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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Particles and radiation (3.2)

A Level Physics (7408) · Section 3.2

81 questions · 272 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

QUESTION	SOURCE	MARKS	PAGE
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2. Q10	7408/1 June 2022	1	7
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5. Q1 <i>also 3.8</i>	7408/1 June 2022	12	10
3.2.1.2 STABLE AND UNSTABLE NUCLEI		11 Qs · 33 marks	13
6. Q12 <i>also 3.8</i>	7408/1 June 2018	1	14
7. Q30	7408/2 June 2019	1	15
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17. Q10	7408/1 June 2018	1	30
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3.2.1.4 PARTICLE INTERACTIONS		7 Qs · 27 marks	38
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37. Q10	also 3.4	7408/1 June 2019	1	62
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QUESTION		SOURCE	MARKS	PAGE
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QUESTIONS

81 questions · 272 marks · 9 sub-topics



SUB-TOPIC 3.2.1.1

CONSTITUENTS OF THE ATOM

Sub-topic 3.2.1.1 · 5 questions · 16 marks · lowest tariff first



0 9

Fluoride ions are produced by the addition of a single electron to an atom of fluorine ${}^{19}_9\text{F}$.

What is the magnitude of specific charge of the fluoride ion?

[1 mark]

A $3.2 \times 10^{-26} \text{ C kg}^{-1}$

☐

B $8.4 \times 10^{-21} \text{ C kg}^{-1}$

☐

C $5.0 \times 10^6 \text{ C kg}^{-1}$

☐

D $4.5 \times 10^7 \text{ C kg}^{-1}$

☐

1 0What is the specific charge of a ${}^{13}_6\text{C}$ nucleus?**[1 mark]**

A $4.4 \times 10^7 \text{ C kg}^{-1}$

☐

B $5.2 \times 10^7 \text{ C kg}^{-1}$

☐

C $8.3 \times 10^7 \text{ C kg}^{-1}$

☐

D $2.1 \times 10^8 \text{ C kg}^{-1}$

☐

0 9

A nucleus contains N neutrons and Z protons.

Which combination of N and Z gives a nucleus with the greatest specific charge?

[1 mark]

	N	Z	
A	6	5	☐
B	8	7	☐
C	16	13	☐
D	20	17	☐



0 8

Which nuclear change results in the nucleus with the greatest specific charge?

[1 mark]

A the alpha decay of a $^{209}_{82}\text{Po}$ nucleus ☐

B the beta-minus decay of a $^{28}_{12}\text{Mg}$ nucleus ☐

C the beta-plus decay of a $^{39}_{20}\text{Ca}$ nucleus ☐

D electron capture by a $^{105}_{47}\text{Ag}$ nucleus ☐



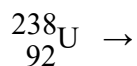
0	1
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Two stable isotopes of helium are ${}^4_2\text{He}$ and ${}^3_2\text{He}$.

0	1	.	1
---	---	---	---

An atom of ${}^4_2\text{He}$ is produced in a rock that contains uranium. It is produced following the radioactive decay of a ${}^{238}_{92}\text{U}$ atom. The decay also creates an atom of thorium (Th).

Write an equation for the decay of ${}^{238}_{92}\text{U}$.

[2 marks]

0	1	.	2
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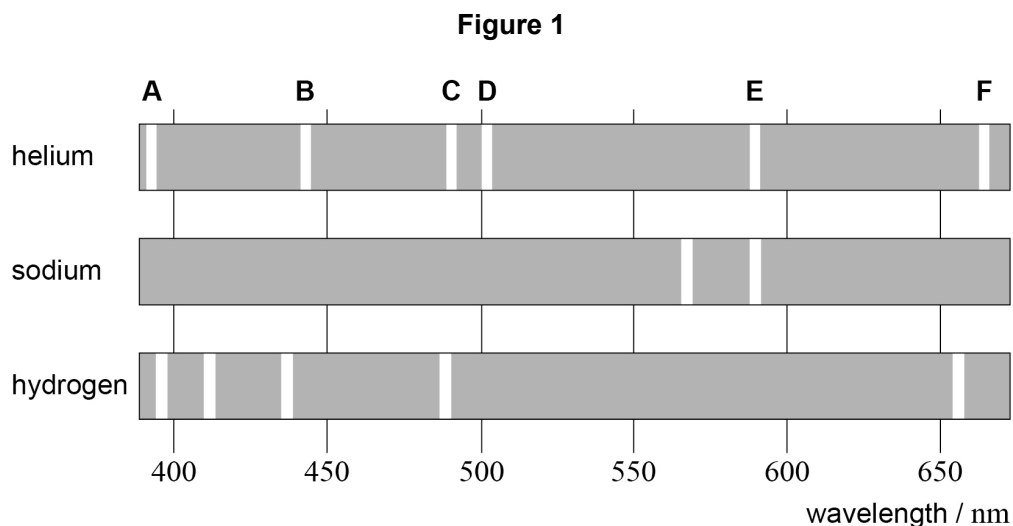
A ${}^3_2\text{He}$ nucleus can be produced by the decay of a tritium nucleus ${}^3_1\text{H}$.

State and explain which exchange particle is responsible for this decay.

[2 marks]

Helium was discovered by analysing the light in the **absorption** spectrum of the Sun.

Figure 1 shows the positions of the brightest lines, labelled **A** to **F**, in the **emission** spectrum of helium. The brightest lines in the emission spectra of sodium and hydrogen are also shown.



0 1 . 3

Before helium was identified, some scientists suggested that the lines of the helium spectrum seen in the absorption spectrum of the Sun were due to the presence of sodium and hydrogen.

Discuss, with reference to the lines **A** to **F** in **Figure 1**, the evidence for and against this suggestion.

[2 marks]

Question 1 continues on the next page

0	1	.	4
---	---	---	---

Calculate, in eV, the change in energy level responsible for the spectral line labelled **E** in **Figure 1**.

[3 marks]

change in energy level = _____ eV

0	1	.	5
---	---	---	---

Explain, with reference to the processes within an atom, the difference between an emission spectrum and an absorption spectrum.

[3 marks]



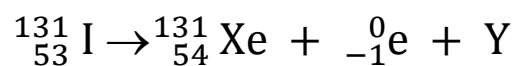
SUB-TOPIC 3.2.1.2

STABLE AND UNSTABLE NUCLEI

Sub-topic 3.2.1.2 · 11 questions · 33 marks · lowest tariff first



- 1 2** An iodine nucleus decays into a nucleus of Xe-131, a beta-minus particle and particle Y.



Which is a property of particle Y?

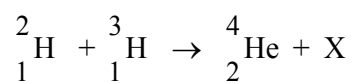
[1 mark]

- A** It has a lepton number of +1
- B** It is an antiparticle
- C** It is negatively charged
- D** It experiences the strong interaction

☐☐☐☐

3 0

A deuterium nucleus and a tritium nucleus fuse together to form a helium nucleus and a particle X. The equation for this process is:



What is X?

[1 mark]

A electron

☐

B neutron

☐

C positron

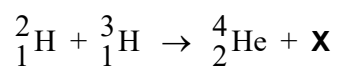
☐

D proton

☐

0 9

A deuterium nucleus and a tritium nucleus fuse together to produce a helium nucleus and particle **X**.



What is **X**?

[1 mark]

A an electron

☐

B a neutron

☐

C a positron

☐

D a proton

☐

0 9

222



1 0

The proton number of uranium is 92 and the proton number of radon is 88

Which series of decays turns a uranium nucleus into a radon nucleus?

[1 mark]

A $\alpha + \beta^- + \beta^- + \alpha + \alpha$

☐

B $\beta^- + \beta^- + \alpha + \beta^- + \alpha$

☐

C $\alpha + \alpha + \alpha + \alpha + \beta^-$

☐

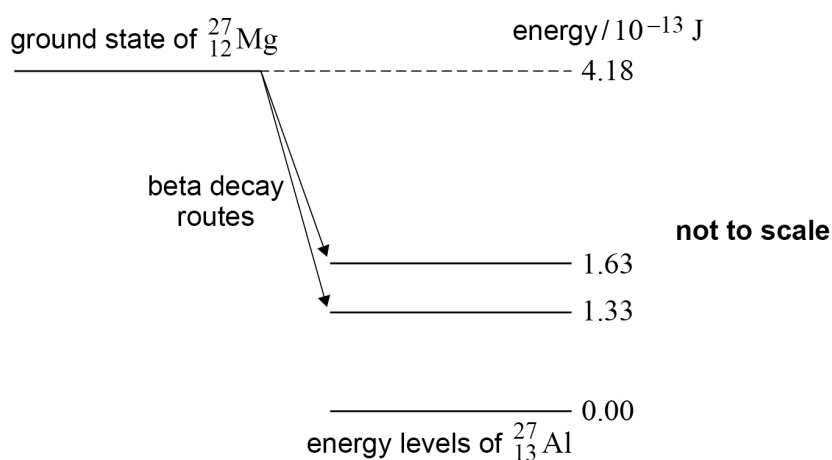
D $\beta^- + \beta^- + \beta^- + \beta^- + \alpha$

☐

3 1

$^{27}_{12}\text{Mg}$ can decay by beta minus emission to one of two possible excited states of $^{27}_{13}\text{Al}$.

Both excited states decay by the emission of a gamma photon directly to the ground state.



The diagram shows the energy levels and two routes for the beta decay.

One route results in the emission of a gamma photon with a higher frequency than the other photon.

What is the maximum possible kinetic energy for the beta particle emitted in this route?

[1 mark]

A 1.33×10^{-13} J

☐

B 1.63×10^{-13} J

☐

C 2.55×10^{-13} J

☐

D 2.85×10^{-13} J

☐

END OF QUESTIONS



1 1

Which row describes the variation with distance of the strong nuclear force?

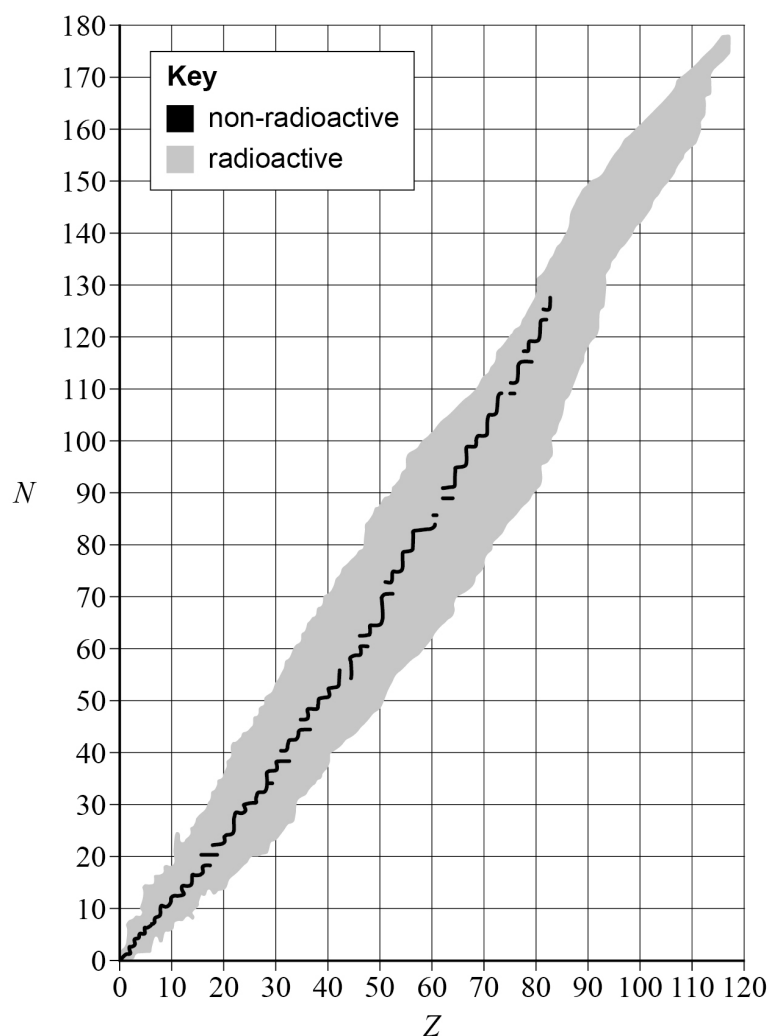
[1 mark]

	Attractive	Repulsive	
A	beyond 3 fm	from 0.5 fm to 3 fm	☐
B	from 0.5 fm to 3 fm	beyond 3 fm	☐
C	from 0.5 fm to 3 fm	up to 0.5 fm	☐
D	up to 0.5 fm	from 0.5 fm to 3 fm	☐



3 0

The graph shows a plot of neutron number N against proton number Z for the known atomic nuclei.



The nuclide $^{115}_{45}\text{Rh}$ is likely to decay by

[1 mark]

A α emission.

☐

B β^+ emission.

☐

C β^- emission.

☐

D electron capture.

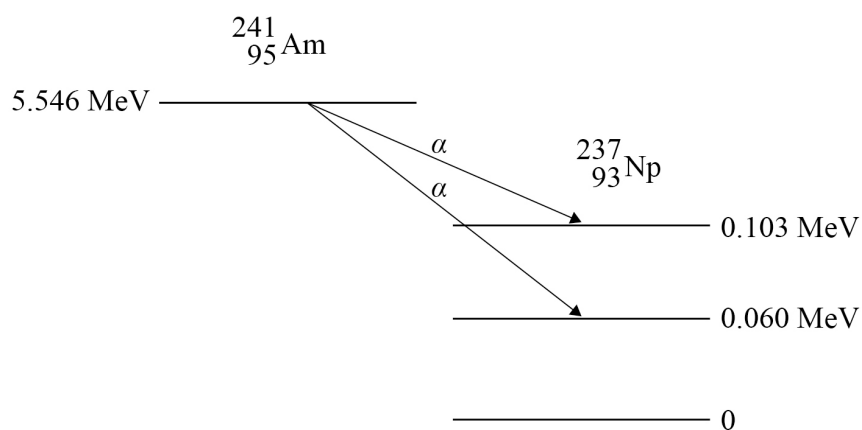
☐

2 6

$^{241}_{95}\text{Am}$ decays to one of two excited states of $^{237}_{93}\text{Np}$ by emitting an alpha particle.

The excited $^{237}_{93}\text{Np}$ nucleus then decays with the emission of a gamma photon.

The diagram shows the energy levels involved in the decay of $^{241}_{95}\text{Am}$.



What is the energy of the emitted gamma photon that has the shortest wavelength?

[1 mark]

A 5.546 MeV ☐

B 5.486 MeV ☐

C 0.103 MeV ☐

D 0.043 MeV ☐

0 1 · 1 Two isotopes of iodine are $^{125}_{53}\text{I}$ and $^{131}_{53}\text{I}$.

Determine, for these two isotopes, the difference between the constituents of the nuclei.

[1 mark]

0 1 · 2 A $^{131}_{53}\text{I}$ nuclide undergoes beta (β^-) decay to form a xenon nuclide.

State the nucleon number of the xenon nuclide.

[1 mark]

0 1 · 3 A $^{125}_{53}\text{I}$ nuclide decays by electron capture to form a tellurium nuclide.

State **two** differences between the constituents of the iodine nucleus and the tellurium nucleus it decays into.

[2 marks]

0 1 · 4 Internal conversion is a process in which a nucleus in an excited state can release its excess energy. In internal conversion all of the excess energy is transferred from the nucleus to an orbital electron through the electromagnetic force. This orbital electron is ejected from the atom.

The tellurium nucleus formed in question **01.3** is in an excited state and can undergo internal conversion.

Discuss **three** differences between internal conversion and beta (β^-) decay.

[3 marks]

- 1

-
-
- 2

-
-
- 3

0 2

Carbon-14 decays into nitrogen-14 with the release of a beta (β^-) particle and an antineutrino ($\bar{\nu}_e$).

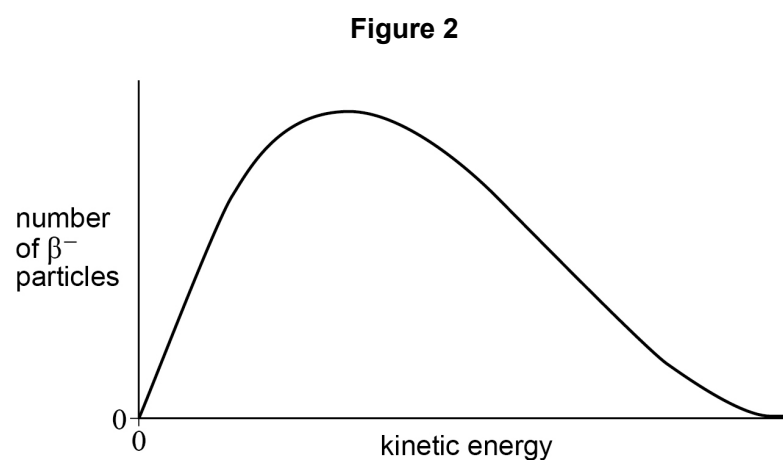
0 2 . 1

State the change of quark character in β^- decay.

[1 mark]

0 2 . 2

Figure 2 shows the distribution of kinetic energies of β^- particles from the decay of carbon-14.

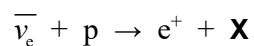


Explain how **Figure 2** supports the existence of the antineutrino.

[2 marks]

Question 2 continues on the next page

The existence of the antineutrino was confirmed by experiments in which antineutrinos interact with protons. The equation for this interaction is:



0 2 3 Identify particle **X**.

[1 mark]

0 2 4 The positron released in this interaction is annihilated when it encounters an electron. A pair of gamma photons is then produced. Particle **X** can be absorbed by a nucleus. This produces another gamma ray. **Table 1** contains data for three gamma photons detected during an antineutrino–proton interaction experiment.

Table 1

Gamma photon	Photon energy / J
G1	5.0×10^{-14}
G2	6.6×10^{-14}
G3	1.0×10^{-13}

Deduce which of the three gamma photons could have been produced by positron annihilation.

[3 marks]

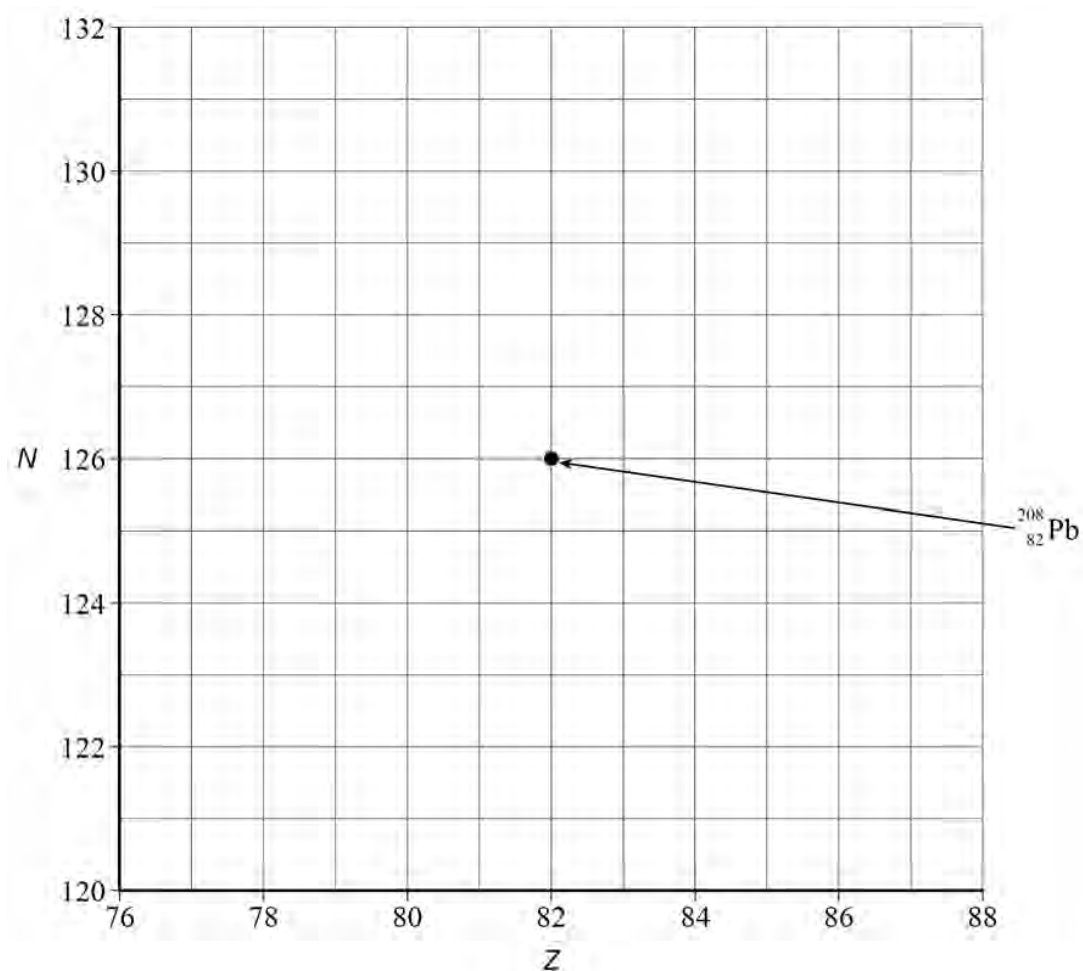


07

A nucleus of polonium Po may decay to the stable isotope of lead $^{208}_{82}\text{Pb}$ through a chain of emissions following the sequence $\alpha \beta^- \beta^- \alpha$.

Figure 13 shows the position of the isotope $^{208}_{82}\text{Pb}$ on a grid of neutron number N against proton number Z .

Figure 13



07.1

Draw **four** arrows on **Figure 13** to show the sequence of changes to N and Z that occur as the polonium nucleus is transformed into $^{208}_{82}\text{Pb}$.

[2 marks]

Question 7 continues on the next page



0 7 . 4 The thallium nucleus is formed in an excited state. Electromagnetic radiation is emitted from the thallium atom following its formation.

Explain the origin and location of **two** sources of this radiation.

[2 marks]

Source 1 _____

Source 2 _____

0 7 . 5 Other nuclides also emit electromagnetic radiation.

Explain why the metastable form of the isotope of technetium $^{99}_{43}\text{Tc}$ is a radioactive source suitable for use in medical diagnosis.

[2 marks]

END OF SECTION A



Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each answer completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

SUB-TOPIC 3.2.1.3

PARTICLES, ANTIPARTICLES AND PHOTONS

Sub-topic 3.2.1.3 · 3 questions · 12 marks · lowest tariff first



1 0

Two gamma photons are produced when a muon and an antimuon annihilate each other.

What is the minimum frequency of the gamma radiation that could be produced?

[1 mark]

A $2.55 \times 10^{16} \text{ Hz}$

☐

B $5.10 \times 10^{16} \text{ Hz}$

☐

C $2.55 \times 10^{22} \text{ Hz}$

☐

D $5.10 \times 10^{22} \text{ Hz}$

☐

0 8

A photon has energy of 1×10^{18} eV.

An object of mass 0.03 kg has kinetic energy equal to the energy of the photon.

What is the speed of the object?

[1 mark]

A 1 m s^{-1}

☐

B 3 m s^{-1}

☐

C 10 m s^{-1}

☐

D 30 m s^{-1}

☐

0	2
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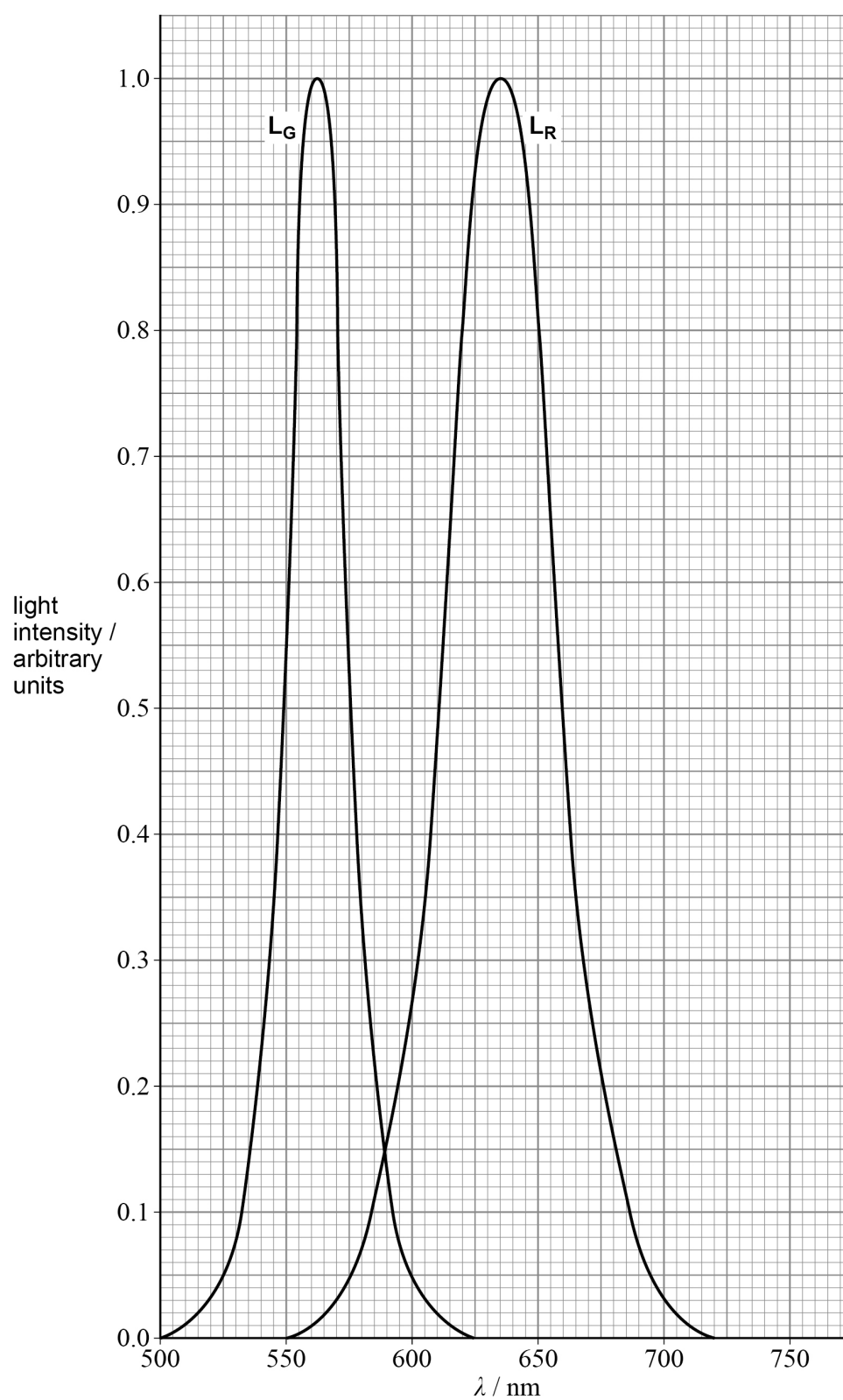
A light-emitting diode (LED) emits light over a narrow range of wavelengths. These wavelengths are distributed about a peak wavelength λ_p .

Two LEDs L_G and L_R are adjusted to give the same maximum light intensity. L_G emits green light and L_R emits red light.

Figure 3 shows how the light output of the LEDs varies with the wavelength λ .



Figure 3



Question 2 continues on the next page

0	2	.	1
---	---	---	---

Light from $\mathbf{L_R}$ is incident normally on a plane diffraction grating.
The fifth-order maximum for light of wavelength λ_p occurs at a diffraction angle of 76.3° .

Determine N , the number of lines per metre on the grating.

[3 marks]

$$N = \text{_____} \text{ m}^{-1}$$

0	2	.	2
---	---	---	---

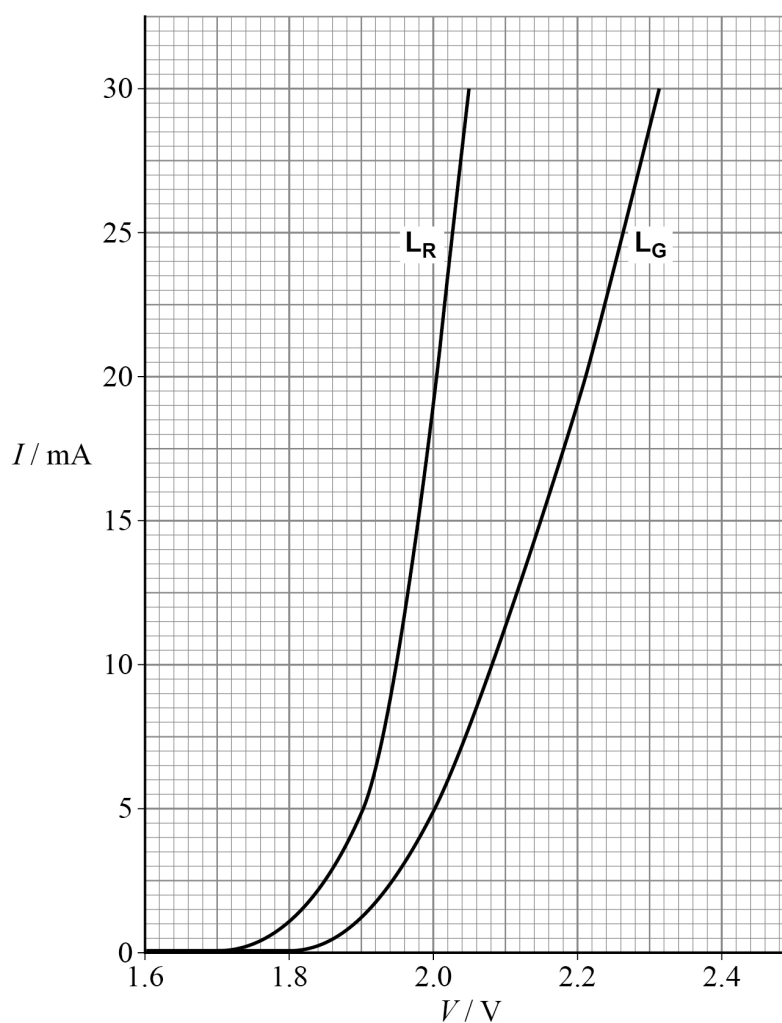
Suggest **one** possible disadvantage of using the fifth-order maximum to determine N .

[1 mark]



0 2 . 3 Figure 4 shows part of the current–voltage characteristics for L_R and L_G .

Figure 4



When the linear part of the characteristic is extrapolated, the point at which it meets the horizontal axis gives the activation voltage V_A for the LED.

V_A for L_G is 2.00 V.

Determine, using **Figure 4**, V_A for L_R .

[2 marks]

V_A for L_R = _____ V

Question 2 continues on the next page



0 2 . 4 It can be shown that:

$$V_A = \frac{hc}{e\lambda_p}$$

where h = the Planck constant.

Deduce a value for the Planck constant based on the data given about the LEDs.

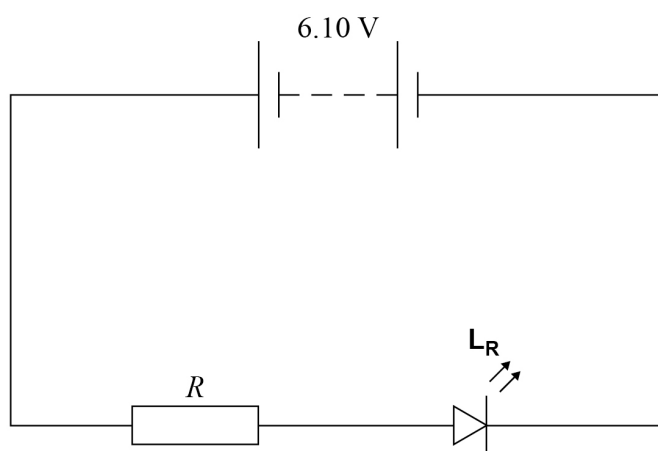
[2 marks]

$h =$ _____ J s



0 2 . 5 Figure 5 shows a circuit with L_R connected to a resistor of resistance R .

Figure 5



The power supply has emf 6.10 V and negligible internal resistance.
The current in L_R must not exceed 21.0 mA.

Deduce the minimum value of R .

[2 marks]

minimum value of $R =$ _____ Ω



SUB-TOPIC 3.2.1.4

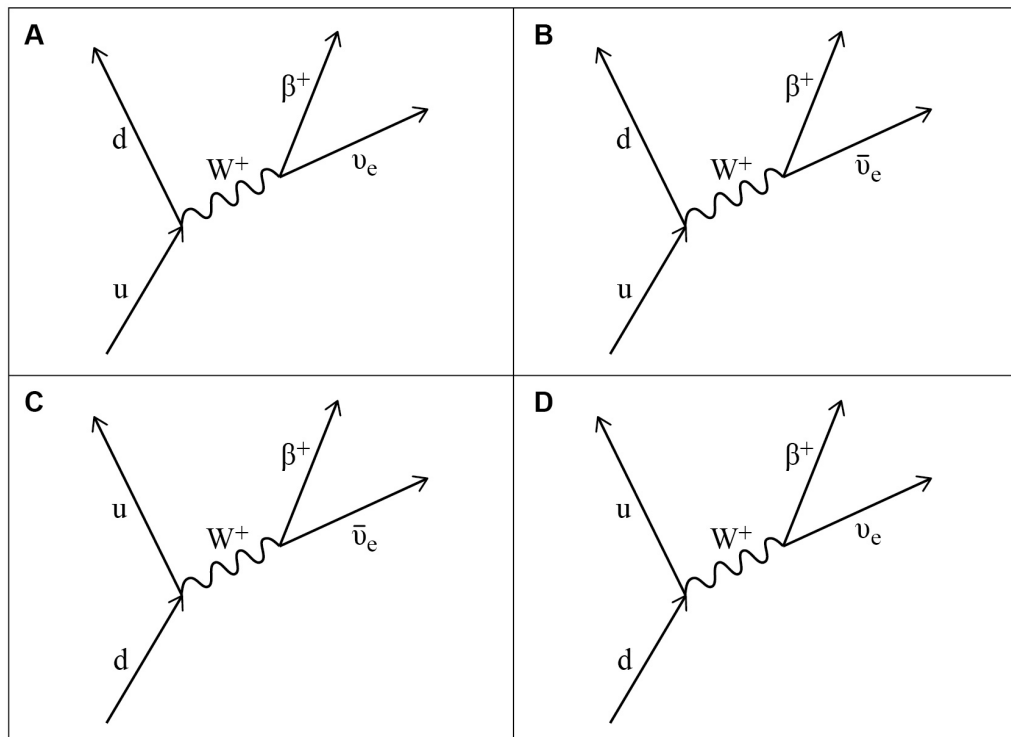
PARTICLE INTERACTIONS

Sub-topic 3.2.1.4 · 7 questions · 27 marks · lowest tariff first



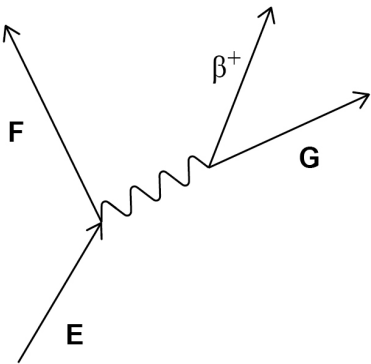
0 9

Which diagram represents the process of beta-plus decay?

[1 mark]**A**☐**B**☐**C**☐**D**☐

1

1

 The diagram represents a particle interaction.

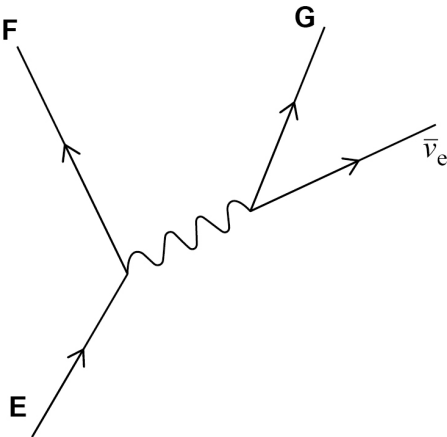
Which row identifies particles **E**, **F** and **G**?

[1 mark]

	E	F	G	
A	up quark	down quark	neutrino	☐
B	down quark	up quark	neutrino	☐
C	up quark	down quark	antineutrino	☐
D	down quark	up quark	antineutrino	☐

11

The diagram represents a quark change in which an electron antineutrino is produced.



What are **E**, **F** and **G**?

[1 mark]

	E	F	G	
A	up quark	down quark	β^-	☐
B	down quark	up quark	β^-	☐
C	up quark	down quark	β^+	☐
D	down quark	up quark	β^+	☐

1	0
---	---

 In β^- decay:

[1 mark]

A energy is conserved.☐**B** an up quark changes into a down quark.☐**C** the interaction occurs outside the nucleus of an atom.☐**D** momentum is not conserved.☐

0	1
---	---

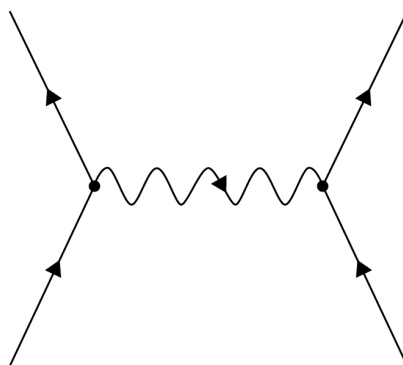
This question is about an isotope of titanium that **only** decays by electron capture.

0	1	.	1
---	---	---	---

Complete **Figure 1** to show the quark change that occurs during electron capture. Label the incoming and outgoing particles and the exchange particle.

[3 marks]

Figure 1



0	1	.	2
---	---	---	---

In some circumstances, a nucleus of this isotope can exist with **no** orbiting electrons.

Explain why a neutral atom of this isotope is less stable than a nucleus that has no orbiting electrons.

[1 mark]

0	1	.	3
---	---	---	---

A nucleus of this isotope of titanium has a proton number of 22 and a specific charge of $4.8 \times 10^7 \text{ C kg}^{-1}$.

Determine the number of neutrons in this nucleus.

[2 marks]

number of neutrons = _____



0 1 . 1 State the names of the four fundamental interactions.

[1 mark]

1 _____

2 _____

3 _____

4 _____

0 1 . 2 State the products of the decay of a free neutron.

[1 mark]

0 1 . 3 Explain which of the fundamental interactions is responsible for the decay of the neutron.

[2 marks]

0 1 . 4 The forces between two moving electrons cause their paths to change.

Explain, using the concept of exchange particles, why the electron paths change.

[3 marks]

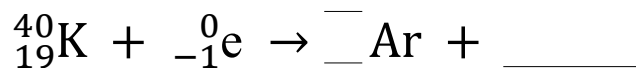


0 1

An isotope of potassium ${}^{40}_{19}\text{K}$ is used to date rocks. The isotope decays into an isotope of argon (Ar) mainly by electron capture.

0 1 . 1

The decay is represented by this equation:



Complete the equation to show the decay by filling in the gaps.

[2 marks]**0 1 . 2**

Explain which fundamental interaction is responsible for the decay in question **01.1**.

[2 marks]

0 1 . 3

One decay mechanism for the decay of ${}^{40}_{19}\text{K}$ results in the argon nucleus having an excess energy of 1.46 MeV. It loses this energy by emitting a single gamma photon.

Calculate the wavelength of the photon released by the argon nucleus.

[3 marks]

wavelength = _____ m

0 1 . 4

The potassium isotope can also decay by a second decay process to form a calcium-40 nuclide (${}^{40}_{20}\text{Ca}$).

Suggest how the emissions from a nucleus of decaying potassium can be used to confirm which decay process is occurring.

[3 marks]

SUB-TOPIC 3.2.1.5

CLASSIFICATION OF PARTICLES, QUARKS AND CONSERVATION LAWS

Sub-topic 3.2.1.5 · 9 questions · 41 marks · lowest tariff first



1 1

The Σ^0 baryon, composed of the quark combination uds , is produced through the strong interaction between a π^+ meson and a neutron.

$$\pi^+ + n \rightarrow \Sigma^0 + X$$

What is the quark composition of X?

[1 mark]**A** $u\bar{s}$ ☐**B** ud ☐**C** $u\bar{d}$ ☐**D** $ud\bar{s}$ ☐

1 2 The quark combination of a particle is $s\bar{u}$.

Which is true for this particle?

[1 mark]

A It has a baryon number of 1

☐

B It has a charge of -1.6×10^{-19} C.

☐

C It is a pion.

☐

D It has a strangeness of $-\frac{1}{3}$

☐

1 2 Which statement is correct?

[1 mark]

- A** All strange particles are mesons. ☐
- B** Strange particles are always created in pairs. ☐
- C** Strangeness can only change in strong interactions. ☐
- D** Strangeness can only have a value of 0 or -1 ☐



1 0

Which statement about muons is correct?

[1 mark]**A** They consist of a quark and an antiquark.☐**B** They include pions and kaons.☐**C** They are subject to the strong interaction.☐**D** They decay into electrons.☐

09

The following equation represents a strong interaction between particle **X** and a proton.

$$\mathbf{X} + \text{p} \rightarrow \text{n} + \pi^0$$

What is the quark configuration of **X**?

[1 mark]

A $\bar{u}\bar{u}\bar{d}$

☐

B $s\bar{u}$

☐

C $d\bar{u}$

☐

D $u\bar{d}$

☐

0	1
---	---

The neutral lambda particle Λ^0 is a baryon with a strangeness of -1

One possible decay for a Λ^0 is

$$\Lambda^0 \rightarrow \pi^0 + \text{n}$$

0	1	.	1
---	---	---	---

Deduce the quark structure of a Λ^0 .

[1 mark]

0	1	.	2
---	---	---	---

State and explain which interaction is involved in this decay.

[2 marks]

0	1	.	3
---	---	---	---

An antiparticle of the neutral lambda particle decays into a neutral pion and particle **X**.

Identify **X**.

[1 mark]



0	1	.	4
---	---	---	---

The rest energy of a Λ^0 is equal to the energy of a photon with a frequency of 2.69×10^{23} Hz.

Determine, in MeV, the rest energy of a Λ^0 .

[1 mark]

rest energy = _____ MeV

0	1	.	5
---	---	---	---

The discovery of particles such as the Λ^0 is made by large international research teams.

Suggest **one** reason for this.

[1 mark]



0 1 . 1 Determine whether the following reaction is a possible decay for the neutral pion π^0 .

$$\pi^0 \rightarrow e^- + \mu^+ + \bar{\nu}_e$$

[2 marks]

0 1 . 2 State the **two** possible quark configurations of a π^0 .

[1 mark]

1

2

0 1 . 3 A student suggests that the kaon K^0 and the anti-kaon $\bar{K}^0$ are the same particle.

Discuss whether this suggestion is correct.

[2 marks]

0 1 . 4 The nucleus is held together by a force. It was predicted that a particle exists that is responsible for this force. The particle itself must experience this force.

The particle would have a rest energy between that of an electron and half that of a nucleon.

Discuss whether a kaon, a muon and a pion **each** have the properties of the predicted particle.

Information about these three particles is in the Data and Formulae Booklet.

[4 marks]



02

A positive pion collides with a neutron and the following interaction is observed:

$$\pi^+ + n \rightarrow K^+ + \Sigma^0$$

Σ^0 is a neutral sigma particle with a strangeness of -1

The interaction can be used to deduce the classifications of the Σ^0 .

02.1

Identify the classifications of each particle in **Table 1**.
Tick (✓) the appropriate boxes for each particle.

[2 marks]

Table 1

Particle	Baryon	Hadron	Lepton	Meson
π^+				
n				
K^+				
Σ^0				

02.2

A conservation rule predicts that the following interaction **cannot** occur:

$$\pi^- + n \rightarrow K^- + \Sigma^0$$

State the conservation rule.
Go on to explain your answer.

[3 marks]

Question 2 continues on the next page

One way in which neutral pions decay is

$$\pi^0 \rightarrow e^- + e^+ + \gamma$$

0 2 . 3

Compare the rest energies of the particles involved in this decay.

[2 marks]

0 2 . 4

The decay of the neutral pion leads to the production of further gamma photons.

Explain why.

[1 mark]

0 2 . 5

The Standard Model is a theory that classifies elementary particles. Evidence for the theory has been collected since about 1950. However, the term Standard Model has only been used since 1973.

Suggest why progress in particle physics is slow.

[1 mark]



0 1

Cosmic rays are high-energy particles that come from space. Most of these particles are protons. There are other particles in cosmic rays, including atomic nuclei.

Table 1 gives the data for one particular nucleus **X**.

Table 1

Mass / kg	8.02×10^{-26}
Specific charge / C kg ⁻¹	4.39×10^7
Kinetic energy / MeV	215

0 1 . 1

Determine the number of neutrons in nucleus **X**.

[3 marks]

number of neutrons = _____

0 1 . 2

Calculate the speed of **X**.
Ignore relativistic effects.

[3 marks]

speed = _____ m s⁻¹



A pion (π^+) and a kaon (K^+) are produced when cosmic rays interact with the upper atmosphere.

0 1 . 3

The π^+ decays to produce a positron and an electron neutrino.

Show how the conservation laws apply to this decay.

[2 marks]

0 1 . 4

The K^+ decays to produce an anti-muon and a muon neutrino.

Explain how strangeness applies in this decay.

[2 marks]

0 1 . 5

Write an equation for a K^+ decay that involves only hadrons.

[2 marks]

SUB-TOPIC 3.2.2.1

THE PHOTOELECTRIC EFFECT

Sub-topic 3.2.2.1 · 11 questions · 22 marks · lowest tariff first



1 4

Photons of wavelength 290 nm are incident on a metal plate. The work function of the metal is 4.1 eV

What is the maximum kinetic energy of the emitted electrons?

[1 mark]

A 0.19 eV

☐

B 4.3 eV

☐

C 6.9 eV

☐

D 8.4 eV

☐

1 0

Light of frequency 2.0×10^{15} Hz is incident on a metal surface. The work function of the metal is 4.6×10^{-19} J.

Which statement is correct?

[1 mark]

A No photoelectrons are released.

☐

B Photoelectrons are released with a maximum kinetic energy of 3.1×10^{-19} J.

☐

C Photoelectrons are released with a maximum kinetic energy of 8.7×10^{-19} J.

☐

D Photoelectrons are released with a maximum kinetic energy of 18×10^{-19} J.

☐

1 0

Light of frequency 2.0×10^{15} Hz is incident on a metal surface. The work function of the metal is 4.6×10^{-19} J.



1 3

Monochromatic light with a photon energy of $4.1 \times 10^{-19} \text{ J}$ is incident on a metal surface. The maximum speed of the photoelectrons released is $4.2 \times 10^5 \text{ m s}^{-1}$.

What is the work function of the metal?

[1 mark]

A $2.5 \times 10^{-19} \text{ J}$

☐

B $3.3 \times 10^{-19} \text{ J}$

☐

C $4.1 \times 10^{-19} \text{ J}$

☐

D $4.9 \times 10^{-19} \text{ J}$

☐

1 **4** In photoelectricity, V_s is the stopping potential.

What quantity is eV_s ?

[1 mark]

A energy of an incident photon

☐

B maximum kinetic energy of a photoelectron

☐

C threshold frequency $\times$ the Planck constant

☐

D work function

☐

1 2

Photoelectrons are released when monochromatic light with a photon energy of $4.2 \times 10^{-19} \text{ J}$ is incident on a metal surface. The work function of the surface is 2.4 eV .

What is the maximum speed of the photoelectrons as they leave the surface?

[1 mark]

A $1.3 \times 10^6 \text{ m s}^{-1}$

☐

B $6.3 \times 10^5 \text{ m s}^{-1}$

☐

C $2.8 \times 10^5 \text{ m s}^{-1}$

☐

D $2.0 \times 10^5 \text{ m s}^{-1}$

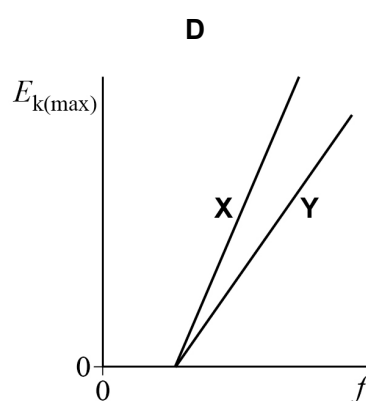
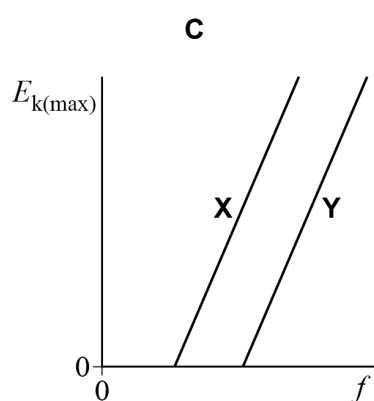
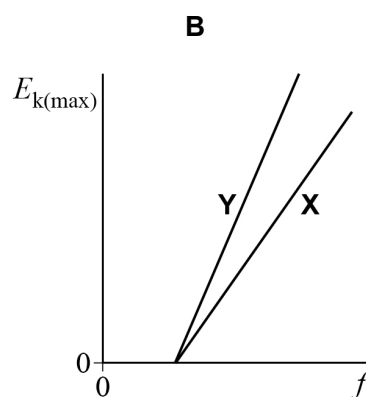
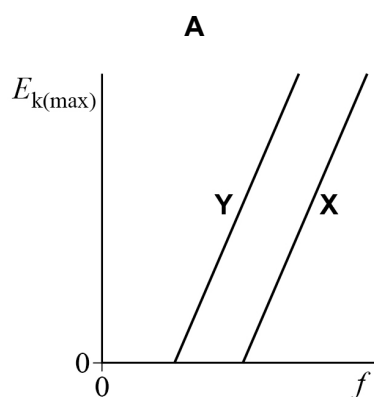
☐

0 9

In two separate experiments, electromagnetic radiation of variable frequency f is incident on the surfaces of plates made from metals **X** and **Y**.

The work function of **X** is greater than the work function of **Y**.

Which graph shows how the maximum kinetic energy $E_{k(\max)}$ of photoelectrons emitted from the surfaces of the plates varies with f ?

[1 mark]**A** ☐**B** ☐**C** ☐**D** ☐

10

Monochromatic light is incident on a metal surface in a vacuum and photoelectrons are emitted from the surface. The photoelectric current I is the rate of flow of charge from the surface.

The maximum kinetic energy of the photoelectrons is $E_{k(\max)}$.

$E_{k(\max)}$ and I are measured.

The frequency of the light is then increased. There is no change to the rate at which energy is incident on the surface.

What happens to $E_{k(\max)}$ and I when the frequency is increased?

[1 mark]

	$E_{k(\max)}$	I
A	increases	decreases
B	increases	no change
C	no change	no change
D	no change	decreases

☐☐☐☐

1 2

In a photoelectric effect experiment, monochromatic light is incident on a metal surface and the stopping potential is measured.

Which change results in a greater stopping potential?

[1 mark]

A using a metal that has a greater work function

☐

B using a light source that emits more photons per second

☐

C using a light source that emits light of a shorter wavelength

☐

D using a metal surface that has a positive charge

☐

2 **2** The work function of a metal is ϕ .

A photon with an energy of $3.8 \times 10^{-19} \text{ J}$ is incident on the metal surface.

Electrons are emitted from the surface with a maximum speed of $2.5 \times 10^5 \text{ m s}^{-1}$.

What is ϕ ?

[1 mark]

A $0.29 \times 10^{-19} \text{ J}$

☐

B $3.5 \times 10^{-19} \text{ J}$

☐

C $3.8 \times 10^{-19} \text{ J}$

☐

D $4.1 \times 10^{-19} \text{ J}$

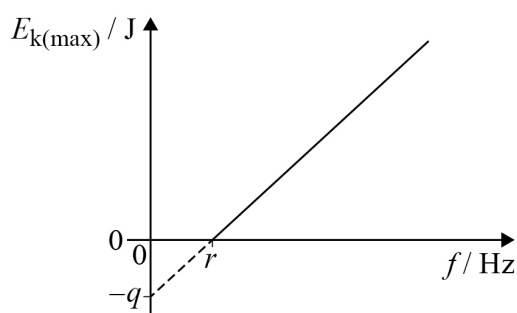
☐

3 0

In a photoelectric experiment, the maximum kinetic energy $E_{\text{k(max)}}$ of the emitted electrons and the frequency f of the incident radiation are measured.

A graph of the variation of $E_{\text{k(max)}}$ with f has:

- a gradient p
- an intercept $-q$ on the $E_{\text{k(max)}}$ axis
- an intercept r on the f axis.



What is the value of the Planck constant?

[1 mark]

A $\frac{p}{r}$

☐

B $\frac{r}{p}$

☐

C $\frac{r}{q}$

☐

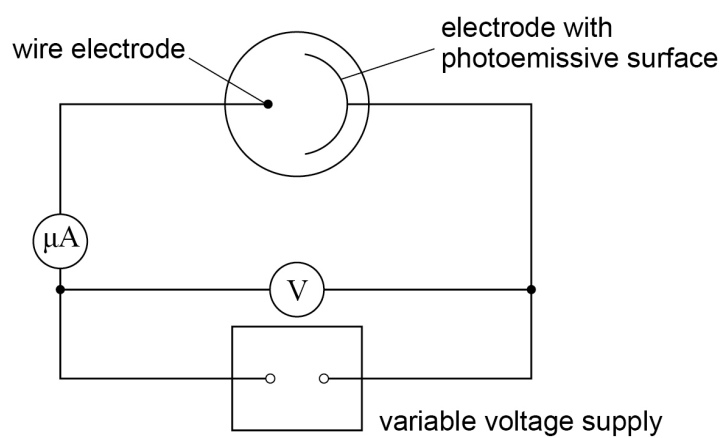
D $\frac{q}{r}$

☐

0 2

Figure 1 shows an arrangement used to investigate the photoelectric effect.

Figure 1



A current is measured on the microammeter only when electromagnetic radiation with a frequency greater than a certain value is incident on the photoemissive surface.

0 2 . 1

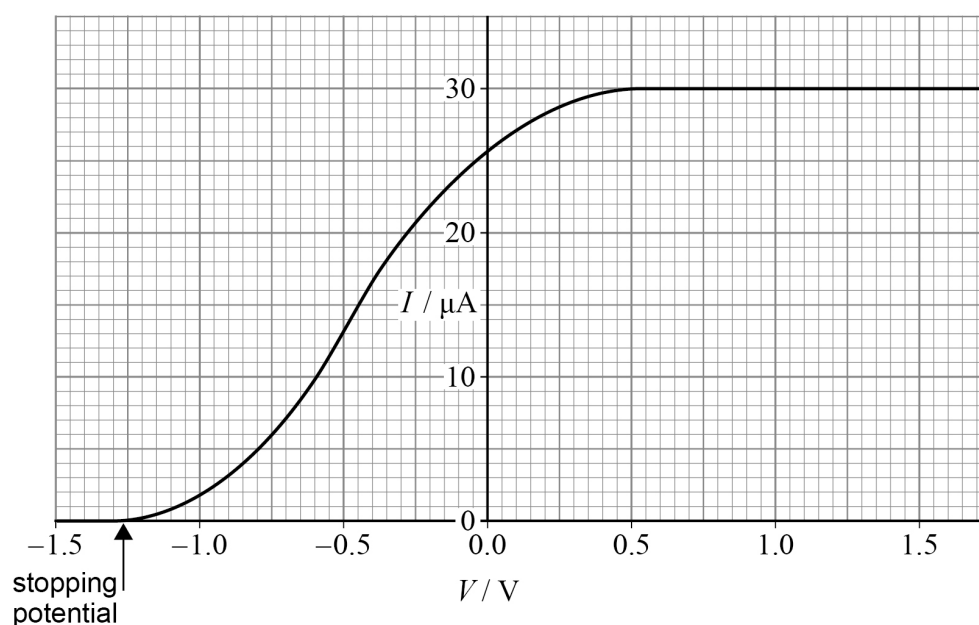
Explain why the frequency of the electromagnetic radiation must be greater than a certain value.

[2 marks]

The apparatus in **Figure 1** is used with a monochromatic light source of constant intensity. Measurements are made to investigate how the current I in the microammeter varies with positive and negative values of the potential difference V of the variable voltage supply.

Figure 2 shows how the results of the investigation can be used to find the stopping potential.

Figure 2



- 0 2 . 2** Determine the number of photoelectrons per second leaving the photoemissive surface when the current is a maximum.

[2 marks]

number of photoelectrons per second = _____

Question 2 continues on the next page

0 2 . 3Explain why I reaches a constant value for positive values of V .**[2 marks]**

0 2 . 4Explain why I decreases as the value of V becomes more negative.**[3 marks]****0 2 . 5**

The investigation is repeated with a different photoemissive surface that has a smaller value of the work function. The source of electromagnetic radiation is unchanged.

Discuss the effect that this change in surface has on the value of the stopping potential.

[3 marks]

SUB-TOPIC 3.2.2.2

EXCITATION, IONISATION AND ENERGY LEVELS

Sub-topic 3.2.2.2 · 10 questions · 17 marks · lowest tariff first



1 2

The diagram shows an energy level diagram for a hydrogen atom.

Electrons with energy 13.0 eV collide with atoms of hydrogen in their ground state.

What is the number of different wavelengths of electromagnetic radiation that could be emitted when the atoms de-excite?

[1 mark]

level 4 ————— -0.54 eV

level 3 ————— -0.85 eV

level 2 ————— -1.51 eV

level 1 ————— -3.4 eV

ground state ————— -13.6 eV

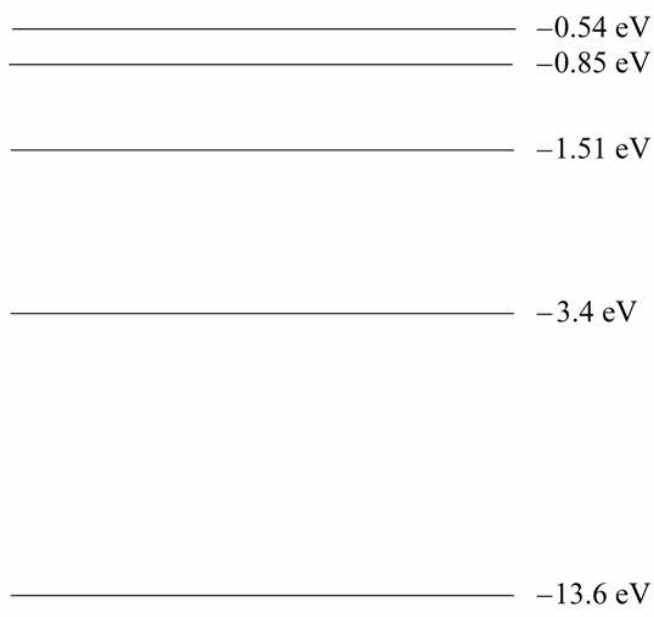
A 0

B 3

C 6

D 7

1 3 The diagram shows an energy-level diagram for a hydrogen atom.



Electrons, each having a kinetic energy of $2.0 \times 10^{-18} \text{ J}$, collide with atoms of hydrogen in their ground state. Photons are emitted when the atoms de-excite.

How many different wavelengths can be observed with incident electrons of this energy? **[1 mark]**

- | | | |
|----------|---|--------------------------|
| A | 1 | ☐ |
| B | 3 | ☐ |
| C | 6 | ☐ |
| D | 7 | ☐ |

0 9

An electron collides with an isolated atom and raises an orbiting electron to a higher energy level.

Which statement is correct?

[1 mark]

- A** The colliding electron is captured by the nucleus of the atom. ☐
- B** A photon is emitted when the electron rises to the higher energy level. ☐
- C** An electron is emitted when the excited electron returns to the ground state. ☐
- D** Energy is transferred from the colliding electron to the orbiting electron. ☐

1 2 3 4 5 6 7 8 9 10 11 12

1 2 3 4 5 6 7 8 9 10 11 12

1 2

An electron collides with an isolated atom and raises an atomic electron to a higher energy level.

Which statement is correct?

[1 mark]

- A** The colliding electron is captured by the nucleus of the atom. ☐
- B** A photon is emitted when the electron rises to the higher energy level. ☐
- C** An electron is emitted when the excited electron returns to the ground state. ☐
- D** The colliding electron transfers energy to the atomic electron. ☐

1 4

What is the role of the mercury vapour in a fluorescent tube?

[1 mark]**A** It absorbs photons of UV light and emits visible light.☐**B** It absorbs photons of visible light and emits UV light.☐**C** It emits photons of visible light following ionisation or excitation.☐**D** It emits photons of UV light following ionisation or excitation.☐

1 5

The diagram shows the three lowest energy levels for an atom.
The energy levels have been drawn to scale.

level 2 _____

level 1 _____

ground state _____

Transitions of electrons between these energy levels produce photons of the following frequencies:

$$4.56 \times 10^{14} \text{ Hz}$$

$$2.46 \times 10^{15} \text{ Hz}$$

$$2.92 \times 10^{15} \text{ Hz.}$$

What is the difference in energy between the ground state and energy level 1?

[1 mark]

A $0.3 \times 10^{-18} \text{ J}$

☐

B $1.3 \times 10^{-18} \text{ J}$

☐

C $1.6 \times 10^{-18} \text{ J}$

☐

D $1.9 \times 10^{-18} \text{ J}$

☐

1 5

A fluorescent tube contains a gas.

The coating of the tube

[1 mark]

A becomes ionised by the gas and emits photons of ultraviolet light.

☐

B absorbs photons of ultraviolet light from the gas and emits visible light.

☐

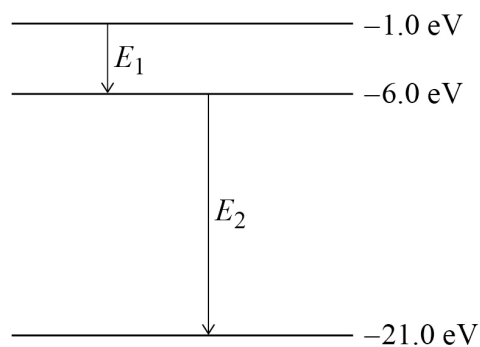
C absorbs photons of ultraviolet light from the gas and emits photoelectrons.

☐

D absorbs several photons of visible light from the gas and then emits one photon of ultraviolet light.

☐

1 1 Three energy levels for an atom are shown.



Energy change E_1 leads to the emission of a photon of wavelength λ_1 .

Energy change E_2 leads to the emission of a photon of wavelength λ_2 .

What is $\frac{\lambda_1}{\lambda_2}$?

[1 mark]

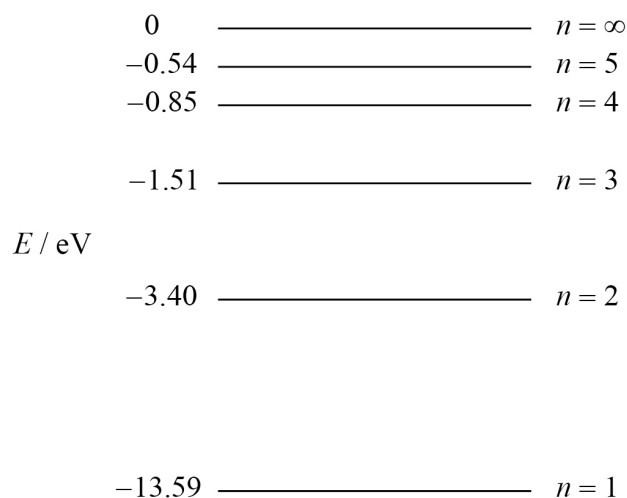
A $\frac{1}{4}$

B $\frac{1}{3}$

C 3

D 4

3 3 The diagram shows some of the energy levels for a hydrogen atom.



Photons of energy 12.74 eV excite hydrogen atoms that are all initially in the ground state ($n = 1$).

How many different photon frequencies are emitted as the atoms return to their ground state?

[1 mark]

- A** 3 ☐
- B** 5 ☐
- C** 6 ☐
- D** 9 ☐

END OF QUESTIONS



08

Electrons in a fluorescent tube are accelerated from rest by a potential difference of 130 V.

08.1

Calculate the maximum speed of an electron that is accelerated from rest by this potential difference.

[2 marks]

maximum speed = _____ m s^{-1}

08.2

Explain why the average speed of the electrons in the tube is much less than the maximum speed you calculated in Question **08.1**.

[1 mark]

Question 8 continues on the next page

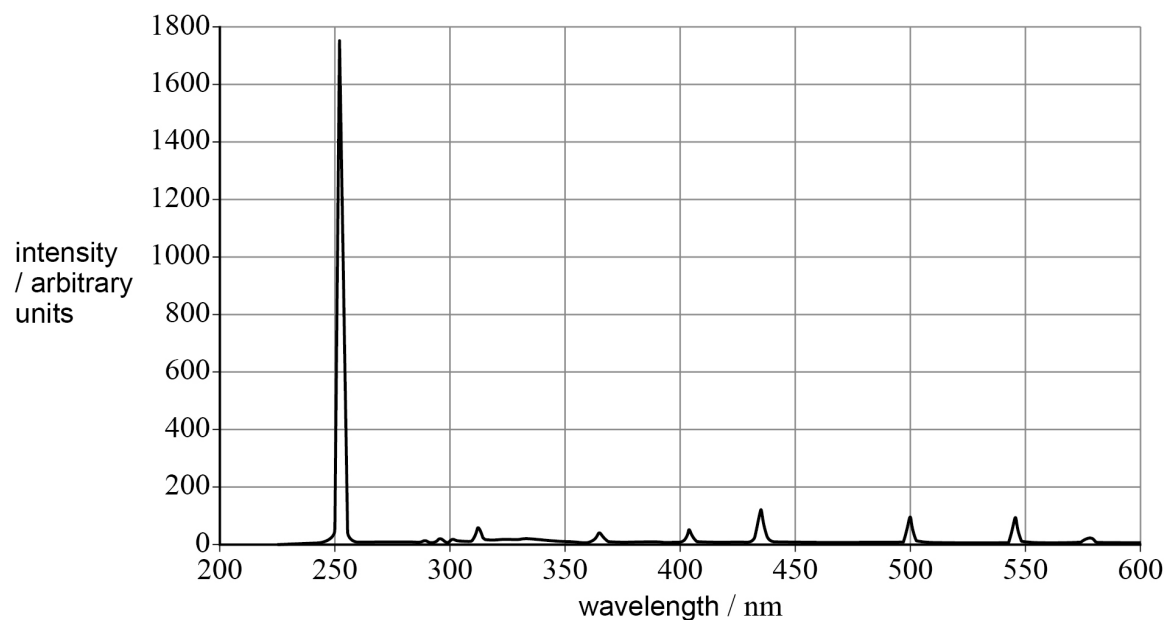


0 8 . 3

Scientists want to replace the mercury in fluorescent tubes with substance **X**.

Figure 12 is an emission spectrum for **X**.

Figure 12



White light consists of the whole range of visible wavelengths from 380 nm to 700 nm.

Explain, with reference to **Figure 12**, whether white light can be produced by a fluorescent tube that uses **X**.

[2 marks]

08.4

Figure 12 shows a maximum intensity peak that occurs at wavelength λ_{peak} .

Calculate, in eV, the energy change of an atom that produces a photon with a wavelength λ_{peak} .

[3 marks]

energy change = _____ eV

END OF SECTION A

Section B

Each of Questions **09** to **33** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked. Do **not** use additional sheets for this working.



SUB-TOPIC 3.2.2.4

WAVE-PARTICLE DUALITY

Sub-topic 3.2.2.4 · 11 questions · 20 marks · lowest tariff first



1	1
---	---

Electrons moving in a beam have the same de Broglie wavelength as protons in a separate beam moving at a speed of $2.8 \times 10^4 \text{ m s}^{-1}$.

What is the speed of the electrons?

[1 mark]

A $1.5 \times 10^1 \text{ m s}^{-1}$

☐

B $2.8 \times 10^4 \text{ m s}^{-1}$

☐

C $1.2 \times 10^6 \text{ m s}^{-1}$

☐

D $5.1 \times 10^7 \text{ m s}^{-1}$

☐

1 1

A photon of ultraviolet radiation has a frequency of 1.5×10^{15} Hz.

What is the momentum of the photon?

[1 mark]

A $3.3 \times 10^{-41} \text{ kg m s}^{-1}$

☐

B $1.3 \times 10^{-40} \text{ kg m s}^{-1}$

☐

C $3.3 \times 10^{-27} \text{ kg m s}^{-1}$

☐

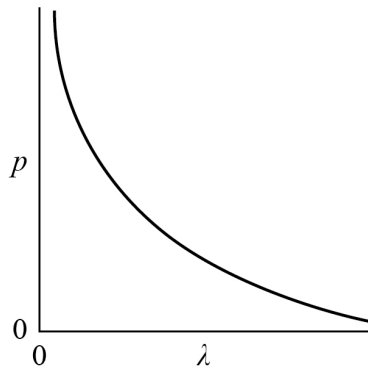
D $1.3 \times 10^{-26} \text{ kg m s}^{-1}$

☐

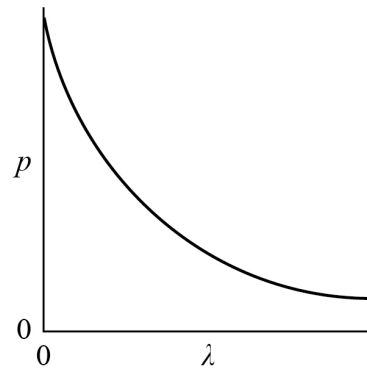
1 3 Which graph shows the variation of momentum p with wavelength λ of a photon?

[1 mark]

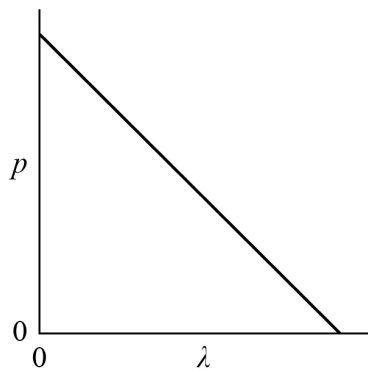
A



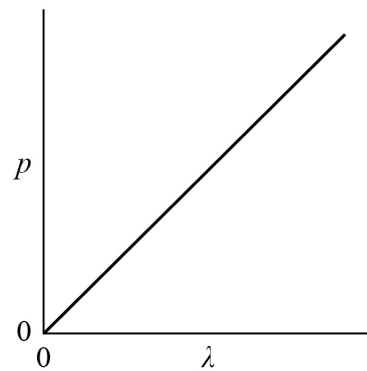
B



C



D



A ☐

B ☐

C ☐

D ☐

1 4

A monochromatic light wave travels from glass into air.

Which row shows what happens to the wavelength, speed and photon energy?

[1 mark]

	Wavelength	Speed	Photon energy	
A	increases	increases	increases	☐
B	does not change	decreases	does not change	☐
C	does not change	decreases	increases	☐
D	increases	increases	does not change	☐



1 6

A muon and an electron are travelling at the same speed.

Which row gives the particle with the greater kinetic energy and the particle with the longer de Broglie wavelength?

[1 mark]

	Greater kinetic energy	Longer de Broglie wavelength	
A	muon	muon	☐
B	muon	electron	☐
C	electron	muon	☐
D	electron	electron	☐

1 6

Which row gives evidence for the wave nature of electrons and evidence for the particulate nature of light?

[1 mark]

	Wave nature of electrons	Particulate nature of light	
A	electron diffraction	photoelectric effect	☐
B	electron diffraction	single-slit diffraction	☐
C	photoelectric effect	single-slit diffraction	☐
D	photoelectric effect	electron diffraction	☐

1 7

Which particle has the smallest de Broglie wavelength?

[1 mark]**A** an electron moving at $4 \times 10^3 \text{ m s}^{-1}$ ☐**B** a proton moving at $4 \times 10^3 \text{ m s}^{-1}$ ☐**C** an electron moving at $8 \times 10^5 \text{ m s}^{-1}$ ☐**D** a proton moving at $8 \times 10^5 \text{ m s}^{-1}$ ☐

1 2

An electron and a proton move with the same speed.

What is $\frac{\text{de Broglie wavelength of electron}}{\text{de Broglie wavelength of proton}}$?

[1 mark]

A 5.5×10^{-4} ☐

B 2.3×10^{-2} ☐

C 42 ☐

D 1800 ☐



1 3

Which row provides evidence for the particle nature of light and the wave nature of light?

[1 mark]

	Evidence for particle nature	Evidence for wave nature	
A	line spectra	photoelectric effect	☐
B	diffraction	line spectra	☐
C	photoelectric effect	diffraction	☐
D	photoelectric effect	line spectra	☐

27

An alpha particle has a speed of $4.5 \times 10^5 \text{ m s}^{-1}$.

What is the de Broglie wavelength of the alpha particle?

[1 mark]

A $2.2 \times 10^{-13} \text{ m}$ ☐

B $4.4 \times 10^{-13} \text{ m}$ ☐

C $8.8 \times 10^{-13} \text{ m}$ ☐

D $3.9 \times 10^{-12} \text{ m}$ ☐

0 2

Table 1 shows results of an experiment to investigate how the de Broglie wavelength λ of an electron varies with its velocity v .

Table 1

$v / 10^7 \text{ m s}^{-1}$	$\lambda / 10^{-11} \text{ m}$
1.5	4.9
2.5	2.9
3.5	2.1

0 2 · 1

Show that the data in **Table 1** are consistent with the relationship $\lambda \propto \frac{1}{v}$

[2 marks]

0 2 · 2

Calculate a value for the Planck constant suggested by the data in **Table 1**.

[2 marks]

Planck constant = _____ J s

Question 2 continues on the next page

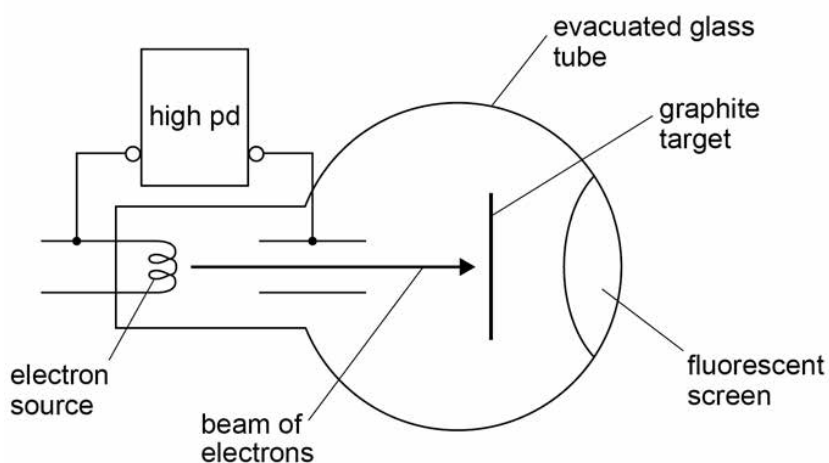


0 2 . 3

Figure 2 shows the side view of an electron diffraction tube used to demonstrate the wave properties of an electron.

Figure 2

Side view



An electron beam is incident on a thin graphite target that behaves like the slits in a diffraction grating experiment. After passing through the graphite target the electrons strike a fluorescent screen.

Figure 3 shows the appearance of the fluorescent screen when the electrons are incident on it.

Figure 3

Explain how the pattern produced on the screen supports the idea that the electron beam is behaving as a wave rather than as a stream of particles.

[3 marks]

0 2 . 4

Explain how the emission of light from the fluorescent screen shows that the electrons incident on it are behaving as particles.

[3 marks]



SUB-TOPIC 3.2.S

SYNOPTIC: NUCLEAR PHYSICS AND FIELDS

Sub-topic 3.2.S · 14 questions · 84 marks · lowest tariff first



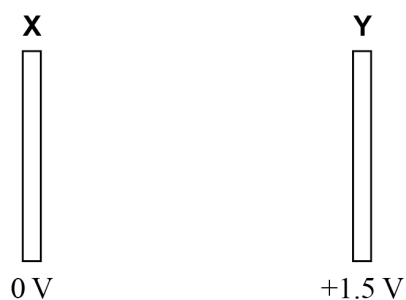
2 6

The Rutherford scattering experiment led to

[1 mark]**A** the discovery of the electron.☐**B** the quark model of hadrons.☐**C** the discovery of the nucleus.☐**D** evidence for wave-particle duality.☐

2 2

Charged plates **X** and **Y** have a potential difference 1.5 V between them.



Which particle gains 3.0 eV of kinetic energy when moving from **Y** to **X**?

[1 mark]

A proton

☐

B positron

☐

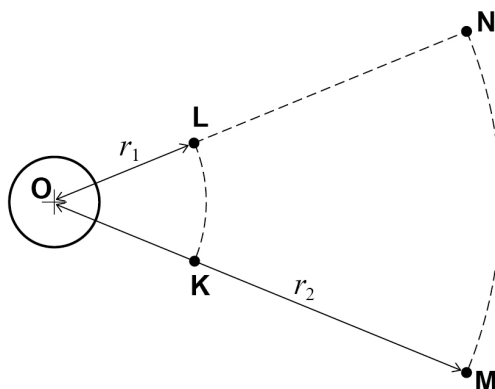
C electron

☐

D alpha particle

☐

1 9 **O** is the centre of a negatively charged sphere.



K and **L** are two points at a distance r_1 from **O**.

M and **N** are two points at a distance r_2 from **O**.

Which statement is true?

[1 mark]

- A** The work done moving an electron from **M** to **K** is the same as that done moving an electron from **K** to **L**.
- B** The work done moving a positron from **K** to **M** is the same as that done moving an electron from **K** to **M**.
- C** No work is done moving an electron from **M** to **N**.
- D** No work is done moving a positron from **L** to **N**.

☐☐☐☐

2 9

Which provides evidence for the existence of energy levels in nuclei?

[1 mark]**A** the Rutherford alpha particle scattering experiment☐**B** the existence of X-ray line spectra☐**C** the existence of gamma radiation☐**D** electron diffraction by crystals☐

2 0

The nuclear radius of an element with nucleon number x is r .

What is the nuclear radius of an element with nucleon number y ?

[1 mark]

A $r\left(\frac{x}{y}\right)^3$ ☐

B $r\left(\frac{y}{x}\right)^3$ ☐

C $r\left(\frac{x}{y}\right)^{\frac{1}{3}}$ ☐

D $r\left(\frac{y}{x}\right)^{\frac{1}{3}}$ ☐

2 7

An ion has a specific charge of $-7.1 \times 10^7 \text{ C kg}^{-1}$.
It is held stationary in a vertical electric field on the surface of the Earth.

What are the magnitude and direction of the electric field?

[1 mark]

A $1.38 \times 10^{-7} \text{ V m}^{-1}$ upwards ☐

B $1.38 \times 10^{-7} \text{ V m}^{-1}$ downwards ☐

C $7.24 \times 10^6 \text{ V m}^{-1}$ upwards ☐

D $7.24 \times 10^6 \text{ V m}^{-1}$ downwards ☐

⏮ ⏪ ⏩ ⏭

electrostatic force

2 8

Which particle pair has the largest magnitude of $\frac{\text{electrostatic force}}{\text{gravitational force}}$ when separated by the same distance?

[1 mark]**A** an electron and a positive pion☐**B** a helium nucleus and a proton☐**C** a proton and a positive pion☐**D** a proton and an electron☐

0	5	.	1
---	---	---	---

Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\text{Co}$.

nuclear mass of $^{59}_{27}\text{Co} = 58.93320 \text{ u}$

[3 marks]

binding energy = _____ MeV

Question 5 continues on the next page



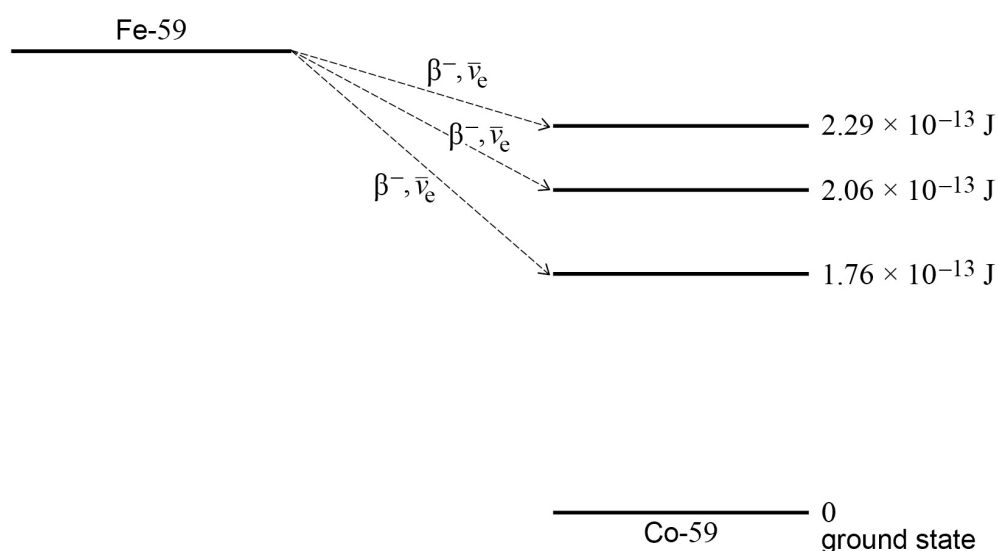
0 5 . 2

A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ -radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown in **Figure 5**. The energies of the excited states are shown relative to the ground state.

Figure 5



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

[2 marks]

maximum kinetic energy = _____ MeV



0	5
---	---

 ·

3

Following the production of excited states of $^{59}_{27}\text{Co}$, γ -radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

[1 mark]

maximum number = _____

0	5
---	---

 ·

4

Calculate the longest wavelength of the emitted γ -radiation.

[3 marks]

longest wavelength = _____ m



0 6 . 1

Explain, in terms of binding energy, why energy can be released when two nuclei undergo nuclear fusion.

[2 marks]

0 6 . 2

During the collapse of a supermassive star, helium-3 and oxygen-17 fuse to release energy. The equation for this reaction is

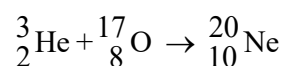


Table 2 gives data for these nuclei.

Table 2

Nucleus	Mass / u
${}^3_2\text{He}$	3.01603
${}^{17}_8\text{O}$	16.99913
${}^{20}_{10}\text{Ne}$	19.99244

Calculate, in J, the energy released when this reaction occurs.

[2 marks]

energy released = _____ J

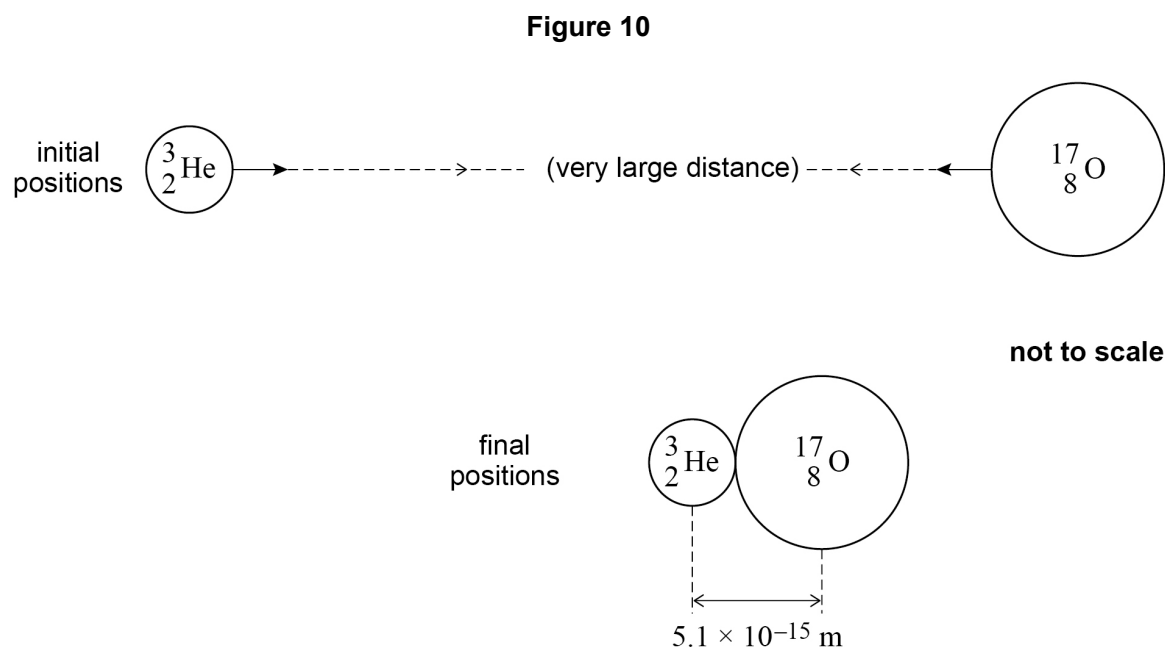


0 6 . 3

One model of nuclear fusion suggests that fusion happens when nuclei touch.

Initially the helium nucleus and oxygen nucleus are separated so that the force between them is negligible. They move towards each other until they fuse. Fusion occurs when their centres are separated by a distance of $5.1 \times 10^{-15} \text{ m}$.

Figure 10 shows the initial positions and final positions of the nuclei.



Calculate the total change in electrostatic potential energy between the initial positions and final positions of the nuclei.

[2 marks]

change in electrostatic potential energy = _____ J

Question 6 continues on the next page

0	6	.	4
---	---	---	---

${}^3_2\text{He}$ can undergo fusion reactions with either ${}^{34}_{16}\text{S}$ or ${}^{17}_8\text{O}$ at the same temperature in a star.

The nucleus has properties that depend on its proton number and its nucleon number. These properties affect the fusion reaction.

Discuss, for this star, how these properties affect the rate of fusion of ${}^{34}_{16}\text{S}$ with ${}^3_2\text{He}$ compared to the rate of fusion of ${}^{17}_8\text{O}$ with ${}^3_2\text{He}$.

[3 marks]

END OF SECTION A



Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown. 

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown. 

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Do **not** use additional sheets for this working.

0 1

Information about the radius of a nucleus can be deduced from the closest approach of alpha particles and from electron diffraction.

0 1 . 1

Alpha particles, each with a kinetic energy of 5.59 MeV, are fired at a thin foil made of gold ($^{197}_{79}\text{Au}$) atoms.

Some of the alpha particles are scattered through an angle of 180° .

Estimate the radius of a $^{197}_{79}\text{Au}$ nucleus from this information.

[3 marks]

radius of nucleus = _____ m

0 1 . 2

Explain why your answer to Question **01.1** is an estimate.

[2 marks]

0 1 . 3

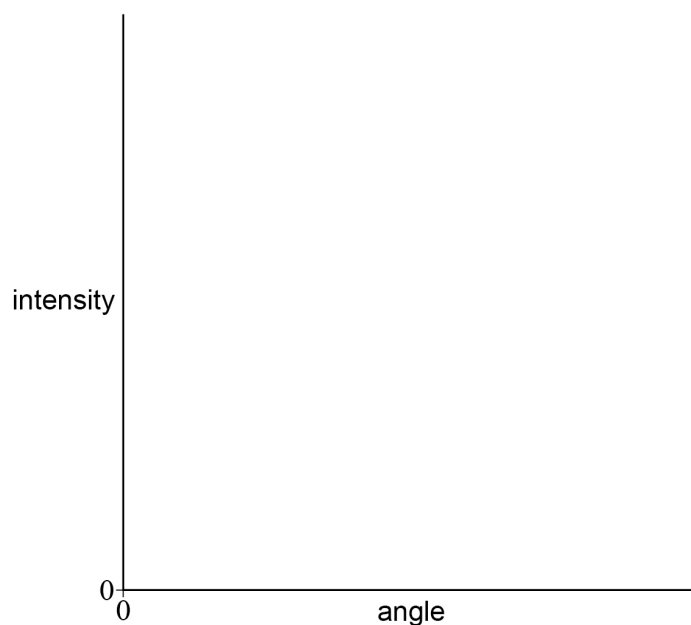
Electron diffraction gives a more precise value for the radius of the nucleus.

Sketch, on **Figure 1**, a graph of intensity against angle for electron diffraction by a nucleus.

Go on to state the feature of this graph that is used to determine the radius of the nucleus.

[2 marks]

Figure 1



Question 1 continues on the next page

0 1 . 4

Results from electron-diffraction experiments lead to the equation:

$$R = R_0 A^{\frac{1}{3}}$$

Show that the equation provides evidence for the constant density of nuclear material.

[2 marks]

1

1



0 6

Fission and fusion are two processes that can result in the transfer of binding energy from nuclei.

0 6 . 1

State what is meant by the binding energy of a nucleus.

[2 marks]

0 6 . 2

Calculate, in MeV, the binding energy for a nucleus of iron ${}_{26}^{56}\text{Fe}$.

$$\text{mass of } {}_{26}^{56}\text{Fe nucleus} = 9.288 \times 10^{-26} \text{ kg}$$

[3 marks]

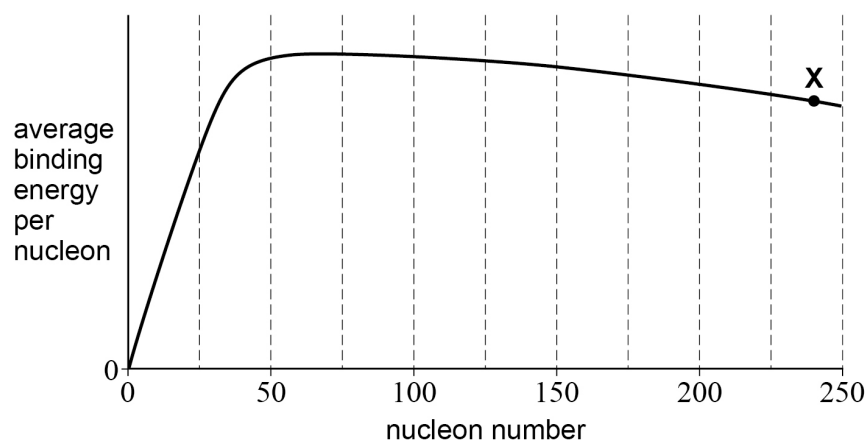
binding energy = _____ MeV

Question 6 continues on the next page



Figure 10 shows a graph of average binding energy per nucleon against nucleon number for common nuclides.

Figure 10



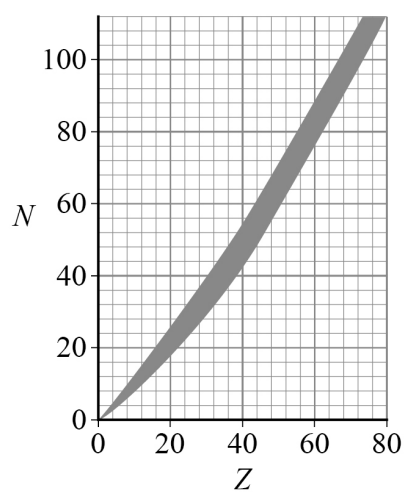
0 6 . 3 The nuclide labelled **X** in **Figure 10** undergoes fission.

Annotate **Figure 10** with F_1 and F_2 to show **one** possible pair of nuclides resulting from the fission of **X**.

[2 marks]

0 6 . 4 Figure 11 shows a graph of N against Z for stable nuclides.

Figure 11



Deduce the likely initial mode of decay of F_1 and F_2 .
Refer to **Figure 11** in your answer.

[3 marks]

END OF SECTION A

Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question, completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



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If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

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Do **not** use additional sheets for this working.

0 6 . 1

Nuclear radii can be estimated using either alpha particles or high-energy electrons.

State **two** advantages of using high-energy electrons rather than alpha particles for this estimate.

[2 marks]

1 _____

2 _____

Question 6 continues on the next page

0 6 . 2

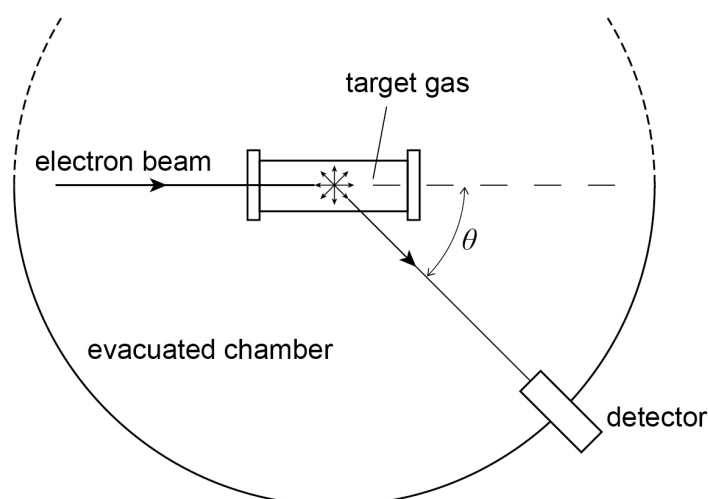
Figure 11 shows a beam of electrons, each with the same high energy, incident on a target gas.

The electrons are diffracted by the nuclei in the gas.

The intensities of these diffracted electrons are measured at various angles θ .

The data are used to determine the nuclear radius R of the atoms in the gas.

Figure 11



Sketch on **Figure 12** a graph showing how the electron intensity varies with θ .

[2 marks]

Figure 12

06.3

The radius R of a nucleus is related to its nucleon number by $R = R_0 A^{\frac{1}{3}}$.

Show that this equation is consistent with the idea that all nuclei have the same density.

[2 marks]

06.4

The equation $R = R_0 A^{\frac{1}{3}}$ is derived from experimental data.

Suggest **one** reason why the constant density of nuclear material derived from this equation is only approximate.

[1 mark]

06.5

The measured radius R of $^{35}_{17}\text{Cl}$ is $4.02 \times 10^{-15} \text{ m}$.

Calculate an estimate of

- the constant R_0
- the density of nuclear material.

[3 marks]

$R_0 =$ _____ m density = _____ kg m^{-3}



0 6

A thermal nuclear reactor uses a moderator to lower the kinetic energy of fast-moving neutrons.

0 6 · 1

Explain why the kinetic energy of neutrons must be reduced in a thermal nuclear reactor.

[1 mark]

0 6 · 2

As a result of a collision with an atom of a particular moderator, a neutron loses 63% of its kinetic energy.

A neutron has an initial kinetic energy of 2.0 MeV.

Calculate the kinetic energy of the neutron after five collisions.

[2 marks]

kinetic energy = _____ eV

Question 6 continues on the next page

0 6 · 3

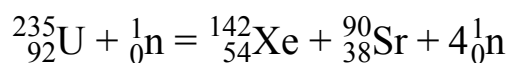
The kinetic energy of a neutron in a thermal nuclear reactor is reduced from about 2 MeV to about 1 eV.

Explain why the number of collisions needed to do this depends on the nucleon number of the moderator atoms.

[2 marks]

0 6 . 4

One fission process which can occur in a thermal nuclear reactor is represented by the equation



Calculate in MeV the energy released in this fission process.

$$\text{mass of } {}_{92}^{235}\text{U} = 235.044 \text{ u}$$

$$\text{mass of } {}_{54}^{142}\text{Xe} = 141.930 \text{ u}$$

$$\text{mass of } {}_{38}^{90}\text{Sr} = 89.908 \text{ u}$$

$$\text{mass of } {}_0^1\text{n} = 1.0087 \text{ u}$$

[3 marks]

energy released = _____ MeV

Question 6 continues on the next page



0 6 . 5 Many magazine and newspaper articles focus on the risks of using nuclear power.

State **three benefits** of using nuclear power.

[3 marks]

1 _____

2 _____

3 _____

END OF SECTION A

Section B

Each of Questions **07** to **31** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.

For each question completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.



You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0	1
---	---

Figure 1 shows a sealed radioactive source used in schools and colleges.

Figure 1



0	1
---	---

.	1
---	---

State **two** safety procedures to reduce risk when using this type of source.

[2 marks]

Safety procedure 1 _____

Safety procedure 2 _____

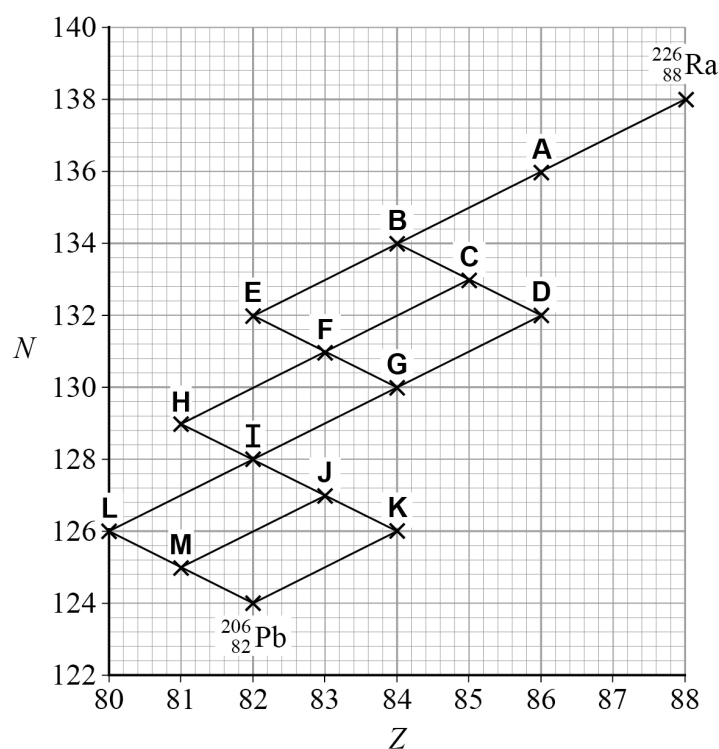
0 1 2 A sealed source contains radium-226 ($^{226}_{88}\text{Ra}$).

$^{226}_{88}\text{Ra}$ decays by emitting α and β^- particles to produce $^{206}_{82}\text{Pb}$ which is stable.

Figure 2 is a graph of neutron number N against proton number Z , showing the different ways that $^{226}_{88}\text{Ra}$ can decay into $^{206}_{82}\text{Pb}$.

Points **A** to **M** represent all the unstable nuclei that may be formed as $^{226}_{88}\text{Ra}$ decays into $^{206}_{82}\text{Pb}$.

Figure 2



Determine the number of routes by which **B** can change into **K**.

[1 mark]

0 1 3 Identify which of the nuclei **A** to **M** are common to all the possible ways that $^{226}_{88}\text{Ra}$ decays into $^{206}_{82}\text{Pb}$.

[3 marks]

Question 1 continues on the next page

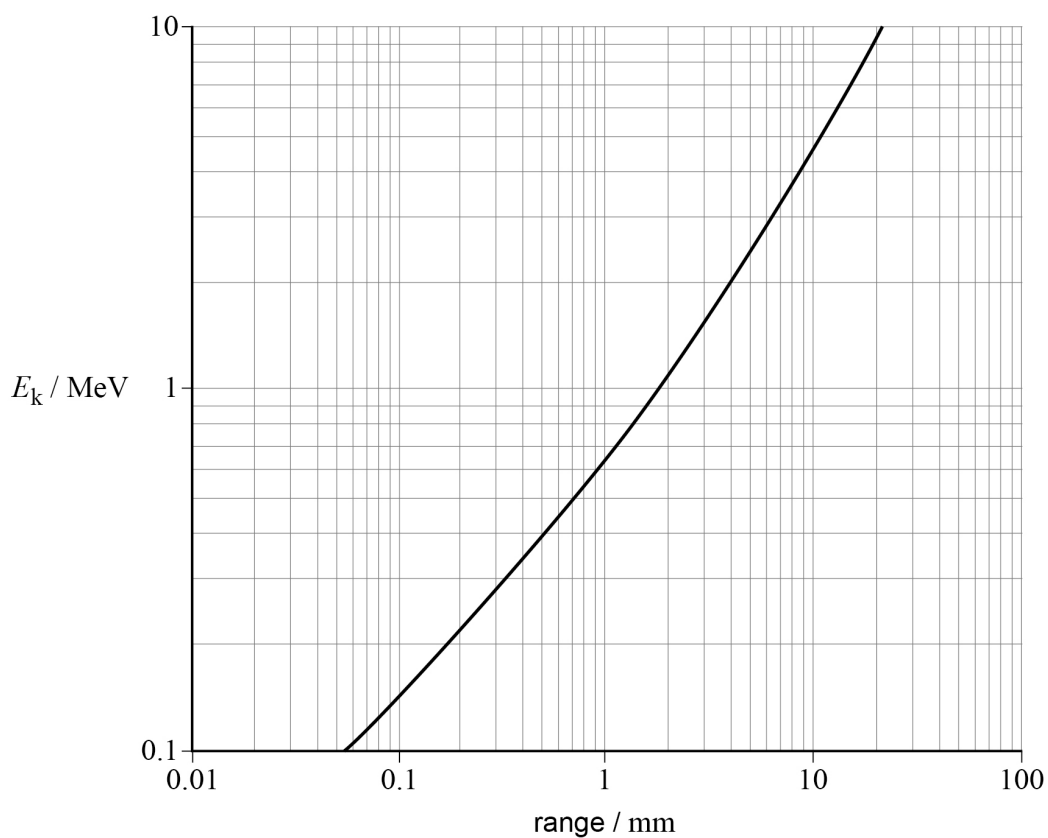


The sealed source emits:

- α particles with energy E_k between 3.8 MeV and 7.8 MeV
- β^- particles with energy E_k between zero and 5.5 MeV.

Figure 4 shows how the range of β^- particles in aluminium depends on E_k .

Figure 4



Deduce the minimum thickness of the aluminium absorber that should be used in the experiment.

[3 marks]

minimum thickness = _____ mm

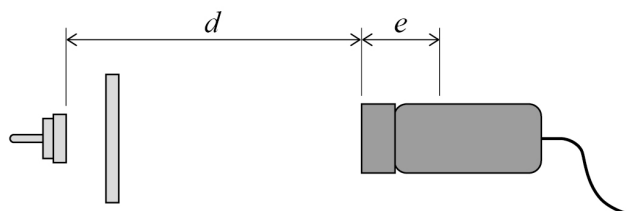
Question 1 continues on the next page



0 1 . 6

Ionisation takes place inside the detector. The effective distance travelled by γ radiation from the source is $(d + e)$.

The distance e , shown in **Figure 5**, cannot be measured directly.

Figure 5

From the inverse-square law for γ radiation, it can be shown that

$$(d + e) = \sqrt{\frac{k}{A}}$$

where A is the count rate, corrected for background radiation
 k is a constant.

The student plots the graph of d against $\frac{1}{\sqrt{A}}$ shown in **Figure 6**.

Deduce k using **Figure 6**.

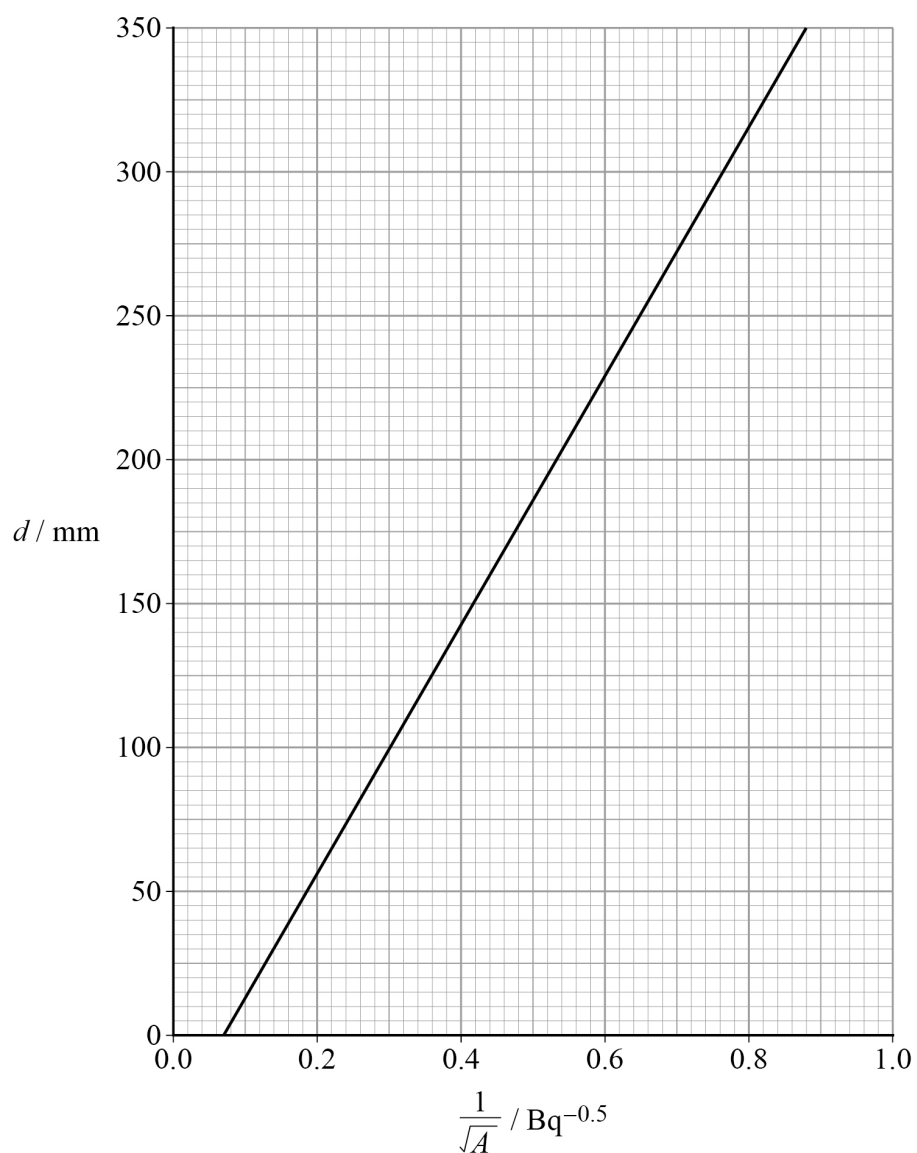
Explain your reasoning.

Give a suitable unit for your result.

[5 marks]

$k =$ _____ unit _____

Figure 6



0 1 . 7 Determine e using **Figure 6**.

[2 marks]

$e =$ _____ mm



MARK SCHEMES

official mark schemes



C



10

A (AO2)

 $4.4 \times 10^7 \text{ C kg}^{-1}$ 

09

B

8

7



08	C	the beta-plus decay of a $^{39}_{20}\text{Ca}$ nucleus	AO2
		$E_{\text{k(max)}}$ / /	AO1



01.1	${}^4_2\alpha + {}^{234}_{90}\text{Th}$ ✓	1 mark each for alpha and Th; numbers must be correct Must see “+” for full marks Condone He for alpha If no other mark is given, one mark can be awarded if He-3 is used and A and Z are correct MAX 1 for extra particles but condone “+ 2e⁽⁻⁾” (not 2β) Ignore symbol that is used for Thorium	2	2 x AO1
------	---	--	---	---------

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Idea that a neutron changes to proton/beta minus decay ✓ The particle is W⁻ because This is a weak interaction / it involves the weak force / there is a quark change and indication that charge is conserved ✓	For MP1 condone “down quark changes to up quark”. Evidence for MP1 can be found in the form of equations or diagrams. Second mark requires some explanation of why particle is negative. MAX 1 for a complete consistent inverse interaction leading to W⁺.	2	1 x AO2 1 x AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	(FOR:) Lines C is in (both) hydrogen (and helium spectra) OR Line E is in (both) sodium (and helium spectra)✓ (AGAINST:) Line D is missing (is in neither the hydrogen nor the sodium spectra) ✓	Treat references to A, B and F in FOR or AGAINST as neutral. Must link line to an element Ignore any discussion of any “missing” lines in the helium spectrum. Condone use of 390 / 440 / 490 / 505 / 590 / 670 (nm) for A/B/C/D/E/F Condone emission for absorption	2	2 x AO3



Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Wavelength = 580 nm to 590 nm ✓ Use of $E = hc/(\text{their wavelength})$ ✓ Conversion of their E in J to eV ✓	Expect to see answer in range 2.11 to 2.14 (eV) ✓ When an energy difference between two spectral wavelengths is correctly calculated, only MP2 and MP3 can be scored.	3	1 x AO3 2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Photon is energy carrier OWTTE ✓ In absorption atom becomes excited/moves to higher energy state/level (by absorbing photon) ✓ In emission atom de-excited/moves to lower energy state (by emitting photon) ✓	Condone omission of reference to energy states/levels in either MP2 or MP3 but not both. Treat discussion of any other irrelevant phenomenon or incorrect physics as talk out in that marking point. Allow “energy shell” but not “shell”. Condone electron for atom Suggestions that limit transitions to/from ground state penalise in either MP2 or MP3 once only.	3	3 x AO1
Total			12	

Question	Answers	Additional comments/Guidelines	Mark	AO
----------	---------	--------------------------------	------	----



B



B



09	B
----	---



10	A	$\alpha + \beta^- + \beta^- + \alpha + \alpha$
----	---	--



31	C	$2.55 \times 10^{-13} \text{ J}$
----	---	----------------------------------



11

C (AO1)

from 0.5 fm to 3 fm

up to 0.5 fm



30

C

 β^- emission.

26	C	0.103 MeV	AO2
		122	122



01.1		Do not credit nucleons. Suggestion of difference in number of protons loses the mark.	1
01.2	131 (nucleons) ✓	If more than one number is given, the nucleon number must be explicit.	1
01.3	The tellurium has 1 more neutron (than iodine-125) ✓ The tellurium has 1 fewer proton (than iodine-125) ✓	Accept reverse arguments. Accept tellurium has 73 neutrons Accept tellurium has 52 protons Condone "proton number". Condone "number of neutrons/protons have increased/decreased <u>by one</u> " Treat any nuclear reactions as neutral. Discussion of electrons in nucleus scores max 1. Accept answer in terms of quarks (one more down and one fewer up). Ignore references to nucleons/mass number.	2



01.4	A (<i>internal conversion</i>: only electron released); <i>beta-decay</i>: (electron and) <u>anti-neutrino</u> released; ✓ B (both statements required for mark) <i>internal conversion</i>: all electrons released will have similar/discrete energies/momenta <i>beta-decay</i>: electrons will have a range of energies/momenta ✓ C (<i>internal conversion</i>: no change in constituents of nucleus/element does not change) <i>beta-decay</i>: neutron converted to proton (allow in terms of quarks)/element changes (to one with (one) more p, different Z, different proton number/different atomic number)) ✓ D (<i>internal conversion</i>: orbital electron lost) <i>beta-decay</i>: electron comes from nucleus / no change in orbital electrons ✓ E (both statements required for mark) <i>internal conversion</i>: mediated by electromagnetic force / virtual photons <i>beta-decay</i>: mediated by weak interaction / W^- ✓	Any 3. Treat each difference, as delimited by the answer book, as a single independent mark. Contradiction within a difference cancels the mark for that difference (on list basis). For a contradiction between separate differences treat the incorrect difference as neutral. Allow: F (both statements required for mark) <i>Internal conversion</i>: may be accompanied by X-ray photon <i>Beta-decay</i>: may be accompanied by gamma photon ✓ Allow “shells” for “orbitals”. Do not award separate marks for force and exchange particle Condone “W boson” or “W particle” but not W^+ and W^-	3
Total			7



Question	Answers	Additional Comments/Guidelines	Mark
	Ray enters (prism) along normal ✓	Allow normal explained eg at right angles <u>to</u> surface	



02.1	down quark changes to up quark ✓	Allow “d→u” Condone udd→uud Condone U for u but not D for d. Do not accept answers with extra particles.	1	AO1
------	----------------------------------	---	---	-----

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Idea that (graph shows that) beta particles (from C-14) have a range of (kinetic) energies ✓ There is a fixed/maximum/total amount of energy (released by C-14) so there must be another particle that carries the energy differences/missing energy away ✓	A mention of conservation of energy on its own is insufficient for MP2.	2	2 x AO1

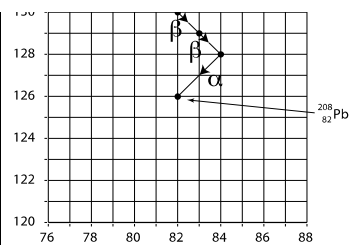
Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	neutron ✓	Condone “n” but not “N”. Do not allow “udd”.	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	Calculation of minimum energy produced in annihilation of positron and electron (from rest mass energy $\times 2$) E.g. $2 \times 0.51 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$ ✓ (2 photons produced so) energy per photon = $8.2 \times 10^{-14} \text{ J}$ ✓ Conclusion consistent with their calculated minimum energy. ✓ ALTERNATIVE One calculation of mass equivalence of photon energy ✓ Calculation of remaining mass equivalents OR deduction about the other two photon energies ✓ Only G3 has sufficient energy to have been made in annihilation. ✓	Calculation of the photon energy based on one particle can get MP2. The 'correct' answer would be a conclusion leading to G3 only. If no other mark awarded, award one mark for determining rest energy of positron or electron in J. Allow mass equivalent calculations in (M)eV Allow explanation in terms of positron and electron for annihilation in alternative MP3	3	3 x AO3
Total			7	

Question	Answers	Additional comments/Guidelines	Mark	AO
		Condone POT error in MP1		



07.1



Arrows are included but in wrong direction with lines.

2

AO2 1f

07.2	Any 3 marking points from 1 to 5 ¹Strong nuclear force (SNF) affects nucleons or protons and neutrons. ✓ ²SNF attraction extends up to 3 fm (allow 1–4 fm) ✓ ³The SNF is repulsive below about 0.8 fm (allow 0.3 to 1 fm and prevents the nucleus totally collapsing) ✓ ⁴Electromagnetic/electrostatic repulsive force (only) acts between protons ✓ ⁵EM forces are long range/infinite/acts across whole nucleus/acts on all protons(so increases as proton number increases) ✓ PLUS one of following that explains the imbalance More neutrons are needed to hold nucleus together / add to binding force/increase instability/reduce stability (owtte) Or Fewer protons are required so as to reduce the repulsion/reduce instability/increase stability (owtte) ✓	Baryons/hadrons may replace nucleons. If 'strong force' rather than 'strong nuclear force' is used only penalise once. Any wrong statement made in the first group of marking points then this section has a maximum 2 marks out of 3.	Max 4	AO2 1a (x2) AO3 1b (x2)
07.3	${}^{205}_{82}\text{Pb} + {}^0_{-1}\text{e} = {}^{205}_{81}\text{Tl} + \nu_{(\text{e})}$	The electron may be represented by e^- or β^- without the super and subscript.	1	AO2 1f

	✓ mark for full equation	Q may be added to the end of the equation. Encouraged by the following question 'gamma' might appear on the RHS of the equation. Simply ignore gamma.		
07.4	Orbiting electrons in the atom <u>fall</u> (to fill the positions vacated by inner orbiting electrons releasing their energy as em (gamma) radiation, ✓ The excited <u>nucleus</u> emits gamma radiation (as it de-excites)✓	Mark leniently in first mark. Just need to see photons are related to outer electron movement. Allow radiation due to it being above 0 kelvin For the second mark 'nucleus' must be mentioned but electrons must not.	2	AO3 1a AO3 1b
07.5	It is because: It only emits γ -rays. γ -rays are weakly ionising/cause less damage to body than other radiations. γ -rays can penetrate/escape from the body. It has low toxicity. Half-life is short enough not to remain in the body for too long after the medical examination. Half-life is long enough to complete the diagnosis. It can be prepared in the hospital/close to the hospital. Any 2 ✓✓		2	AO1 1a
Total			11	

Keys to Objective Test Questions (each correct answer is worth 1 mark)													
Qu	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans	A	C	C	B	B	A	D	C	B	D	C	A	C
Qu	21	22	23	24	25	26	27	28	29	30	31	32	
Ans	D	D	B	C	C	C	C	A	A	C	C	D	



C



08	B
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		$N = \frac{0.194}{\text{their } \lambda_p}$ (allow ECF for λ_p out of range but not if due to POT)		
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	identifies an appropriate physical characteristic that makes the measurement of the (5 th) maximum more difficult ✓	take 'it' to be the 5th maximum / peak (see rubric marking point 3.3) (centre difficult to locate because) (5th) 'maximum is wider' / 'peak less pronounced' / 'less defined' or wtte; allow 'maximum more spread out' / 'less pronounced' OR maximum 'is fainter' / 'less bright' / 'intensity reduced'; reject 'not as clear' OR (cannot use edges to determine location of centre because) 'whole maximum (may be) not visible' / 'can't see edges' OR (L_R produces a range of wavelengths so) 4th and 5th / adjacent fringes may overlap	1	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	extrapolation of linear region of the L_R characteristic $_1\checkmark$ V_A for L_R in range 1.91 to 1.93 (V) $_2\checkmark$	for $_1\checkmark$ reads off where a ruled extrapolation to the linear region of the L_R characteristic reaches the horizontal axis the line must be free from discontinuities; condone a ruled dashed line condone tangent meeting curve at $I \geq 10$ mA for $_2\checkmark > 3$ sf acceptable if rounding to 3 sf	2	AO1-1b

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	any fully correct calculation of the Planck constant $_1\checkmark$	for $_1\checkmark$ allow 2 sf use of $c = 3(.00) \times 10^8$ AND $e = 1.6(0) \times 10^{-19}$ AND EITHER V_A from 02.3 AND λ_p in range 620 to 650 nm / ECF their λ_p from 02.1 OR $V_A = 2.00$ AND λ_p in range 550 to 580 nm;	1	AO3-1b

	calculates mean of two valid calculations of the Planck constant; result in range 6.10 to 6.50×10^{-34} (J s) 2✓	for 2✓ Planck constant result rounding to correct 3 sf (check very carefully working leading to data booklet value 6.63×10^{-34})	1	AO1-1b
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	V_F corresponding to $I_F = 21$ mA read from L_R graph in Figure 4 ; calculates R from $\frac{6.1 - \text{their } V_F}{21(.0 \times 10^{-3})}$ 1✓	use of $V_F = 2.01$ (V) leading to $R = 195$ (Ω) earns both marks for 1✓ accept evidence of working on Figure 4 condone 2 sf eg $V_F = 2.0$ (V) allow POT error for I_F	1	AO1-1b
	$R = 195$ (Ω) from $\frac{6.10 - 2.01}{21(.0) \times 10^{-3}} = 195$ 2✓	for 2✓ evidence to show use of $V_F = 2.01 \pm 0.01$ (V) must be seen, ie allow $\frac{6.10 - 2.00}{21(.0) \times 10^{-3}} = 195$ OR $\frac{6.10 - 2.02}{21(.0) \times 10^{-3}} = 194$	1	AO2-1d
Total			10	



Question

Answers

Additional comments/Guidelines

Mark

AO



A



11	A	up quark	down quark	neutrino
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11	B	down quark up quark β^-
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10

A

energy is conserved.

AO1



01.1	Diagram with: Up becoming down ₁✓ Electron becoming (electron) neutrino ₂✓ W connecting the two, with a boson charge consistent with their diagram ₃✓	Accept uud changes to udd. Do not accept capital D for d. Accept e or e⁻ for electron but reject β⁻. Condone ve for ν_e (ie same size e on same line) Accept v (roman) for ν (greek). Boson charge must be consistent bottom left to top right AND bottom right to top left. Do not accept a change in boson arrow direction in ₃✓.	3	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	In order for the nucleus to decay it needs (orbiting) electrons because it (only) decays by electron capture ✓	Treat irrelevant right or wrong comments as neutral. Accept reverse argument. Condone suggestion that probability of electron capture is decreased. Mention of 'ionisation' is neutral.	1	AO3

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	Evidence of $22 \times 1.6 \times 10^{-19}$ or 3.52×10^{-18} (to determine charge) OR $\frac{\text{their charge}}{4.8 \times 10^7}$ (to determine mass) _{1✓} Evidence of calculation leading to 22 neutrons, e.g. number of neutrons = their nucleon number (44) – 22 = 22 (neutrons) _{2✓}	Expect to see mass = $\frac{22 \times 1.6 \times 10^{-19}}{4.8 \times 10^7} = 7.3 \times 10^{-26}$ (kg) number of nucleons = $\frac{7.3 \times 10^{-26}}{1.67 \times 10^{-27}} = 44$ Accept alternatives for the nucleon mass Accept for _{1✓} the idea that specific charge is $0.5 \times$ specific charge of proton Do not accept '22' without some evidence. Evidence to support _{2✓} can be seen earlier in the calculation e.g. subtraction of masses.	2	1 × AO2 1 × AO3
Total			6	

Question	Answers	Additional comments/Guidance	Mark	AO
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01.1	gravity, weak (nuclear), strong (nuclear), electromagnetic ✓	Any order, all four must be correct. Condone any reference to “interaction” or “force” Condone “gravitational” Do not accept ‘electrostatic’, ‘gravitational potential’, ‘em’, ‘EM’	1	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	proton, beta minus, (electron) antineutrino all correct ✓	Allow alternative ways of writing beta minus: electron/ e^- / β^- Accept p and P for proton and $\bar{\nu}_e$ or $\bar{\nu}$ for antineutrino Condone ‘anti electron neutrino’	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	weak (nuclear) ✓ it involves leptons (which do not experience strong interaction/force) OR there is a change in quark (flavour) ✓	Accept reference to W^- or W together with transfer of charge (from neutron) Accept d (quark) converted to u (quark) MP2 is conditional on award of MP1	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	idea that the exchange particle is a (virtual) photon ✓ (virtual) photons/the exchange particles have momentum ✓ conservation of momentum (means that photon interchange) enables the electron momentum/path to change ✓	Accept γ for photon.	3	AO1
Total			7	

7

Question	Answers	Additional comments/Guidelines	Mark	AO
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01.1	${}_{19}^{40}\text{K} + {}_{-1}^0e \rightarrow {}_{18}^{40}\text{Ar} + \nu_{(e)} \checkmark \checkmark$	first mark for 40 and 18 second mark for electron neutrino if negative superscript on neutrino mark not awarded	1 1
01.2	is the weak interaction/weak nuclear force $\checkmark$ because involves leptons <u>and</u> hadrons/ because quark character/flavour/identity/type changed $\checkmark$	allow change in quark composition allow second mark if applied to stated interaction e.g. up quark changes to down quark	1 1
01.3	(use of $E=hf$) energy in J = $1.46 \times 10^6 \times 1.6 \times 10^{-19} \checkmark (= 2.336 \times 10^{-13})$ $f = (\frac{E}{h}) = \frac{2.336 \times 10^{-13}}{6.63 \times 10^{-34}} \text{ AND } \lambda = \frac{3 \times 10^8}{f}$ OR $\lambda = \left(\frac{hc}{E} \right) = \frac{3 \times 10^8 \times 6.63 \times 10^{-34}}{2.336 \times 10^{-13}} \text{ seen directly } \checkmark$ $8.51 \times 10^{-13} \text{ m } \checkmark$	1 for the attempt at the conversion to J allowing POT 1 for attempt to sub in hf and c/λ (or hc/λ) allow energy substituted in MeV or eV for second mark 1 for the correct answer (not awarded if eV used or MeV or if POT error) Accept 8.52×10^{-13}	1 1 1
01.4	identifies the decay as beta emission $\checkmark$ <i>so will expect to see:</i> electron released (from nucleus) correct details of how electron detected antineutrino released no photon released } 2 from 4	If state incorrect interaction e.g. beta plus decay the wrong Physics and no consequential error(CE) and therefore zero. If no interaction stated then can score next 2 marks. e.g. cloud chamber or absorption If give correct equation for beta decay award mark for	3

		electron and antineutrino	
Total			10

Question	Answers	Additional Comments/Guidelines	Mark
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A



12	B	It has a charge of -1.6×10^{-19} C.
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12

B (AO1)

Strange particles are always created in pairs.



10	D	They decay into electrons.
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09

C

 $d\bar{u}$

AO1



01.1	uds ✓	Do not accept $\bar{u}$ for $\bar{d}$. Penalise extra particles	1	AO3
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	weak (interaction / force)✓ strangeness changes (in this decay)✓ (from -1 to 0 and strangeness can only change in a weak interaction)	MP2: Reject negative arguments (eg 'strangeness is conserved in a strong interaction') Reject the idea that strangeness always changes in a weak interaction. General statement of strangeness conservation in the weak interaction on its own is insufficient. Accept "strangeness is not conserved (in this decay)". Condone "strangeness is lost".	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	anti-neutron ✓	Accept $\bar{n}$ Reject ambiguous answers unless supported by other evidence. Do not accept answer solely in terms of quarks	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	$1.1(1) \times 10^3$ (MeV) ✓	Reject incorrectly rounded answers. Accept: 1100 MeV (2sf) / 1110 MeV (3sf) / 1115 MeV (4sf) etc Calculator value: 1114.66875 MeV	1	AO1



Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Any one from ✓ (teams must be large and international) because: • research is expensive / requires funding from many countries • both scientists and engineers are required (because the machines used for research are complex/large pieces of civil engineering) • research is multi-faceted / multi-disciplinary (because computation/theory/ etc. is required) • research is round-the-clock (so teams are large to work on shift basis) • they are needed to process the large amounts of data produced	Treat idea of peer review as neutral (this argues for independent teams). Do not accept idea that it 'avoids bias' or 'reproducibility'.	1	AO1
Total			6	

Question	Answers	Additional comments/Guidelines	Mark	AO



01.1	<u>Award each mark independently</u> Lepton number not conserved therefore not possible✓ Lepton numbers for particles correct ✓ Eg $0 = 1 -1 -1$ (for lepton number) OR $0 = 0 -1 +0$ (for muon lepton number)	Any incorrect quantum number equation (for Q, B or S) loses MP2. Alternative for MP2 reference to missing <u>muon neutrino</u> in order to balance/conserves (muon) lepton number.	2	2× AO1a
01.2	up anti-up AND down anti-down✓	Either order Credit symbols But do not condone any use of capital letter	1	AO1a
01.3	Identification of quarks in either neutral kaon correct, ie kaon $d \bar{s}$ OR anti-kaon $\bar{d} s$ ✓ Identification of quarks in other kaon correct, with statement that they are not the same. ✓	Alternative: Kaon has strangeness +1✓ Anti-kaon has strangeness -1 and is therefore not the same.✓ Allow max 1 if - quark configurations wrong way round. - value of strangeness is wrong way round - statement that strangeness is different without reference to value. - strangeness and quarks given but one of them is incorrect.	2	AO1a AO1b

Question	Answers	Additional comments/Guidelines	Mark	ID details
01.4	<u>Award each mark independently</u> Links hadrons to strong nuclear force (snf) OR identifies snf as forcing holding nucleus together✓ Reason why it cannot be the kaon✓ Reason why it cannot be the muon✓ pion is the particle as it (has mass in range and) is a <u>hadron</u> (and therefore experiences snf) ✓	For MP2: kaon rest energy is not between those of electron and half that of nucleon. (values quoted from data booklet) OR (only) pion and muon have correct rest energy with no mention of kaon. For MP3: muon is a <u>lepton</u> (and does not experience snf) An incorrect statement amount a particle negates the mark for that particle. Rest energies/MeV: kaon 493.821 or 497.762 pion 139.576 or 134.972 muon 105.659 nucleon 938.257 or 939.551	4	AO3.1b
Total			9	

7

Question	Answers	Additional comments/Guidelines	Mark	ID details
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02.1	All four rows correct $_1\checkmark_2\checkmark$ Any two rows correct $_1\checkmark$	<table border="1" data-bbox="1140 122 1594 437"> <thead> <tr> <th>Particle</th><th>Baryon</th><th>Hadron</th><th>Lepton</th><th>Meson</th></tr> </thead> <tbody> <tr> <td>π^+</td><td></td><td>$\checkmark$</td><td></td><td>$\checkmark$</td></tr> <tr> <td>n</td><td>$\checkmark$</td><td>$\checkmark$</td><td></td><td></td></tr> <tr> <td>K^+</td><td></td><td>$\checkmark$</td><td></td><td>$\checkmark$</td></tr> <tr> <td>Σ^0</td><td>$\checkmark$</td><td>$\checkmark$</td><td></td><td></td></tr> </tbody> </table> Accept any reasonable notation for $\checkmark$	Particle	Baryon	Hadron	Lepton	Meson	π^+		$\checkmark$		$\checkmark$	n	$\checkmark$	$\checkmark$			K^+		$\checkmark$		$\checkmark$	Σ^0	$\checkmark$	$\checkmark$			2	$1 \times \text{AO1}$ $1 \times \text{AO2}$
Particle	Baryon	Hadron	Lepton	Meson																									
π^+		$\checkmark$		$\checkmark$																									
n	$\checkmark$	$\checkmark$																											
K^+		$\checkmark$		$\checkmark$																									
Σ^0	$\checkmark$	$\checkmark$																											

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Identifies strangeness as the consideration as interaction would be strong/not weak $\checkmark$ K^- and Σ^0 have same strangeness of -1 $\checkmark$ Demonstration that LHS and RHS strangeness not equal AND that the LHS is zero $\checkmark$	Do not award MP1 for suggestion that any other quantum number is not conserved. Evidence for MP2 and MP3 can be seen in a correct use of strangeness values e.g. $0 + 0 \rightarrow -1 -1$	3	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	clear assignment of each particle to its correct rest mass including the photon ✓ idea that LHS mass > RHS mass ✓	Electron AND positron rest energy = 0.510999 MeV π^0 rest energy = 134.972 MeV Gamma/photon rest mass = 0 Allow rounded values for rest mass.	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	annihilation of the positron with an electron ✓	Do not allow answers such as 'elimination'	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	Idea that international collaboration/co-operation/verification is required OR (investment in) expensive equipment/hardware/infrastructure is required ✓	Accept idea that (people with) particular/specialist talents/technology/infrastructure must be in place. Ignore references to peer review or vague statements such as 'it takes a long time' or 'it/the research is expensive'.	1	AO1
Total			9	

Question	Answers	Additional comments/Guidelines	Mark	AO
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01.1	MP1 is for evidence of determining the charge on the nucleus. ✓ MP2 is for evidence of determining either the number of protons OR the number of nucleons. ✓ MP3 is for determining number of neutrons. ✓	Charge = $4.39 \times 10^7 \times 8.02 \times 10^{-26}$ kg (= 3.52×10^{-18} C) Number of protons = charge/1.6×10^{-19} (= 22) OR Number of nucleons = $8.02 \times 10^{-26} / 1.67 \times 10^{-27}$ (= 48) Number of neutrons = 48 – 22 = 26 Note use of 1.7 gives 27 neutrons and loses MP3	3	3×AO2.1f
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Evidence of conversion of MeV to J ✓ Substitution into KE equation ✓ Correct final answer ✓	Energy = $2.15 \times 10^8 \times 1.6 \times 10^{-19}$ (= 3.44×10^{-11} J) - allow POT error in MP1 $v^2 = 2E/m = 8.58 \times 10^{14}$ $v = 2.9(3) \times 10^7$ m s⁻¹	3	1×AO1.1b 2×AO2.1f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	$\pi^+ \rightarrow e^+ + \nu_e$ OR charge: $1 = 1 + 0$ ✓ B: $0 = 0 + 0$ AND L: $0 = -1 + 1$ ✓ (S: $0 = 0 + 0$)		2	2×AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	$(K^+ \rightarrow \mu^+ + \nu_\mu)$ Correct strangeness $+1 = 0 + 0$ ✓ <u>Weak</u> interaction so strangeness can change (by 0, +1 or -1) ✓		2	2×AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Decay consistent with Q B L conservation✓ Equation involving pions ✓	e.g. $K^+ \rightarrow \pi^+ + \pi^+ + \pi^-$ $K^+ \rightarrow \pi^+ + \pi^0$	2	1×AO1.1a 1×AO1.1b
Total			12	

Question	Answers	Additional comments/Guidelines	Mark	AO
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A



C

13	B	$3.3 \times 10^{-19} \text{ J}$
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14

B (AO2)

maximum kinetic energy of a photoelectron



12

C

$$2.8 \times 10^5 \text{ m s}^{-1}$$



09

A

 $\frac{\quad}{\quad}$ 

| 10

| A

increases

decreases

| AO2



12

C

using a light source that emits light of a shorter wavelength

AO1



22

B

$$3.5 \times 10^{-19} \text{ J}$$

AO2



30	D	$\frac{q}{r}$	AO1
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02.1	Frequency related to energy (of photon) $E = hf$ ✓ There is a minimum energy (of a photon) required to remove photoelectron; (minimum energy relates to minimum frequency). ✓	MP1 is for linking photon energy to frequency MP2 is for explaining what is meant by the work function. If no other mark awarded, one mark can be given for relevant mention of work function. Do not credit mention of threshold frequency unless explained If no mention of a photon, 1 max. Ignore references to energy levels.	2	AO1a AO1a
02.2	Evidence of use of maximum current ÷ charge on electron ✓ 1.9×10^{14} (electrons per second) ✓	Expect to see $30 \times 10^{-6} \div 1.6 \times 10^{-19}$ Condone e for 1.6×10^{-19} in MP1 Allow POT error for current in MP1 Correct answer only for MP2	2	AO3.1a AO2.1f
02.3	Number of photoelectrons released (per second) depends on intensity of em radiation/number of (incident) photons (per second) (not pd.) ✓ Constant current reached when <u>all</u> photoelectrons released (each second) reach anode (due to anode pd). ✓	MP1 is for relating the intensity to either the no. of incident photons or released photoelectrons per second MP2 is for linking constant current to all photoelectrons being detected. Condone 'go round the circuit' for 'reach anode'.	2	AO1b

02.4	MP1 is for range of KE✓ MP2 for what happens when V is negative in terms of kinetic energy or potential energy or work done on/by electron✓ MP3 is for link to fewer photoelectrons having necessary KE. ✓	Example statements: MP1: photoelectrons are released with a range of KE. MP2: (When V negative) photoelectrons lose KE/gain (E)PE crossing to anode. MP3: (As V is increasingly negative) fewer of the photoelectrons (released per second) have sufficient (initial) KE to cross to anode (so current decreases).	3	AO1b
02.5	<u>Award each mark independently</u> Stopping potential related to <u>maximum</u> kinetic energy of photoelectrons/ $KE_{max} = eV_s$✓ (Max) KE = energy of photon – work function/ ϕ. OR (max) KE increases as (work function is lower and) radiation same✓ (max) KE increases, so stopping potential increases. ✓	If no mention of <u>maximum</u> KE do not award MP1. Alternative Reference to Einstein equation in the form: $hf = \phi + eV_s \quad \checkmark$ rearranged to $V_s = \frac{hf - \phi}{e} \quad \checkmark$ So lower work function, (with hf and e constant,) gives higher V_s. ✓	3	AO3.1a
Total			12	

Question	Answers	Additional comments/Guidelines	Mark	ID details
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C



B



D



12	D
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14	D	It emits photons of UV light following ionisation or excitation.
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15	C	$1.6 \times 10^{-18} \text{ J}$
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15

B (AO1)

absorbs photons of ultraviolet light from the gas and emits visible light.



11

C

3

AO1



33

C

6

AO1

08.1	$QV = \frac{1}{2}mv^2$ OR $v = \sqrt{\frac{2QV}{m}}$ ✓ To get answer that rounds to $6.8 \times 10^6 \text{ (m s}^{-1}\text{)}$ ✓		2	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
08.2	Idea that the (average) KE of (current) electrons is reduced through inelastic collisions (with mercury atoms) ✓	Condone 'electrons transfer (kinetic) energy to mercury/gas atoms' Allow particles for atoms	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
08.3	Yes AND idea that the graph shows that substance X released (most) photons in the UV part of the spectrum ✓ Idea that UV radiation excites (atoms in) the coating to give longer wavelength radiation (when atoms de-excite)✓	Accept appropriate synonym for 'radiation' Accept for 'coating': phosphor/lining/fluorescent material	2	1 × AO3 1 × AO1

Question	Answers	Additional comments/Guidance	Mark	AO
08.4	Max 2 from ✓✓ $2.55 \times 10^{-7} \text{ m}$ used their energy = $\frac{hc}{\text{their wavelength}}$ Converts their energy to eV 4.9 eV ✓	Do not condone POT error in MP1 bullet point 1 Acceptable range: 250 nm to 260 nm Energy: 4.77 eV to 4.97 eV Accept 5.0	3	1 × AO1 2 × AO2
Total			8	

Question	Key	Answer	AO		
09	C	$d\bar{u}$	AO1		
10	A	energy is conserved.	AO1		
11	A	<table><tr><td>1 mN</td><td>1 km</td></tr></table>	1 mN	1 km	AO1
1 mN	1 km				
12	C	using a light source that emits light of a shorter wavelength	AO1		
13	C	<table><tr><td>photoelectric effect</td><td>diffraction</td></tr></table>	photoelectric effect	diffraction	AO1
photoelectric effect	diffraction				
14	A	$\frac{1}{\text{diameter of the wire}}$	AO1		
15	C	light from adjacent slits arrives at the screen in phase.	AO1		
16	A	The resistance of the diode decreases as V increases for $V > V_s$.	AO1		
17	D	$\frac{Y_s}{\lambda D}$	AO1		
18	D	2.32	AO2		

19	B	$2.1 \times 10^8 \text{ m s}^{-1}$	AO2		
20	D	17	AO2		
21	B	The drag force when her velocity is v_2 is equal to the drag force when her velocity is v_1 .	AO2		
22	B	$3.5 \times 10^{-19} \text{ J}$	AO2		
23	B	5.3°	AO2		
24	D	4.7 N	AO2		
25	B	<table><tr><td>maximum</td><td>minimum</td></tr></table>	maximum	minimum	AO1
maximum	minimum				
26	A	$\rho_1 + \rho_2$	AO2		
27	A	$2.2 \times 10^{-13} \text{ m}$	AO1		
28	C	<table><tr><td>18</td><td>18</td></tr></table>	18	18	AO2
18	18				
29	A	1.44 C	AO1		

30	D	$\frac{q}{r}$	AO1
31	A	190 g	AO2
32	B	1.1 Hz	AO2
33	C	6	AO1

D



C

13	A
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14	D
----	---



16	B	muon electron
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16	A (AO1)	electron diffraction photoelectric effect
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17

D (AO2)

a proton moving at $8 \times 10^5 \text{ m s}^{-1}$ 

12	D	1800	AO2
12	D	1800	AO2



13	C	photoelectric effect	diffraction	AO1
		1		

27

A

$$2.2 \times 10^{-13} \text{ m}$$

AO1



02.1	three correct values plus conclusion ✓ ratio approach $v_1/v_2 = \lambda_2/\lambda_1$ shown for 2 sets of data ✓ shown for two other sets of data + conclusion ✓	May predict one of the values assuming inverse proportionality and compare with table value (once for 1 mark; twice for 2 marks)	
02.2	$h = \lambda mv$ or substitution of correct data in any form ✓ 6.7(0) x 10⁻³⁴ from first and third data set; 6.6(0) x 10⁻³⁴ from second ✓	May determine average value using mean constant from 2.1 or average 3 calculations in this part.	1 1

02.3	Particle behaviour would only produce a patch/circle of light /small spot of light or Particles would scatter randomly✓ Wave property shown by diffraction/ interference✓ Graphite causes (electron)waves/beam to spread out /electrons to travel in particular directions✓ Bright rings/maximum intensity occurs where waves interfere constructively/ are in phase✓ for a diffraction grating maxima when $\sin\theta = n\lambda/d$ ✓	Marks are essentially for 1. Explaining appearance of screen if particle 2. Identifying explicitly a wave property 3. Explaining what happens when diffraction occurs 4. Explaining cause of bright rings 5. Similar to diffraction grating formula (although not same) NB Not expected: For graphite target maxima occur when $\sin\theta = \lambda/2d$ (d =spacing of atomic layers in crystal)	Max 3 1 1 1
02.4	Electrons must provide enough (kinetic) energy 'instantly' to cause the excitation OR the atom or energy transfer in 1 to 1 interaction OR Electron can provide the energy in discrete amounts OR energy cannot be provided over time as it would be in a wave Any 2 from Idea of light emission due to excitation and de-excitation of electrons/atoms✓ Idea of collisions by incident electrons moving electrons in atoms between energy levels/shells/orbits✓ Light/photon emitted when atoms de-excite or electrons move to lower energy levels✓	Description of Photoelectric effect = 0 Not allowed: any idea that wave cannot pass on energy, e.g. waves pass through the screen	1 1 1

Total			10
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	Waves travel to the boundaries and are reflected✓	Not bounce off	Max 3
	two waves travelling in opposite directions interfere/superpose✓	Not superimpose or interferes with itself	1
	Fixed boundaries (cannot move so) are nodes✓	creates nodes and antinodes bland =0	1



C



D



19	C	No work is done moving an electron from M to N .
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29

C (AO1)

the existence of gamma radiation



20	D	$r\left(\frac{y}{x}\right)^s$
		R



27

B

 $1.38 \times 10^{-7} \text{ V m}^{-1}$ downwards

28	A	an electron and a positive pion
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05.1	(using mass defect = $\Delta m = Z m_p + N m_n - M_{\text{Co}}$) $\Delta m = 27 \times 1.00728 + 32 \times 1.00867 - 58.93320$ (u) ✓ $\Delta m = 0.5408$ (u) ✓ Binding Energy = $0.5408 \times 931.5 = 503.8$ (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.	Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0. If subtraction is the wrong way round lose 1 mark. Data may come from rest mass eg $m_n = 939.551$ MeV or 1.675×10^{-27} kg or 1.00867 u. So if kg route used $\Delta m = 8.83 \times 10^{-28}$ kg BE = 7.95×10^{-28} J and 497 MeV. Conversion mark (2 nd) may come from a wrong value worked through. 0.47(5)	3
05.2	$(2.52 - 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J ✓ $7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV ✓ (0.475 MeV)	Correct answer scores both marks.	2
05.3	6 (specific wavelengths)		1
05.4	(longest wavelength = lowest frequency = smallest energy) $(2.29 \times 10^{-13} - 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓ $\lambda (= h c / E) = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 2.3 \times 10^{-14}$ ✓ $\lambda = 8.6 - 8.7 \times 10^{-12}$ (m) ✓ (8.6478×10^{-12} m)	Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state. The allowed energy gaps for CE are: 2.29, 2.06, 1.76, 0.53, 0.30 all $\times 10^{-13}$ J Note substitution rather than calculation gains mark. The final mark must be as shown here and not from a CE above.	3
Total			9

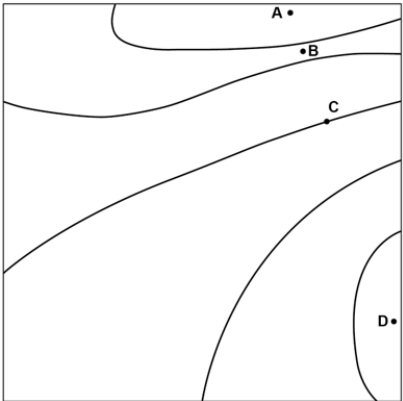
Question	Answers	Additional Comments/Guidelines	Mark
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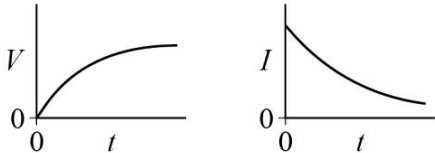
06.1	Total Mass of nuclei is more than the mass of the fusion product ✓₁ Binding energy or Binding energy per nucleon increases when a nucleus is formed by fusion ✓₂	✓₁ Alternatively the B/A of the fusion product is greater than B/A of both the starting nuclei. ✓₂ In order to release energy, the total binding energy of the two nuclei must be less than the binding energy of the nuclide formed	2	3.8.1.6 AO1 1b ×2
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	$(\Delta m = (\text{mass } {}^3_2\text{He} + \text{mass } {}^{17}_8\text{O}) - \text{mass } {}^{20}_{10}\text{Ne})$ $\Delta m = 0.02272 \text{ (u)}$ ✓₁ Energy released = $3.38 \text{ to } 3.40 \times 10^{-12} \text{ J}$ ✓₂ (allow an ecf for the conversion of units)	✓₁ $\Delta m = (3.01603 + 16.99913) - 19.99244 = 0.02272 \text{ u}$ (must have at least 3 sig fig) ✓₂ $\Delta m = 0.02272 \times 1.661 \times 10^{-27} \text{ kg} = 0.02272 \times 1.661 \times 10^{-27} \times (3.00 \times 10^8)^2 \text{ J} = 3.39 \times 10^{-12} \text{ J}$ OR $\Delta m = 0.02272 \times 931.5 \text{ MeV}$ $= 21.16 \times 1.60 \times 10^{-13} \text{ J} = 3.39 \times 10^{-12} \text{ J}$	2	3.8.1.6 AO2 1f ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Mark for use of potential energy formula and identifying the 2(e) and the 8(e) ✓₁ $\left(V = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r} = \frac{2 \times 8 \times (1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 5.1 \times 10^{-15}} \right)$ $V = 7.2(2) \times 10^{-13}$ (J) ✓₂ (correct answer only)	✓₁ condone other numerical errors ✓₂ correct final answer gains both marks	2	3.8.1.5 AO2 1f ×2

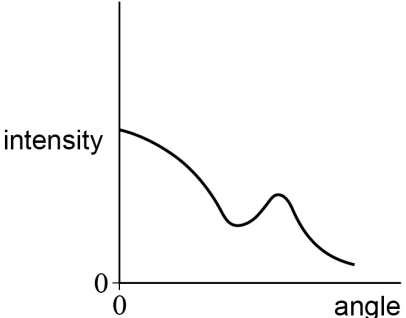
Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Making reference to the doubling charge which increases the gain in potential energy or force needed (to bring nuclei together) ✓₁ (owtte) (So) the larger charge (of $^{34}_{16}\text{S}$) requires greater kinetic energy or pressure for fusion and decreases the rate of fusion ✓₂ (owtte) Making reference to the larger radius/size of the sulphur nucleus compared to the oxygen nucleus (So) the larger radius (of $^{34}_{16}\text{S}$) (requires smaller kinetic energy or pressure for fusion) and the separation can be larger for fusion to take place so increases the rate of fusion ✓₃ (owtte)	✓₁ no computation is expected Condone increase instead of doubling ✓₃ A full calculation is not expected, such as $\frac{R_S}{R_O} = \sqrt[3]{\frac{A_S}{A_O}} = \sqrt[3]{\frac{34}{17}} = \sqrt[3]{2}$ If no marks are awarded accept number of protons for charge in mp1.	3	3.8.1.5 AO2 1b AO3 1b ×2
Total			9	

Question	Key	Answer
7	A	0.10 kg s^{-1} .
8	B	u
9	B	temperature in $^{\circ}\text{C}$ pressure in Pa
10	A	4.3 m s^{-1}
11	B	
12	B	$4g$
13	A	7.2 J
14	D	a repulsive force of $\frac{3}{4}F$
15	C	10^{36}
16	C	$\frac{QV}{d}$
17	D	72 mm
18	D	$\frac{E}{9}$ $\frac{V}{3}$
19	C	No work is done moving an electron from M to N .

20	D	
21	A	lift upwards away from the wires.
22	A	one
23	D	The peak-to-peak voltage is 650 V.
24	B	$\frac{9}{2}P$
25	B	200 0.45
26	A	Its rate of change of momentum is at a minimum.
27	C	10
28	B	16N
29	C	to decrease neutron speeds
30	A	$2.3 \times 10^8 \text{ W}$
31	C	$2.55 \times 10^{-13} \text{ J}$

01.1	Any one from: ✓ • $(\Delta)E_k = (\Delta)E_p$ seen • $E_k = 1.60 \times 10^{-19} \times 5.59 \times 10^6$ or 8.94×10^{-13} seen • $Q_\alpha = 2e$ and $Q_{\text{Au}} = 79e$ An energy $= \frac{Q_\alpha Q_{\text{Au}}}{4\pi\epsilon_0 r}$ seen in any form ✓ $r \left(= \frac{2 \times 1.60 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 5.59 \times 10^6 \times 1.60 \times 10^{-19}} \right)$ ($\leq$) 4.1×10^{-14} (m) ✓ (allow 1 sf) cao	MP1 may be seen in substitution for r Condone PoT error in MP1 and MP2. In MP2: Allow use of $E = QV$ and $V = \frac{Q}{4\pi\epsilon_0 r}$ with Q_α and Q_{Au} in either order. Condone use of k for $\frac{1}{4\pi\epsilon_0}$ unless contradicted by use of 1.38×10^{-23} Condone use of E_k in MeV. Condone 10^{-14} if supported by some correct substitution. Correct answer to at least 1 SF gains all 3 marks.	3	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	Any two from: ✓✓ - Idea that alpha particles give an upper limit on size of the nucleus / estimate is larger than nuclear radius - Idea that (distance of closest approach) depends on the energy of the alpha particle - Idea that recoil of nucleus is ignored - Idea that alpha particle has finite size	Ignore references to shape of nucleus. bullet 1: condone idea that it does not hit the nucleus. Referencing the distance of closest approach is not enough. bullet 2: is for the idea that the closest approach method does not give a single value Condone does not take into account neutrons / only considers charge / only considers number of protons. If no other mark awarded allow max 1 for reference to not taking into account the effect of the strong nuclear force.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	When angle = 0 there is a maximum and first minimum is not zero and at least one subsequent smaller maximum ✓ Idea that nuclear radius is determined from (first diffraction) minimum ✓	 Allow subsequent peaks Condone the line meeting the intensity axis at non-zero but negative gradient. Do not allow double slit (even superposed with single slit) or diffraction grating (light-like) patterns. Allow suitable annotation of diagram for answer Ignore any equation given.	2	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.4	Any one of: ✓ • volume of a nucleus is (approximately) spherical • $V = \frac{4}{3}\pi R^3$ or $V = \frac{4}{3}\pi R_0^3 A$ • volume is proportional to A • mass = $A \times$ mass of nucleon • mass (/kg) = $A \times 1.661 \times 10^{-27}$ • mass is proportional to A Density $\left(= \frac{m}{V} \right) = \frac{Am_{(n)}}{\frac{4}{3}\pi R_0^3 A} = \frac{m_{(n)}}{\frac{4}{3}\pi R_0^3}$ AND where all are constants / equation is independent of A. OR Combining of two proportional statements and cancelling of A ✓	Do NOT accept bullets 3, 4,5 or 6 when A is referred to as area, activity or any other incorrect quantity. $R \propto A^{\frac{1}{3}}$ or $R^3 \propto A$ is not enough. Accept alternative values or u in bullet 5	2	AO1
Total			9	

Question	Answers	Additional comments/Guidance	Mark	AO
		Any suggestion that particles do not follow		



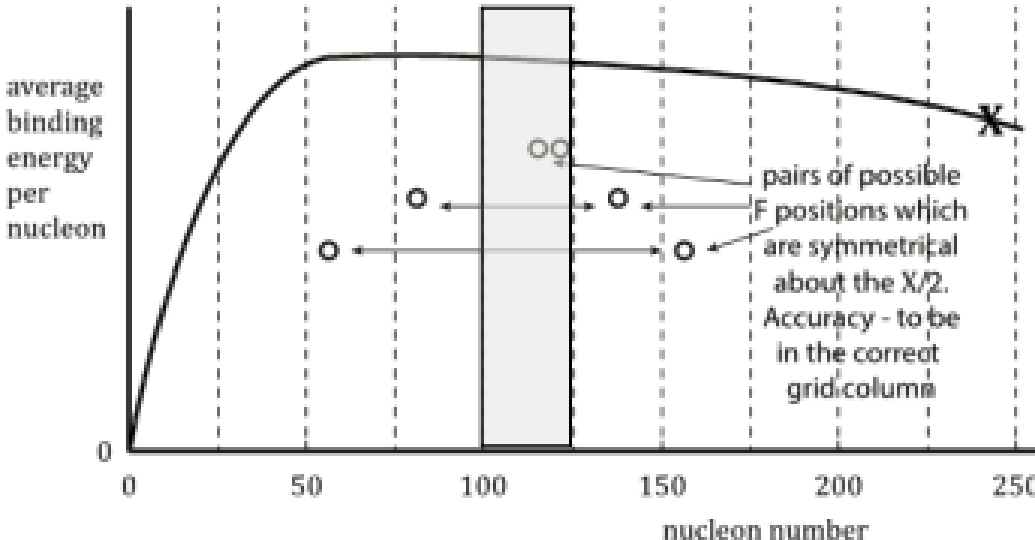
06.1	Energy required/work done to separate the nucleus ✓ into its individual nucleons/protons and neutrons ✓ OR Energy given out when a nucleus is formed ✓ from its individual nucleons/protons and neutrons ✓	MP2 can only be awarded when there is some reference to energy via MP1. Alternative words may be used instead of 'separate' but when used they must convey the correct idea. If no other marks are awarded, condone the idea that "binding energy is how much greater the rest energy/mass of the constituent nucleons is than that of the nucleus" for one mark.	2	2 x AO1 3.8.1.6
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	Statement of binding energy/mass defect = (mass of nucleons) – (mass of nucleus) ✓₁ (which may be seen from a full equation with data or implied from clear statements of what numbers represent) Standing alone or contained in the binding energy equation show the total mass of nucleon constituents of $^{56}_{26}\text{Fe}$. ✓₂ the correct binding energy converted to MeV = 490 ± 10 (MeV) Or use of data booklet values and $E=mc^2$ = 340 ± 10 (MeV) ✓₃	Use of Data Booklet values leads to a correct answer of 338 (337.6) MeV. Allow 340 ± 10 RB TO CONFIRM. ✓₁ condone simple numerical errors such as powers of 10 if mark comes from substituted equation. ✓₂ for giving data to at least 4 sig figs but calculations can use less. Examples looked for are $26 \times 1.673 \times 10^{-27} + 30 \times 1.675 \times 10^{-27}$ (= 9.375×10^{-26} kg) OR $26 \times 938.257 + 30 \times 939.551$ (= 52580 MeV) OR $26 \times 1.00728 + 30 \times 1.00867$ (= 56.44938 u) ✓₃ no ecf. and mark is only available if the mass of a neutron and proton are different in part 2. Might see	3	3 x AO2 3.8.1.6

		$(9.375 \times 10^{-26} - 9.288 \times 10^{-26}) \times 931.5 / 1.661 \times 10^{-27}$ $= 488 \pm 2 \text{ MeV}$ OR $52580 - (9.288 \times 10^{-26} \times 931.5 / 1.661 \times 10^{-27})$ $= 492 \pm 2 \text{ MeV}$ OR $\{56.44938 - 9.288 \times 10^{-26} / 1.661 \times 10^{-27}\} \times 931.5$ $= 495 \pm 2 \text{ MeV}$ OR when the calculation involves the use of $E=mc^2$ $338 \pm 2 \text{ MeV}$ Note calculations may vary being dependant on how many sig figs are retained and how many individual stages of calculation are used.		
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Both F_1 and F_2 to be to the right of the peak and marked on the graph or x-axis ✓₁ F_1 and F_2 to be in correct grid regions t symmetrical about half the nucleon number corresponding to X. ✓₂ 	Note that an F position cannot have a nucleon lower than the peak. So the 3 examples shown indicate the possible range of an answer. The position of F_1 and F_2 are taken from the centre of the cross or blob drawn by the candidate. The range of each grid region includes the boundary dotted line. ✓₁ If it is clear that nucleon numbers of F_1 and F_2 add to 240 give mark The circles shown in the diagram show the horizontal positions – to gain the marks the circles have to be on the line or the x-axis.	2	2 x AO2 3.8.1.6

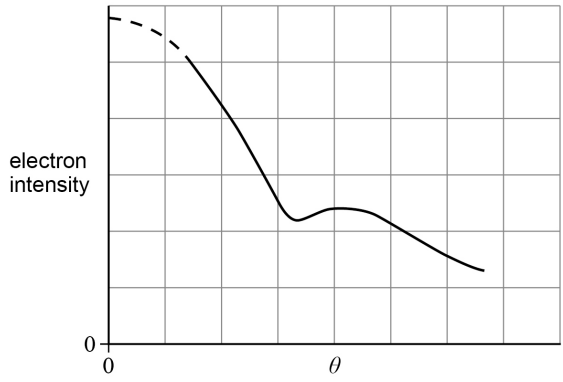
Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	The starting point of the fission fragments is given the first mark $\checkmark_1$ (normally the initial decay mode is) β^- $\checkmark_2$ Moves closer to the stable region as: a neutron changes to a proton OR position (on the graph) moves down and to the right $\checkmark_3$	$\checkmark_1$ fission fragments have a high N/Z ratio OR fission fragments are positioned above/left of the line plot in Fig 11 too many neutrons is not given a mark – high N/Z ratio or neutron rich terms must be used $\checkmark_2$ Mark may be given in isolation but the minus must be indicated The discussion of the decay and positioning of F_1 and F_2 must be the same. Any differences will be marked as a contradiction. $\checkmark_3$ the mark could be seen on Fig 11	3	1 x AO1 2 x AO3 3.8.1.4
Total			10	



Question	Key	Answer
07	A (AO2)	150 K
08	D (AO2)	pressure of the gas internal energy of the gas
09	D (AO2)	$\frac{R}{\sqrt{2}}$ $2M$
10	B (AO1)	$2.7 \times 10^{-6} \text{ rad s}^{-1}$
11	B (AO2)	$\sqrt{2gR}$
12	C (AO2)	$2\pi\sqrt{\frac{R^3}{GM}}$
13	D (AO2)	the orbital period of the satellite
14	A (AO2)	$\frac{R}{8}$
15	B (AO2)	$2\sqrt{2}u$
16	A (AO1)	135 μJ
17	A (AO2)	1.3×10^{-2} X to Y
18	C (AO2)	After a time T the pd across the capacitor is 1.5 V.
19	C (AO2)	$9C$

20	C (AO2)	$2E$
21	D (AO2)	$\frac{1}{e^4}$
22	B (AO2)	$3.9 \times 10^{-2} \text{ T}$
23	B (AO2)	$\frac{1}{4f}$
24	B (AO2)	P
25	C (AO1)	Some particles were deflected through angles greater than 90° .
26	A (AO1)	Is it deflected by a magnetic field? yes yes no
27	C (AO2)	15.6 g
28	B (AO2)	10 s^{-1} and 10^2 s^{-1} .
29	C (AO1)	the existence of gamma radiation
30	D (AO1)	When it is absorbed it makes the absorber radioactive.
31	C (AO1)	Slow neutrons are required for this induced fission.

06.1	Any two from: ✓✓ • using electrons gives greater resolution (as the wavelength can be made very small) • electrons can get closer to the nuclei (as there is no electrostatic repulsion) • electrons have less recoil (as their mass is small compared to the nucleus) • free electrons are easier to accelerate OR give energy to (as charge-to-mass ratio is higher) • electrons are easier to produce • scattering distributions are easier to interpret OR strong nuclear interaction is not involved • using alpha particles only gives the distance of closest approach/upper limit to the radius.	OWTTE on each advantage Allow reverse arguments	2	AO1 AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
06.2	A curved line showing an decrease in intensity with increase in θ. ✓ There is a single non-zero minimum. ✓	Do not allow U-shaped graphs. The initial part of the curve may be absent. Award MAX 1 for a line that covers less than half the θ axis. 	2	AO1 ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.3	Density (= mass÷volume) = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi R^3}$ ✓₁ (substituting density = $\frac{Am_{\text{nucleon}}}{\frac{4}{3}\pi \left(R_0 A^{\frac{1}{3}}\right)^3}$) Density = $\frac{3m_{\text{nucleon}}}{4\pi(R_0)^3}$ (in which) all (terms are) constant OR the expression does not depend on A ✓₂	✓₁ Do not accept <i>M</i> unlabelled. Accept <i>m</i> (ie lowercase) unlabelled. Condone <i>m_n</i> (mass of neutron in Data sheet) for <i>m_{nucleon}</i>. Accept only 1.67×10^{-27} (kg) for mass of nucleon (ie to 3 sf). Allow ecf to MP2 for any misrepresentation of <i>m</i> provided it is clear that it signifies mass of a single nucleon. ✓₂ If the constants are identified the equation may be converted into a ratio. The equation may be rearranged to have <i>R₀</i> as the subject with work to show that this is a constant <i>when the density is constant</i>.	2	AO1 AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
06.4	Any one of: ✓ The mass of the nucleus is not exactly $A \times m_{\text{nucleon}}$ (because this ignores the binding energy) OR The volume equation assumes that the nucleus is a perfect sphere (which is not true) OWTTE OR The density equation that uses the nuclear radius formula implies that the density is uniform within a nucleus which is not true. OWTTE OR Protons have a slightly different mass to a neutron	Do not accept “density of individual nucleons can be different from each other”. It is not allowed as it does not occur in the working equation.	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
06.5	$R_0 = \left(\frac{R}{A^{\frac{1}{3}}} = \frac{4.02 \times 10^{-15}}{(35)^{\frac{1}{3}}} \right) = 1.2(3) \times 10^{-15} (\text{m}) \quad \checkmark_1$ Substitutes values into density equation $\checkmark_2$ Density = $2.1 \times 10^{17} (\text{kg m}^{-3}) \quad \checkmark_3$	$\checkmark_2$ e.g. Density = $\left(\frac{\text{mass}}{\text{volume}} = \frac{Am}{\frac{4}{3}\pi R^3} \right) =$ $\frac{35 \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi (4.02 \times 10^{-15})^3}$ $\checkmark_3$ Evidence of a calculation must be given to gain this mark Accept 2.15 but not 2.2	3	AO2 ×3
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
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06.1	Or To allow the neutron to be absorbed by the <u>fuel/U-235</u> ✓	alternative. Reject inaccurate descriptions for example ones that imply the neutrons are undergoing fission.	1	AO2-1a-1
06.2	$E_{\text{final}} = (1 - 0.63) E_{\text{incident}}$ or $E_{\text{final}} = 0.37 E_{\text{incident}}$ ✓ ₁ (continuing this idea, $E_1 = (1 - 0.63) E_0$ $E_2 = (1 - 0.63) E_1$ so $E_2 = (1 - 0.63)^2 E_0$ and $E_5 = (1 - 0.63)^5 E_0$ $E_5 = (1 - 0.63)^5 \times 2.0 \times 10^6$) $= 1.4 \times 10^4$ eV ✓ ₂ (1.39×10^4 eV)	If no marks are scored a single mark can be given: if the final answer that has a power of 10 error possibly by not using the M in the eV. OR using 0.63 rather than $(1 - 0.63)$ in the calculation giving the answer $2(.0) \times 10^5$ (eV) ✓ ₂ A correct final answer gains full marks	2	AO2-1b-1 AO2-1f-1 Math2-2
06.3	A link made between the change in kinetic energy or	✓ ₁ Ref. to mass is needed. {Essence of marking point: The mass	2	AO2-1g-1

	momentum to the masses of the (two) particles involved in the collision. ✓₁ A consistent argument that results in a statement 'as nucleon number/number of nucleons in the nucleus increases more collisions are required. ✓₂	determines how much KE/momentum is lost} ✓₂ Ref to nucleon number or equivalent needed but mass is not. {Essence of marking point: If N is high then not much KE is lost so more collisions are needed} An example of an argument could be: More (kinetic) energy is lost when the mass of the moderator atom/nucleus is closer to the mass of the neutron So the number of collisions needed increases with nucleon number		AO3-1a-1
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Question	Answers	Additional Comments/Guidance	Mark	ID details
06.4	Mass difference $= (\text{mass}_U + \text{mass}_n) - (\text{mass}_{Xe} + \text{mass}_{Sr} + 4 \text{ mass}_n)$ $= (235.044 + 1.0087) - (141.930 + 89.908 + 4 \times 1.0087) \checkmark_1$ $= 0.180 \text{ u} \checkmark_2$ {if no unit present take u as the default unit} $(= 0.180 \times 931.5)$ $= 168 \text{ (MeV)} \checkmark_3$	$\checkmark_1$ Mark for word equation or substitution, one neutron may be cancelled from both parts of the subtraction. Condone any simple slip in transferring the numbers. Also the mark can be awarded for giving or comparing the mass on the LHS with the RHS. $\checkmark_2$ Only allow correct answer. $\checkmark_3$ This mark can stand alone for the conversion of any number of u converted to MeV. 2 sig figs is acceptable. The conversion mark can come from any part of this question not just the final line. $\{1 \text{ kg} = 6.02 \times 10^{26}\}$ A correct answer gains all 3 marks.	3	AO2-1f-3 Math2-1
06.5	1. (Small amounts of fossil fuel used) so <u>little</u> greenhouse gas emissions/less global warming/less CO ₂ /less climate change. {not <u>no</u> greenhouse gas} 2. (Less fossil fuel used) so cleaner air. 3. Small amounts of fuel consumed to get the same/large amount of power/energy. 4. Nuclear power can be produced continuously{condone use of constant} (whereas renewables are dependent on sunlight/wind etc). 5. Some (but not all) nuclear power stations can adjust their output quickly. 6. Benefit of producing medical isotopes.	Just one of the examples may be from the following: At present nuclear fuel is obtained from stable allied countries (as opposed to oil/gas). Facilitates nuclear weapon production. (Less fuel used) so less transportation needed. Examples of rejected ideas because they are incomplete or wrong: Produces more energy. There is more uranium than fossil fuel. Damages the environment less. Provides jobs. More efficient than others.	3	AO1-1a-1 AO3-1a-2

	✓✓✓any three points	Reference to cost. It's a renewable source.		
Total			11	

Keys to Objective Test Questions (each correct answer is worth 1 mark)													
Qu	07	08	09	10	11	12	13	14	15	16	17	18	19
Ans	C	B	B	C	D	C	A	B	D	D	D	D	A
Qu	20	21	22	23	24	25	26	27	28	29	30	31	
Ans	C	C	B	B	C	C	D	A	B	D	B	C	



01.1	₃✓ is about shielding using a <u>named</u> absorber stand behind a <u>lead</u> absorber / screen (when source is in the open) ₄✓ is safe use of source <u>when removed</u> from castle <u>never point</u> (open end of) the source at anyone / at yourself OR do not <u>look directly</u> at / look <u>into</u> the source ₅✓ is about good practice read local <u>rules</u> (about the use of radioactive sources) / OR read / post <u>warning</u> / <u>notice</u> on the door	source sealed' for ₃✓ accept aluminium or steel for lead; use of lead apron for ₄✓ accept 'avoid <u>eyes</u>' treat as neutral: 'avoid direct contact' / 'don't touch source' / 'always point source at ground' for ₅✓ accept 'report any damage to a source' treat as neutral: 'use safety screen' / 'don't stand in front' / 'don't ingest / swallow' / 'wash hands after use' / 'wear safety glasses / goggles / gloves / lab coats' / 'use film badge' no credit for procedures that are the responsibility of the teacher / radiation protection adviser, eg 'obtained signed consent form'	AO2-1g = MAX 2
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01.2	5 ✓	correct answer only	AO3-1a = 1
01.3	A OR $^{222}_{86}\text{Rn}$ / radon 222 / Rn 222 ✓ B OR $^{218}_{84}\text{Po}$ / polonium 218 / Po 218 ✓ I OR $^{210}_{82}\text{Pb}$ / lead 210 / Pb 210 ✓	if candidates have provided more than 3 responses, each extra error / contradiction negates one correct response; if there are 3 or more errors / contradictions, award no marks answers may be given in any order accept unnamed isotope with correct A, Z eg $^{222}_{86}\text{X}$ eg while the suggestion that A, B and I are correct earns 3 the suggestion that A, B, I and J are correct earns 3 – 1 = 2	AO3-1a = 3



01.4	suitable procedures to eliminate systematic error are: remove (all radioactive) <u>source(s)</u> (from the room) OR measure A_b before the source is present / in another room OR put source in (lead) castle / (lead) container / behind a (lead) absorber ₁✓ zero / reset the <u>counter</u> AND/OR <u>stopwatch</u> (before use) OR check the <u>counter</u> AND/OR <u>stopwatch</u> has no zero error ₂✓ measure A_b on same day as experiment is carried out ₃✓ measure A_b in same room / location / area as that where experiment is to be carried out ₄✓ suitable procedure to reduce percentage uncertainty in A_b is: use long(er) (integration) time / prolonged time OR (total of) at least 100 s ₅✓	do not insist on references to systematic or random error but give no credit for explicit talk-out eg 'use a long integration time to eliminate systematic error' for ₁✓ treat as neutral: 'measure A_b with no source near' / 'check source is shielded / far away / out of range / sealed' / 'in another area' / 'point detector away from the source (or vice-versa)' / 'don't point source at counter' / 'put detector behind source' for ₂✓ treat as neutral: 'zero / reset the equipment (before use)' / 'zero the detector' for ₃✓ treat as neutral: 'measure A_b after experiment to double-check' for ₄✓ treat as neutral: / 'keep detector in the same position' / 'measure A_b in different positions' for ₅✓ accept idea of a suggested <u>total</u> time, taking account of repeats, exceeding 100 s (eg 10 repeated 10 s counts and 1 single 100 s single count amount to the same thing) treat as neutral: 'repeat and average' ignore anomalous results' / 'use room with high background count / record large reading' / 'use more than one detector'	AO2-1g = MAX 3
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01.5	use of 5.5 MeV shown by working on Figure 4 _{1✓} minimum thickness MAX 3sf that rounds to 12 mm _{2✓3✓} OR minimum thickness MAX 3sf that rounds to 11 mm / MAX 3sf that rounds to 13 mm _{23✓}	for _{1✓} use of 5.5 MeV can be inferred from Figure 4 as a (horizontal) line, a mark on the vertical axis or a mark on the curve / intersection between curve and a vertical line, above 5 MeV and below 6 MeV; a single line / mark between 5 and 6 MeV with no subsequent working can score _{1✓} any line does not have to be ruled or perfectly parallel to the grid line; allow a cross or a small blob as the mark on the curve; do not insist on seeing a vertical line if more than one line is drawn / mark is made then mark as per scheme if a clear decision has been made about which read-off has been used to provide the result for the thickness; allow only one thickness given as final answer _{2✓3✓} OR _{23✓} can be earned without any working on the grid / other intermediate working	AO3-1a = 1 AO3-1b = 2
	OR use of 7.8 MeV shown by working on Figure 4 AND minimum thickness is 16, 17 or 18 mm _{123✓}	for _{123✓} use of 7.8 MeV can be inferred from Figure 4 as a line, mark on axis / curve etc above 7 MeV and below 8 MeV; accept MAX 3 sf result that rounds to 16, 17 or 18 mm	

01.6	$d = \sqrt{k} \times \frac{1}{\sqrt{A}} - e$ OR $d = \sqrt{k} \times \sqrt{\frac{1}{A}} - e$ OR $d = \sqrt{\frac{k}{A}} - e$ seen ₁✓ states $\sqrt{k}$ = gradient OR k = gradient² ₂✓ gradient from Δd divided by $\Delta \frac{1}{\sqrt{A}}$ with $\Delta \frac{1}{\sqrt{A}} \geq 0.5$ ₃✓ k minimum 2 sf in range $1.7(0) \times 10^5$ to $1.9(5) \times 10^5$ ₄✓ unit for k = mm² Bq or mm² s⁻¹ ₅✓ for statement that k = gradient mark as follows: for $d = k \times \frac{1}{\sqrt{A}} - e$ AND k = gradient ₁₂✓ = 1 MAX; award ₃✓ as above ₄₅✓ = 1MAX ecf for the following: k in range 410 to 450 or 2 sf 4.1 to 4.5×10^2 mm Bq^{0.5} or mm s^{-0.5} OR k in range 0.41(0) to 0.45(0) m Bq^{0.5} or m s^{-0.5} OR k in range 41.(0) to 45(.0) cm Bq^{0.5} or cm s^{-0.5}	for ₁✓ d must be the subject; allow obvious slips, eg D for d for ₂✓ allow $\sqrt{k} = m$ if $y = mx + c$ is quoted so inference that $\sqrt{k}$ = gradient is clear; this mark is for explaining the step and not for performing the calculation for ₃✓ the mark is for the process, not the result; evidence of acceptable steps on grid with plausible result are enough; no credit if false origin missed allow working subsumed into calculation of k for ₄✓ gradient based on d in mm (expected = 433 mm Bq^{0.5}) POT 10⁵ required for ₅✓ the unit given for k must be consistent with the POT of the result for k / gradient² order not important Bq mm² is acceptable; do not accept incorrect symbol, eg bq for Bq otherwise: if for ₄✓ gradient based on d in m (expected ≈ 0.43 m Bq^{0.5}) k in range 0.17(0) to 0.19(5) then for ₅✓ m² Bq or m² s⁻¹ if for ₄✓ gradient based on d in cm (expected ≈ 43 cm Bq^{0.5}) k in range $1.7(0) \times 10^3$ to $1.9(5) \times 10^3$ then for ₅✓ cm² Bq or cm² s⁻¹	AO2-1d = 2 AO2-1h = 1 AO3-1b = 2
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01.7	second mark ($_2\checkmark$) is contingent on award of first ($_1\checkmark$) an unsupported answer or an answer obtained by scale drawing or by extrapolation off the grid score zero attempts to find e by <u>calculation</u> by any valid method using gradient or k with all data correctly substituted in their expression; allow use of y for d, x for $\frac{1}{\sqrt{A}}$, m for $\sqrt{k}$ and c for e; attempts to solve for e $_1\checkmark$ ≥ 2 sf result in range $\geq 28(.0)$ and $\leq 32(.0)$ (mm) $_2\checkmark$	for $_1\checkmark$ use of $y = mx + c$ with recognisable data correctly substituted, eg $e = \text{their gradient} \times \frac{1}{\sqrt{A}} - d$ with substitution of their gradient and values of values of d and $\frac{1}{\sqrt{A}}$ from a point on the line from Figure 6 OR $e = \sqrt{k} \times \frac{1}{\sqrt{A}} - d$ with substitution of their k etc OR $(-e) = \text{gradient} \times \text{horizontal intercept}$, with substitution of their gradient and horizontal intercept ignore POT errors in their gradient / their k; allow mixed units and read-off errors of 1 small square for $_2\checkmark$ answer in range only (no ecf from 01.6) allow negative answer	AO2-1d = 1 AO3-1b = 1
Total			19

Question	Answers	Additional Comments/Guidelines	Mark
	general procedure - collect water for a measured time; divide measured / calculated volume by time to determine rate ₁✓	static volume should be measured after timing , eg reject 'measure time to fill cylinder' or ₁ ✓ = 0 accept 'find V for different t, plot V against t, gradient = Q' but not if by continuous flow method	AO2-1g = 1
	names 2 suitable instruments ₂ ✓	for time use <u>stopwatch</u> or <u>stopclock</u> ; treat as neutral: 'timer' or 'light gate / data logger' for volume use <u>measuring cylinder</u> / graduated beaker; treat as neutral: 'measuring beaker' / 'burette' OR for mass use <u>balance</u> ; use of $V = \frac{m}{\rho}$ (any subject) condone 'volume of 1 g is 1 cm ³ '; reject 'weigh'/'weighed'	AO2-1g = 1