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physics
aqa spec
atoms and isotopes
with solutions

1 Scientists sometimes replace one scientific model with a different model.

For example, in the early 20th Century the plum pudding model of the atom was replaced by the nuclear model of the atom.

Explain what led to the plum pudding model of the atom being replaced by the nuclear model of the atom.

- alpha particle scattering experiment
- alpha particles directed at gold foil
- most alpha particles pass straight through
- (so) most of atom is empty space
- a few alpha particles deflected through large angles
- (so) mass is concentrated at centre of atom
- (and) nucleus is (positively) charged
- plum pudding model has mass spread throughout atom
- plum pudding model has charge spread throughout atom

(Total 6 marks)

2 A student models the random nature of radioactive decay using 100 dice.

He rolls the dice and removes any that land with the number 6 facing upwards.

He rolls the remaining dice again.

The student repeats this process a number of times.

The table below shows his results.

Roll number	Number of dice remaining
0	100
1	84
2	70
3	59
4	46
5	40
6	32
7	27
8	23

(a) Give **two** reasons why this is a good model for the random nature of radioactive decay.

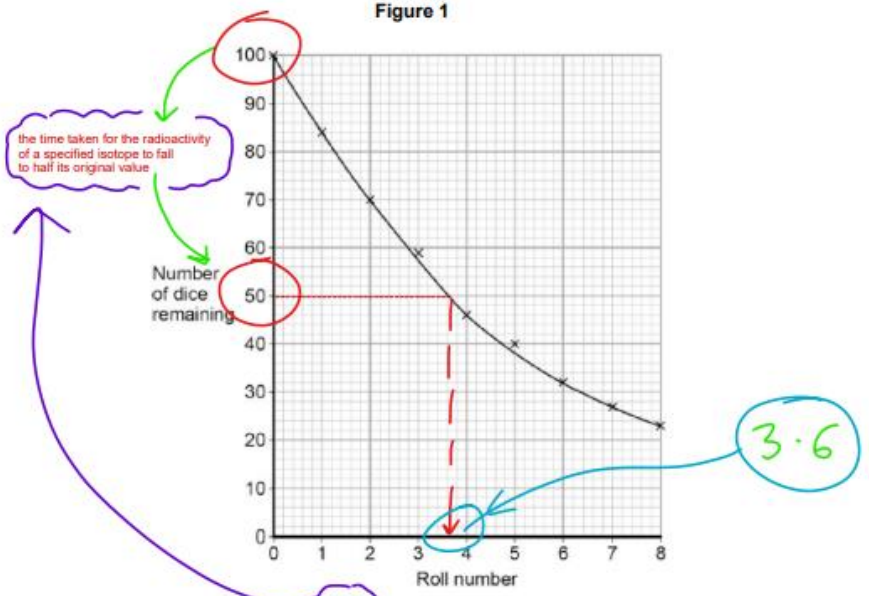
1 Cannot predict which dice or atom will decay (roll of 6)

2 Cannot predict when dice or atom will decay

(2)

(b) The student's results are shown in **Figure 1**.

Figure 1



Use **Figure 1** to determine the half-life for these dice using this model.

Show on **Figure 1** how you work out your answer.

Half-life = 3·6 rolls

(2)

(c) A teacher uses a protactinium (Pa) generator to produce a sample of radioactive material that has a half-life of 70 seconds.

In the first stage in the protactinium generator, uranium (U) decays into thorium (Th) and alpha (α) radiation is emitted.

$^{4}_{2}\alpha$

The decay can be represented by the equation shown in **Figure 2**.

Figure 2

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + \alpha$$

−4 −2 90

Determine the atomic number of thorium (Th) 234.

Atomic number = 90

(1)

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(d) When protactinium decays, a new element is formed and radiation is emitted.

The decay can be represented by the equation shown in **Figure 3**.

Figure 3

$$^{234}_{91}Pa \rightarrow {}^{234}_{92}X + radiation$$

92 = Uranium

When protactinium decays, a new element, **X**, is formed.

Use information from **Figure 2** and **Figure 3** to determine the name of element **X**.

= 92

.....

(1)

(e) Determine the type of radiation emitted as protactinium decays into a new element.

Give a reason for your answer.

Beta

since the atomic number or proton no. increased by 1.

Also in the nucleus a neutron decays into a proton, emitting an e^-.

(2)

(f) The teacher wears polythene gloves as a safety precaution when handling radioactive materials.

The polythene gloves do **not** stop the teacher's hands from being irradiated.

Explain why the teacher wears polythene gloves.

Prevents contamination, which can cause long term damage.

.....

.....

(2)

(Total 10 marks)

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3 Atoms are different sizes.

One of the heaviest naturally occurring stable elements is lead.

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

mass no.

atomic/proton no.

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

Atoms with different number of neutrons, but the same number of protons

(2)

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

= 82

(1)

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

206 − 82 = neutrons

Protons

= 124

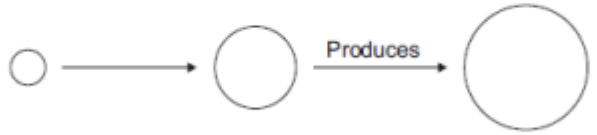
(Protons + neutrons)

(1)

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

This is shown in **Figure 1**.

Figure 1



Nucleus Large nucleus Heavy nucleus

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

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

$$^{58}_{26}Fe + ^{208}_{82}Pb = ^{265}_{108}Hs + ^{1}_{0}X$$

(3)

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

an electron	a proton	a neutron

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

(1)

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

The speed of light is 3.00×10^8 m / s. (300 000 000 m/s x 0·1)

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

using $v = \frac{s}{t}$ $t = \frac{s}{v} = \frac{12000}{30000000}$

Time taken = 0·0004 s or 4.0×10^{-4} s

(2)

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

Suggest why.

particles need to travel a large distance

equipment would have to be very long

with circular paths long distances can be accommodated in a smaller space

(3)

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

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

Tick (✓) **two** boxes.

the time taken for the radioactivity of a specified isotope to fall to half its original value

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

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

$$^{265}_{108}Hs = \frac{261}{106}Sg + \frac{4}{2}\alpha$$

(2)

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

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

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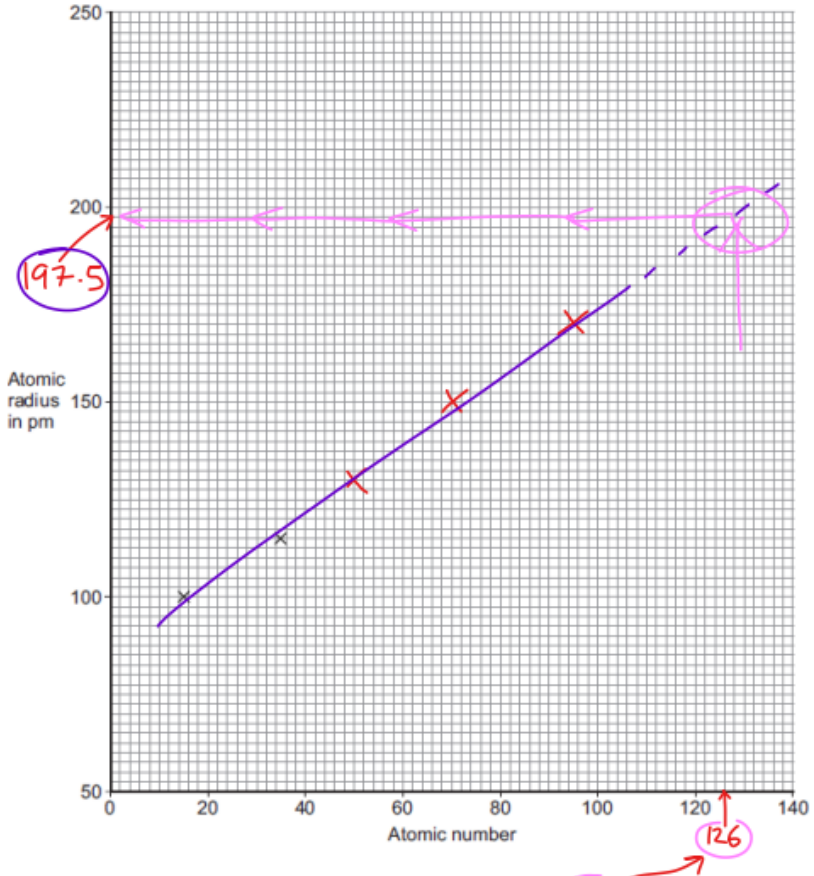
1 pm = 10^{-12} m

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

Two points have been plotted for you.

Figure 2



(2)

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

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

Atomic radius = 197.5 pm

answer between {190 - 205}

(1)

(Total 20 marks)

(b) Two scientists named Rutherford and Marsden devised an experiment to investigate the plum pudding model of the atom. The experiment involved firing alpha particles at a thin sheet of gold. The scientists measured how many of the alpha particles were scattered.

Using the plum pudding model, the scientists predicted that only a few of the alpha particles would be scattered by more than 4°.

Over several months, more than 100 000 measurements were made.

(i) The results from this experiment caused the plum pudding model to be replaced by a new model of the atom.

Explain why.

a (significant) number of alpha particles were scattered by more than 4°
or
alpha particles deflected backwards

measurements / results could not be explained by 'plum pudding' model
or
measurements / results did not support predictions

(2)

(ii) Suggest **one** reason why other scientists thought this experiment provided valid evidence for a new model of the atom.

many / (over)100 000 measurements / results taken

also can say that Rutherford(and Marsden) were respected scientists

(1)

(c) **In this question you will be assessed on using good English, organising information clearly and using specialist terms where appropriate.**

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Describe the model now used for the structure of an atom.

In your answer you should:

- give details of the individual particles that make up an atom
- include the relative masses and relative charges of these particles.

Do **not** include a diagram in your answer.

.....

contains protons, neutrons and electrons
protons are positive
electrons are negative
neutrons are uncharged
has a nucleus
relative charge
proton +1
electron -1
neutron 0
relative mass
proton 1
neutron 1
electron (about) 1 / 2000

protons and neutrons make up the nucleus
electrons orbit the nucleus
electrons are in shells
most of the atom is empty space
nucleus occupies a very small fraction of the volume of the atom
electrons orbit at a relatively large distance from the nucleus
most of the mass of the atom is contained in the nucleus
the nucleus as a whole is positively charged total number of protons in the nucleus
equals the total number of electrons orbiting it in an atom

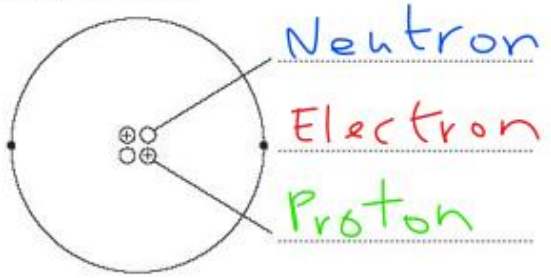
.....

.....

.....

(6)

26 The diagram shows a helium atom.



(a) (i) Use the words in the box to label the diagram.

electron	neutron	proton

(2)

(ii) An alpha particle is the same as the nucleus of a helium atom.

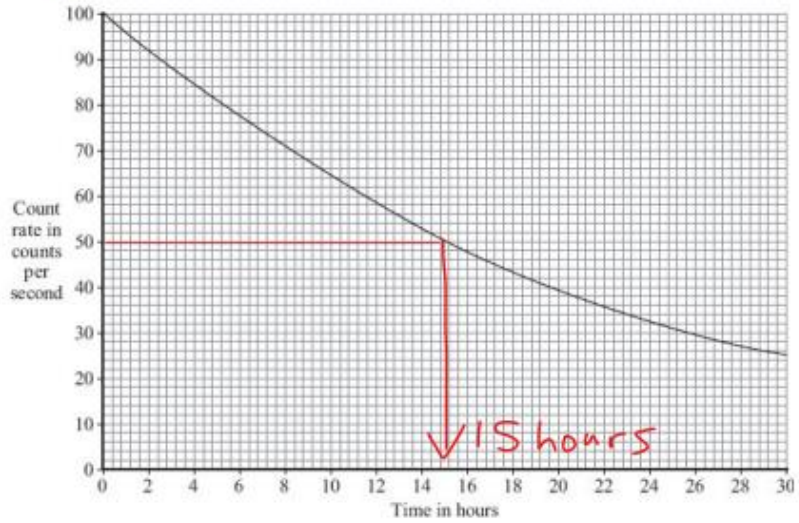
How is an alpha particle different from a helium atom?

Does not contain electrons

.....

(1)

(b) The graph shows how the count rate from a sample of radioactive sodium-24 changes with time.



(i) How many hours does it take for the count rate to fall from 100 counts per second to 50 counts per second?

Time = 15 ..... hours

(1)

(ii) What is the half-life of sodium-24?

Half-life = 15 ..... hours

(1)

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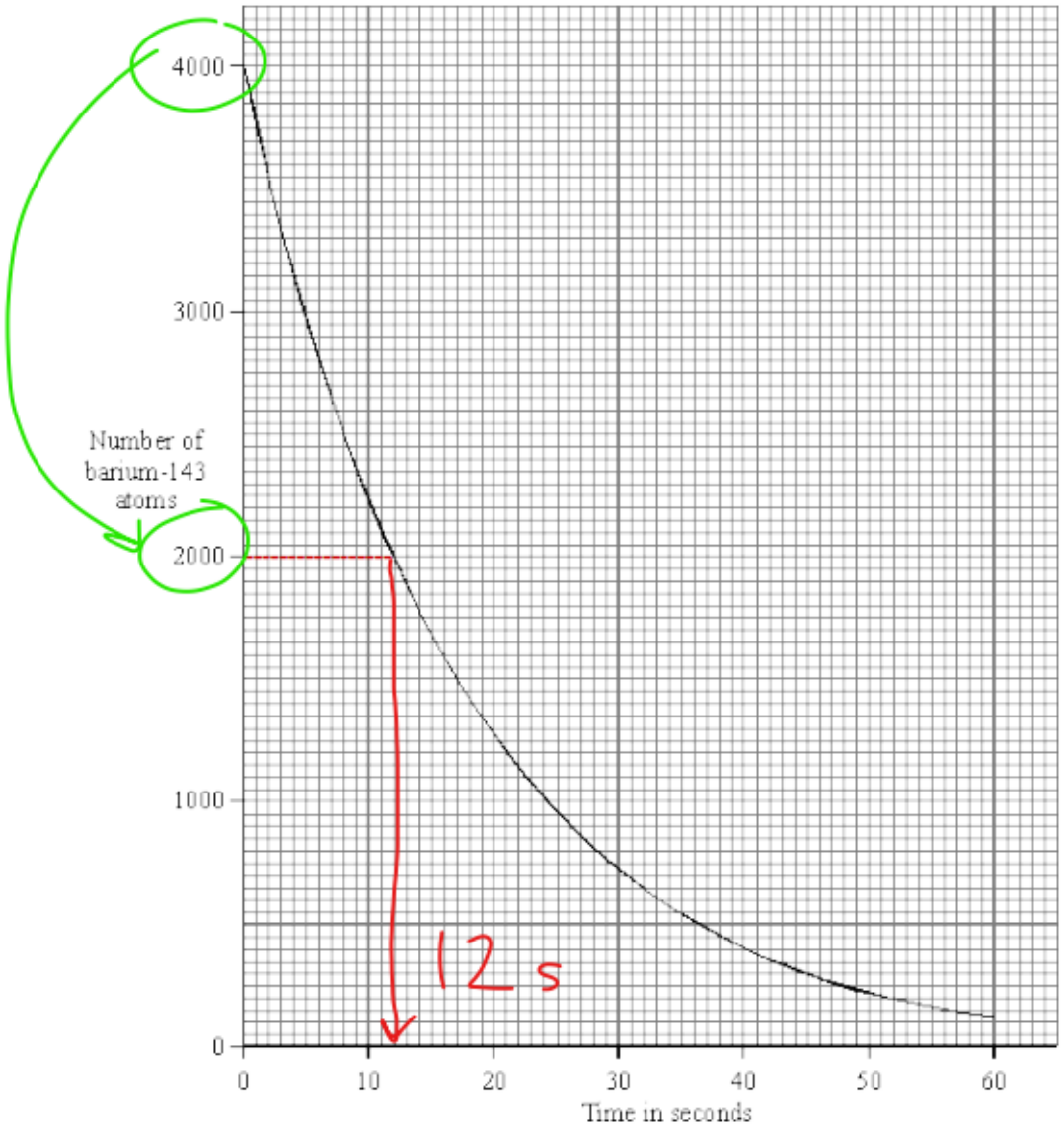
11 (a) The graph shows how a sample of barium-143, a radioactive *isotope* with a short *half-life*, decays with time.



(i) What is meant by the term *isotope?*

element with equal number of protons, different number neutrons
or
same atomic/proton number different mass/nuclear number

(1)

(ii) What is meant by the term *half-life*?

time taken for activity or count rate or number of nuclei to decrease to half

(1)

(iii) Use the graph to find the half-life of barium-143.

Half-life = 12 seconds

(1)

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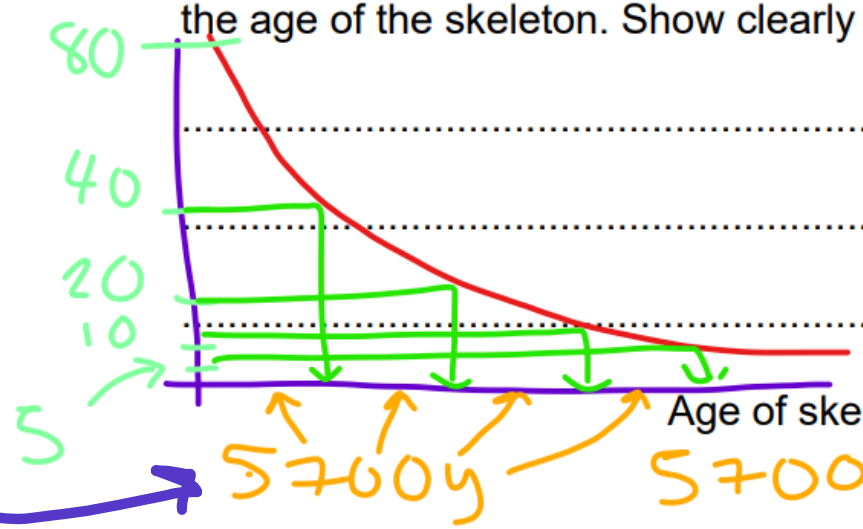
(b) Humans take in the radioactive isotope carbon-14 from their food. After their death, the proportion of carbon-14 in their bones can be used to tell how long it is since they died. Carbon-14 has a half-life of 5700 years.

(i) A bone in a living human contains 80 units of carbon-14. An identical bone taken from a skeleton found in an ancient burial ground contains 5 units of carbon-14. Calculate the age of the skeleton. Show clearly how you work out your answer.



.....

.....

.....

Age of skeleton = 22 800 ..... years

(2)

(ii) Why is carbon-14 unsuitable for dating a skeleton believed to be about 150 years old?

decay (of carbon 14) over 150 years is insignificant

.....

.....

(1)

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(c) The increased industrial use of radioactive materials is leading to increased amounts of radioactive waste. Some people suggest that radioactive liquid waste can be mixed with water and then safely dumped at sea. Do you agree with this suggestion? Explain the reason for your answer.

FOR

– massive dilution of waste

– reduces concentration (within a given volume) to insignificant levels

– distant from habitation

AGAINST

– pollution (of the sea/beach)

– mutation or harm caused to living things (animals/plants)

– effect on food chain

– long period of time necessary

(3)

(Total 9 marks)

52 A radioactive source emits alpha (α), beta (β) and gamma (γ) radiation. The diagram shows what happens to the radiation as it passes between two charged metal plates.

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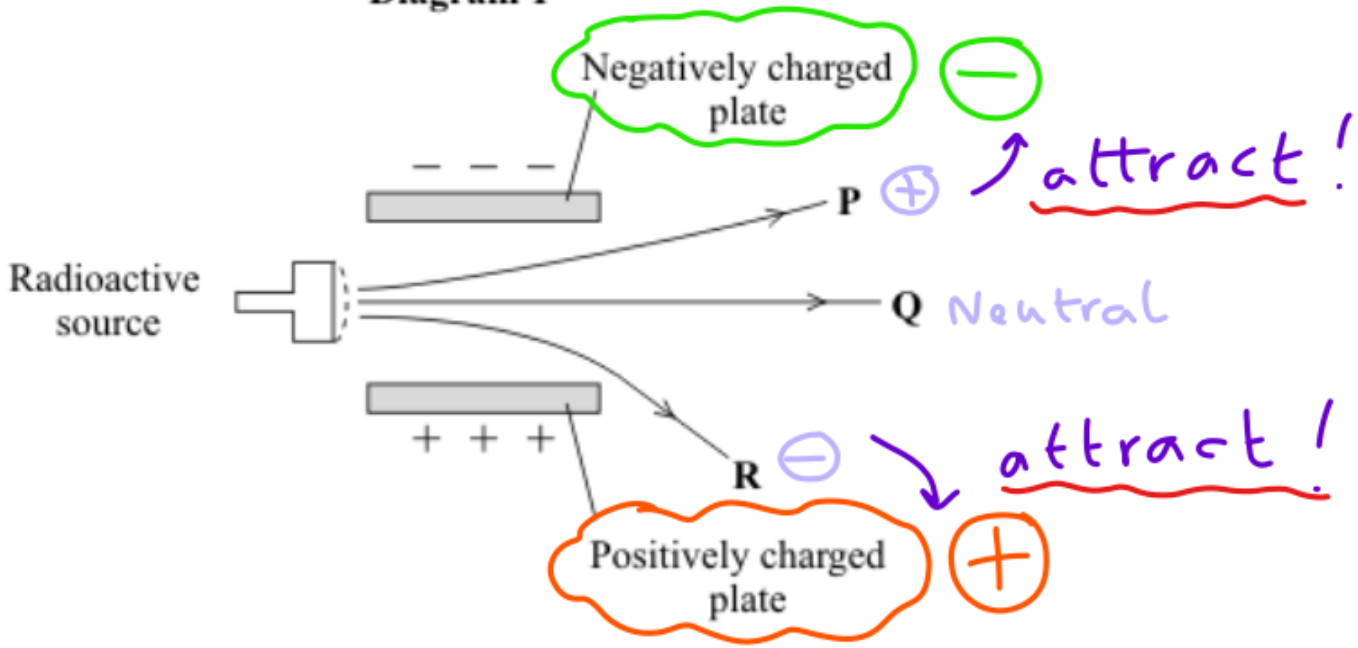
Diagram 1



(a) Which line **P**, **Q** or **R** shows the path taken by:

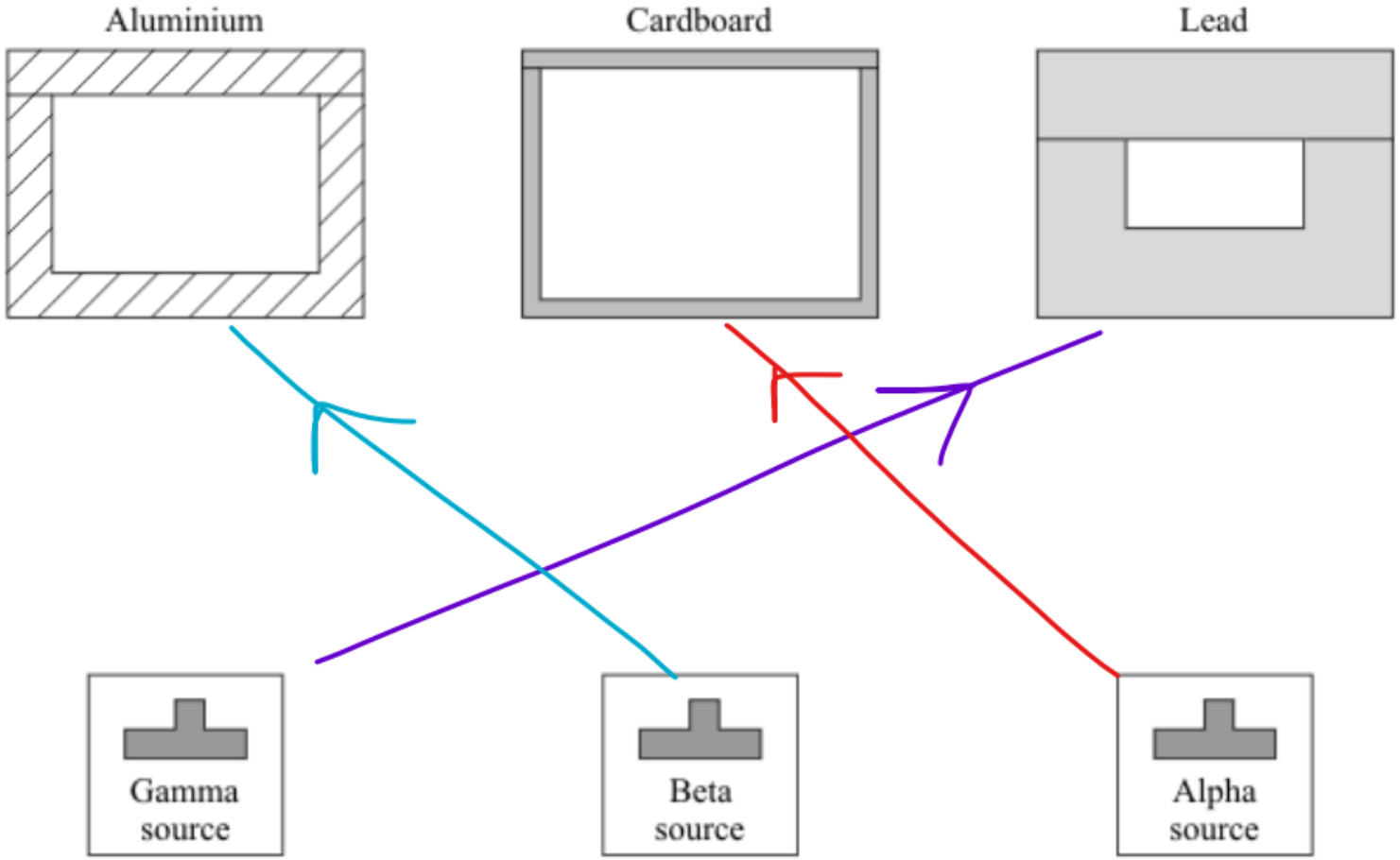
(i) alpha radiation ..... P .....

(1)

(ii) gamma radiation? ..... Q .....

(1)

(b) The diagram shows three different boxes and three radioactive sources. Each source emits only one type of radiation and is stored in a different box. The box reduces the amount of radiation getting into the air.



Draw **three** lines to show which source should be stored in which box so that the minimum amount of radiation gets into the air.

(2)

1 Electricity is generated in a nuclear power station.

Fission is the process by which energy is released in the nuclear reactor.

(a) **Figure 1** shows the first part of the nuclear fission reaction.

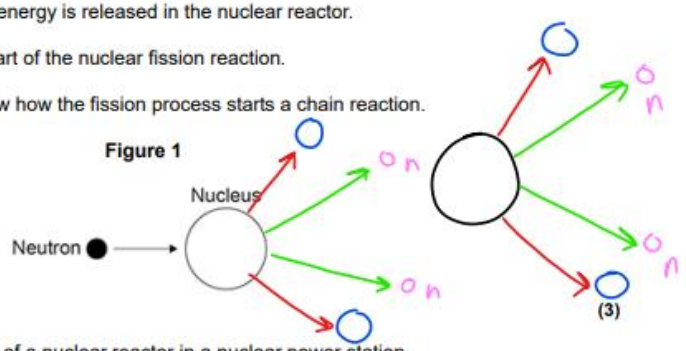
Complete **Figure 1** to show how the fission process starts a chain reaction.

Nucleus splitting into two fragments and releasing two or three neutrons

(at least one) fission neutron shown to be absorbed by additional large nucleus and causing fission

two or three additional neutrons released from fission reaction

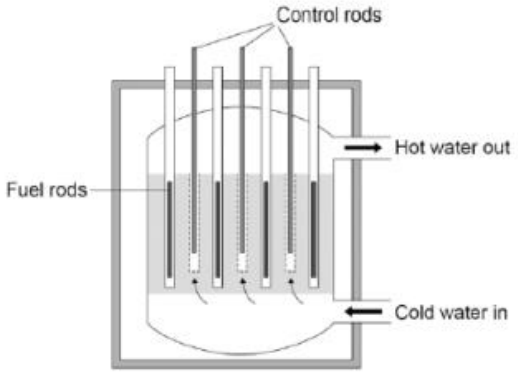
Figure 1



(3)

(b) **Figure 2** shows the inside of a nuclear reactor in a nuclear power station.

Figure 2



In a nuclear reactor a chain reaction occurs, which causes neutrons to be released.

The control rods absorb neutrons.

The control rods can be moved up and down.

Explain how the energy released by the chain reaction is affected by moving the control rods.

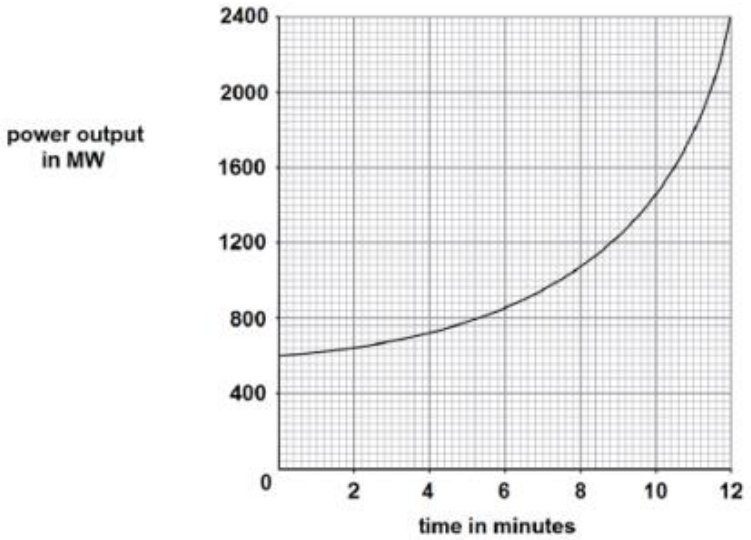
lowering the control rods increases the number of neutrons absorbed or heightening them will decrease the number of neutrons absorbed

(so) energy released decreases

(2)

(c) **Figure 3** shows how the power output of the nuclear reactor would change if the control rods were removed.

Figure 3



Calculate the rate of increase of power output at 10 minutes.

rate of increase between 240 and 276 (MW / min)

Rate of increase of power output = ... MW / minute

(2)

(Total 7 marks)

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0 5 Polonium-210 ($^{210}_{84}Po$) is a radioactive isotope that decays by emitting alpha radiation.

0 5 . 1 Complete the decay equation for polonium-210

[2 marks]

$$^{210}_{84}Po \longrightarrow \boxed{206}\ \boxed{82}Pb + {}^{4}_{2}He$$

0 5 . 2 Explain why contamination of the inside of the human body by a radioactive material that emits alpha radiation is highly dangerous.

[3 marks]

alpha radiation is highly ionising

causing an increased risk of cancer **or** organ failure **or** radiation sickness / poisoning

or mutation of genes / DNA **or** damage to cells / tissues / organs

until the radioactive material is removed / excreted

or

activity of radioactive material reaches / approaches background radiation levels

0 5 . 3 A sample of polonium-210 was left for 414 days.

After this time it had a mass of 1.45×10^{-4} g

The half-life of polonium-210 is 138 days.

414/138=3 (half-lives)

1.45 × 10-4 × 2 × 2 × 2

= 1.16 × 10-3 (g)

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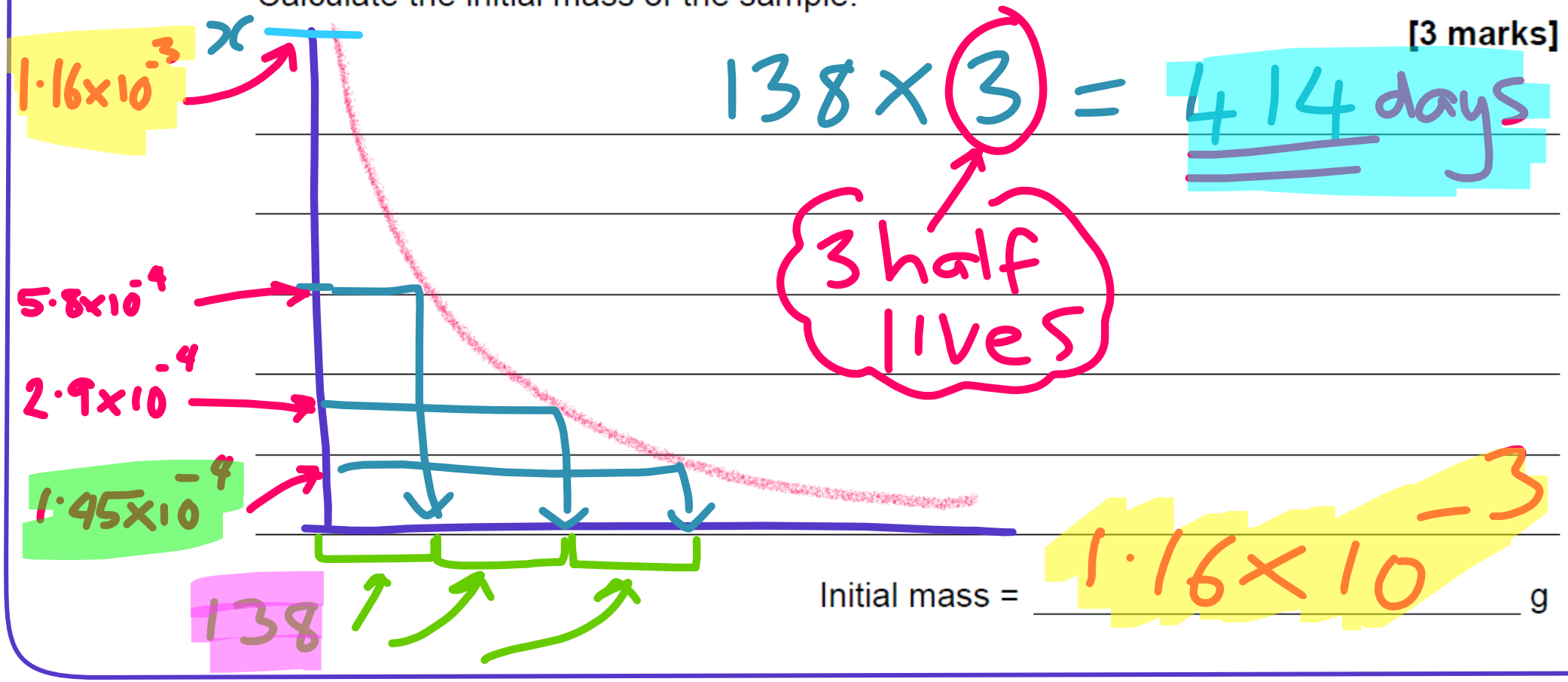
Calculate the initial mass of the sample.

[3 marks]



138 × 3 = 414 days

3 half lives

Initial mass = 1·16 × 10⁻³ g

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0 2 Different radioactive isotopes emit different types of nuclear radiation.

A polonium-210 (Po) nucleus emits an alpha particle (α) and turns into a lead (Pb) nucleus.

This can be represented by the equation:

$$^{210}_{84}\text{Po} \longrightarrow {}^{A}_{Z}\text{Pb} + \alpha$$

0 2 . 1 What is the value of A in the equation?

[1 mark]

Tick (✓) **one** box.

A = 206 ☑ A = 208 ☐ A = 210 ☐ A = 211 ☐

0 2 . 2 What is the value of Z in the equation?

[1 mark]

Tick (✓) **one** box.

Z = 80 ☐ Z = 82 ☑ Z = 85 ☐ Z = 86 ☐

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0 2 . 3 A strontium-89 nucleus (Sr) emits a beta particle (β) and turns into an yttrium nucleus (Y).

This can be represented by the equation:

$$^{89}_{38}\text{Sr} \longrightarrow {}^{A}_{Z}\text{Y} + \beta$$

What are the values of A and Z in the equation?

[2 marks]

A = 89

Z = 39

0 2 . 4 Gamma radiation is another type of nuclear radiation.

What does gamma radiation consist of?

[1 mark]

Tick (✓) **one** box.

- [ ] High energy neutrons
- [x] Electromagnetic waves
- [ ] Particles with no charge
- [ ] Positively charged ions

0 2 . 5 Explain the differences between the properties of alpha, beta and gamma radiations.

[6 marks]

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alpha radiation

- an alpha particle is the same as a helium nucleus
- alpha is the least penetrating
- alpha is stopped by paper or skin
- alpha has the shortest range in air
- alpha will travel a few cm in air
- because alpha is most ionising
- because alpha has a charge of +2

beta radiation

- a beta particle is an electron (emitted from the nucleus)
- beta penetrates less than gamma and more than alpha
- beta is stopped by a thin sheet of aluminium
- beta has a shorter range than gamma
- beta will travel up to 1m in air
- because beta is more ionising that gamma and less ionising than alpha
- because beta has a charge of -1

gamma radiation

- gamma radiation is an electromagnetic wave
- gamma is the most penetrating
- gamma is reduced/stopped by several cm of lead or thick concrete
- gamma has the largest range in air
- gamma will travel very large distances in air
- because gamma is least ionising
- because is uncharged

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0 5 Radioactive waste from nuclear power stations is a man-made source of background radiation.

0 5 . 1 Give **one** other man-made source of background radiation.

[1 mark]

- (medical) x-rays
- radiotherapy
- nuclear weapons (testing)
- named nuclear disaster

eg Chernobyl / Fukushima / Three Mile Island.

Nuclear power stations use the energy released by nuclear fission to generate electricity.

0 5 . 2 Give the name of **one** nuclear fuel.

[1 mark]

uranium / plutonium

0 5 . 3 Nuclear fission releases energy.

Describe the process of nuclear fission inside a nuclear reactor.

[4 marks]

neutron absorbed by a uranium nucleus

nucleus splits into two parts

and (2 / 3) neutrons (are released)

and gamma rays (are emitted)

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0 5 . 4 A new type of power station is being developed that will generate electricity using nuclear fusion.

Explain how the process of nuclear fusion leads to the release of energy.

[2 marks]

lighter nuclei join to form heavier nuclei

some of the mass (of the nuclei) is converted to energy (of radiation)

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0 5 . 5 Nuclear fusion power stations will produce radioactive waste. This waste will have a much shorter half-life than the radioactive waste from a nuclear fission power station.

Explain the advantage of the radioactive waste having a shorter half-life.

[2 marks]

activity decreases quickly

risk of harm decreases quickly

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0 2 Different radioactive isotopes emit different types of nuclear radiation.

A polonium-210 (Po) nucleus emits an alpha particle (α) and turns into a lead (Pb) nucleus.

This can be represented by the equation:

$$^{210}_{84}\text{Po} \longrightarrow {}^{A}_{Z}\text{Pb} + \alpha$$

4
2 α
no. decreases by 4 / 2

0 2 . 1 What is the value of A in the equation?

Tick (✓) **one** box.

A = 206 ☑ A = 208 ☐ A = 210 ☐ A = 211 ☐

[1 mark]

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0 2 . 2 What is the value of Z in the equation?

[1 mark]

Tick (✓) **one** box.

Z = 80 ☐ Z = 82 ☑ Z = 85 ☐ Z = 86 ☐

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0 2 . 3 A strontium-89 nucleus (Sr) emits a beta particle (β) and turns into an yttrium nucleus (Y).

This can be represented by the equation:

$$^{89}_{38}\mathrm{Sr} \longrightarrow {}^{A}_{Z}\mathrm{Y} + \beta$$

β = $^{0}_{-1}\beta$

What are the values of A and Z in the equation?

[2 marks]

A = 89

Z = 39

A stays the same

Z increases by 1

0 2 . 5 Explain the differences between the properties of alpha, beta and gamma radiations.

[6 marks]

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alpha radiation

- an alpha particle is the same as a helium nucleus
- alpha is the least penetrating
- alpha is stopped by paper or skin
- alpha has the shortest range in air
- alpha will travel a few cm in air
- because alpha is most ionising
- because alpha has a charge of +2

beta radiation

- a beta particle is an electron (emitted from the nucleus)
- beta penetrates less than gamma and more than alpha
- beta is stopped by a thin sheet of aluminium
- beta has a shorter range than gamma
- beta will travel up to 1m in air
- because beta is more ionising that gamma and less ionising than alpha
- because beta has a charge of -1

gamma radiation

- gamma radiation is an electromagnetic wave
- gamma is the most penetrating
- gamma is reduced/stopped by several cm of lead or thick concrete
- gamma has the largest range in air
- gamma will travel very large distances in air
- because gamma is least

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0 6 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.

0 6 . 1 Why is rolling dice a suitable model for radioactive decay?

[1 mark]

both are random processes

0 6 . 2 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.

[3 marks]

144 → 72 → 36 → 18 → 9

4 half lives

20/4 = 5 (rolls of the dice)

Answer = _____ rolls of the dice

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0 6 . 3 The number of times the dice have to be rolled to halve the original number of dice in the tray represents the half-life.

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Figure 7 shows an eight-sided dice and a six-sided dice.

Figure 7

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.

[2 marks]

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

so dice with 8 sides will have a greater half-life

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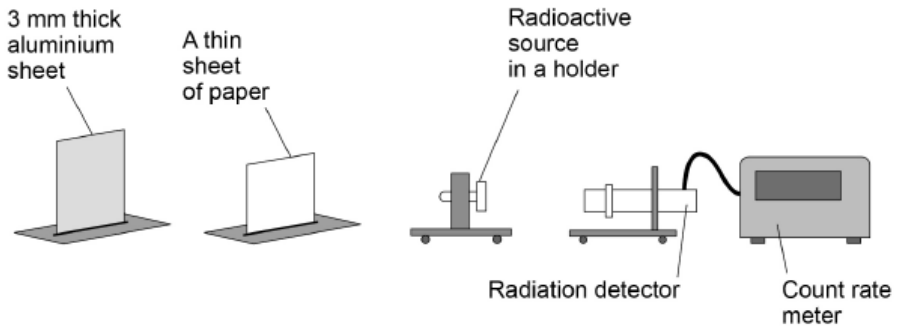
0 2 . 4 A teacher wants to demonstrate that the radioactive source emits alpha, beta and gamma radiation.

Figure 3 shows the equipment the teacher has.

Figure 3



Describe a method the teacher could use.

[6 marks]

- move the detector very close to the source
- record the count rate

- position the paper between the source and the detector
- record the new count rate
- alpha radiation will not penetrate through paper
- if the count rate with the paper is (significantly) less than without then the source emits alpha radiation

- remove the paper and position the aluminium between the source and the detector
- record the new count rate
- (alpha and) beta radiation will not penetrate through the aluminium
- if the count rate has (significantly) reduced compared with using paper then beta radiation is present
- if radiation penetrates through the aluminium then gamma radiation is present

- the experiment should be repeated and mean results calculated because radioactivity is a random process

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0 7 Alpha particles, beta particles and gamma rays are types of nuclear radiation

0 7 . 1 What does an alpha particle consist of?

He nucleus

[1 mark]

2 protons
2 neutrons

0 7 . 2 A krypton (Kr) nucleus decays into a rubidium (Rb) nucleus by emitting a beta particle.

Complete the nuclear equation for this decay by writing the missing number in each box.

[2 marks]

85

$$\square_{36}\mathrm{Kr} \longrightarrow \square^{85}\mathrm{Rb} + {}^{0}_{-1}\mathrm{e}$$

37