Answer ALL questions.

Some questions must be answered with a cross in a box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 This is a question about radioactivity.

(a) Which of these is the unit of activity?

(1)

☒ **A** becquerel

☒ **B** kilogram

☒ **C** newton

☒ **D** pascal

(b) Which of these is the correct description of the term **half-life**?

(1)

☒ **A** time taken for the activity of a substance to halve

☒ **B** half of the time taken for the mass of a substance to decay

☒ **C** time taken for the activity to decay completely

☒ **D** time taken for the mass of a substance to decay twice

(c) A teacher demonstrates how the activity of a radioactive sample changes with time.

(i) The box gives the names of different pieces of equipment.

ruler	stopwatch	balance	newton meter
protractor	GM tube	voltmeter	ammeter

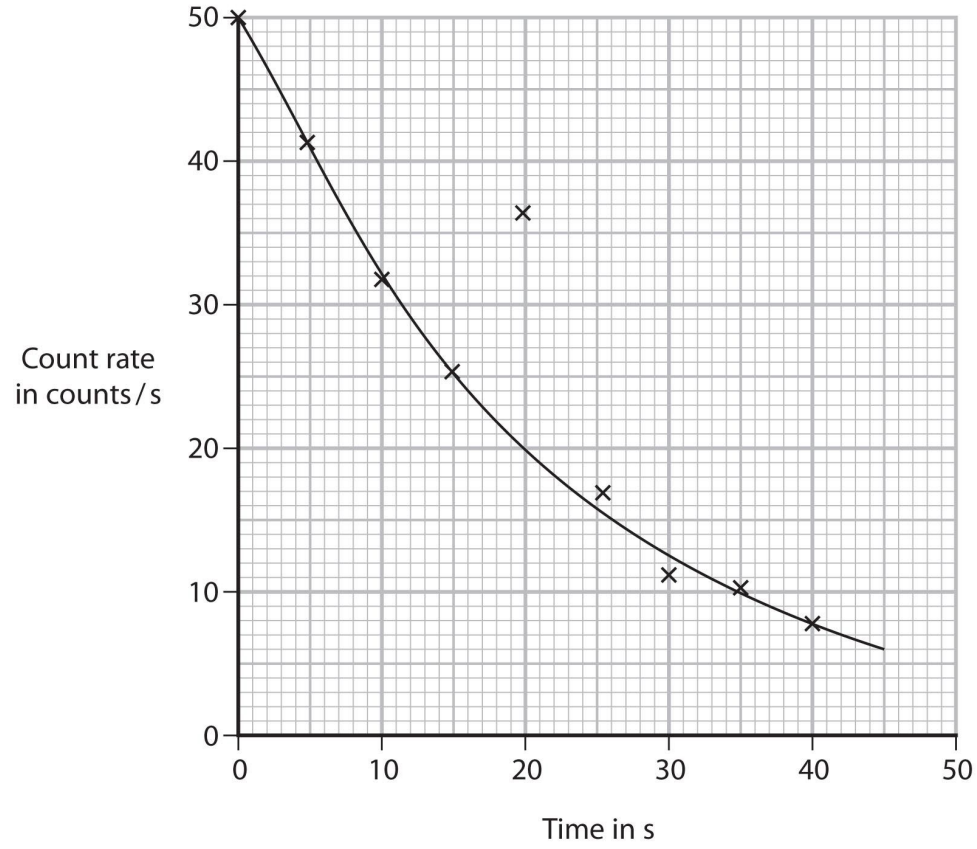
Complete the sentences using words from the box.

(2)

The teacher measures time with a ..... .

The teacher measures the count rate with a ..... and a counter.

(ii) The graph shows the teacher's results.



Draw a circle around the anomalous result.

(1)

(iii) Use the graph to determine the half-life of the radioactive sample.

(2)

half-life = ... s

(iv) Give a reason why the teacher should not expect the data points to lie exactly on the curve of best fit.

(1)

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.....

(Total for Question 1 = 8 marks)

Question number	Answer	Notes	Marks
1 (a)	A (becquerel); B is incorrect because it is the unit of mass C is incorrect because it is the unit of force D is incorrect because it is the unit of pressure		1
(b)	A (time taken for the activity of a substance to halve); B is incorrect because the substance will not completely decay C is incorrect because the substance will not completely decay D is incorrect because the substance cannot decay twice		1
(c) (i)	stopwatch; GM tube;		2
(ii)	point at t = 20s identified;		1
(iii)	any indication of a halving in activity;	e.g. 50→25 40→20 etc. seen in working allow ÷2, ×½ seen in working	2
	half-life = 15 (s);	allow full credit in range 14–16 (s)	
(iv)	any indication that decay is random;	allow unpredictable allow references to background radiation/count varying	1

Total for Question 1 = 8 marks

2 Protactinium is an element with several different radioactive isotopes.

(a) Protactinium-234 has a half-life of 6.7 hours.

A sample of protactinium-234 has an initial activity of 800 units.

(i) Give a suitable unit for activity.

(1)

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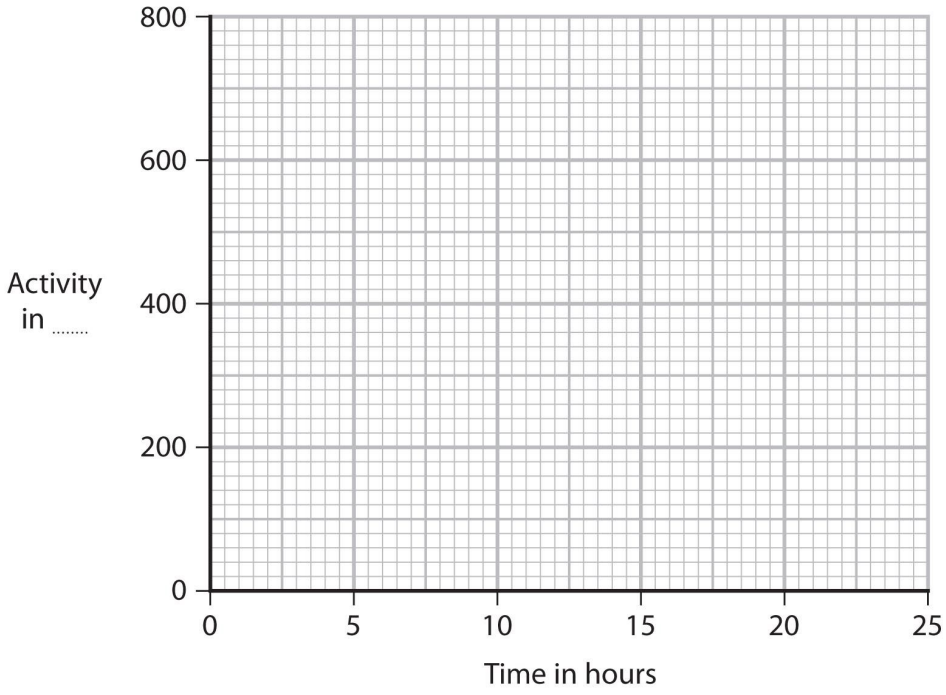
(ii) On the axes below, sketch a graph for the decay of the sample of protactinium-234 during its first three half-lives.

(3)



(iii) When protactinium-234 undergoes beta (β^-) decay it becomes uranium-234.

The incomplete nuclear equation shows this process.

$$\square\,{}^{234}\mathrm{Pa} \longrightarrow {}^{234}_{92}\mathrm{U} + \square\,\beta$$

Complete the nuclear equation to show the beta decay of protactinium-234.

Write your answers in the dashed boxes.

(2)

(b) A student suggests an experiment to determine the type of radiation emitted by a different isotope of protactinium, protactinium-231.

This is the suggested method.

Step 1 connect a suitable radiation detector to a radiation counter

Step 2 place a source of protactinium-231 at a fixed distance of 3 cm from the radiation detector

Step 3 record the count of detected radiation for a time of one minute

Step 4 place a sheet of paper between the source and detector

Step 5 record the count of detected radiation for a time of one minute

Step 6 repeat Steps 4 and 5 using a sheet of aluminium and then a sheet of lead instead of the sheet of paper

The table shows the results of the investigation when it is done by a teacher.

Material between source and detector	Count
no material	261
paper	14
aluminium	11
lead	13

(i) Which of these is the dependent variable in the investigation?

(1)

☒ **A** count measured by the detector

☒ **B** distance between source and detector

☒ **C** material between source and detector

☒ **D** time the count is measured

(ii) The student's method does not allow for background radiation.

Describe how the student's method should be modified to allow for background radiation.

(3)

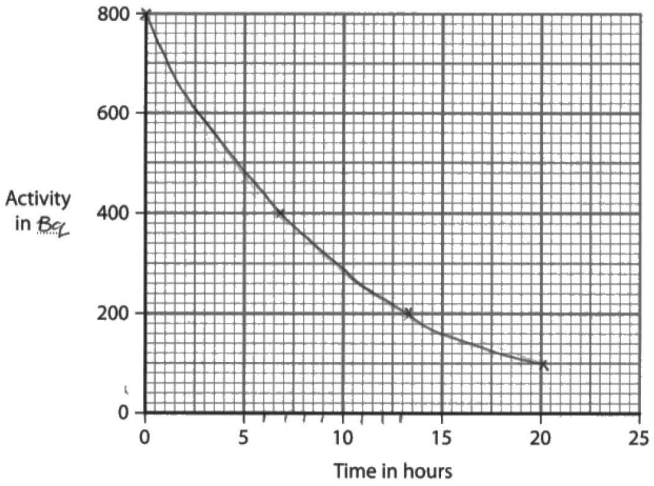
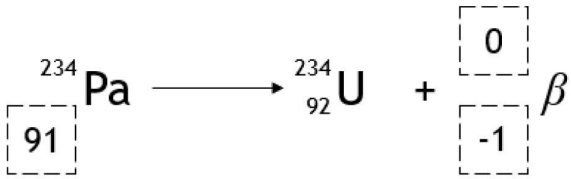
(iii) Describe how the student's method could be modified to improve the reliability of the results.

(2)

(iv) Evaluate the data from the experiment to conclude the type of radiation emitted by protactinium-231.

(3)

(Total for Question 2 = 15 marks)

Question number	Answer	Notes	Marks
2 (a) (i)	becquerel(s);	allow kilobecquerels, Bq, kBq, curie, Ci allow recognisable spelling allow mixed case letters	1
(ii)			3
	evidence that sketch starts at (0,800)	accept plotted point	
	evidence sketch passes through (6.7,400)	accept plotted point	
	smooth curve decreases with decreasing steepness		
			
(iii)	both numbers for beta correct; atomic number of protactinium = 91; e.g. 		2

(b)	(i)	A (count measured by the detector); B is incorrect because this is a control variable C is incorrect because this is the independent variable D is incorrect because this is a control variable		1
	(ii)	idea of removing source (from the experiment); measure count(for a minute); subtract background count from results;	e.g. pointing source away, keeping source in its box, (huge) increase in distance, take count before using source	3
	(iii)	idea of repeating measurements (of count); to determine a mean value;	allow idea of using repeats to identify anomalies condone average for mean	2
	(iv)	count decreases (significantly) using paper; no (additional) effect on the count when using aluminium AND lead / eq; radiation must be alpha consistent with candidate's discussion;	both must be mentioned for this mark allow idea that count with aluminium and lead is background radiation / in the range of 11-14	3

Total for Question 2 = 15 marks

3 A teacher investigates the count rate detected from a radioactive source.

(a) (i) State one source of background radiation.

(1)

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(ii) Describe how the teacher could measure the count rate from a radioactive source and correct the count rate for background radiation.

(4)

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(b) The teacher places a piece of lead sheet between the radioactive source and a radiation detector.

The teacher determines the corrected count rate from the radioactive source three times and calculates the mean.

They repeat this process using different thicknesses of lead sheet.

The table shows their results.

Thickness of lead in mm	Count rate in Bq			
	trial 1	trial 2	trial 3	mean
0.0	480	504	469	484
2.0	374	337	357	356
4.0	247	239	229	238
6.0	141	154	148	
8.0	110	104	131	115
10.0	88	91	85	88

(i) Calculate the mean count rate when the thickness of lead is 6.0 mm.

(2)

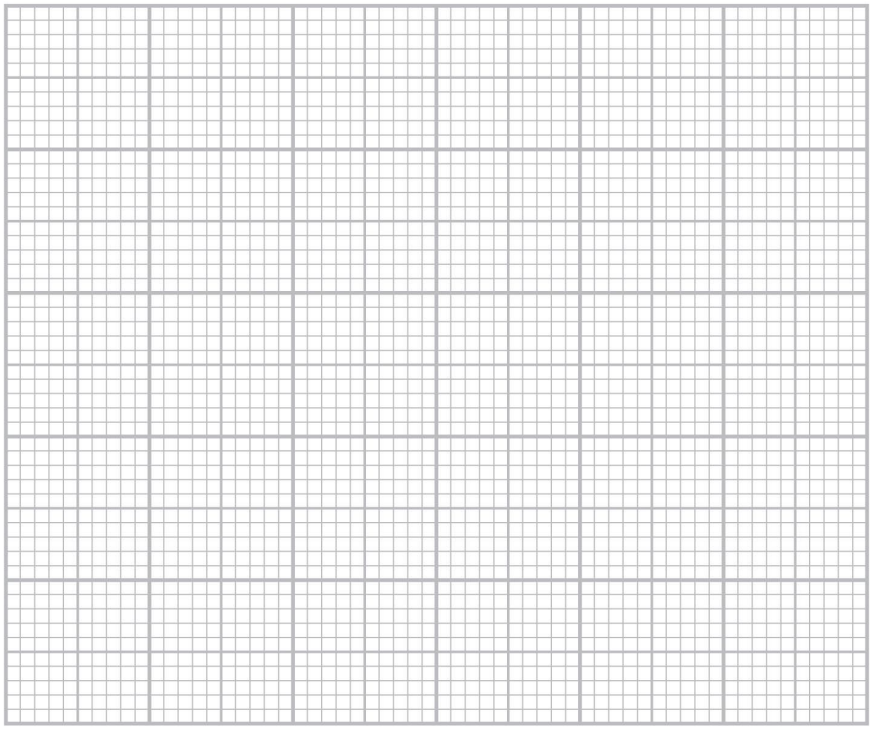
mean count rate = ... Bq

(ii) Plot a graph of mean count rate against thickness of lead.

(3)

(iii) Draw the curve of best fit.

(1)



(iv) When there is not a sheet of lead between the radioactive source and the radiation detector, the mean count rate is 484 Bq.

Use the graph to determine the thickness of lead needed to reduce the mean count rate by 25%.

(2)

thickness = ... mm

(c) The radioactive source emits only one type of radiation.

Explain which type of radiation this radioactive source emits.

(2)

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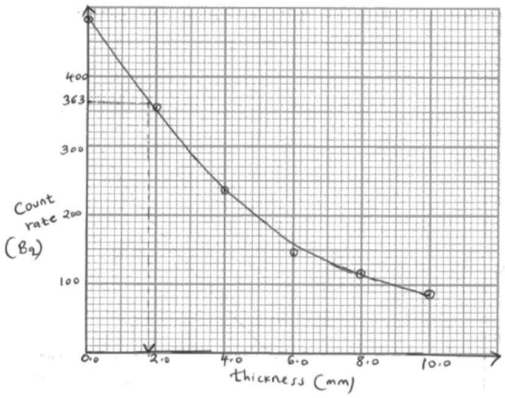
(Total for Question 2 = 15 marks)

Question number	Answer	Notes	Marks
3 (a) (i)	(the) Sun / cosmic rays / rocks / radon (in the air) / weapons testing / food / (named) nuclear disasters / medical equipment;	reject CMBR allow soil	1
(ii)	use of GM tube (and counter, timer); idea of removing source (from room); idea of measuring background count several times and calculating mean; subtract background count from readings;	allow radiation detector, Geiger counter for GM tube e.g. measuring count with source and without source	4
(b) (i)	correctly calculated mean; correctly rounded to 0 decimal places; e.g. (mean =) 147.666… (mean =) 148	answer of 147 gains 1 mark	2
(ii)	suitable linear scale chosen (>50% of grid used); axes labelled with quantities and unit; plotting correct to nearest half square;	ignore orientation allow ecf from (i) reject if non-linear scale used	3
(iii)	acceptable curve of best fit drawn;  	i.e. smooth curve with points distributed equally either side allow ecf from (ii) ignore curve outside given data range	1
(iv)	calculated value of 75% of initial count rate; correct read-off from candidate's graph; e.g. (count rate =) 363 (Bq) (lead thickness =) 1.8 (mm)	 allow 1 mark max. for correctly reading from 25% of initial count rate allow 1.7 – 1.9 (mm)	2
(c)	gamma; idea that all beta/alpha would be absorbed by lead / only gamma can penetrate through (thin) lead;		2

Total for Question 4 = 15 marks

4 A material called granite is used as a work surface in a kitchen.

(Source: Ksana_uk/Shutterstock)

(a) Granite is formed naturally and contains radioactive isotopes.

The granite work surface contributes to the background radiation in the kitchen.

Give another naturally occurring source of background radiation.

(1)

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(b) Granite contains the isotope thorium-232 ($^{232}_{90}$Th).

Thorium-232 decays by a sequence of alpha decays and beta decays to form radon-220 ($^{220}_{86}$Rn).

(i) State two differences between alpha radiation and beta radiation.

(2)

1 .....

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2 .....

.....

(ii) The incomplete nuclear decay equation summarises the decay sequence of thorium-232 into radon-220.

$$^{232}_{90}\text{Th} \longrightarrow {}^{220}_{86}\text{Rn} + \boxed{}\,{}^{4}_{2}\alpha + \boxed{}\,{}^{0}_{-1}\beta$$

Calculate the number of alpha particles and the number of beta particles emitted in this decay sequence.

(3)

number of alpha particles = ...

number of beta particles = ...

(c) Thorium-232 is a solid and remains in the work surface.

Radon-220 is a gas and is emitted from the work surface.

Thorium-232 and radon-220 both emit alpha radiation.

Discuss the hazards due to the granite work surface when a person is working in the kitchen.

Refer to contamination and irradiation in your answer.

(3)

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(Total for Question 5 = 9 marks)

Question number	Answer	Notes	Marks
4 (a)	any suitable natural source; e.g. (the) Sun, cosmic rays, rocks, (named) food, radon etc.	reject if contradicted by a list allow named radioactive isotopes e.g. carbon-14, uranium-235, uranium-238 ignore "space", cosmic microwave background radiation (CMBR)	1
(b) (i)	any two **described** differences from: MP1. alpha has more mass; MP2. alpha has more charge; MP3. alpha is positive and beta is negative; MP4. alpha has shorter range (in air); MP5. alpha is slower; MP6. alpha is less penetrating; MP7. alpha is more ionising; MP8. alpha is a helium nucleus but beta is an electron;	allow RA throughout allow alpha is heavier allow oppositely charged allow alpha stopped by air/paper and beta stopped by aluminium/thin metal allow alpha is 2 protons and 2 neutrons but beta is an electron	2
(ii)	evidence of trying to balance nuclear equation; correct number of alphas; correct number of betas; e.g. $90 = 86 + 2\alpha$ number of alpha = 3 number of beta = 2	e.g. 232 – 220 = 12 also gains first mark also gains first mark this balances atomic number despite mass number not balancing (if no beta was present)	3
(c)	any three from: MP1. (alpha) can cause cell mutation / cancer; MP2. idea that alpha is only dangerous when inside body; MP3. alpha is blocked by skin / few cm of air; MP4. thorium can only cause irradiation (since it remains in work surface); MP5. radon / gas can cause (both) contamination (and irradiation) (since it can go inside body / food); MP6. radon / gas can be inhaled / enter body; MP7. thorium cannot enter body;	 allow both (thorium and radon) can cause irradiation	3

Total for Question 4 = 9 marks

5 Radon is a radioactive gas that contributes to background radiation.

(a) Describe what is meant by the term **background radiation**.

(2)

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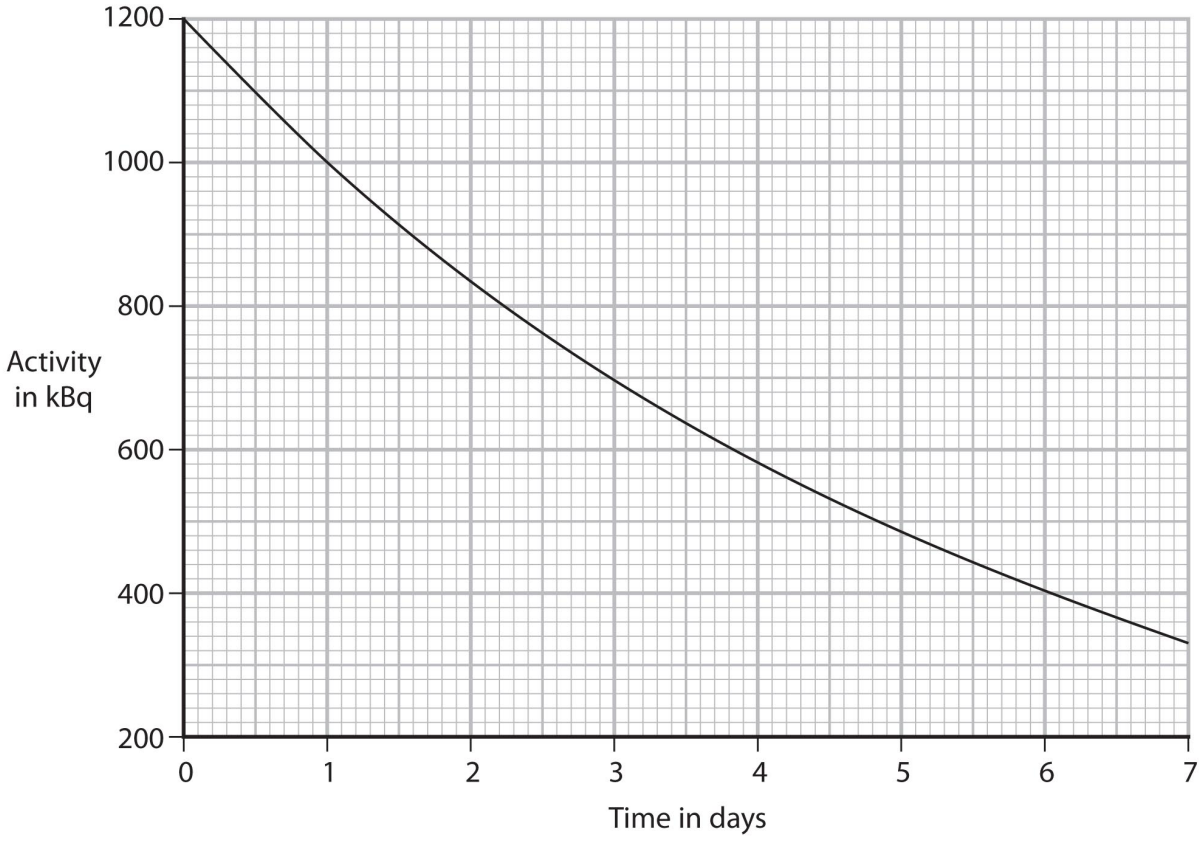
(b) The graph shows the activity of a sample of radon-222.



(i) State what is meant by the term **half-life**.

(2)

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(ii) Use the graph to determine the half-life of radon-222.

(2)

half-life = ... days

(c) Radon-222 is formed by multiple alpha decays of uranium-234.

Complete the nuclear equation by giving the missing information.

(3)

$$^{234}_{92}U \rightarrow {}^{222}_{\square}Rn + 3\,^{\square}_{\square}\alpha$$

(d) Radon-222 also emits alpha radiation.

Explain the hazard to humans of breathing in air contaminated with radon-222.

(2)

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(Total for Question 7 = 11 marks)

Question number	Answer	Notes	Marks
5 (a)	idea of radiation from sources in the environment; idea that background is ever present/all around;	allow idea of 'no other sources present'	2
(b) (i)	time taken; and either of for the (radio)activity to halve; for half of the (radioactive) nuclei / atoms/ isotope /mass to decay;	allow "how long it takes" reject "half the time" allow count rate for activity ignore substance	2
(ii)	evidence of graph used correctly; 3.8 (days);	i.e. line drawn across from 600 to curve and down to time axis allow full marks for 3.8-3.85	2
(c)	4 (for alpha nucleon number); 2 (for alpha proton number); 86 (for Rn proton number);	 ECF for incorrect alpha proton number then multiplied by 3	3
(d)	any TWO from: MP1. idea of irradiation of internal organs; MP2. alphas are {highly/very/most} ionizing; MP3. causes mutations/cancer;	 allow idea that there is no 'dead skin' layer for alphas to penetrate allow 'damages tissue' or 'damages cells/DNA'	2

(Total for Question 7 = 11 marks)

6 (a) A speed camera is positioned at the side of a road.

The camera measures the speed of a vehicle on the road to determine whether the vehicle is travelling too fast.

The camera takes two photographs of the vehicle 0.25 s apart.

The photographs are used to measure the distance travelled by the vehicle during this time.

(i) State the formula linking average speed, distance moved and time taken.

(1)

(ii) In the time between the two photographs, the car travels a distance of 6.5 m.

Calculate the average speed of the car.

(2)

average speed = ... m/s

(iii) The speed limit of the road is 80 kilometres per hour.

Determine whether the car is exceeding the speed limit.

(2)

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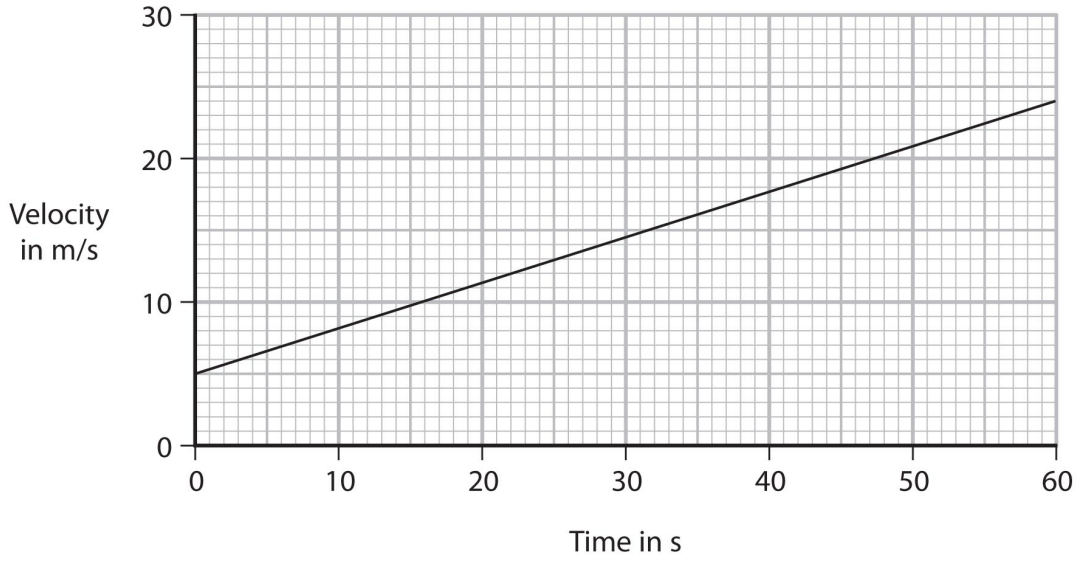
(b) The velocity-time graph shows how the velocity of a lorry changes with time.



(i) Explain how the graph shows that the lorry has a constant acceleration.

(2)

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(ii) State the formula linking acceleration, change in velocity and time taken.

(1)

(iii) Calculate the acceleration of the lorry.

(3)

acceleration = ... m/s^2

(Total for Question 6 = 11 marks)

Question number			Answer	Notes	Marks
6	(a)	(i)	(average) speed = distance (moved) / time (taken);	allow standard symbols and rearrangements e.g. v = s / t allow s for speed, d for distance	1
		(ii)	substitution; evaluation; e.g. (speed =) 6.5 / 0.25 (speed =) 26 (m/s)		2
		(iii)	correct conversion of EITHER m to km OR s to h; full conversion from m/s to km/h AND consistent conclusion;;	allow ECF from (ii) allow ECF from (ii) allow conversion of km/h to m/s e.g. 80km/h = 22.2m/s	2
			e.g. 26 (m/s) = 0.026 (km/s) OR 26 (m/s) = 93600 (m/h) 94 (km/h) => too fast	 allow 93.6 (km/h)	
	(b)	(i)	acceleration is the gradient (of the graph); graph has a constant gradient;	 allow line on graph is straight	2
		(ii)	acceleration = change in velocity / time;	allow standard symbols and rearrangements e.g. a = (v-u) / t, a = Δv / t	1
		(iii)	correct reading of either two velocity values or time interval taken from graph; correct substitution into formula; evaluation; e.g. u = 5 (m/s), v = 24 (m/s) OR t = 60 (s) (a =) 24-5 / 60 (a =) 0.32 (m/s^2)	allow attempt at gradient calculation allow (v – u =) 19 seen allow range of 0.30-0.32	3

Total for Question 2 = 11 marks

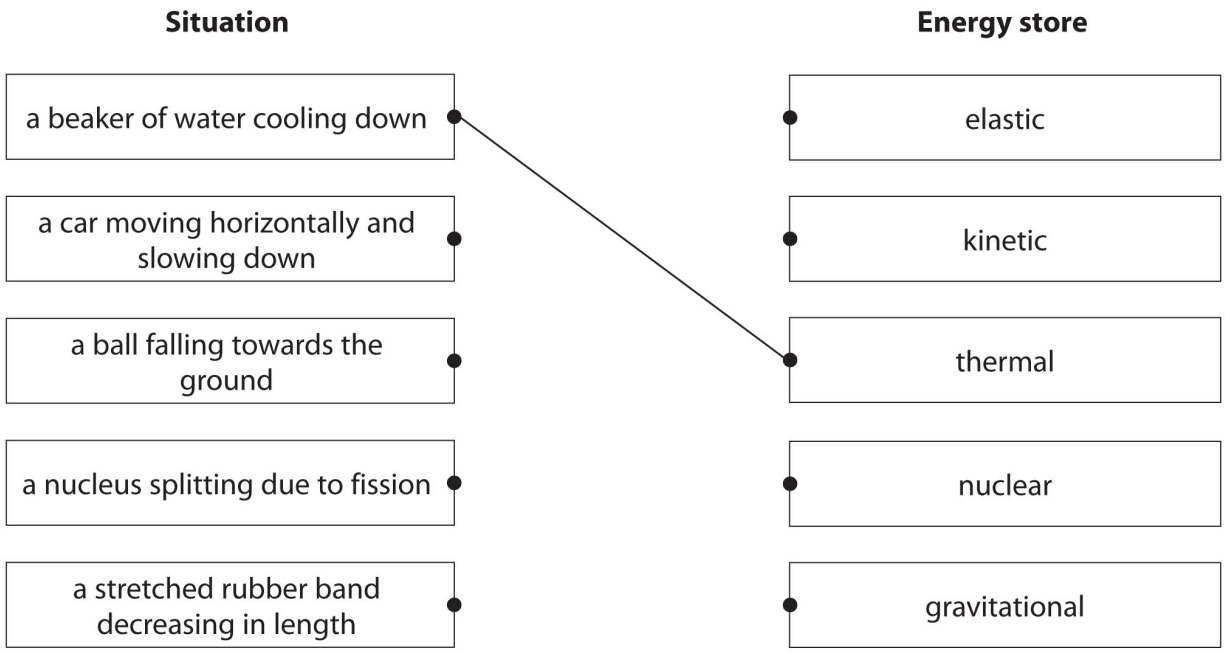
Answer ALL questions.

7 (a) The boxes give some situations and some energy stores.

Draw one straight line from each situation to the energy store that decreases for that situation.

The first one has been done for you.

(4)



(b) Energy is transferred when a filament lamp is connected to a battery.

(i) Which method of energy transfer takes place between the battery and the lamp?

(1)

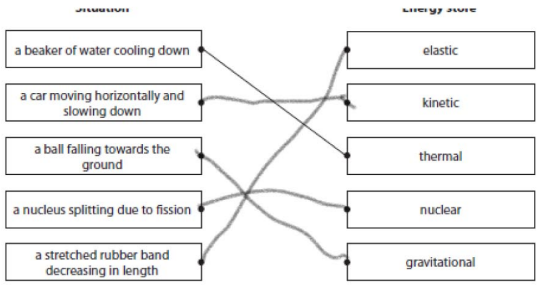
- ☒ **A** electrical
- ☒ **B** heating
- ☒ **C** mechanical
- ☒ **D** radiation

(ii) Which method of energy transfer takes place between the lamp and the surroundings?

(1)

- ☒ **A** electrical
- ☒ **B** light radiation
- ☒ **C** mechanical
- ☒ **D** sound radiation

(Total for Question 1 = 6 marks)

Question number	Answer	Notes	Marks
7 (a)		-1 for each additional line	4
(b) (i)	A - electrical;		1
(ii)	B - light radiation;		1

(Total for Question 1 = 6 marks)

8 Cobalt-60 is a radioactive isotope of cobalt.

The table gives the activity of a sample of cobalt-60 over a period of 10 years.

Time in years	Activity
0	8000
2	6350
4	4900
6	3800
8	2900
10	2100

(a) Give a suitable unit for activity.

(1)

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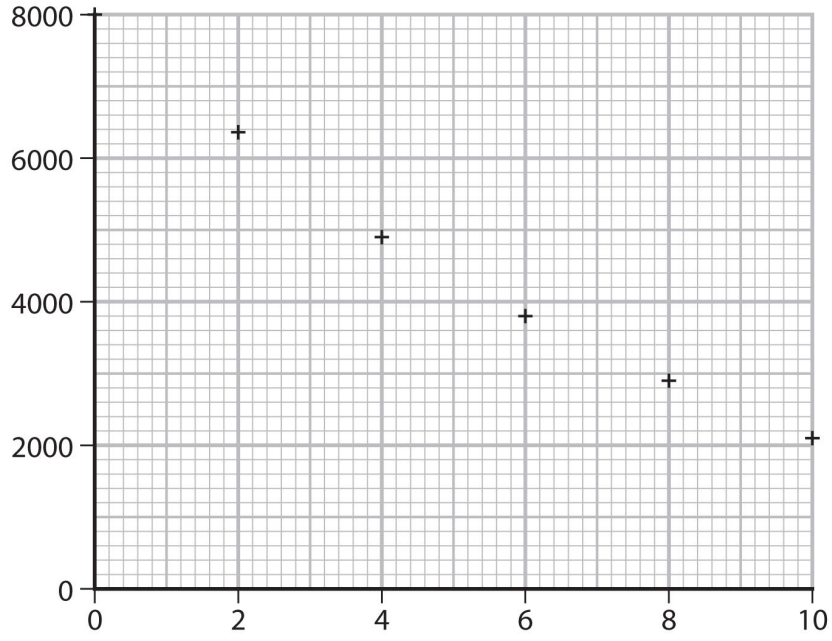
(b) The graph shows the data.



(i) Label both axes.

(1)

(ii) Draw the curve of best fit.

(1)

(iii) Use the graph to determine the half-life of cobalt-60.

(2)

half-life = ... years

(iv) Estimate the time taken for the activity to decrease to $\frac{1}{8}$ of its initial value.

(2)

time = ... years

(c) Cobalt-60 is produced when a neutron is absorbed by the nucleus of a stable atom of cobalt-59.

The nuclei of these two isotopes can be represented as

$$^{60}_{27}\text{Co} \qquad\qquad ^{59}_{27}\text{Co}$$

Describe a similarity and a difference for the nuclei of these two isotopes of cobalt.

(2)

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(d) Cobalt-60 decays by beta emission.

Describe what happens to the nucleus of a cobalt-60 atom during beta decay.

(2)

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(e) Cobalt-60 also emits gamma radiation.

Cobalt-60 is produced in a nuclear reactor.

Discuss the hazards involved and the precautions taken when disposing of cobalt-60.

(4)

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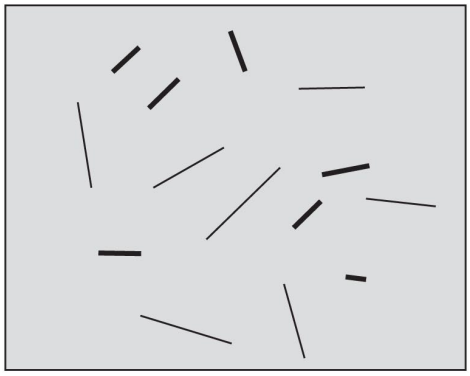
(Total for Question 4 = 15 marks)

Question number	Answer	Notes	Marks
8 (a)	becquerel(s) / Bq;	allow recognisable spellings allow if written in table	1
(b) (i)	vertical axis labelled “activity” AND horizontal axis labelled “time in years”;	ignore unit on vertical axis	1
(ii)	smooth curve of best fit drawn;	curve should pass within 1 small square of each data point condone curve starting at second point	1
(iii)	evidence of working on graph or in working space; half-life = 5.6 (years);	e.g. lines shown on graph or evidence of halving 8000 etc. allow range of 5.4-5.8	2
(iv)	3 half-lives; (3 × 5.6 =) 16.8 (years);	allow 16.2-17.4 (years) allow ecf from (iii)	2
(c)	both have same number of protons; cobalt-60 has one more neutron;	allow RA ignore references to atomic/mass numbers	2
(d)	nucleus loses a neutron; nucleus gains a proton;	“neutron becomes a proton” scores both marks condone plurals e.g. neutrons, protons	2
(e)	any four from: **Hazards (max. 2 marks)** MP1. radiation from them can cause cancer / cell damage / damage to organisms / people; MP2. radiation is highly penetrating; MP3. risk of theft / eq; MP4. remain radioactive for some time; MP5. risk of contamination of land/water; **Precautions (max. 2 marks)** MP6. need for shielding; MP7. use of machines to remove from reactor; MP8. need for security (to prevent public access/protect from hijacking/eq); MP9. need to be suitably protected against damage; MP10. special facilities required, not landfill; MP11. relatively short half-life means that very long-term storage is not necessary;	 e.g. lead, concrete etc. e.g. from earthquakes, overheating etc. e.g. stored underground/underwater, measures to avoid leakage	4

Total for Question 4 = 15 marks

9 (a) The diagram shows tracks produced by radiation in a device called a cloud chamber.

The tracks are formed when particles ionise the material in the cloud chamber.



Alpha particles produce the shorter, thicker tracks.

Beta particles produce the longer, thinner tracks.

Explain why alpha particles produce the shorter, thicker tracks.

(2)

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(b) Uranium-235 is an isotope of uranium that can decay by emitting an alpha particle.

(i) Describe what is meant by the term **isotope**.

(2)

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(ii) Complete the equation for the decay of uranium-235

(2)

$$^{235}_{92}U \rightarrow \square^{231}Th + \square^{}_{2}\alpha$$

(iii) Uranium-235 decays to thorium-231 with a half-life of 700 million years.

When a rock was formed, it contained 6400 million uranium-235 nuclei and no thorium-231 nuclei.

Show that after 2100 million years there are seven times more thorium nuclei than uranium nuclei in the rock.

(5)

(Total for Question 7 = 11 marks)

Question number	Answer	Notes	Marks
9 (a)	any two from: MP1. alphas do not penetrate as far; MP2. alphas are more ionizing; MP3. alphas are more likely to collide (with material); MP4. alphas have more mass / move slower;	 allow RA allow RA allow RA allow RA	2
(b) (i)	(nuclei with) same numbers of protons; (nuclei with) different numbers of neutrons;	allow (nuclei with) same atomic number allow (nuclei with) different mass number	2
(ii)	one mark for each correct number;; $^{235}_{92}U \rightarrow {}^{231}_{\boxed{90}}Th + {}^{\boxed{4}}_{2}\alpha$		2
(iii)	any indication that 2100 million years is 3 half-lives; evaluation of number of uranium nuclei after 1 half-life; (after 2100 million years) there are 800 million uranium nuclei; (after 2100 million years) there are 5600 million thorium nuclei; 5600 (million) / 800 (million) = 7;	 3200 (million) uranium nuclei after one half-life scores first three marks allow total number of nuclei is constant allow 7 × 800 = 5600	5

Total for Question 7 = 11 marks

10 A teacher uses a radioactive source containing atoms of the isotope radium-226.

(a) Give a safety precaution that would reduce the teacher's exposure to radiation when working with the radioactive source.

(1)

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(b) Radium-226 can be represented using the symbol

$$^{226}_{88}Ra$$

How many neutrons are in the nucleus of an atom of radium-226?

(1)

- ☒ **A** 88
- ☒ **B** 138
- ☒ **C** 226
- ☒ **D** 314

(c) The teacher investigates the type of radiation emitted from the radioactive source.

(i) Give the name of a piece of apparatus that detects ionising radiation.

(1)

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(ii) The teacher finds that the radiation emitted from the radioactive source is not detected when the detector is more than 5 cm away from the source.

State the type of radiation emitted by the radioactive source.

(1)

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(d) The number of radium-226 atoms in the source decreases over time, with a half-life of 1600 years.

(i) State what is meant by the term **half-life**.

(2)

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(ii) The radioactive source contains 2.66×10^{21} atoms of radium-226.

Approximately how many atoms of radium-226 will remain in the source after 800 years?

(1)

☒ **A** 0.67×10^{21}

☒ **B** 1.33×10^{21}

☒ **C** 1.88×10^{21}

☒ **D** 2.66×10^{21}

(Total for Question 5 = 7 marks)

Question number	Answer	Notes	Marks
10 (a)	any one from: • handling source with tongs/gloves; • storing source in lead box (when not in use); • minimising time handling source; • maximising distance from source; • taking care with direction of emission from source; • use of lead apron/shielding;	ignore if mention of other room etc.	1
(b)	B (138); A is incorrect because this is the number of protons C is incorrect because this is the number of nucleons D is incorrect because this is the number of nucleons + protons		1
(c) (i)	photographic film / Geiger-Muller tube;	allow GM tube, GM detector condone Geiger counter allow spark counter	1
(ii)	alpha / α;		1
(d) (i)	time taken; and either of • for (radio)activity to halve; • for half of the (radioactive) nuclei / atoms / isotope to decay;	allow "how long it takes" reject "half the time" allow count rate for activity	2
(ii)	C (1.88×10^{21}); A is incorrect because this is the number of atoms after 3200 years B is incorrect because this is the number of atoms after 1600 years D is incorrect because this is the initial number of atoms		1

Total for Question 5 = 7 marks

11 An aircraft travels along a runway.

(a) The aircraft starts from rest and has a constant acceleration of 4.1 m/s^2.

Calculate the distance required to reach take-off speed of 75 m/s.

(3)

distance = ... m

(b) The aircraft takes off and reaches its maximum height above the ground.

At maximum height, the background radiation count rate is higher than on the ground.

(i) Explain what is meant by background radiation.

(2)

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(ii) Suggest why there is a limit to the number of hours that an airline pilot can fly at maximum height.

(3)

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(Total for Question11 = 8 marks)

Question number	Answer	Notes	Marks
11 (a)	substitution into $v^2 = u^2 + 2as$; rearrangement; evaluation; e.g. $75^2 = (0^2 +) 2 \times 4.1 \times s$ $s = 5625 / 8.2$ (s =) 690 (m)	allow alternative method of finding the time taken and then using **average** speed = distance/time 1371-1372 = 2 marks allow 686, 685.9756...	3
(b) (i)	any two from: MP1. idea of radiation that is always present / present everywhere; MP2. idea of no 'obvious' source; MP3. any valid source of background radiation given e.g. radon/rocks/cosmic rays/medical or military activity/the Sun etc.;		2
(ii)	any three from: MP1. idea that excessive exposure time can be harmful/increases risk; MP2. idea that dosage is higher (at maximum height); MP3. idea that increased risk of cancer; MP4. idea that there is less atmosphere to absorb cosmic radiation; MP5. cosmic rays/radiation is increased;	allow cell mutation for cancer	3

(Total for Question 5 = 8 marks)

12 Technetium-98 and technetium-99 are isotopes of the element technetium.

(a) (i) Describe the difference between the nuclei of technetium-98 and technetium-99

(2)

(ii) Technetium-99 is formed when the element molybdenum-99 decays.

Complete the nuclear equation for the decay of molybdenum into technetium-99

(2)

$$^{99}_{42}\text{Mo} \rightarrow {}^{99}_{\square}\text{Tc} + {}^{0}_{\square}\beta$$

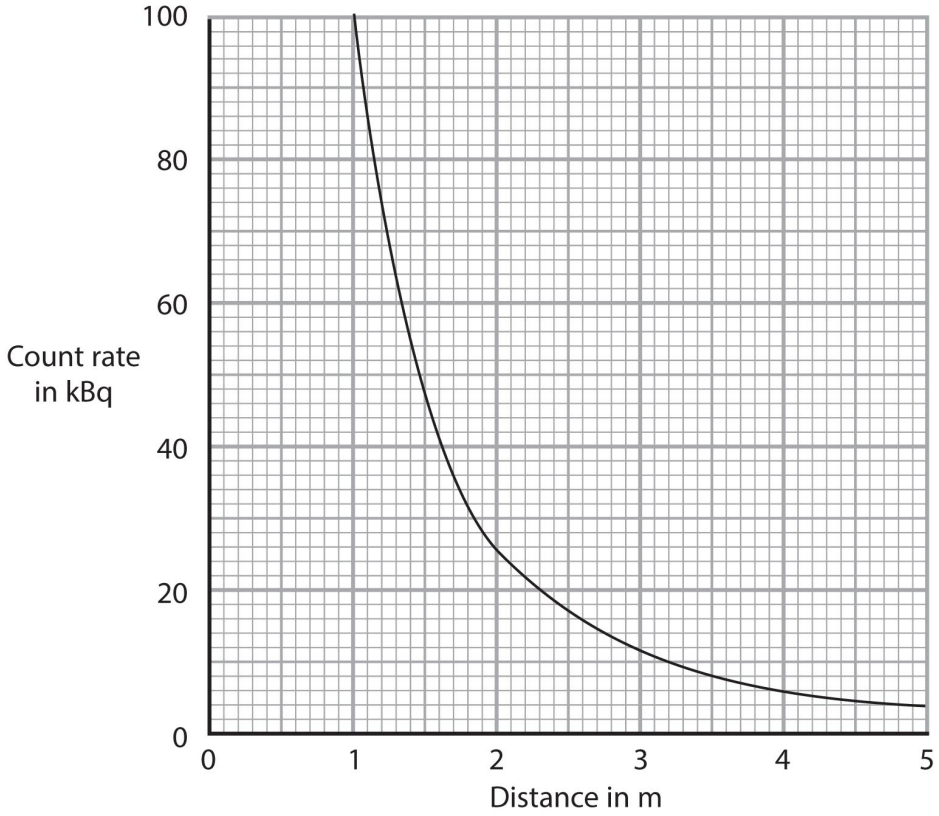
(b) Describe an experiment that a scientist could use to demonstrate that the emission from technetium-99 is gamma radiation.

Include details of a safety precaution in your answer.

(5)

(c) A scientist measures the count rate at different distances from the technetium source.

The graph shows how the count rate changes with distance from the technetium source.



The scientist suggests that the relationship between the count rate and distance is

$$(\text{distance})^2 \times \text{count rate} = \text{constant}$$

Use data from the graph to determine whether these results support this relationship.

(4)

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(Total for Question 10 = 13 marks)

Question number	Answer	Notes	Marks
12 (a) (i)	different number of neutrons; technetium-99 has 1 more neutron;	reject if number of protons is given as different DOP condone technetium-99 has 99 neutrons and technetium-98 has 98 neutrons	2
(ii)	43; -1;		2
(b)	any four max. from: MP1. use of GM tube + counter/GM tube/photographic film; MP2. measure count (rate) without source / find background count; MP3. measure count (rate) with source; MP4. (subtraction to) find corrected count (rate); MP5. repeat readings to obtain mean; MP6. idea that paper / aluminium does not affect count / reading; MP7. idea that lead reduces count rate **significantly**; PLUS any safety precaution from: MP8. idea of keeping distance from source; MP9. minimise exposure time; MP10. use of shielding;	allow 'reading' for count rate allow Geiger counter; allow lead blocks (all) radiation e.g. tongs/moving away from source e.g. keeping source in lead-lined box, use of lead apron / gloves, working in a different room from source	5
(c)	use of one data point; evaluation of distance^2 × count rate; second data point and second evaluation of distance^2 × count rate; conclusion reached consistent with the two evaluations; e.g. (1,100) gives $1^2 \times 100 = 100$ (4,6) gives $16 \times 6 = 96$ 96 is approximately equal to 100 so relationship is verified	reject idea that evaluations are inconsistent unless there is a significant difference between them e.g. due to ECF (1,100) gives constant = 100 (2,25) gives constant = 100 (3,11) gives constant = 99 (4,6) gives constant = 96 (5,4) gives constant = 100	4

Total for Question 12 = 13 marks

13 A teacher investigates the penetrating ability of the gamma rays from a gamma source.

This is the teacher's method.

- place the gamma source at a distance of 25 cm from a radiation detector
- place a 1 cm thick absorbing material between the source and the detector
- measure the radiation count from the source for a time period of 3 s
- calculate the count rate in counts per second
- repeat the measurement two more times

The teacher repeats this method for different absorbing materials.

(a) Name a suitable radiation detector that the teacher could use.

(1)

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(b) State the independent variable in the teacher's investigation.

(1)

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(c) Explain why every absorbing material used in the investigation has a thickness of 1 cm.

(2)

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(d) Suggest one improvement the teacher could make to this method.

(1)

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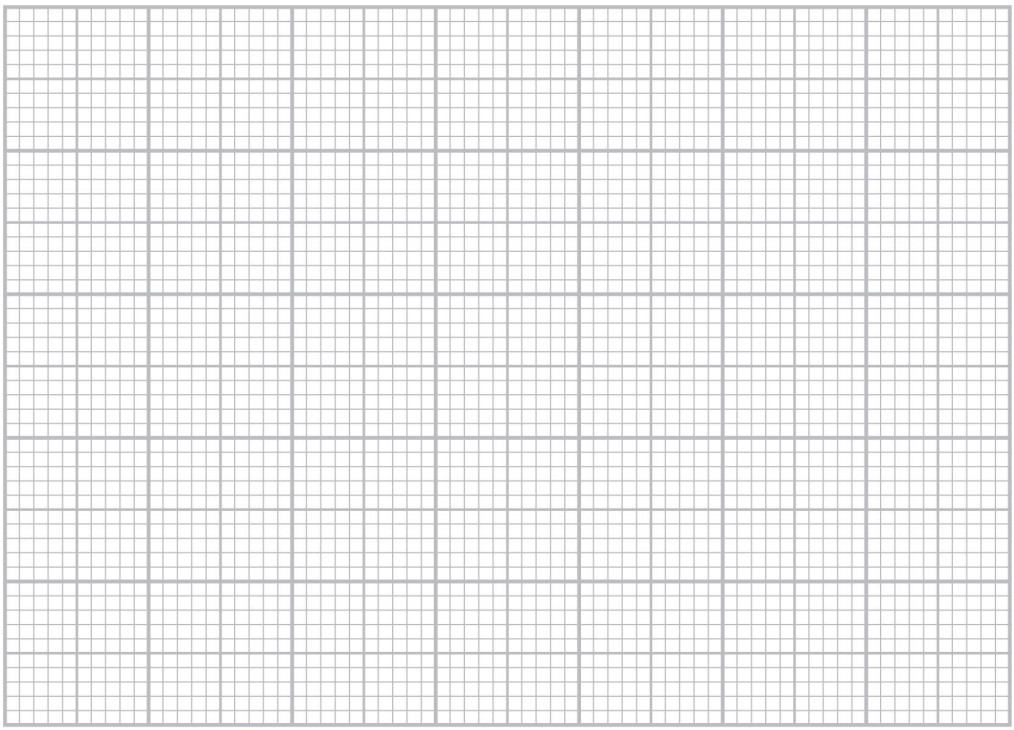
(e) The table shows the teacher's results for seven different absorbing materials.

Absorbing material	Count rate in counts per second			
	Test 1	Test 2	Test 3	Mean
plastic	248	230	226	235
copper	138	127	147	137
wood	226	231	224	227
aluminium	204	211	190	202
lead	96	102	92	97
glass	204	192	190	195
stone	205	200	205	203

(i) On the grid, plot a bar chart of the mean count rate for each absorbing material.

(3)



(ii) Why is a bar chart the correct way to display the results?

(1)

☒ **A** absorbing material is a continuous variable

☒ **B** absorbing material is not a continuous variable

☒ **C** count rate is a continuous variable

☒ **D** count rate is not a continuous variable

(iii) A student concludes that plastic is the best absorber of gamma radiation because plastic gives the largest mean count rate.

Evaluate the student's conclusion.

(2)

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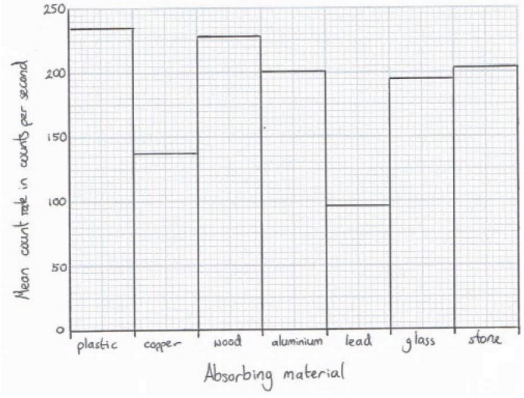
(Total for Question 9 = 11 marks)

Question number	Answer	Notes	Marks
13 (a)	Geiger-Muller tube / GM tube;	allow Geiger counter, Geiger meter, GM detector	1
(b)	(absorbing) material;	allow absorber	1
(c)	any two from: MP1. idea that thickness also affects the count/results; MP2. idea that thickness is a control variable; MP3. idea of making experiment valid;	 allow fair test for valid	2
(d)	measure count over longer time / take more repeats / measure background count;	allow quoted time longer than 3 seconds	1
(e) (i)	suitable linear scale chosen (>50% of grid used); axes labelled with quantities and unit; all bar plotting correct to nearest half square;  	ignore orientation do not accept multiples of 30 for scale **Absorbing material** / **Mean** plastic 235 copper 137 wood 227 aluminium 202 lead 97 glass 195 stone 203	3
(ii)	B (absorbing material is not a continuous variable); A is incorrect because absorbing material is not a continuous variable C is incorrect because line graphs are drawn for continuous variables D is incorrect because count rate is a continuous variable		1
(iii)	idea that the lower the count, the better the absorber; lead is the best absorber;	ignore student is right/wrong allow RA allow that plastic is the worst absorber	2

Total for Question 9 = 11 marks

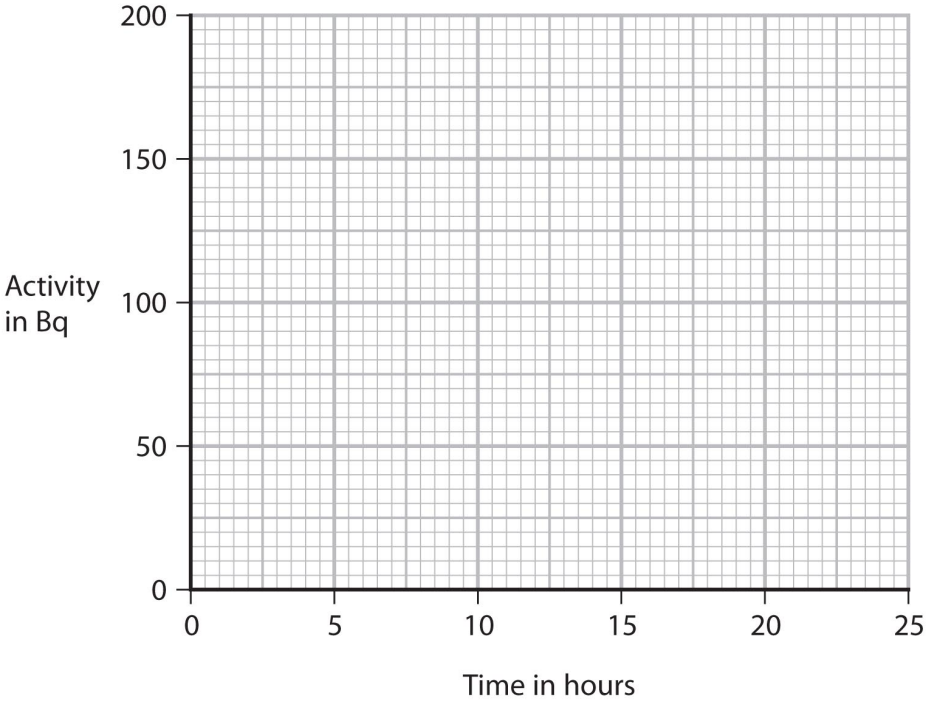
14 Technetium-99m is an isotope of the element technetium.

(a) Technetium-99m has a half-life of 6 hours.

A sample of technetium-99m has an initial activity of 160 Bq.

Complete the graph to show how the activity of this sample of technetium-99m changes over a period of 24 hours.

(3)



(b) Technetium-99m has a half-life of 6 hours and can be used as a medical tracer.

It is injected into a patient's blood and moves around the patient's body.

Technetium-99m emits gamma radiation, which is used to locate the position of the tracer in the patient's body.

(i) Technetium-99m does not exist naturally.

Suggest why technetium-99m is usually made at the hospital where it is used.

(1)

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(ii) Explain why technetium-99m is an effective isotope to use as a medical tracer.

(2)

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(c) The gamma radiation emitted by technetium-99m is potentially harmful to humans.

Discuss the risks of using technetium-99m to doctors and to patients.

(3)

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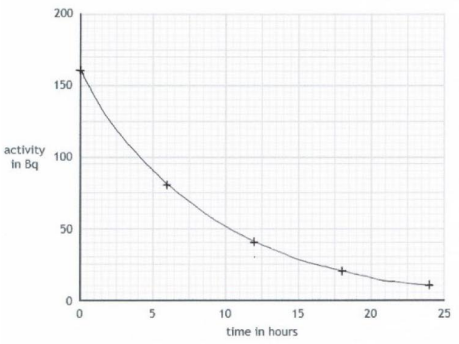
(Total for Question 11 = 9 marks)

Question number	Answer	Notes	Marks
14 (a)	activity shown to decrease over time; descending curve getting shallower starting at (0,160); line passes through two other valid points; • (6,80) • (12,40) • (18,20) • (24,10)  		3
(b) (i)	idea that it decays very quickly / activity will be zero by the time it is injected / there will be no technetium-99m left;	ignore 'it has a short half-life'	1
(ii)	any **one** from: • idea that gamma can penetrate out of the body; • idea that gamma can be detected outside the body; any **one** from: • idea that half-life is long enough to complete the procedure; • idea that activity will fall to safe level in a day / quickly;	marks must be from separate lists allow idea that technetium will not be in body for very long	2
(c)	harmful effect of gamma radiation given; idea that patient will have procedure very rarely / only when necessary (so risk is low); idea that doctor will administer procedure regularly (so risk is higher) / doctor limits time exposure to patient (to reduce risk);	e.g. • cancer • cell damage • cell mutation allow suggestion that risk to patients is higher as they receive greater dose allow idea that doctor increases distance from patient (to reduce risk)	3

Total for Question 11 = 9 marks

15 The photograph shows a glass plate made from uranium glass.

© Laura Healey/Shutterstock

Uranium oxide is used to give the glass a green colour.

(a) Uranium-238 is the most common isotope of uranium and can be represented using this symbol.

$$^{238}_{92}U$$

(i) State what information the numbers 92 and 238 give about the nucleus of this isotope of uranium.

(2)

92 .....

238 .....

(ii) Uranium-238 decays by alpha emission.

Describe how the nucleus of a uranium-238 atom changes as a result of alpha emission.

(2)

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(b) The table gives some information about the uranium glass plate.

mass of plate	1.1 kg
percentage (%) of plate made of uranium-238 (by mass)	4.5%
mass of uranium-238 atom	4.0×10^{-27} kg

(i) Calculate the number of uranium-238 atoms in the plate.

(2)

number of atoms = ...

(ii) Uranium-238 is an alpha emitter and has a half-life of 4.5 billion years.

Explain why it is safe to eat food from the uranium glass plate.

(3)

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(Total for Question 7 = 9 marks)

Question number	Answer	Notes	Marks
15 (a) (i)	(92 =) number of protons (238 =) number of nucleons / number of protons <u>and</u> neutrons	ignore atomic number allow mass ignore mass number	2
(ii)	(nucleus) loses two protons; (nucleus) loses two neutrons;		2
(b) (i)	evaluation of mass of U-238 in plate; evaluation of number of atoms; e.g. mass = $(1.1 \times 0.045) = 0.0495$ kg $(n = 0.0495 / 4.0 \times 10^{-27} =) 1.2 \times 10^{25}$	accept 49.5 g or 0.0495 kg or correct standard form 1.2375×10^{25}	2
(ii)	any three from idea that food is irradiated / not contaminated; alpha cannot penetrate skin or body / range of alpha insufficient to reach body; contains low percentage of uranium(-238); (long half-life means that) activity will be very low / decays very slowly;	ignore references to paper Accept 'mass' for 'percentage'	3

Total for Question 7 = 9 marks

16 A deioniser is a device used in rooms where workers build sensitive electronic circuits.

The deioniser contains a small block of polonium-210.

(a) (i) Complete the equation that shows the alpha decay of polonium-210 into lead-206.

(2)

$$^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + \square\ \alpha$$

(ii) The alpha particle ionises air molecules in the room.

State what is meant by the term **ionisation**.

(1)

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(iii) Explain why workers in the same room as the deioniser are not at risk from the alpha radiation it emits.

(2)

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(b) The half-life of polonium-210 is 140 days.

(i) State what is meant by the term **half-life**.

(2)

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(ii) The initial activity of the polonium-210 source in the deioniser is 70 kBq.

Calculate the activity of the source after 420 days.

(3)

activity = ... kBq

(Total for Question 9 = 10 marks)

Question number	Answer	Notes	Marks
12 (a) (i)	4; 2;		2
(ii)	removal of electron(s) (from an atom);	allow gaining electron(s)	1
(iii)	alpha particles are **absorbed** by/cannot **penetrate/ stopped** by a few cm **in air**; so alphas do not reach the workers;	allow do not penetrate **casing** (of deionser) condone 'do not penetrate skin/clothes'	2
(b) (i)	time taken; for (radio)activity/mass/number of (remaining) nuclei to half;	accept any synonym e.g. period/amount of time/	2
(ii)	evidence of halving of 70; 420 days means 3 half-lives; evaluation of 8.75 (kBq);	 accept however presented i.e. 70→35→17.5→8.75 allow 9 (kBq)	3

Total for Question 9 = 10 marks