CAMBRIDGE
International Education

Cambridge International AS & A Level

PHYSICS **9702/42**

Paper 4 A Level Structured Questions **May/June 2026**

MARK SCHEME

Maximum Mark: 100

Published

This mark scheme contains the instructions and marking guidance that our examiners used to mark candidate responses for this component.

Before they start marking, examiners complete a standardisation process. They review a range of candidate responses and discuss the mark scheme in detail to agree which answers can and cannot be accepted. Examiners award marks where it is clear that candidate responses have met the requirements of the mark scheme. These requirements may vary between different components or different versions of the same component, depending on the exact requirements of the question and the candidate responses seen during the standardisation process.

Sometimes, our mark schemes may allow marks to be awarded to responses which contain elements that are factually incorrect or for content not covered by the syllabus. We do this in response to the demands of a specific question to support candidates and make sure that our assessments are fair. However, these allowances should not be used as a guide for teaching and learning.

We cannot discuss the mark scheme with schools, and we recommend that schools read the mark scheme together with the assessment material and the Principal Examiner Report for Teachers.

This document consists of **24** printed pages.

[Turn over

General marking principles

All examiners must apply these marking principles when marking candidate responses.

1	Examiners must award marks for each response in line with: • the specific **content** defined in the mark scheme • the specific **skills** defined in the mark scheme or in the level descriptions • the **standard of response** required as exemplified by the standardisation scripts.
2	Examiners must award **whole marks** (not half marks, or other fractions).
3	Examiners must award marks **positively**. This means that: • marks are not deducted for errors or omissions • marks are awarded for correct/valid answers as defined in the mark scheme and also for **other valid answers** which go beyond the scope of the syllabus and mark scheme referring to your team leader as appropriate • the quality of spelling, punctuation and grammar are judged **only** when the mark scheme indicates that these features are **specifically assessed** in the question. However, the meaning of all responses must be unambiguous.
4	Examiners must **consistently** apply the requirements of the mark scheme and any rules for what to do when candidates have not followed instructions correctly.
5	Examiners must use the **full range of marks** defined in the mark scheme, unless limited by the quality of the candidate responses seen.
6	Examiners must award marks according to the mark scheme and **must not** award marks with grade thresholds or grade descriptions in mind.

Science-Specific Marking Principles

1	Examiners should consider the context and scientific use of any keywords when awarding marks. Although keywords may be present, marks should not be awarded if the keywords are used incorrectly.
2	The examiner should not choose between contradictory statements given in the same question part, and credit should not be awarded for any correct statement that is contradicted within the same question part. Wrong science that is irrelevant to the question should be ignored.
3	Although spellings do not have to be correct, spellings of syllabus terms must allow for clear and unambiguous separation from other syllabus terms with which they may be confused (e.g. ethane / ethene, glucagon / glycogen, refraction / reflection).
4	The error carried forward (ecf) principle should be applied, where appropriate. If an incorrect answer is subsequently used in a scientifically correct way, the candidate should be awarded these subsequent marking points. Further guidance will be included in the mark scheme where necessary and any exceptions to this general principle will be noted.
5	<u>'List rule' guidance</u> For questions that require ***n*** responses (e.g. State **two** reasons …): • The response should be read as continuous prose, even when numbered answer spaces are provided. • Any response marked *ignore* in the mark scheme should not count towards ***n***. • Incorrect responses should not be awarded credit but will still count towards ***n***. • Read the entire response to check for any responses that contradict those that would otherwise be credited. Credit should **not** be awarded for any responses that are contradicted within the rest of the response. Where two responses contradict one another, this should be treated as a single incorrect response. • Non-contradictory responses after the first ***n*** responses may be ignored even if they include incorrect science.

6	Calculation specific guidance Correct answers to calculations should be given full credit even if there is no working or incorrect working, **unless** the question states 'show your working'. For questions in which the number of significant figures required is not stated, credit should be awarded for correct answers when rounded by the examiner to the number of significant figures given in the mark scheme. This may not apply to measured values. For answers given in standard form (e.g. $a \times 10^n$) in which the convention of restricting the value of the coefficient (a) to a value between 1 and 10 is not followed, credit may still be awarded if the answer can be converted to the answer given in the mark scheme. Unless a separate mark is given for a unit, a missing or incorrect unit will normally mean that the final calculation mark is not awarded. Exceptions to this general principle will be noted in the mark scheme.
7	Guidance for chemical equations Multiples / fractions of coefficients used in chemical equations are acceptable unless stated otherwise in the mark scheme. State symbols given in an equation should be ignored unless asked for in the question or stated otherwise in the mark scheme.

Annotations guidance for centres

Examiners use a system of annotations as a shorthand for communicating their marking decisions to one another. Examiners are trained during the standardisation process on how and when to use annotations. The purpose of annotations is to inform the standardisation and monitoring processes and guide the supervising examiners when they are checking the work of examiners within their team. The meaning of annotations and how they are used is specific to each component and is understood by all examiners who mark the component.

We publish annotations in our mark schemes to help centres understand the annotations they may see on copies of scripts. Note that there may not be a direct correlation between the number of annotations on a script and the mark awarded. Similarly, the use of an annotation may not be an indication of the quality of the response.

The annotations listed below were available to examiners marking this component in this series.

Annotations

Annotation	Meaning
AE	arithmetic error
BOD	benefit of the doubt given
CON	contradiction in response, mark not awarded
	correct point or mark awarded
ECF	error carried forward applied
SF	error in number of significant figures
I	incorrect or insufficient point ignored while marking the rest of the response
XP	incorrect physics
	incorrect point or mark not awarded
^	information missing or insufficient for credit

Annotation	Meaning
MO	mandatory mark not awarded
SEEN	point has been noted, but no credit has been given or blank page seen
POT	power of ten error
TE	transcription error

Abbreviations

/	Alternative and acceptable answers for the same marking point.
( )	Bracketed content indicates words which do not need to be explicitly seen to gain credit but which indicate the **context** for an answer. The context does not need to be seen but if a context is given that is incorrect then the mark should not be awarded.
___	Underlined content must be present in answer to award the mark. This means either the exact word or another word that has the same technical meaning.
AFC	Automatic full credit (**A** and **C** marks) for correct numerical answer (see science-specific marking principle 6).

Mark categories

B marks	These are <u>independent</u> marks, which do not depend on other marks. For a **B** mark to be awarded, the point to which it refers must be seen specifically in the candidate's answer.
M marks	These are <u>mandatory</u> marks upon which **A** marks later depend. For an **M** mark to be awarded, the point to which it refers must be seen specifically in the candidate's answer. If a candidate is not awarded an **M** mark, then the later **A** mark cannot be awarded either.
C marks	These are <u>compensatory</u> marks which can be awarded even if the points to which they refer are not written down by the candidate, providing subsequent working gives evidence that they must have known them. For example, if an equation carries a **C** mark and the candidate does not write down the actual equation but does correct working which shows the candidate knew the equation, then the **C** mark is awarded. If a correct answer is given to a numerical question, all of the preceding **C** marks are awarded automatically. It is only necessary to consider each of the **C** marks in turn when the numerical answer is not correct.
A marks	These are <u>answer</u> marks. They may depend on an **M** mark or allow a **C** mark to be awarded by implication.

Question	Answer	Marks	Guidance
1(a)	acceleration is (always) perpendicular to velocity	**B1**	
	velocity and acceleration have constant magnitude **or** velocity and acceleration change direction	**B1**	Accept in terms of either velocity or acceleration (both not needed). 'Constant speed', with no reference to magnitude of velocity, is insufficient. **Allow** 'acceleration is (always) directed towards the centre of the circle'. **Allow** 'velocity is (always) tangential to the circle'.
1(b)(i)	only other force is weight, which is vertical **or** weight has no horizontal component **or** vertical component of lift is equal (and opposite) to the weight	**B1**	**Allow** 'gravitational force' for 'weight'. **Allow** 'balances' or 'cancels' for 'equal to'.
	lift must have a horizontal component to cause centripetal acceleration	**B1**	**Allow** 'Horizontal component of lift provides / is the resultant / centripetal force'.
1(b)(ii)	arrow drawn from aircraft, horizontally to the left	**B1**	Arrow does not need to touch the aircraft but be pointing away from the aircraft and pass through some part of the aircraft when extended. **Allow** tolerance ± 5°. Treat any other arrows that (extended if necessary) pass through some part of the aircraft as contradictory unless labelling clearly conveys that one is the resultant force or the other arrows are not.
1(b)(iii)	$a = v^2 / r$	**C1**	**Allow** $a = \omega^2 r$ **and** $v = r\omega$.
	$a = 180^2 / 7200$ $= 4.5\ \text{m s}^{-2}$	**A1**	Correct to at least 2 significant figures. AFC.

Question	Answer	Marks	Guidance
1(b)(iv)	vertical component of lift balances the weight **or** horizontal component of lift causes the centripetal acceleration **or** $mg = L\cos\theta$ **and** $ma = L\sin\theta$	**B1**	**Allow** 'equals' for 'balances'. **Allow** 'provides … force' for 'causes … acceleration'. **Allow** F for L. **Allow** 'W' for 'mg' and 'F_C' or 'mv^2/r' for 'ma'.
	$\tan\theta = a / g$	**C1**	
	$\tan\theta = 4.5 / 9.81$ $\theta = 25°$	**A1**	Possible ECF from **1(b)(iii)**. Correct to at least 2 significant figures. (24.6)

Question	Answer	Marks	Guidance
2(a)(i)	force per unit mass (at the point)	**B1**	Ratio must be clear. **Ignore** symbols unless defined. **Ignore** references to units.
2(a)(ii)	four straight parallel lines perpendicular to ground approximately evenly spaced	**B1**	**Allow** more than four lines. **Allow** tolerance ±5° to the vertical. Lines do not need to reach the Earth's surface. Judge even spacing only in relative to the other lines. Assess spacing by eye; **Do not allow** only if the spacing is so uneven that there is no need to check with a ruler.
	lines pointing towards the ground	**B1**	Minimum one arrow needed, but all arrows shown must be towards the ground.
2(b)(i)	$g = GM / R^2$	**C1**	
	mass = $9.81 \times (6.37 \times 10^6)^2 / (6.67 \times 10^{-11})$ $= 5.97 \times 10^{24}$ kg	**A1**	Must be given to 3 significant figures. AFC.
2(b)(ii)	$\phi = -(6.67 \times 10^{-11} \times 5.97 \times 10^{24}) / (6.37 \times 10^6)$ **or** $\phi = -9.81 \times 6.37 \times 10^6$	**C1**	**Allow** the C1 mark without the minus sign. Possible ECF from **2(b)(i)** for first method.
	$\phi = -6.25 \times 10^7$ J kg^{-1}	**A1**	Must be given to 3 significant figures. AFC. Answer must be negative for the A1 mark. Unit needed with answer for the A1 mark. **Allow** N m kg^{-1} or m^2 s^{-2} for J kg^{-1}.

Question	Answer	Marks	Guidance
2(b)(iii)	GPE = potential × mass = (–) GMm / R $= -(6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 96.0) / ((6.37 + 1.93) \times 10^{6})$	**C1**	**Allow** the C1 mark without the minus sign. Possible ECF from **2(b)(i)**. Use of only 6.37 or only 1.93 in radius of orbit is XP in the C1 mark.
	$= -4.61 \times 10^{9}$ J	**A1**	Correct to at least 2 significant figures. AFC. (4.61) Treat AFC answer as -4.6×10^{9} J. Must be negative unless lack of minus sign was the direct cause of the A1 mark not being awarded in **2(b)(ii)**.

Question	Answer	Marks	Guidance
3(a)	thermal energy per unit mass (to change temperature)	**B1**	**Do not allow** if context is state change.
	thermal energy per unit change in temperature	**B1**	**Allow** 'increase' or 'decrease' for 'change'. Both marking points: Ratio must be clear. **Allow** 'heat' for 'thermal energy'. **Ignore** symbols unless defined. **Ignore** references to units. 'Thermal energy per unit [mass × temperature change]' gains both marks. Special case: **Allow** 1 mark for use of 'energy' without 'thermal' if the response is otherwise fully correct.
3(b)(i)	$W = p\Delta V$	**C1**	
	$= 1.01 \times 10^5 \times (1.00 - 0.80) \times 0.0243 = 491$ J	**A1**	Full substitution and answer needed. **Allow** '1.0 – 0.8' or '0.2' for '1.00 – 0.80'. 80% of 0.0243 may be shown to be calculated separately, and then subtracted from 0.0243. **Allow** the subtraction either way around. **Ignore** the sign of the answer. Unit not needed but any unit given must be correct.
3(b)(ii)	volume decreases so (work done on the gas is) positive	**B1**	**Allow** 'gas is compressed' for 'volume decreases'. **Ignore** references to changes in particle separation.

Question	Answer	Marks	Guidance
3(b)(iii)	internal energy is proportional to (thermodynamic) temperature **or** (thermodynamic) temperature is proportional to volume **or** internal energy is proportional to volume	**B1**	**Ignore** any discussion of work done and transfer of thermal energy. **Allow** symbols U, V and T without explanation.
	internal energy decreases to 80% of initial value, so increase is (negative and) equal to 0.20×3676 (i.e. –735 J)	**B1**	For full credit, both B1 marks must come from the same method.
	or		
	ΔU is given by $(3/2)Nk\Delta T$ **or** U is given by $(3/2)NkT$	**(B1)**	
	$\Delta U = (3/2) \times 6.00 \times 10^{23} \times 1.38 \times 10^{-23} \times (-0.20 \times 296) = -735$ J	**(B1)**	For full credit, both B1 marks must come from the same method.
3(b)(iv)	$-735 = Q + 491$	**C1**	**Allow** C1 for any additive / subtractive combination of (only) 735, 491 and Q.
	$Q = -1226$ J	**A1**	Correct to at least 3 significant figures. AFC. (AFC answer is –1230 J). Answer must be negative for the A1 mark. Answers of ±244 J or +1230 J imply C1.

Question	Answer	Marks	Guidance
3(b)(v)	$\Delta T = 0.20 \times 296$ (= 59 K)	**C1**	Value of 59 K (to 2 SF) for ΔT implies C1. 296 K – 237 K in the working implies C1. **Ignore** sign of ΔT. Use of 296 K or 237 K as ΔT is XP in the C1 mark.
	$c = 1226 / (6.00 \times 10^{23} \times 6.64 \times 10^{-27} \times 0.20 \times 296)$ $= 5200\ \text{J kg}^{-1}\ \text{K}^{-1}$	**A1**	Possible ECF from **3(b)(iv)**. Correct to at least 2 significant figures. AFC. **Ignore** sign of answer. Information: The ECF answer from $Q = 244$ J is $1030\ \text{J kg}^{-1}\ \text{K}^{-1}$ (but usual ECF rules apply). Important: The answer $1.0 \times 10^{3}\ \text{J kg}^{-1}\ \text{K}^{-1}$ can also be reached by an XP in ΔT, so need to check the working.
3(c)	(same temperature change so) same change in internal energy	**B1**	**Ignore** symbol ΔU unless defined.
	(constant volume so) no work done (on/by gas)	**B1**	**Ignore** symbol W unless defined.
	less thermal energy supply needed (for same temperature change) so specific heat capacity is less	**B1**	**Allow** 'heat' for 'thermal energy'. **Allow** use of symbols Q and c without explanation (as defined in the question paper).

Question	Answer	Marks	Guidance
4(a)	collisions are instantaneous	**B1**	List Rules apply. **Allow** duration of collisions is negligible compared with time between collisions.
	collisions are elastic	**B1**	**Ignore** references to conservation of energy.
4(b)(i)	change in momentum = $2mu$	**A1**	**Ignore** sign of answer.
4(b)(ii)	time = $2L / u$	**A1**	
4(b)(iii)	mean force $= \Delta p / t$ $= 2mu / (2L / u)$ $= mu^2 / L$	**A1**	**Ignore** sign of answer.
4(b)(iv)	clear application of Newton's third law (e.g. force exerted on face by particle equal (and opposite) to force exerted on particle by face)	**B1**	
	$p = F / A$ $= (mu^2 / L) / L^2$ $= mu^2 / L^3$	**A1**	**Ignore** sign of answer.

Question	Answer	Marks	Guidance
4(c)	volume of cube is L^3 (which is V, so equation becomes $pV = mu^2$)	**B1**	Any explicit equating of V with L^3 is sufficient.
	particles moving in 3 dimensions, so u^2 becomes $\frac{1}{3}\langle c^2\rangle$	**B1**	Not just algebra, need to see the explanation. **Allow** 'all' for '3'. **Allow** 'directions' for 'dimensions'. **Allow** 'c_x' for 'u'. **Allow** '$\langle c\rangle^2$' for '$\langle c^2\rangle$ for this marking point.
	N particles (rather than 1 particle) so (pV) multiplied by N **or** multiply by N to get pV for all particles (rather than just 1 particle)	**B1**	Not just algebra, need to see the explanation. May be seen as an expression for p or pV without N followed by the same expression with N, with reasoning that this is because there are N particles.

Question	Answer	Marks	Guidance
5(a)(i)	$\omega = 2\pi / 1.7 = 3.7$ rad s^{-1}	**A1**	Working and answer needed. Unit not needed, but any unit given must be correct.
5(a)(ii)	(magnitude of) maximum displacement (of block) from equilibrium position	**B1**	**Allow** 'mean position' for 'equilibrium position'. **Do not allow** 'rest position' for 'equilibrium position'.
5(a)(iii)	$E = ½ m\omega^2 x_0^2$	**C1**	
	$13 \times 10^{-6} = ½ \times 27 \times 10^{-3} \times 3.7^2 \times x_0^2$	**C1**	No ECF from **5(a)(i)**.
	amplitude = 8.4×10^{-3} m	**A1**	Correct to at least 2 significant figures. AFC. (8.37)
5(b)	dome-shaped curve with correct curvature and a single peak with maximum E_K shown at 13 μJ	**B1**	**Allow** tolerance ±½ small square vertically.
	curve symmetrical about E_K-axis, with single peak at $x = 0$, end points at $E_K = 0$ and x-axis intercepts at the same positions in the positive and negative directions	**B1**	**Allow** tolerance ±1 small square horizontally. Vertically, end-points must get to within ½ small square of the x-axis. Does not need to have the correct curvature but must have a single peak and end points at $E_K = 0$.
	x-axis scale marked with a consistent scale that corresponds with the end points of the line being at ± values of x equal to the answer in **5(a)(iii)**	**B1**	At least one scale marking needed in each half (positive and negative) of the x-axis. All scale markings given must be consistent with the scale to within ½ small square. Scale does not need to conform to practical exam standards, it just needs to convey the correct intercept values to a ½ small square tolerance. Line does not need to be dome-shaped for this marking point.

Question	Answer	Marks	Guidance
6(a)	work done per unit charge	**B1**	Ratio must be clear. **Allow** 'energy' for 'work done'. **Ignore** any symbols unless they are defined. **Ignore** any reference to units. **Ignore** $V = Q / 4\pi\varepsilon_0 r$.
	work done (on charge) in moving positive charge from infinity (to the point)	**B1**	**Allow** any combination of positive/negative, on/by and from/to infinity that gives a positive sign. E.g. 'work done on negative charge in moving to infinity', 'work done by negative charge in moving from infinity' etc.
6(b)(i)	$V_0 = Q / 4\pi\varepsilon_0 R$, where ε_0 is the permittivity of free space	**B1**	**Ignore** sign of answer.
6(b)(ii)	curve from $x = R$ to $x = 3R$ with decreasing magnitudes of V and gradient, starting at (R, V_0)	**B1**	**Ignore** anything drawn in the $x = 0$ to $x = R$ region. If curves are drawn in both + and – regions, **both** curves must meet the requirements for MP1 & MP2. **Allow** tolerance ±½ small square horizontally. **Allow** this mark if curve starts at $(R, -V_0)$. Line may become horizontal at the end for no more than 4 small squares, and must not show an increasing magnitude of more than ½ small square.
	line passing through $(2R, \frac{1}{2}V_0)$ **and** $(3R, \frac{1}{3}V_0)$	**B1**	**Allow** tolerance ±½ small square vertically. For the V value at $3R$, expect the line to pass on or above the third minor division above the x-axis. **Allow** this mark for $(2R, -\frac{1}{2}V_0)$ **and** $(3R, -\frac{1}{3}V_0)$.
	line entirely within the positive V region	**B1**	**Allow** any shape for this mark, but **do not allow** if anything is drawn in the negative V region. **Allow** curve to touch the x-axis but **not** cross it.
6(c)(i)	$Q = (-)4.80 \times 10^4 \times 4\pi \times 8.85 \times 10^{-12} \times 0.119$	**C1**	**Allow** C1 without the minus sign. **Allow** '$1 / (8.99 \times 10^9)$' for '$4\pi \times 8.85 \times 10^{-12}$'.
	$= -6.35 \times 10^{-7}$ C	**A1**	Correct to at least 3 significant figures. AFC. (6.352) Answer must be negative for the A1 mark.

Question	Answer	Marks	Guidance
6(c)(ii)	stores energy / charge	**B1**	**Allow** 'Can be charged / discharged'.
6(c)(iii)	$C = Q / V$	**C1**	**Allow** $C = 4\pi\varepsilon_0 R$.
	$C = (6.35 \times 10^{-7}) / (4.80 \times 10^{4})$ $= 1.32 \times 10^{-11}$ F	**A1**	Q / V method: Possible ECF from answer in **6(c)(i)**. $4\pi\varepsilon_0 R$ method: Possible ECF from R value from **6(c)(i)** with if a POT or TE error that led directly to a mark not being awarded is repeated. Correct to at least 3 significant figures. AFC. (1.323) **Allow** 13.2 pF provided unit is clear. Unit needed with answer for A1 mark. **Allow** $C\,V^{-1}$, $s\,\Omega^{-1}$, $A^2\,kg^{-1}\,m^{-2}\,s^4$.
6(c)(iv)	$E = \frac{1}{2}QV$ **or** $E = \frac{1}{2}CV^2$ **or** $E = Q^2 / 2C$	**C1**	
	$= \frac{1}{2} \times 6.35 \times 10^{-7} \times 4.80 \times 10^{4}$ $= 0.0152$ J	**A1**	Possible ECF from **6(c)(i)** and/or **6(c)(iii)**. Correct to at least 2 significant figures. AFC. Treat AFC answer as 0.015 J.

Question	Answer	Marks	Guidance
7(a)(i)	PSZW and QRYX	**B1**	All four letters needed for each face (but can be in any order).
7(a)(ii)	*n*: number density of charge carriers	**B1**	**Allow** 'number per unit volume' for 'number density'. **Allow** 'free electrons' for 'charge carriers'. **Do not allow** just 'density' or just 'number' for 'number density'.
	q: charge on one / each charge carrier	**B1**	**Allow** 'electron' or 'carrier' for 'charge carrier'. **Do not allow** multiple charge carriers. 'Elementary charge' by itself is insufficient.
	t: thickness **or** distance PS / QR / XY / WZ	**B1**	Incorrect distance labels contradict 'thickness'.
7(b)(i)	Any three points from: • charge carriers experience a force due to (current in) magnetic field • force on charge carriers is perpendicular to *I* and *B* • charge carriers deflect towards one face (and away from the opposite face) • charge separation between faces causes a p.d. between the faces • steady state when force due to magnetic field is equal and opposite to force due to resulting electric field	**B3**	**Allow** 'electrons' for 'charge carriers' throughout. **Allow** 'side' or 'plate' for 'face'. **Allow** 'accumulate on' for 'deflect towards'. **Allow** 'potential gradient' or 'electric field' for 'p.d.'. **Allow** 'accumulation stops', 'V_H becomes a maximum' for 'steady state'.
7(b)(ii)	the electrons deflect towards face QRYX so PSZW (is higher) **or** deflection is towards QRYX and the charge carriers are negative so PSZW (is higher)	**B1**	**Allow** 'deflection is towards QRYX so if the charge carriers are positive then QRYX (is higher)'. **Allow** 'holes' for 'positive charge carriers'.

Question	Answer	Marks	Guidance
8(a)(i)	diode	**B1**	
8(a)(ii)	capacitor	**B1**	
8(b)(i)	peak V_{IN} = 3.6 V	**A1**	Correct to at least 2 significant figures. AFC.
8(b)(ii)	period = 0.040 s	**A1**	Correct to at least 2 significant figures. AFC. **Allow** '0.04 s' given to 1 significant figure.
8(c)	<u>Any three points from:</u> • the rectification is half-wave • frequency (of input) = 25 Hz **or** angular frequency (of input) = 160 rad s^{-1} • r.m.s. input voltage = 2.5 V • time constant (of smoothing circuit) = 0.058 s • ripple / variation in (output) voltage = 1.6 V or 44%	**B3**	<u>List Rules apply.</u> All numerical values must be given with a unit and be correct to at least 2 significant figures. The symbols V_{IN} and V_{OUT} may be used without explanation. Otherwise, quantities must be identified by name. **Ignore** points that are simply descriptions of or direct read-offs from the graphs. **Ignore** working space. No ECF. (157 rad s^{-1}). (2.546 V). **Allow** 2.55 V. **Do not allow** 2.6 V (double rounding). **Allow** range 0.056 s to 0.059 s.

Question	Answer	Marks	Guidance
9(a)	wavelength associated with a moving particle	**B1**	**Ignore** any named particles.
9(b)	wave nature (matter): electron diffraction / interference	**B1**	**Allow** diffraction of protons, neutrons or any named nuclide.
	particle nature (matter): e.g. states of matter / state changes / gas behaviour / quantisation of charge / Kirchhoff's first law / electrostatics / radioactive decay / properties of ionising radiation / Rutherford scattering / matter–antimatter annihilation	**B1**	**Allow** 'Brownian motion'. **Allow** 'pair' for 'matter – antimatter'.
	wave nature (EM radiation): diffraction / interference / polarisation in light / Doppler effect in light	**B1**	**Allow** 'refraction in light'. **Allow** 'redshift' for 'Doppler effect'. **Allow** any named part of the EM spectrum for 'light'. **Allow** 'Young's slits experiment' without the need to qualify as 'with light'.
	particle nature (EM radiation): photoelectric effect	**B1**	**Allow** 'photoelectric emission' or 'photoemission'. **Allow** emission / absorption spectra. **Allow** 'Compton scattering'.
9(c)(i)	$qV = \frac{1}{2}mv^2$	**C1**	
	$1.60 \times 10^{-19} \times 3500 = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$	**C1**	
	speed = 3.5×10^7 m s^{-1}	**A1**	Correct to at least 2 significant figures. AFC. (3.51)
9(c)(ii)	wavelength = h / mv	**C1**	**Allow** $\lambda = h / p$ **and** $p = mv$.
	$= (6.63 \times 10^{-34}) / (9.11 \times 10^{-31} \times 3.5 \times 10^7)$ $= 2.1 \times 10^{-11}$ m	**A1**	Possible ECF from **9(c)(i)**. Correct to at least 2 significant figures. AFC.

Question	Answer	Marks	Guidance
10(a)	energy required to separate (all) the nucleons (in the nucleus)	**M1**	**Allow** 'energy released when nucleons come together (to form nucleus)'. **Allow** 'work done' for 'energy required'. **Allow** 'protons and neutrons' for 'nucleons'. **Do not allow** any impression of a single nucleon.
	to infinity	**A1**	**Expect** 'from infinity' if the alternative M1 version of the M1 mark is given.
10(b)(i)	positron	**B1**	**Allow** 'beta +'. 'Beta' is incomplete. 'Beta–' is incorrect. **Ignore** symbols.
10(b)(ii)	$E = (\Delta)mc^2$	**C1**	
	$= 0.030377 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$ $= 4.54 \times 10^{-12}$ J	**A1**	Full substitution and answer needed. Unit not required but any unit given must be correct.
10(c)(i)	$F = L / 4\pi d^2$	**C1**	
	$= (7.98 \times 10^{27}) / (4\pi \times (8.15 \times 10^{16})^2)$ $= 9.56 \times 10^{-8}$ W m^{-2}	**A1**	Correct to at least 3 significant figures. AFC.

Question	Answer	Marks	Guidance
10(c)(ii)	number of He-4 nuclei formed per unit time $= (7.98 \times 10^{27}) / (4.54 \times 10^{-12})$	**C1**	<u>The three C1 marks are all independent.</u> No ECF from **10(b)(ii)**. Value $1.76 \times 10^{39}\ s^{-1}$ implies C1.
	number of H-1 nuclei fused = 4 × number of He-4 nuclei produced	**C1**	Value $7.03 \times 10^{39}\ s^{-1}$ implies first two C1 marks.
	mass of H-1 = 1.67×10^{-27} × number of H-1 nuclei	**C1**	**Allow** use of 1.66×10^{-27}. Inclusion of 0.030377 in the mass calculation is XP.
	mass rate = $(4 \times 1.67 \times 10^{-27} \times 7.98 \times 10^{27}) / (4.54 \times 10^{-12})$ $= 1.17 \times 10^{13}\ kg\ s^{-1}$	**A1**	This line implies all three C1 marks. Correct to at least 3 significant figures. AFC.