

# Atomic Structure 5

Name: \_\_\_\_\_

Class: \_\_\_\_\_

Date: \_\_\_\_\_

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Time: **84 minutes**

Marks: **77 marks**

Comments:

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1.

A student modelled radioactive decay by rolling some dice in a tray.

Dice that landed on the number six were removed from the tray.

The removed dice represent nuclei that have decayed.

(a) Why is rolling dice a suitable model for radioactive decay?

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(1)

(b) The student rolled 144 dice and removed all those that landed on the number six.

The student rolled the remaining dice and again removed all those that landed on the number six.

When the student had rolled the dice 20 times there were 9 dice left.

Calculate the most likely number of times that the student had rolled the dice before the number of dice had halved.

You should show how you work out your answer.

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Answer = \_\_\_\_\_ rolls of the dice

(3)

- (c) The number of times the dice have to be rolled to halve the original number of dice in the tray represents the half-life.

The image below shows an eight-sided dice and a six-sided dice.



The student now used eight-sided dice to model radioactive decay. Dice that landed on the number six were again removed from the tray.

The half-life represented by rolling eight-sided dice is likely to be different from the half-life represented by rolling six-sided dice.

Explain how.

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(2)

- (d) A teacher has two radioactive sources, **A** and **B**.

Source **A** has a longer half-life than source **B**.

What can be deduced about the nuclei in source **A** compared with the nuclei in source **B**?

Do **not** refer to isotopes in your answer.

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(1)

(Total 7 marks)

2.

In an experiment, a beam of alpha particles was directed at a thin sheet of gold foil.

(a) Most of the alpha particles passed straight through the gold foil.

Alpha particles which passed close to the nucleus of a gold atom did **not** pass straight through.

What happened to the alpha particles which passed close to the nucleus of a gold atom?

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(1)

(b) The results suggested that the diameter of the nucleus of a gold atom is  $\frac{1}{6000}$  of the diameter of the atom.

The diameter of a gold atom is 0.18 nm

Calculate the diameter of a gold nucleus in nm

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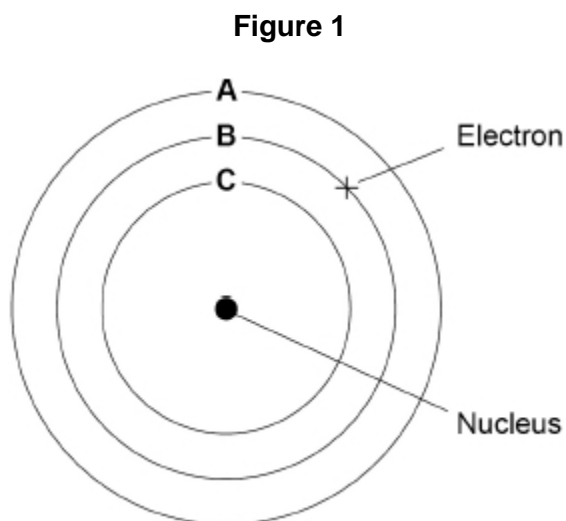
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Diameter = \_\_\_\_\_ nm

(2)

- (c) Further experiments showed that gold nuclei are surrounded by electrons in different energy levels.

**Figure 1** shows three of the energy levels around the nucleus of a gold atom.



The electron in energy level **B** absorbs electromagnetic radiation.

Which energy level will the electron be in after it has absorbed the electromagnetic radiation?

Tick (✓) **one** box.

**A**

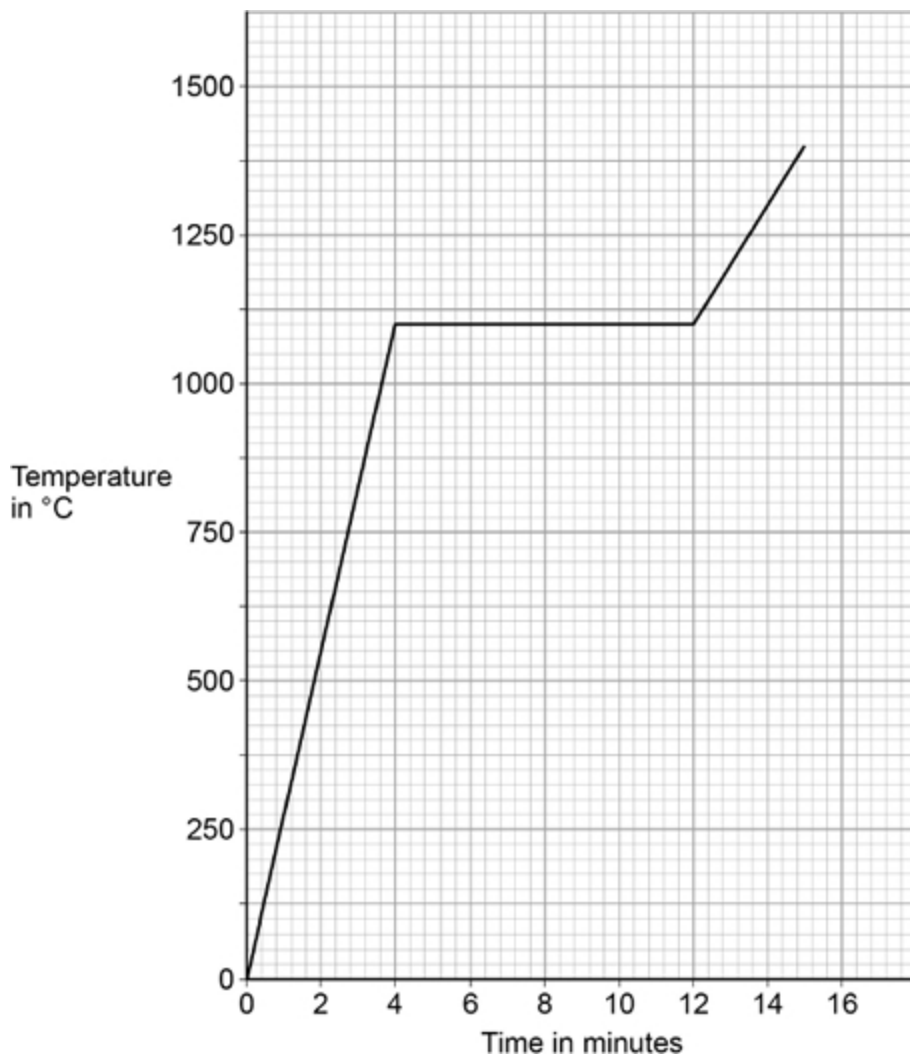
**B**

**C**

(1)

Figure 2 shows how the temperature of a small sample of gold changes as it is heated from a solid to a liquid.

Figure 2



(d) What is the melting point of the gold?

Melting point = \_\_\_\_\_ °C

(1)

(e) How many minutes did it take for all of the gold in the sample to change from solid to liquid?

Time taken = \_\_\_\_\_ minutes

(1)

(f) What does the gradient of the graph in **Figure 2** represent?

Tick (✓) **one** box.

The internal energy of the gold

The rate of change of temperature of the gold

The specific heat capacity of the gold

(1)

(Total 7 marks)

3.

Lanthanum-140 is a radioactive isotope.

(a) A nucleus of lanthanum-140 emits gamma radiation.

What happens to the mass number and the charge of the nucleus when gamma radiation is emitted?

Tick (✓) **one** box.

Mass number	Charge	
Decreases	Decreases	<input type="checkbox"/>
Decreases	Stays the same	<input type="checkbox"/>
Stays the same	Decreases	<input type="checkbox"/>
Stays the same	Stays the same	<input type="checkbox"/>

(1)

(b) Why is it difficult to detect gamma radiation?

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(1)

(c) Activity is the rate at which a radioactive source decays.

A teacher measured the count-rate from a sample of lanthanum-140 using a Geiger-Muller (G-M) tube.

Explain why the count rate was less than the activity of the sample of lanthanum-140

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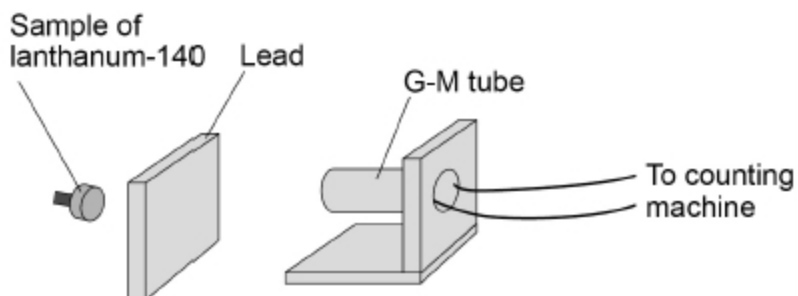
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(2)

The teacher investigated how the thickness of lead affected the amount of gamma radiation that could pass through it.

Figure 1 shows the apparatus.

Figure 1



(d) Explain why the teacher stood as far away from the apparatus as possible.

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(2)

The table shows the results.

Thickness of lead in cm	Count rate in counts per second
0.5	110
1.0	60
1.5	33
2.0	18
2.5	10

- (e) The teacher concluded that the count rate was **not** inversely proportional to the thickness of lead.

Explain why the teacher was correct.

Use the data in the table above.

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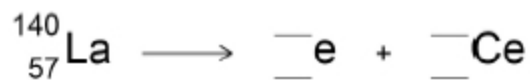
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(3)

- (f) Lanthanum-140 can also emit beta radiation and change into cerium.

Complete the equation showing the decay of lanthanum (La) 140 into cerium (Ce).



(2)

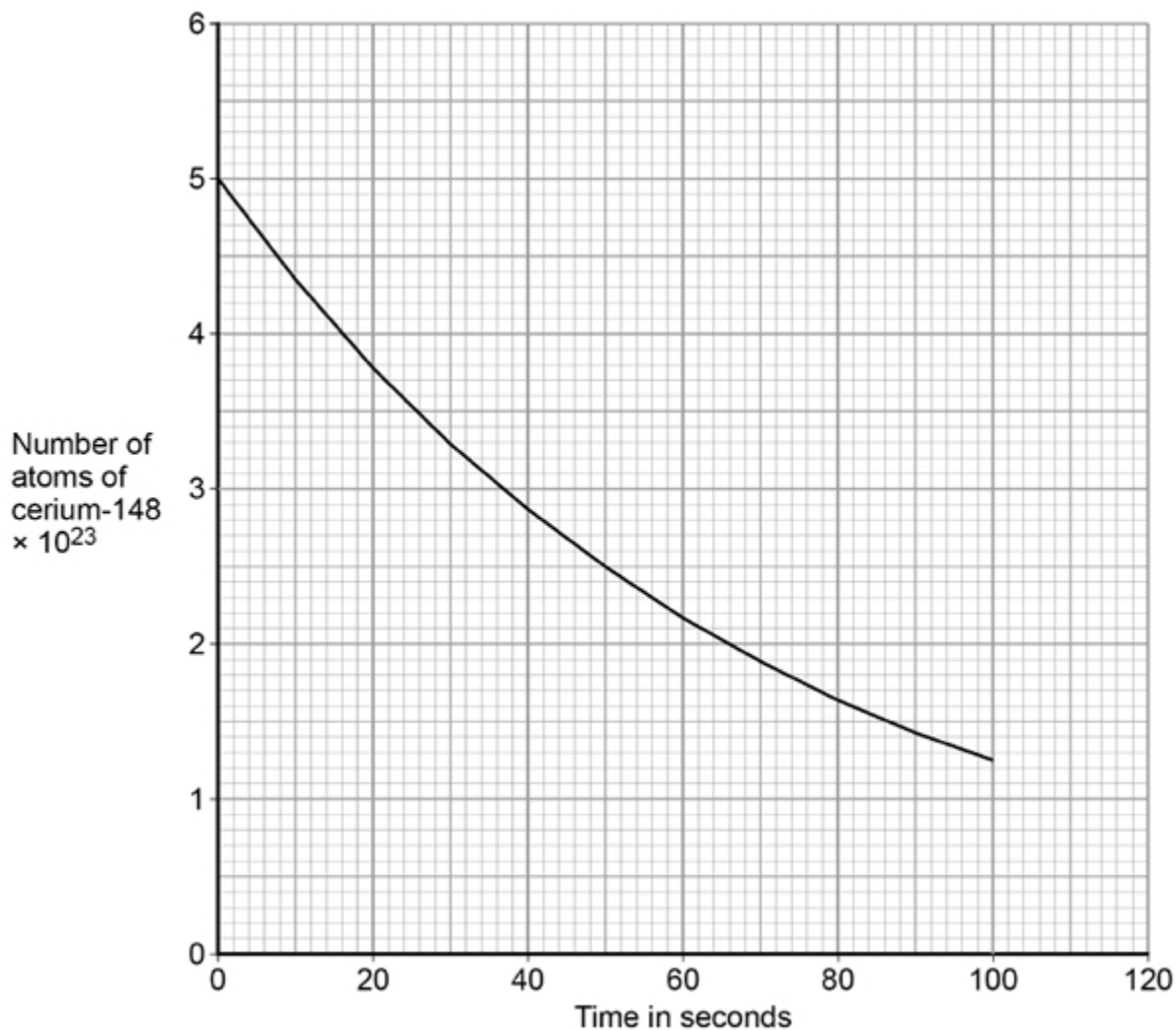
There are other isotopes of cerium which are radioactive.

Different isotopes of cerium have different half-lives.

The half-life of an isotope can be found by studying how the number of atoms changes over time.

**Figure 2** shows how the number of atoms of cerium-148 in a 120 g sample changes over time.

**Figure 2**



- (g) Determine the ratio of the number of cerium atoms in the sample when it was 100 seconds old compared with when the sample was 350 seconds old.

Use data from **Figure 2**.

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Ratio = \_\_\_\_\_

**(4)**

- (h) Determine the activity of the sample of cerium when the sample was 20 seconds old.

Use **Figure 2**.

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Activity = \_\_\_\_\_ Bq

**(3)**

**(Total 18 marks)**

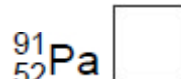
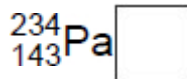
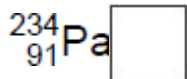
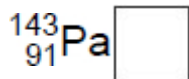
4.

Protactinium (Pa) is radioactive.

(a) An atom of one isotope of protactinium contains 91 protons and 143 neutrons.

What is the correct symbol for this atom?

Tick (✓) **one** box.



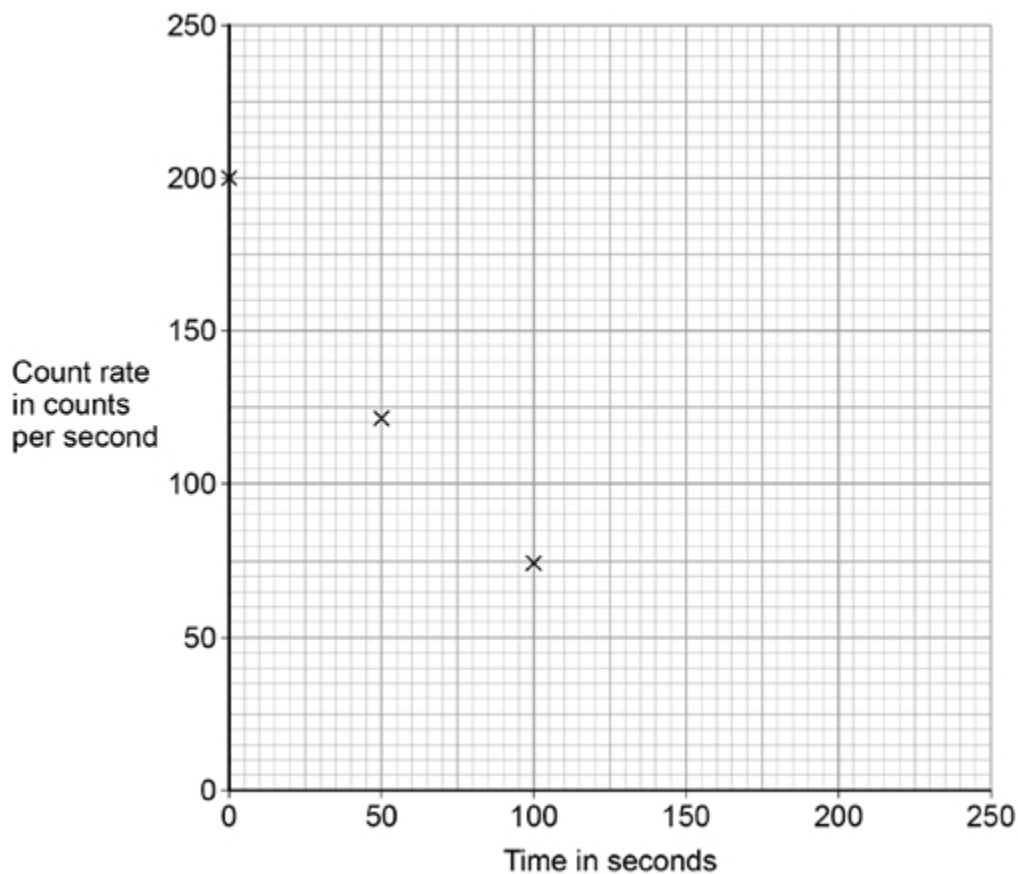
(1)

A teacher investigated how the count rate from a sample of protactinium changed over time.

The table shows the results.

Time in seconds	Count rate in counts per second
0	200
50	122
100	74
150	45
200	27

The graph below shows some of the teacher's results.



(b) Complete the graph.

Use data from the table above.

Draw the line of best fit.

(2)

(c) How much time did it take for the count rate to change from 200 counts per second to 100 counts per second?

\_\_\_\_\_

Time taken = \_\_\_\_\_ s

(1)

(d) What is the half-life of protactinium?

Half-life = \_\_\_\_\_ s

(1)

(e) The nuclear radiation from the protactinium can pass through paper.

This radiation can only be detected up to 1 metre away from the protactinium.

What type of radiation is emitted by the protactinium?

Tick (✓) **one** box.

Alpha

Beta

Gamma

Neutron

(1)

(f) The teacher read an article about the effects of radiation on the human body.

Why are articles in scientific journals generally more trustworthy than articles in newspapers?

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(1)

(Total 7 marks)

5.

Radioactive nuclei can emit alpha, beta or gamma radiation.

(a) Which type of radiation is the most penetrating?

Tick **one** box.

Alpha ( $\alpha$ )

Beta ( $\beta$ )

Gamma ( $\gamma$ )

(1)

(b) Which type of radiation is the most ionising?

Tick **one** box.

Alpha ( $\alpha$ )

Beta ( $\beta$ )

Gamma ( $\gamma$ )

(1)

(c) Which type of radiation has the longest range in air?

Tick **one** box.

Alpha ( $\alpha$ )

Beta ( $\beta$ )

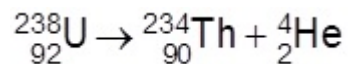
Gamma ( $\gamma$ )

(1)

When radioactive isotopes in the Earth's crust decay they release energy.

The decay causes the heating of rocks in the crust.

(d) The diagram below shows the decay of uranium-238 (U-238) into thorium-234 (Th-234).



Complete the table below to show the number of neutrons and protons in the nuclei.

Isotope	Number of neutrons	Number of protons
uranium-238	146	
thorium-234		90

(2)

(e) Geothermal power stations pump water through heated rocks.

The temperature of the water increases from 20 °C to its boiling point of 100 °C

Calculate the change in thermal energy when the mass of water heated is 150 kg

Specific heat capacity = 4 200 J/kg °C

Use the Physics Equations Sheet.

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Change in thermal energy = \_\_\_\_\_ J

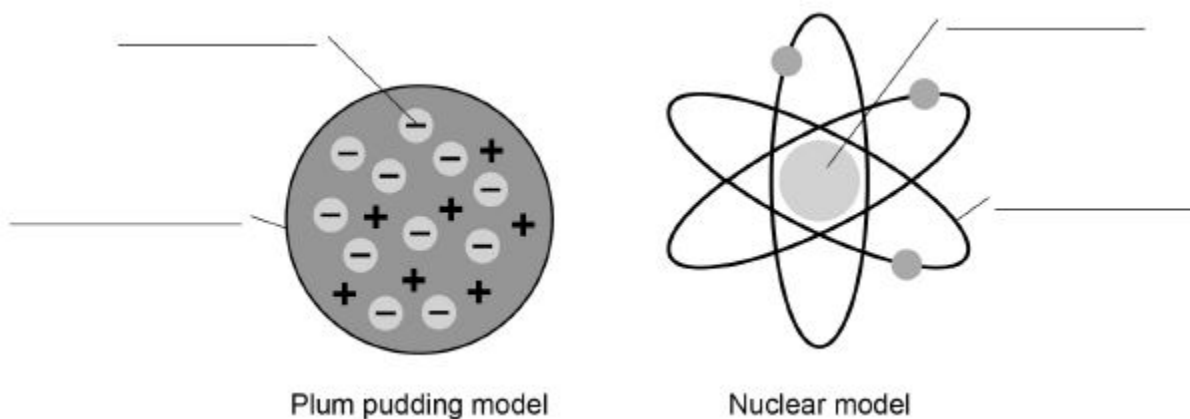
(3)

(Total 8 marks)

6.

Figure 1 shows two models of the atom.

Figure 1



(a) Write the labels on **Figure 1**

Choose the answers from the box.

atom	electron	nucleus
neutron	orbit	proton

(4)

(b) Explain why the total positive charge in every atom of an element is always the same.

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(2)

(c) The results from the alpha particle scattering experiment led to the nuclear model.

Alpha particles were fired at a thin film of gold at a speed of 7% of the speed of light.

Determine the speed of the alpha particles.

Speed of light = 300 000 000 m/s

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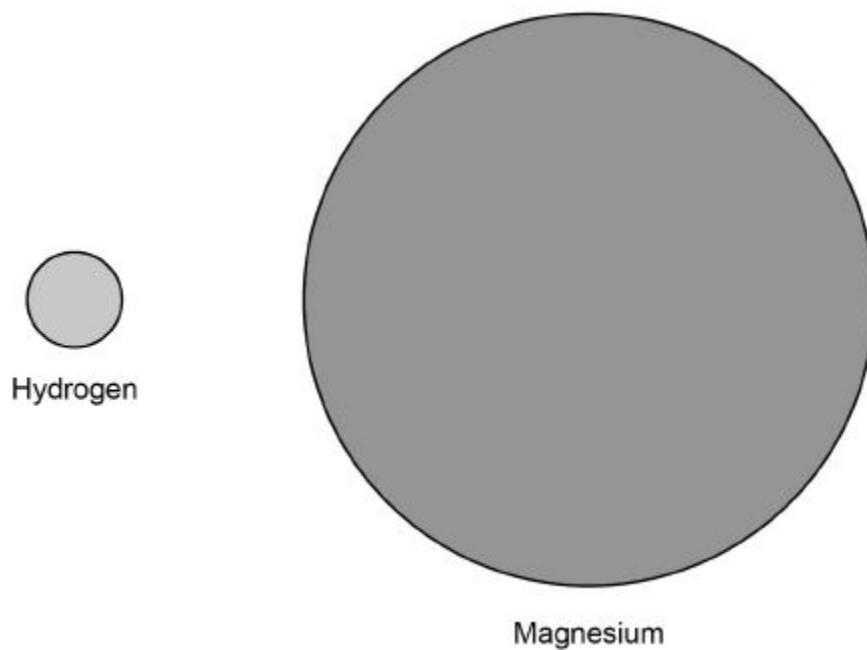
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Speed = \_\_\_\_\_ m/s

(2)

(d) **Figure 2** shows two atoms represented as solid spheres.

**Figure 2**



A hydrogen atom has a radius of  $2.5 \times 10^{-11}$  m

Determine the radius of a magnesium atom.

Use measurements from **Figure 2**

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Radius = \_\_\_\_\_ m

(2)

(Total 10 marks)

7.

The Chernobyl disaster was a nuclear accident that happened in 1986

Radioactive isotopes were released into the environment.

The radioactive isotopes emitted alpha, beta and gamma radiation.

(a) What is an alpha particle?

Tick **one** box.

2 charged particles and 2 neutral particles.

2 charged particles and 4 neutral particles.

4 charged particles and 2 neutral particles.

4 charged particles and 4 neutral particles.

(1)

(b) Which statement about beta radiation is true?

Tick **one** box.

It is the fastest moving type of radiation.

It is the type of radiation with a negative charge.

It is the type of radiation with the greatest mass.

It is the type of radiation with the greatest range in air.

(1)

(c) Which statement about gamma radiation is true?

Tick **one** box.

It is a low frequency electromagnetic wave.

It causes the charge of the nucleus to change.

It causes the mass of the nucleus to change.

It has a very long range in air.

(1)

The table below shows the half-lives of two of the radioactive isotopes that contaminated the environment.

Isotope	Half-life
Caesium-137	30 years
Iodine-131	8 days

(d) A soil sample was taken from the area around Chernobyl in 1986

The soil sample was contaminated with equal amounts of caesium-137 and iodine-131

Explain how the risk linked to each isotope has changed between 1986 and 2018

Both isotopes emit the same type of radiation.

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**(4)**

(e) Determine the year when the activity of the caesium-137 in the soil sample will be  $\frac{1}{32}$  of its original value.

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Year = \_\_\_\_\_

**(3)**

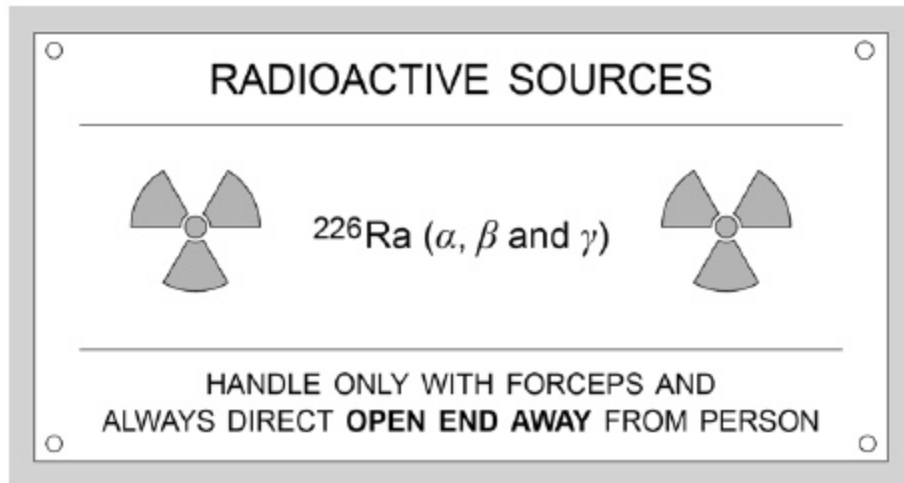
**(Total 10 marks)**

8.

Figure 1 shows the label from a box containing radium-226

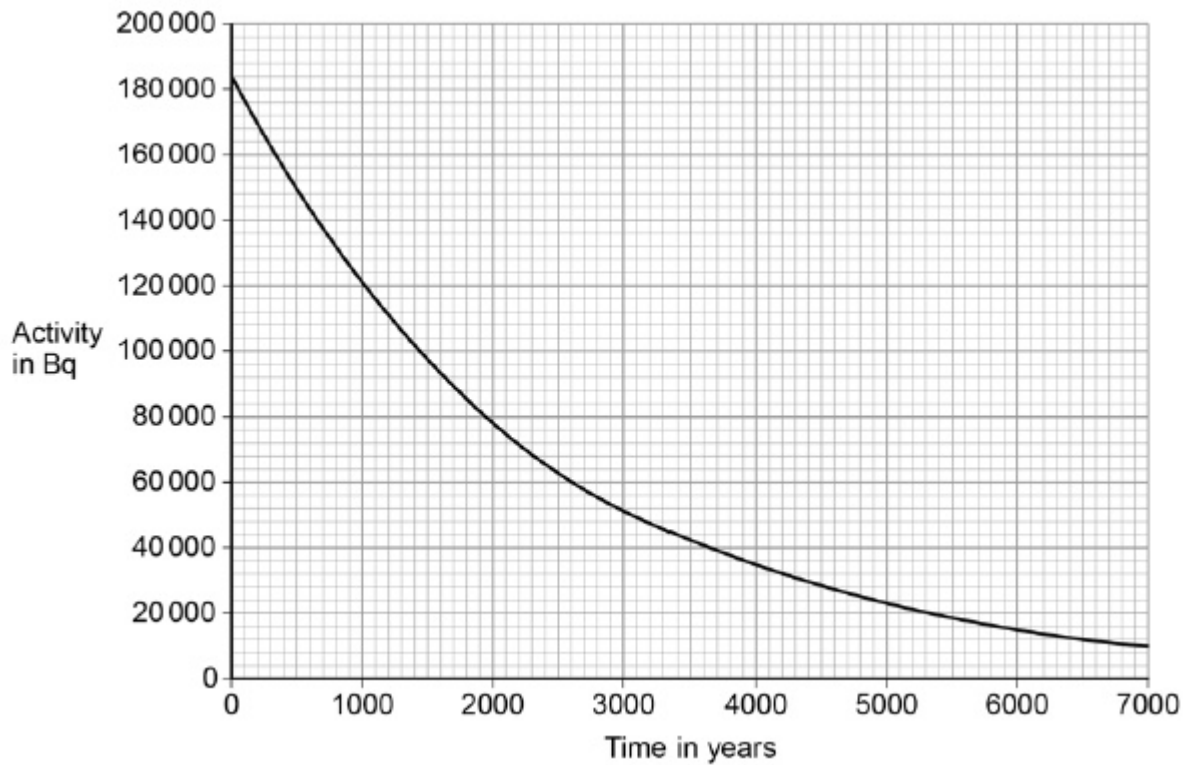
Radium-226 emits  $\alpha$ ,  $\beta$  and  $\gamma$  radiation.

Figure 1



(a) Figure 2 shows how the activity of the radium-226 will change.

Figure 2





## Mark schemes

1.

- (a) both are random processes

*allow rolling dice is a random process*

*allow radioactive decay is a random process*

1

- (b)  $144 \rightarrow 72 \rightarrow 36 \rightarrow 18 \rightarrow 9$

*allow the probability of not getting a 6 is 5/6*

1

4 half lives

*allow  $144 \times (5/6)^4 = 69$*

1

$\frac{20}{4} = 5$  (rolls of the dice)

*allow 69 is closest to 72 so 4 (rolls of the dice) some credible working must be shown to gain this mark*

1

- (c) a dice with 8 sides will have a smaller chance of decay (in one roll)

*allow answers in terms of the 6-sided dice or in terms of more or fewer sides.*

*allow the 8 sided dice has a 1/8 chance of decay, whereas the 6 sided dice has a 1/6 chance of decay*

1

so dice with 8 sides have a greater half-life

1

- (d) nuclei in source **A** are more stable than nuclei in source **B**

*allow nuclei in source A are less likely to decay (in a given time period)*

1

[7]

2.

- (a) they changed direction

*allow*

*deflected/reflected/repelled*

1

- (b)

*an answer of 0.000 03 (nm) or  $3.0 \times 10^{-5}$  (nm) scores 2 marks*

$$\text{diameter} = \frac{0.18}{6000}$$

1

$$= 0.000 030 \text{ (nm)}$$

*allow  $3.0 \times 10^{-5}$  (nm)*

1

- (c) A 1
- (d) 1100 (°C) 1
- (e) 8 (minutes)  
*allow 12 (minutes)* 1
- (f) the rate of change of temperature of the gold 1

[7]

3.

- (a) mass number stays the same, charge stays the same 1
- (b) gamma radiation is only weakly ionising  
**or**  
most gamma radiation will pass through any detector  
*allow gamma radiation is very penetrating* 1
- (c) any two from
- the radiation spreads out in all directions
  - only some of the radiation goes into the G-M tube
  - only some of the radiation passing into the GM tube is detected
- allow 2 marks for only some of the radiation passing into the GM tube is detected because gamma is weakly ionising* 2
- (d) to reduce the amount of radiation received  
*allow to reduce irradiation (of the teacher)* 1
- because radiation increases the risk of cancer or (genetic) mutation  
*allow causes cancer or (genetic) mutation* 1
- ignore references to contamination*

(e) a calculation of the product of thickness and count rate

*examples of calculations*

$$0.5 \times 110 = 55$$

$$1.0 \times 60 = 60$$

$$1.5 \times 33 = 50$$

$$2.0 \times 18 = 36$$

$$2.5 \times 10 = 25$$

1

a second calculation of the product of thickness and count rate

1

a comparison of the calculated values and a recognition that they are different

1

**OR**

A calculation of half the count rate (1)

$$\text{e.g. } \frac{110}{2} = 55$$

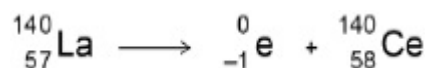
A comparison with the count rate for double that thickness (1)

*the first two marks may be scored for a count rate divided by 3, 4 or 5 compared with the corresponding count rate for 3, 4 or 5 times the thickness*

A recognition that the values are different (1)

$$\text{e.g. } 55 \neq 60$$

(f)



*allow 1 mark for correct numbers on electron*

*allow 1 mark for correct numbers on Ce*

2

(g) half-life = 50 seconds

*this may be indicated on **Figure 3***

1

250 seconds difference in age = 5 half lives

*allow 100 seconds = 2 half lives **and** 350 seconds = 7 half lives*

1

$$\text{ratio} = \left(\frac{1}{2}\right)^5$$

or

$$\text{ratio} = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$$

allow this mark if they have halved  $1.25(\times 10^{23})$  five times to get  $0.0390625(\times 10^{23})$

for example  $1.25(\times 10^{23}) \rightarrow 0.625(\times 10^{23}) \rightarrow 0.3125(\times 10^{23}) \rightarrow 0.15625(\times 10^{23}) \rightarrow 0.078125(\times 10^{23}) \rightarrow 0.0390625(\times 10^{23})$

1

$$\text{ratio} = \frac{1}{32}$$

or

$$\text{ratio} = 1:32$$

allow ratio = 0.031

allow 32:1 or 32

an answer of  $\frac{1}{32}$  or equivalent scores 4 marks

1

(h) tangent drawn on graph

do not allow a line drawn that crosses the graph line

1

$$\text{use of gradient} = \frac{(\Delta \text{ no. of atoms})}{\Delta \text{ time}}$$

values must be taken from their tangent drawn at 20 seconds

1

$$\text{gradient} = 5.3 (\times 10^{21}) \text{ (Bq)}$$

allow gradient =

$$0.053 (\times 10^{23}) \text{ (Bq)}$$

allow a range between

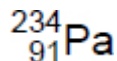
$$4.7 (\times 10^{21}) \text{ (Bq) and } 5.9 (\times 10^{21}) \text{ (Bq)}$$

1

[18]

4.

(a)



1

(b) points correctly plotted to within 1 mm

1

a curved line of best fit passing within 1 mm of all 5 points

ignore any line beyond 200 seconds

1

(c) 70 (s)

*allow an answer between 65 and 75 (s)*  
*allow an answer consistent with their drawn line*

1

(d) 70 (s)

*allow an answer between 65 and 75 (s)*  
*allow their answer to part (c)*

1

(e) beta

1

(f) articles in scientific journals are peer reviewed

*allow articles in scientific journals are based on evidence/data*  
*allow newspaper articles may be oversimplified/inaccurate/biased*

1

[7]

5.

(a) gamma

1

(b) alpha

1

(c) gamma

1

(d)

isotope	number of neutrons	number of protons
uranium-238	146	<b>92</b>
thorium-234	<b>144</b>	90

1

1

(e)  $\Delta\theta = 80\text{ }^\circ\text{C}$

1

$$E = 150 \times 4200 \times 80$$

1

$$E = 50\,400\,000\text{ (J)}$$

*allow 50 000 000 (J)*

1

*allow **max 2** marks for correct calculation using incorrect value of  $\Delta\theta$*

*allow **1** mark for correct calculation using  $\theta = 20$   
**or**  $\theta = 100$*

*an answer of 50 400 000 scores **3** marks*

[8]

<b>6.</b>	(a) electron	1
	atom	1
	nucleus	1
	orbit	1
	(b) positive charge is provided by protons	1
	(every atom of the same element contain the) same number of protons <i>do <b>not</b> accept same number of protons and neutrons</i> <i>ignore reference to electrons</i>	1
	(c) $v = 300\,000\,000 \times \left(\frac{7}{100}\right)$ <i>allow any correct method of determining 7% of 300 000 000</i>	1
	$v = 21\,000\,000$ (m/s) <i>allow <math>2.1 \times 10^7</math> (m/s)</i>  <i>an answer of 21 000 000 scores <b>2</b> marks</i>	1
	(d) $r = 6 \times 2.5 \times 10^{-11}$  <i>allow a ratio in the range of 5.7–6.3 or measurements that would give this range, correctly substituted</i>	1
	$r = 1.5 \times 10^{-10}$ (m) <i>allow <math>1.4 \times 10^{-10}</math> to <math>1.6 \times 10^{-10}</math></i> <i>their ratio <math>\times 2.5 \times 10^{-11}</math> correctly calculated scores <b>1</b> mark</i>  <i>an answer in the range <math>1.4 \times 10^{-10}</math> to <math>1.6 \times 10^{-10}</math> scores <b>2</b> marks</i>	1
		<b>[10]</b>

<b>7.</b>	(a) 2 charged particles and 2 neutral particles	1
	(b) it is the type of radiation with a negative charge	1
	(c) it has a very long range in air	1

(d) risk / activity associated with iodine-131 has decreased by a large amount 1

because of short half-life

*allow many half-lives have passed*

*allow half-life is only 8 days*

*2nd marking point dependent on 1st marking point*

1

risk / activity associated with caesium-137 will not have decreased by much

*allow activity has halved*

1

because of long half-life

*allow only one half-life has passed*

*4th marking point dependent on 3rd marking point*

1

(e) 5 half-lives

*allow any correct method*

*e.g.  $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 1/32$*

1

$$5 \times 30 = 150$$

1

$$1986 + 150 = 2136$$

1

*any calculation using a value of 137 scores zero*

*an answer of 2136 scores 3 marks*

[10]

8.

(a) horizontal line drawn from  
92 000 Bq

*allow 90 000–94 000*

1

1600 years

*allow 1500–1700*

1

(b) only (119) years have passed

1

activity has not dropped by much

1

(c)

<b>Level 3:</b> Relevant points (reasons/causes) are identified, given in detail and logically linked to form a clear account.	5-6
<b>Level 2:</b> Relevant points (reasons/causes) are identified, and there are attempts at logically linking. The resulting account is not fully clear.	3-4
<b>Level 1:</b> Points are identified and stated simply, but their relevance is not clear and there is no attempt at logical linking.	1-2
No relevant content	0
<b>Indicative content</b> <b>properties</b> <ul style="list-style-type: none"><li>• alpha is the least penetrating</li><li>• alpha is the most ionising</li><li>• alpha has least range in air</li><li>• beta is the second most penetrating</li><li>• beta is the second most ionising</li><li>• beta has the second longest range in air</li><li>• gamma is the most penetrating</li><li>• gamma is the least ionising</li><li>• gamma has the greatest range in air</li></ul> <b>hazard</b> (linked to correct property) <ul style="list-style-type: none"><li>• short-range alpha most dangerous</li><li>• mid-range beta most dangerous</li><li>• long range gamma most dangerous</li></ul>	

6

[10]