Markscheme

May 2026

Physics

Higher level

Paper 2

19 pages

Subject Details: Physics HL Paper 2 Markscheme

Mark Allocation

Candidates are required to answer ALL questions. Maximum total = [90 marks].

1. Each row in the "Question" column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the "Total" column.

3. Each marking point in the "Answers" column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by "max" written after the mark in the "Total" column. The related rubric, if necessary, will be outlined in the "Notes" column.

5. An alternative wording is indicated in the "Answers" column by a slash (/). Either wording can be accepted.

6. An alternative answer is indicated in the "Answers" column by "***OR***" between the alternatives. Either answer can be accepted.

7. An alternative markscheme is indicated in the "Answers" column under the heading ***ALTERNATIVE* 1** *etc*. Any alternative can be accepted.

8. Words in angled brackets **« »** in the "Answers" column are not necessary to gain the mark.

9. Words that are underlined are essential for the mark.

10. The order of marking points does not have to be as in the "Answers" column, unless stated otherwise in the "Notes" column.

11. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the "Answers" column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the "Notes" column.

12. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. "Allow ECF" will be displayed in the "Notes" column.

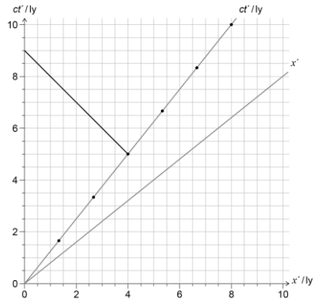
14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

15. Allow reasonable substitutions where in common usage, *eg* ^{c} for rad

Question			Answers	Notes	Total
1.	a	i	Voltage across 180 Ω resistor / 12 – 3.0 = 9.0 V ✓ I«$= \frac{V}{R}$» $= \frac{9}{180} =$ «0.050A» ✓	***MP1*** *can be awarded if 9/180 is seen without showing the subtraction.* *Calculation needed for* ***MP2***	**[2]**
	a	ii	***ALTERNATIVE 1*** Total resistance of thermistor and 240 Ω resistor is $R = \frac{3.0}{0.050} = 60\,\Omega$ ✓ $\frac{1}{60} = \frac{1}{240} + \frac{1}{R} \Rightarrow R = 80\,\Omega$ ✓ ***ALTERNATIVE 2*** Current in 240 Ω resistor $\mathrm{I} = \frac{3.0}{240} = 0.0125\mathrm{A}$ so current in thermistor is $\mathrm{I} = 0.050 - 0.0125 = 0.0375\,\mathrm{A}$ ✓ $R = \frac{3.0}{0.0375} = 80\,\Omega$ ✓		**[2]**
	b		resistance decreases in total circuit/parallel combination ✓ hence current increases ✓ «since pd across R1 increases» pd across R2 will decrease ✓		**[3]**

Question			Answers	Notes	Total
2.	a	i	$v^2 = 2gl = 2 \times 9.8 \times 0.80$ ***OR*** v = 3.96 ms^{-1} ✓	*Allow use of g = 10 m s^{-2}.* *Must see full substitution **OR** answer to 3 (or more) significant figures.*	**[1]**
	a	ii	***ALTERNATIVE 1*** $T - mg = m\frac{v^2}{L}$ ✓ $T = 0.2 \times 9.8 + 0.2 \times \frac{3.96^2}{0.80} = 5.88 \approx 5.9\text{N}$ ✓ ***ALTERNATIVE 2*** $T - mg = m\frac{v^2}{L}$ ✓ $T = mg + 2mg = 3mg = 3 \times 0.20 \times 9.8 = 5.88 \approx 5.9\text{N}$ ✓		**[2]**
	b		« $mv = 2mu \Rightarrow u =$ » 2 ms^{-1} ✓ « $h = \frac{v^2}{2g} = \frac{2^2}{2 \times 9.8} =$ » so h = 0.20 m ✓		**[2]**

Question			Answers	Notes	Total
3.	a		An amount of energy of $0.25 \times 2100 \times 32 = 1.680 \times 10^4$ J will be transferred to the ice from the water «bringing the ice to 0 ºC » ✓ A mass $\frac{1.680 \times 10^4}{334 \times 10^3} = 0.0503\,\text{kg}$ of water will freeze into ice «at to 0 ºC» ✓	*Must see full substitution* **OR** *answer to 3 (or more) significant figures.* *Watch for backwards working (setting the two Qs equal and using the 50* g *to confirm equality).This only earns MP1.*	**[2]**
	b	i	Internal energy consists of the random/average kinetic energy of molecules and their «intermolecular» potential energy ✓ The KE stays the same «because the temperature was constant» ✓ But the PE decreases/changes «because the latent heat of fusion was removed» so the internal energy decreases/changes ✓	*Must see random or average KE for* ***MP1*** *Allow molecules/particles/atoms*	**[3]**
	b	ii	$\Delta S = \frac{Q}{T} = -\frac{1.680 \times 10^4}{273} = -61.54 \approx -62\,\text{JK}^{-1}$ ✓	*ECF from (a) for Q* *Do* ***not*** *penalize absence of minus sign*	**[1]**
	b	iii	Entropy of the ice has increased ✓ This increase is greater than entropy change of the water ✓		**[2]**

Question			Answers	Notes	Total
4.	**a**		0.8c ✓	*Allow other options such as 8/10c, 4/5c, 2.4 x 10^8 m s^{-1}, etc.*	**[1]**
	b	**i**	Negative 45 degree line from (4,5) to (0, 9) ✓		**[1]**
	b	**ii**	«Δs^2 = » 0 ✓		**[1]**

	c		***ALTERNATIVE 1*** $\gamma = \frac{5}{3} = 1.67$ ✓ $ct' = \gamma\left(ct - \frac{v}{c}x\right) = \frac{5}{3}(9.0 - 0) = 15$ ly / time is 15 yr ✓ ***ALTERNATIVE 2*** Use of similar triangles: $ct = \frac{9}{5}$ ly corresponds to $ct' = 3$ ly ✓ So, $ct = 9$ ly corresponds to $ct' = \frac{3 \times 9}{\frac{9}{5}} = 15$ ly ✓ ***ALTERNATIVE 3*** T is the time of flight of the photon from R to S according to R: $cT = 0.80cT + \frac{4}{\frac{5}{3}} \Rightarrow T = 12$ yr / $T = \frac{2.4}{0.20} = 12$ yr ✓ Time at emission for R was 3.0 yr so time at arrival is 3.0 + 12 = 15 yr ✓	*Accept answers in ly or yr.*	**[2]**

Question			Answers	Notes	Total
5	a		Calculation of d = 2.5 x 10^{-6} m ✓ $\phi = \text{«}\sin^{-1}\left(2\times 7.00\times 10^{-7}\times 400\times 10^{-3}\right) - \sin^{-1}\left(2\times 4.00\times 10^{-7}\times 400\times 10^{-3}\right)\text{»} = 15.4°$ ✓	*Radian answer is 0.269 rad.*	**[2]**
	b		Use of θ = 90° OR sin θ = 1✓ $n = 3.57 \rightarrow 3$, third-order ✓	*Must see 3 or third, do **not** award **MP2** for 3.57.*	**[2]**

Question			Answers	Notes	Total
6.	a	i	$E = \frac{V}{d} = \frac{14}{3.0\times10^{-2}} = 4.7\times10^{2}$ ✓ NC^{-1} ***OR*** $V\,m^{-1}$ ✓	*Allow 4.7* V cm^{-1} ***if*** *proper unit is shown.* *Accept other units (e.g.* kg m s^{-3} A^{-1} *or* kg m s^{-2} C^{-1}*) that are valid units of E Field strength regardless of answer in* ***MP1****.*	**[2]**
	a	ii	$F = qE = 1.6\times10^{-19}\times467 = 7.47\times10^{-17}$ N ✓ $a = \frac{F}{m} = \frac{7.47\times10^{-17}}{1.673\times10^{-27}} = 4.46\times10^{10}\ m\,s^{-2}$ ✓	*Award* ***[1 max]*** *for "backwards working" from show that value.* *Must see full substitution* ***OR*** *answer to 3 (or more) significant figures for* ***MP2.***	**[2]**

	a	**iii**	***ALTERNATIVE 1*** Time to travel length of plates is $t = \left(\frac{L}{v} = \frac{16\times10^{-2}}{2.0\times10^{5}}\right) = 8.0\times10^{-7}\ \text{s}$ ✓ Vertical distance fallen in this time is $y = \left(\frac{1}{2}at^2 = \frac{1}{2}\times4.46\times10^{10}\times\left(8.0\times10^{-7}\right)^2\right) = 1.43\times10^{-2}\ \text{m}$ ✓ 1.43 cm < 1.5 cm so proton does not hit plate ✓ ***ALTERNATIVE 2*** Time to fall 1.5 cm $t = \left(\sqrt{\frac{2s}{a}} = \sqrt{\frac{2\times1.5\times10^{-2}}{4.46\times10^{10}}}\right) = 8.20\times10^{-7}\ \text{s}$ ✓ Horizontal distance travelled in this time is $x = (vt = 2.0\times10^{5}\times8.165\times10^{-7}) = 0.164\,\text{m}$ ✓ 16.4 cm > 16 cm so proton does not hit plate ✓ **ALTERNATIVE 3** Time to travel length of plates is $t = \left(\frac{L}{v} = \frac{16\times10^{-2}}{2.0\times10^{5}}\right) = 8.0\times10^{-7}\ \text{s}$ ✓ Time to fall 1.5 cm $t = \left(\sqrt{\frac{2s}{a}} = \sqrt{\frac{2\times1.5\times10^{-2}}{4.46\times10^{10}}}\right) = 8.20\times10^{-7}\ \text{s}$ ✓ 800 ns < 820 ns so does not hit plate ✓	*Award marks from **only one** ALT.* *In all alternative responses we must see an explicit comparison (it is not enough just to say yes or no)*	**[3]**

	b	**i**	Alpha particle has more «4x» the mass AND more charge «2x» therefore the acceleration is smaller « half » ✓ It will not hit the plate ✓		**[2]**
	b	**ii**	$B = «\frac{E}{v} = \frac{4.667 \times 10^{2}}{2.0 \times 10^{5}} =» 2.3 \times 10^{-3}$ T ✓ Into the page « by any rule for magnetic direction » ✓	*Do **not** accept just "down" but allow* ⊗.	**[2]**

Question			Answers	Notes	Total
7.	**a**		KE converted to Joules « $5 \times 10^{6} \times 1.6 \times 10^{-19} =$ »8×10^{-13} J ✓ $Z = « \frac{5.0 \times 10^{6} \times 1.60 \times 10^{-19} \times 1.61 \times 10^{-14}}{2 \times 8.99 \times 10^{9} \times \left(1.60 \times 10^{-19}\right)^{2}} = 27.98 \approx »\ 28$ ✓	*Do **not** accept 27.98 for **MP2** (must be a whole number)*	**[2]**
	b	**i**	Use of $R = R_o A^{\frac{1}{3}}$ ✓ $\frac{d}{R} = \frac{1.61 \times 10^{-14}}{\left(1.2 \times 10^{-15}\right)\left(58^{\frac{1}{3}}\right)} = 3.47$ ✓	$R = (1.2 \times 10^{-15})(58)^{1/3}$ *shown anywhere can earn **MP1**.* *Must see the substitution of R_o for **MP1** for complete "use of".* *Do not allow backwards working (watch for candidates that calculate d using 3.5) for **MP2**.* *Must see full substitution* **OR** *answer to 3 (or more) significant figures for **MP2**.*	**[2]**

	b	**ii**	all isotopes of the same element have the same proton number/charge / *d* depends on *Z* ✓ «therefore» No change ✓		**[2]**
	c	**i**	The distance of closest approach decreases ✓ The alpha particle would come within the range of the strong nuclear force ✓ Rutherford scattering assumes only the electric force is acting ✓		**[2] max**
	c	**ii**	$E \sim \frac{1}{d}$ ***OR*** use of $E_k = k\frac{q_1 q_2}{r}$ ✓ so *E* = 17.5 MeV ***OR*** 2.8 x 10^{-12} J ✓	*Allow ECF for proton number from 7(a) if used to calculate q of nucleus.*	**[2]**

Question			Answers	Notes	Total
8.	a		Force is proportional to the stretch/extension/compression/displacement ***OR*** Force is equal to the spring constant times the stretch/extension/compression/displacement ✓	*Accept $F=kx$ with all variables defined.* *Do **not** accept "linear" for proportional.*	**[1]**
8.	b	i	Use of $v^2 = 0^2 + 2gL \Rightarrow v = \sqrt{2gL}$ / $mgL = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2gL}$ ✓ $v = \text{«}\sqrt{2 \times 9.8 \times 2.2} \text{»} 6.567 \text{ m s}^{-1} \approx 6.6 \text{ m s}^{-1}$ ✓		**[2]**
8.	b	ii	***ALTERNATIVE 1*** Use of conservation of energy at S and B: $\frac{1}{2}kx^2 = mg(L + x)$ ✓ $k = \text{«}\frac{2 \times 4.0 \times 9.8 \times (2.2 + 0.58)}{0.58^2} \text{»} 648 \text{ Nm}^{-1}$ ✓ ***ALTERNATIVE 2*** Use of conservation of energy at A and B: $\frac{1}{2}kx^2 = mgx + \frac{1}{2}mv^2$ ✓ $k = \text{«}\frac{2 \times 4.0 \times 9.8 \times 0.58 + 4.0 \times 6.567^2}{0.58^2} \text{»} 648 \text{ Nm}^{-1}$ ✓	*Must see full substitution **OR** answer to 3 (or more) significant figures for **MP2**.*	**[2]**
8.	b	iii	No ✓ because the net force is non-zero ***OR*** forces are not balanced ***OR*** object is accelerating upwards ***OR*** tension force is greater than gravitational force ✓	*Award **[1 max]** for "yes" <u>only</u> if candidate specifies that the forces are balanced.*	**[2]**

8.	**b**	**iv**	***ALTERNATIVE 1: Impulse Momentum*** Δp «= 4(6.57) » = 26.28 kg m s^{-1} ✓ F_{net} «= $\frac{\Delta p}{\Delta t} = \frac{26.28}{0.13}$ » = 202.2 N ✓ F_{rope} «= F_{net} + mg = 202.16 + 39.24» = 241.4 N ✓ ***ALTERNATIVE 2: Average Acceleration*** a «= $\frac{\Delta v}{\Delta t} = \frac{6.57}{0.13}$ » = 50.5 m s^{-2} ✓ F_{net} «= ma = 4.0 x 50.5» = 202.2 N ✓ F_{rope} «= F_{net} + mg = 202.16 + 39.24» = 241.4 N✓		**[3]**

8.	**c**	**i**	***ALTERNATIVE 1*** $T = 2\pi\sqrt{\frac{m}{k}} \Rightarrow f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ ✓ $f = \frac{1}{2\pi}\sqrt{\frac{504}{0.200}} = 7.99\,\text{Hz}$ ✓ ***ALTERNATIVE 2*** $T = «2\pi\sqrt{\frac{m}{k}} =» 2\pi\sqrt{\frac{0.200}{504}} = 0.12516\,\text{s}$ ✓ $f = \frac{1}{2\pi}\sqrt{\frac{504}{0.200}} = \frac{1}{0.12516} = 7.99\,\text{Hz}$ ✓ ***ALTERNATIVE 3*** $\omega^2 = \frac{k}{m} = \frac{504}{0.2} = 2520\,\text{s}^{-1}$ leading to $\omega = 50.2\,\text{s}^{-1}$ ✓ $f = «\frac{\omega}{2\pi} =» \frac{50.2}{(2\pi)} = 7.99\,\text{Hz}$ ✓	*Must see full substitution **OR** answer to 3 (or more) significant figures for **MP2.*** *Do not allow a simple* $\frac{1}{T}$ *= 8 for **ALT 2 MP2** (must see* $\frac{\textbf{1}}{\textbf{MP1}}$ *result).*	**[2]**
8.	**c**	**ii**	$\lambda = \frac{v}{f} = \frac{1.6}{8.0}$ ***OR*** $\lambda = vT = 1.6 \times 0.125$ ✓	*Must see the equation used **AND** the full substitution for the mark.*	**[1]**
8.	**c**	**iii**	Path difference (p.d.) is 2λ/whole number of wavelengths/lengths are divisible by λ/ both path lengths are multiples of λ ✓ hence waves are in phase at P ✓	*Do **not** award **MP2** if **MP1** is missing*	**[2]**

8.	**c**	**iv**	A maximum/peak/constructive interference/double amplitude « will be observed » ✓ Because the path difference at Q is $6.5\lambda - 5.5\lambda = \lambda$ / an integral multiple of the wavelength ***OR*** arrive trough to trough ***OR*** maxima line up ***OR*** waves arrive in phase ✓		**[2]**
8.	**d**		***ALTERNATIVE 1*** Next possible p.d. is $n = 3$ ***OR*** 3λ ✓ $\lambda = \frac{\text{p.d.}}{n} = \frac{0.4}{n} = \frac{0.4}{3} = 0.13$ m ✓ $f = \frac{v}{\lambda} = \frac{1.6}{0.13} = 12.3$ Hz ✓ ***ALTERNATIVE 2*** $0.40 = n\lambda = n\frac{v}{f} = n\frac{1.6}{f}$ ✓ $f = n\frac{1.6}{0.40} 4n$ ✓ $f_{min} = 4 \times 3 = 12$ Hz ✓		**[3]**

Question			Answers	Notes	Total
9.	a	i	The minimum speed «in a gravitational field» to reach infinity/escape the gravitational field of the planet ✓	*Must see "minimum" speed specifically or by explanation (e.g. the "necessary" speed).* *Do **not** allow "escape from orbit"*	**[1]**
9.	a	ii	$\frac{1}{2}m(1.40\times10^3)^2-\frac{GMm}{R}=\frac{1}{2}mv^2-0$ ✓ $v^2=(1.40\times10^3)^2-\frac{2GM}{R}=(1.40\times10^3)^2-(1.20\times10^3)^2$ ✓ $v=7.21\times10^2\ \text{m s}^{-1}$ ✓		**[3]**
9.	a	iii	***ALTERNATIVE 1*** Use of $g=\frac{\Delta V}{\Delta r}$ and $\Delta V=\frac{W}{m}$ «leading to $\Delta V=\frac{1}{2}(1.1\times10^3)^2-\frac{1}{2}(1.05\times10^3)^2$ » ✓ $g=\text{«}\frac{(1.10\times10^3)^2-(1.05\times10^3)^2}{2\times2.15\times10^4}\text{=» }2.50\ \text{N kg}^{-1}$ ✓ ***ALTERNATIVE 2*** Use of conservation of energy leading to $\frac{1}{2}mv^2-\frac{1}{2}mu^2=m\Delta V=mgr$ ✓ $g=\text{«}\frac{(1.10\times10^3)^2-(1.05\times10^3)^2}{2\times2.15\times10^4}\text{=» }2.50\ \text{N kg}^{-1}$ ✓		**[2]**
9.	b	i	Use of $v_{esc}=\sqrt{\frac{2Gm}{R}}$ ✓ $v_{esc}=3.04\times10^8\ \text{m s}^{-1}$ ✓	*Must see full substitution **OR** answer to 3 (or more) significant figures for **MP2**.*	**[2]**

9.	**b**	**ii**	The escape speed is equal/larger than the speed of light ✓ Light/any material object cannot escape from this star ***OR*** escape is impossible ***OR*** object is a black hole ✓		**[2]**
9.	**c**	**i**	Helium ✓		**[1]**
9.	**c**	**ii**	The «inward» gravitational pressure ✓ is balanced by the outward radiation/ thermal pressure ✓	*Accept forces instead of pressure.*	**[2]**
9.	**d**	**i**	$\Delta m = 2 \times 15.9949 - 27.9769 - 4.0026$ ***OR*** 1.03×10^{-2} u ✓ $Q = «1.03 \times 10^{-2} \times 931.5 =» 9.6$ MeV ✓		**[2]**
9.	**d**	**ii**	High Z nuclei must overcome a high coulomb/electrostatic repulsion «barrier in order to fuse»✓ This requires high «core» temperatures «that can only be found in order to fuse» ✓		**[2]**
9.	**d**	**iii**	For elements heavier than iron, fusion would require energy/energy is absorbed «rather than released» ✓ Iron has the highest/maximum binding energy per nucleon ✓ Iron is at the peak of the binding energy per nucleon curve ✓		**[1] max**
9.	**d**	**iv**	It is/will become a supergiant ***AND*** then will explode/supernova ✓ It will become a neutron star/black hole ✓		**[2]**