do not accept** prevents anomalies / more reliable / more accurate	1
	(b)		Plots (allow ± ½ small square division) (2) -1 for each error to a maximum of 2. Smooth curve of best fit drawn from last given point (4 rolls) onwards but must encompass all points (1)	3
	(c)	(i)	About 4 [rolls]. Accept any x where $4 > x > 3.6$ inclusive	1
		(ii)	Method shown on grid (1)[line across or down probably at 200] ~3.8 [rolls] (1-value taken from their graph ± 0.1)	2
		(iii)	Allows (more) <u>precise / accurate</u> value to be obtained / to nearest 0.1 of a roll **Accept** graph is more accurate **Don't accept** exact value / more reliable value	1
		(iv)	7.6 (1-value taken from graph ± 0.1) value is approximately 2 half-lives (1) **Don't accept** ¼ of original value	2
	(d)	(i)	Identifying 3 half-lives (1) $\frac{210}{3}$ = 70 [s] (1-ans) **Don't accept** 80→40→20→10 without any qualification	2
		(ii)	5 half-lives required (1) 5×70(**ecf**) = 350 [s] (1)	2
		(iii)	becquerel, **accept** bq, Bq, any reasonable spelling	1
			Question total	**[15]**

2.

Question			Marking details	Mark
1.	(a)	(i)	The time/how long it takes/it takes 6000 years for half of the undecayed atoms/mass/amount/activity/count rate to fall by half.	1
		(ii)	The **nucleus** emits/loses (1) an **electron** (1) OR identifies the nucleus (1) in which neutron splits into proton and electron (1) **Either mark can be awarded on its own but only award 2 marks if they are linked.**	2
	(b)	(i)	plots correct (2) [lose 1 for each incorrect plot allow ± ½ small square division up to a maximum of 2 marks] reasonable curve through the points (1)	3
		(ii)	Value to be taken from candidate's graph ±10 [About 130]. Credit an answer of between 120-140 when no line is drawn.	1
		(iii)	10 (1) **x 6 000** (1) = [60 000 years]	2
	(c)	(i)	7 400 years (value to be taken from candidate's graph)(1)	1
		(ii)	reduce activities from the graph by a factor of 10 (1), line from 320 on graph to find time (1) or converse, (or reference to) lines drawn on graph at 320 (and down to the time axis). **Alternative -** for an extended graph and lines drawn at 80 (1) and "32" drawn on an extended line (1), award both marks for method either explained or drawn. N.B. **No marks can be awarded for the age** because of the uncertainty in this method.	2
			Question total	**[12]**

3.

Question			Answer / Explanatory Notes	Marks Available
6.	*(a)*	(i)	Helium nucleus/nuclei / 2 protons and 2 neutrons (accept 2p and 2n)	1
		(ii)	Gamma more penetrating [than alpha] / so would not be blocked by smoke / wouldn't change the current / weakly ionising. **Any 2 x (1) due to all points being interlinked.** **Or** gamma is more weakly ionising (1) so doesn't cause an electric current (1) (Don't accept gamma is not ionising.)	2
		(iii)	Distance between detector / ceiling and the human body (1) so / hence alpha is easily absorbed by the air / case (1) (Answer must be relevant to this context so **don't accept alpha will be blocked by skin / paper**.)	2
	(b)	(i)	Longer ½-life (1) (don't accept longer to decay) so detector stays active / works longer or doesn't need replacing [as often] (1)	2
		(ii)	I. becquerel [accept [Becquerel!] / Bq / bq	1
			II. 26 000 is half of 52 000 (1 – method) so time is one ½-life = 432 [years] (1) (Accept $\frac{52000}{2}$ as recognition of half-life – don't allow any other value divided by 2).	2
			III. $\frac{864}{432} = 2$ or 864 years is 2 ½-lives or implied (1) so ¼ of the mass remains = 0.1 [μg] (1)	2
			Question total	**[12]**

4.

Question				Marking details	Marks
7.	(a)	(i)		[Same] number (accept amount) of protons / 53 protons / [same] proton number / Don't accept: same number of protons and electrons or same atomic number or 53 or reference to the mass number being equal to 53.	1
		(ii)		[Different] number of neutrons / nucleons Accept [different] number of protons and neutrons / one has 70 neutrons and the other has 78 neutrons. Don't accept different mass numbers or 123 and 131.	1
	(b)	(i)		[fast moving / high energy] electron (accept slow electron) Don't accept positive electron.	1
		(ii)		$I \rightarrow {}^{131(1)}Xe + {}_{-1(1)}\beta + \gamma$	2
	(c)			Gamma is less ionising (1) so is easily detected outside of the body / penetrates the body or skin well / is less harmful (1). OR because beta would be more ionising (1) so is less penetrating / less likely to get out of the body / more harmful (1). OR Iodine-123 has a shorter half-life [13 hours] (1) so it decays quicker (1) don't accept escapes quicker **Either mark can be awarded on its own but only award 2 marks if they are linked.**	2
	(d)	(i)		Plots (2) allow ± ½ small square division (deduct 1 mark for each incorrect plot) smooth curve (1) allow **ecf** Don't accept double lines /whispy / thick / disjointed / wobbly lines.	3
		(ii)		Lines/points on grid from 12 and 3 to the curve or down to time axis (1) time interval of 16 [days] ± 1 [day] / equal to two half-lives (1). Apply **ecf** for the graph.	2
				Question total	**[12]**

5.

Question Number		Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
FT	HT								
2		(a)			2	Ticks in boxes 3 and 4 (2)	Crosses in boxes		Extra crosses in other boxes (minus 1 for each)
		(b)	(i)		1	400 [counts/min]			
			(ii)		1	100 [days]			
			(iii)		1	Same answer as (ii)			
			(iv)		1	Line drawn below the curve from (0,800) Allow ± one small square tolerance on (0,800) plot	Line that curves upwards at the end Line that does not extend all the way to 400		A straight line. A line that crosses / touches the one given / touches the time axis. Line on previous grid.
		Total Mark			6				

6.

Question Number FT	HT	Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
	2	(a)	(i)		2	**No credit is given for just naming the radioisotope** **Astatine** Alpha particles highly ionising **or** easily absorbed [by cancer cells] **or** would not penetrate beyond the tumour [to affect healthy cells] (1) It decays [to a safe level] quickly or equivalent (1) **Alternative solution:** **Tellurium** Beta penetrates all of the tumour (1) It decays [to a safe level] quickly or equivalent (1)	Alpha is not able to spread far [The source] won't last long in the body		**Answers for any other radioisotope** Attacks / kills the cancer cells the best. It is highly ionising. Any statement implying that it leaves the body quickly / the half-life is short.
			(ii)		2	**Cobalt / Caesium** Beta / gamma will penetrate the packaging/box **or** kills bacteria (1) It won't need replacing for a long time / it lasts a long time (1)			It has a long half-life
		(b)	(i)		1	5			
			(ii)		2	288 – 144 – 72 – 36 – 18 - 9 Process of halving from 288 (1) 5 times to arrive at 9 (1) **ecf**	Answer only of 9 **gets 2 marks**		An incorrect answer with no workings shown e.g. 18 except for 4 half-lives in (b)(i) which gets 2 marks
		Total Mark			7				

7.

	ii		1	Helium nucleus / 2 protons + 2 neutrons			helium helium atom helium ion ^4_2He
	iii		2	Alpha particles have low penetrating power (1) so, cannot get through plastic or air to reach people (1) **The 2nd mark can only be awarded if it is linked to the 1st mark.**	Alpha is highly ionising for the 1st mark Alpha can't travel far through air = 2 marks	Cannot get through the skin, paper	
Total			**12**				

	ii		1	Helium nucleus / 2 protons + 2 neutrons			helium helium atom helium ion ^4_2He
	iii		2	Alpha particles have low penetrating power (1) so, cannot get through plastic or air to reach people (1) **The 2nd mark can only be awarded if it is linked to the 1st mark.**	Alpha is highly ionising for the 1st mark Alpha can't travel far through air = 2 marks	Cannot get through the skin, paper	
Total			**12**				

8.

Question Number FT	HT	Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
		(a)	(i)	I	1	250 [cpm] ± 10			
				II	1	12 000 [years] (no tolerance)			
				III	1	6 000 [years] (no tolerance)			
			(ii)		1	**Answer must be the same as (a)(iii)** i.e. 6 000 [years]			
		(b)			3	14 - (1) 6 - (1) 8 - (1)			**ecfs** on 14 or 6
		Total			**7**				

9.

						1-2 marks The candidate makes some relevant points, such as those in the indicative content, showing limited reasoning. The answer addresses the question with significant omissions. The candidate uses limited scientific terminology and inaccuracies in spelling, punctuation and grammar. **0 marks** The candidate does not make any attempt or give a relevant answer worthy of credit.			
		(b)	(i)		2	95 (1) 237 (1)			
			(ii)		2	Radiation is alpha **or** it is alpha (1) Which is stopped by the plastic casing **or** which is stopped by air between the source and people (1) **The 2nd mark should be linked to the 1st mark.**	Source emits alpha which only travels a few cm in air (2)	Stopped by paper or skin (2nd mark)	
		Total			**10**				

						1-2 marks The candidate makes some relevant points, such as those in the indicative content, showing limited reasoning. The answer addresses the question with significant omissions. The candidate uses limited scientific terminology and inaccuracies in spelling, punctuation and grammar. **0 marks** The candidate does not make any attempt or give a relevant answer worthy of credit.			
		(b)	(i)		2	95 (1) 237 (1)			
			(ii)		2	Radiation is alpha **or** it is alpha (1) Which is stopped by the plastic casing **or** which is stopped by air between the source and people (1) **The 2nd mark should be linked to the 1st mark.**	Source emits alpha which only travels a few cm in air (2)	Stopped by paper or skin (2nd mark)	
		Total			**10**				

10.

	ii		1	Helium nucleus / 2 protons + 2 neutrons			helium helium atom helium ion $^{4}_{2}He$
	iii		2	Alpha particles have low penetrating power (1) so, cannot get through plastic or air to reach people (1) **The 2nd mark can only be awarded if it is linked to the 1st mark.**	Alpha is highly ionising for the 1st mark Alpha can't travel far through air = 2 marks	Cannot get through the skin, paper	
Total			**12**				

	ii		1	Helium nucleus / 2 protons + 2 neutrons			helium helium atom helium ion $^{4}_{2}He$
	iii		2	Alpha particles have low penetrating power (1) so, cannot get through plastic or air to reach people (1) **The 2nd mark can only be awarded if it is linked to the 1st mark.**	Alpha is highly ionising for the 1st mark Alpha can't travel far through air = 2 marks	Cannot get through the skin, paper	
Total			**12**				

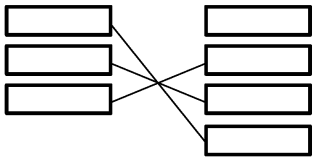
11.

Question Number FT	HT	Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
		(a)			2	beta - high energy/fast moving electron (1) gamma - electromagnetic wave (1)	em wave One is a fast moving electron and one is an em wave – award 1 mark only Beta is an electron and gamma is a wave – award 1 mark only	Properties of beta and gamma	Beta is a particle and gamma is a wave
		(b)			2	The activity/mass/number of [unstable] nuclei (1) halves [in this time / in 59.4 days] (1)	Count rate		Atoms Molecules Radiation Radioactivity
		(c)	(i)		2	It has a suitable half-life / not too long a half-life / not too short a half-life (1) so it doesn't decay [too] quickly / so it doesn't decay [too] slowly (1) **OR** Emits beta (1) which is absorbed in tumour (1) **The 1st mark must be linked to the 2nd mark.**	Relatively short Relatively long	Half-life is 8.4 days	 Gamma and beta Can't penetrate the tumour or ionises the tumour Kills cancer cells
			(ii)		3	12 weeks = 84 days (1) No. of half-lives = 10 (1) [award for method of calculating no. of half-lives] $\frac{1}{1024}$ or 0·09765% (1)	$1/2^{10}$ award 2 marks If no workings shown 10 on the answer line award 2 marks / $\frac{1}{10}$ award 1 mark Halving 131 ten times (0.1279) award 2 marks		
		Total			9				

12.

Question Number FT	**HT**	**Sub-section**			**Mark**	**Answer**	**Accept**	**Neutral answer**	**Do not accept**
		(a)			2	The time taken for the mass / number of un-decayed particles / count rate / cpm / activity / number of nuclei / number of atoms (1) to reduce by half (1)	Amount of radioactive material	Reference to named radioisotope	Size / volume Decay Radioactivity Amount Radiation Radioactive substance Atom Particles
		(b)			2	At least one construction line demonstrating halving (1) Half-life = 11 ± 0.4 [days] (1)			
		(c)			2	Convert values or graph scale by some suitable factor [draw lines across and down to find the required time interval] (1) To give a pair of stated values that fall within the range of the graph (1) Note that the lowest stated value can't be lower than 20			
		Total			**6**				

13.

Question Number		Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
FT	HT								
		(a)			3	 3 marks for all 3 lines correct 2 marks for 2 lines correct 1 mark for 1 line correct Deduct 1 mark for each extra line drawn			
		(b)	(i)		1	80 [cpm]			
			(ii)		1	40 [hours]			
			(iii)		1	2 × answer to (b)(ii) i.e. 80 [hours]			
			(iv)		1	Decay line drawn above the given line from 160 with < one small square tolerance	Line that falls short but > 80 hours	Lines may touch between 0 and 20 hours	Line touches other than between 0 and 20
		TOTAL			7				

14.

Question			Answer / Explanatory Notes	Marks Available
			Question total	**[8]**
2.	*(a)*	(i)	Helium <u>nucleus/nuclei</u> / 2 protons and 2 neutrons (accept 2p and 2n)	1
		(ii)	Gamma more penetrating than alpha / so would not be blocked by smoke / wouldn't change the current / weakly ionising. **<u>Any 2 x (1) due to all points being interlinked.</u>** **Or** gamma is more weakly ionising (1) so doesn't cause an electric current (1) (Don't accept gamma is not ionising.)	2
		(iii)	Distance between detector / ceiling and the human body (1) so / hence alpha is easily absorbed by the air / case (1) (Answer must be relevant to this context so **don't accept alpha will be blocked by skin**.)	2
	(b)	(i)	<u>Longer ½-life</u> (1) (don't accept longer to decay) so detector stays active / works longer or doesn't need replacing [as often] (1)	2
		(ii)	I. becquerel [accept [Becquerel!] / Bq / bq	1
			II. 26 000 is half of 52 000 (1 – method) so time is one ½-life = <u>432</u> [years] (1) (Accept $\frac{52000}{2}$ as recognition of half-life – don't allow any other value divided by 2).	2
			III. $\frac{864}{432} = 2$ or 864 years is 2 ½-lives (1) so ¼ of the mass remains = <u>0.1</u> [µg] (1)	2
			Question total	**[12]**

15.

Question				Marking details	Marks
2.	(a)	(i)		[Same] number (accept amount) of protons / 53 protons / [same] proton number / Don't accept: same number of protons and electrons or same atomic number or 53 or reference to the mass number being equal to 53.	1
		(ii)		[Different] number of neutrons / nucleons Accept [different] number of protons and neutrons / one has 70 neutrons and the other has 78 neutrons. Don't accept different mass numbers or 123 and 131.	1
	(b)	(i)		[fast moving / high energy] electron (accept slow electron) Don't accept positive electron.	1
		(ii)		$I \rightarrow {}^{131(1)}Xe + {}_{-1(1)}\beta + \gamma$	2
	(c)			Gamma is less ionising (1) so is easily detected outside of the body / penetrates the body or skin well / is less harmful (1). OR because beta would be more ionising (1) so is less penetrating / less likely to get out of the body / more harmful (1). OR Iodine-123 has a shorter half-life [13 hours] (1) so it decays quicker or loses its radioactivity quicker (1) don't accept escapes quicker. **Either mark can be awarded on its own but only award 2 marks if they are linked.**	2
	(d)	(i)		Plots (2) allow ± ½ small square division (deduct 1 mark for each incorrect plot) smooth curve (1) allow **ecf** Don't accept double lines / whispy /thick/ disjointed / wobbly lines.	3
		(ii)		Lines on grid from 12 and 3 [to the curve and] down to time axis (1) time interval of 16 [days] ± 1 [day] / equal to two half-lives (1). Apply **ecf** for the graph.	2
				Question total	**[12]**

16.

Question			Marking details	Marks
5.	(a)		To smooth out random fluctuations in data / even out variations / reduces [the effect of] anomalies **Accept** less anomalies / odd results / closer estimate **Do not accept** prevents anomalies / more reliable / more accurate	1
	(b)		Plots (allow ± ½ small square division) (2) -1 for each error to a maximum of 2. Smooth curve of best fit drawn from last given point (4 rolls) onwards but must encompass all points (1)	3
	(c)	(i)	About 4 [rolls]. Accept any x where $4 > x > 3.6$ inclusive	1
		(ii)	Method shown on grid (1)[line across or down probably at 200] ~3.8 [rolls] (1-value taken from their graph ± 0.1)	2
		(iii)	Allows (more) <u>precise / accurate</u> value to be obtained / to nearest 0.1 of a roll **Accept** graph is more accurate **Don't accept** exact value / more reliable value	1
		(iv)	7.6 (1-value taken from graph ± 0.1) value is approximately 2 half-lives (1) **Don't accept** ¼ of original value	2
	(d)	(i)	Identifying 3 half-lives (1) $\frac{210}{3}$ = 70 [s] (1-ans) **Don't accept** 80→40→20→10 without any qualification	2
		(ii)	5 half-lives required (1) 5×70**(ecf)** = 350 [s] (1)	2
		(iii)	becquerel, **accept** bq, Bq, any reasonable spelling	1
			Question total	**[15]**

17.

Question				Marking details	Marks
3.	(a)	(i)		Emits an electron	1
		(ii)		<u>It is the time taken to halve</u> / it takes <u>5 720 years to halve</u>(1) the number of C-14 nuclei (or atoms) / the mass (or amount) of C-14 / the activity / count rate (1) Treat radioactivity as neutral.	2
	(b)			$^{14}_{7}N$ (2) $^{0}_{-1}e$ (1) beware of missing minus sign	3
	(c)	(i)		It takes 4 half-lives (1) so time = $4 \times 5\,720 = 22\,880$ [years] (1)	2
		(ii)		100 years is only a [small] fraction or $\frac{1}{57}$ of a half-life (1) so difference in C-14 readings will be small / won't have decayed by very much (1) **To award both marks both statements must be linked.**	2
				Question total	**[10]**

18.

Question				Marking details	Marks
3.	(a)	(i)		4 (half-lives) (1)	1
		(ii)		2 or 120 (allow **ecf** from (i) above) (1). Hours or minutes (1). **Unit must complement the answer.** Accept min or h but not m for unit. If the unit is given with the answer, the unit given must agree with it.	2
		(iii)		4 [grams] (allow **ecf** from (i) above) If answer of 16 in (i) then award **no mark** here for 64/16	1
	(b)			Emits gamma (1) so it would not ionise [cells] much / radiation can be detected outside of the body / can get out of the body (1) **Don't accept** doesn't harm. Only gamma passes through the skin **award 1 mark** only **OR** Has a short half-life / has a half-life of only 30 mins (1) but doesn't last for long in the body / decays quicker (1). **Accept** safe after a short time. **Don't accept** escape quickly. **To award both marks both statements must be linked.**	2
				Question total	**[6]**

19.

Question			Marking details	Mark
6.	(a)	(i)	The time/how long it takes/it takes 6 000 years for half of the undecayed atoms/mass/amount/activity/count rate to fall by half.	1
		(ii)	The **nucleus** emits/loses (1) an **electron** (1) OR identifies the nucleus (1) in which neutron splits into proton and electron (1) **Either mark can be awarded on its own but only award 2 marks if they are linked.**	2
	(b)	(i)	plots correct (2) [lose 1 for each incorrect plot allow ± ½ small square division up to a maximum of 2 marks] reasonable curve through the points (1)	3
		(ii)	Value to be taken from candidate's graph ±10 [About 130]. Credit an answer of between 120-140 when no line is drawn.	1
		(iii)	10 (1) **x 6 000** (1) = [60 000 years]	2
	(c)	(i)	7 400 years (value to be taken from candidate's graph)	1
		(ii)	reduce activities from the graph by a factor of 10 (1), line from 320 on graph to find time (1) or converse, (or reference to) lines drawn on graph at 320 (and down to the time axis). **Alternative -** for an extended graph and lines drawn at 80 (1) and "32" drawn on an extended line (1), award both marks for method either explained or drawn. N.B. **No marks can be awarded for the age** because of the uncertainty in this method.	2
			Question total	**[12]**

20.

Question Number								
FT	HT	Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
		(c)			2	Emits α radiation (1) so will not penetrate the RTG / or RTG stops radiation escaping (1)	There is no beta or gamma emitted which would pass through the RTG (1)	Can't penetrate e.g. paper or skin Only harmful when swallowed	
		TOTAL			16				

Question Number								
FT	HT	Sub-section			Mark	Answer	Accept	Neutral answer	Do not accept
		(c)			2	Emits α radiation (1) so will not penetrate the RTG / or RTG stops radiation escaping (1)	There is no beta or gamma emitted which would pass through the RTG (1)	Can't penetrate e.g. paper or skin Only harmful when swallowed	
		TOTAL			16				

21.

Question Number									
FT	**HT**	**Sub-section**			**Mark**	**Answer**	**Accept**	**Neutral answer**	**Do not accept**
		(a)			1	The mass / number of un-decayed particles / count rate / cpm / activity / number of nuclei / number of atoms	Amount of radioactive material	Reference to named radioisotope	Size / volume Decay Radioactivity Amount Radiation Radioactive substance Atom Particles
		(b)	(i)		2	All plots correct (2) 3 plots correct (1) Less than 3 (0) Plotting tolerance of $<$ 1 small square **No mark for drawing line.**			
			(ii)		1	110 [cpm]			
			(iii)		1	55 ± 1 [cpm]			
			(iv)		1	8 [days]			
		Total			**6**				