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Physics

Standard level

Paper 3

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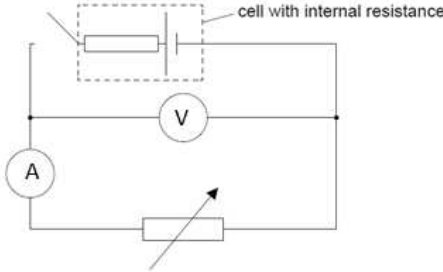
Section A

Question			Answers	Notes	Total
1.	a		it is not possible to draw a straight line through all the error bars OR the line of best-fit is curved/not a straight line ✓	<i>Treat as neutral any reference to the origin.</i> Allow “linear” for “straight line”.	1
	b	i	$d = 0.35 \pm 0.01$ AND $\Delta d = 0.05 \pm 0.01$ «cm» ✓ $\left\langle \frac{\Delta d}{d} = \frac{0.05}{0.35} \right\rangle = 0.14$ OR $\frac{1}{7}$ or 14 % or 0.1 ✓	Allow final answers in the range of 0.11 to 0.18. Allow [1 max] for 0.03 to 0.04 if $\lambda = 5 \times 10^6$ m is used.	2
	b	ii	28 to 30 % ✓	Allow ECF from (b)(i), but only accept answer as a %	1
	c	i	a: m ² ✓ b: m ✓	Allow answers in words	2

(continued...)

(Question 1 continued)

Question		Answers	Notes	Total
c	ii	<p>ALTERNATIVE 1 – if graph on page 4 is used</p> <p>$d^2 = 0.040 \times 10^{-4} \text{ «m}^2 \text{»} \checkmark$</p> <p>$d = 0.20 \times 10^{-2} \text{ «m»} \checkmark$</p> <p>ALTERNATIVE 2 – if graph on page 2 is used</p> <p>any evidence that d intercept has been determined \checkmark</p> <p>$d = 0.20 \pm 0.05 \text{ «cm»} \checkmark$</p>	<p><i>For MP1 accept answers in range of 0.020 to 0.060 «cm²» if they fail to use given value of “a”.</i></p> <p><i>For MP2 accept answers in range 0.14 to 0.25 «cm».</i></p>	2

Question		Answers	Notes	Total
2.	a	correct labelling of both instruments ✓	 <p>The diagram shows a circuit with a cell (labeled 'cell with internal resistance') connected in series with an ammeter (A) and a variable resistor. A voltmeter (V) is connected in parallel across the variable resistor.</p>	1
	b	$V = E - Ir$ ✓ large triangle to find gradient and correct read-offs from the line OR use of intercept $E = 1.5\text{ V}$ and another correct data point ✓ internal resistance = $0.60\ \Omega$ ✓	<p><i>For MP1 – do not award if only $R = \frac{V}{I}$ is used.</i></p> <p><i>For MP2 points at least 1A apart must be used.</i></p> <p><i>For MP3 accept final answers in the range of $0.55\ \Omega$ to $0.65\ \Omega$.</i></p>	3

(continued...)

(Question 2 continued)

Question		Answers	Notes	Total
	c	i	a non-zero reading when a zero reading is expected/no current is flowing OR a calibration error ✓	OWTTE Do not accept just “systematic error”. 1
	c	ii	the error causes «all» measurements to be high/different/incorrect ✓ effect on calculations/gradient will cancel out OR effect is that value for r is unchanged ✓	Award [1 max] for statement of “no effect” without valid argument. OWTTE 2

Section B

Option A — Relativity

Question		Answers	Notes	Total
3.	a	the speed of light is a universal constant/invariant OR c does not depend on velocity of source/observer ✓ electric and magnetic fields/forces unified/frame of reference dependant ✓		1 max
	b	observer X will measure zero «magnetic or electric» force ✓ observer Y must measure both electric and magnetic forces ✓ which must be equal and opposite so that observer Y also measures zero force ✓	Allow [2 max] for a comment that both X and Y measure zero resultant force even if no valid explanation is given.	3

Question	Answers	Notes	Total
4.	<p>ALTERNATIVE 1 — for answers in terms of time</p> <p>overall idea that more muons are detected at the ground than expected «without time dilation» ✓</p> <p>« Earth frame transit time = $\frac{2000}{0.98c}$ » = 6.8 « μs » ✓</p> <p>« Earth frame dilation of proper half-life = $2.2 \mu\text{s} \times 5$ » = 11 « μs »</p> <p>OR</p> <p>« muon's proper transit time = $\frac{6.8 \mu\text{s}}{5}$ » = 1.4 « μs » ✓</p> <p>ALTERNATIVE 2 – for answers in terms of distance</p> <p>overall idea that more muons are detected at the ground than expected «without time dilation» ✓</p> <p>« distance muons can travel in a proper lifetime = $2.2 \mu\text{s} \times 0.98c$ » = 650 « m » ✓</p> <p>« Earth frame lifetime distance due to time dilation = $650 \text{ m} \times 5$ » = 3250 « m »</p> <p>OR</p> <p>« muon frame distance travelled = $\frac{2000}{5}$ » = 400 « m » ✓</p>	<p>Accept answers from one of the alternatives.</p>	<p>3</p>

Question			Answers	Notes	Total
5.	a	i	the gamma factor is $\frac{5}{3}$ or 1.67 ✓ $L = \frac{450}{\frac{5}{3}} = 270 \text{ «m»} \checkmark$	Allow ECF from MP1 to MP2.	2
	a	ii	$u' = \left\langle \frac{u-v}{1-\frac{uv}{c^2}} \right\rangle = \frac{0.20c - 0.80c}{1 - 0.20 \times 0.80}$ <p>OR</p> $0.2c = \frac{0.80c + u'}{1 + 0.80u'}$ $u' = \langle - \rangle 0.71c \checkmark$	Check signs and values carefully.	2
	b	i	$\Delta t' = \left\langle \gamma \left(\Delta t - \frac{v \Delta x}{c^2} \right) \right\rangle = \frac{5}{3} \times \left(0 - \frac{(0.80c \times 9000)}{c^2} \right) \checkmark$ $\Delta t' = \langle - \rangle 4.0 \times 10^{-5} \text{ «s»} \checkmark$	Allow ECF for use of wrong γ from (a)(i).	2
	b	ii	lamp 2 turns on first ✓	Ignore any explanation	1

(continued...)

(Question 5 continued)

Question		Answers	Notes	Total
c	i	<p>x coordinate as shown ✓ ct coordinate as shown ✓</p>	<p>Labels must be clear and unambiguous. Construction lines are optional.</p>	2
c	ii	<p>«in any other frame» ct is greater ✓ the interval $ct' = 1.0$ «m» is proper time OR ct is a dilated time OR $ct = \gamma ct'$ «γ» ✓</p>	<p>MP1 is a statement MP2 is an explanation</p>	2
c	iii	<p>use of $c^2t^2 - x^2 = c^2t'^2 - x'^2$ ✓ $c^2t^2 - x^2 = 1^2 - 0^2 = 1$ «m^2» ✓</p>	<p>for MP1 equation must be used. Award [2] for correct answer that first finds x (1.33 m) and ct (1.66 m)</p>	2

Option B — Engineering physics

Question			Answers	Notes	Total
6.	a	i	zero ✓		1
	a	ii	the torque of each force is $9.60 \times 10^3 \times 6.0 = 5.76 \times 10^4$ «Nm» ✓ so the net torque is $2 \times 5.76 \times 10^4 = 1.15 \times 10^5$ «Nm» ✓	Allow a one-step solution.	2
	b		the angular acceleration is given by $\frac{1.15 \times 10^5}{1.44 \times 10^4}$ « $= 8.0 \text{ s}^{-2}$ » ✓ $\omega = \alpha t = 8.0 \times 2.00 = 16$ « s^{-1} » ✓		2
	c	i	$1.44 \times 10^4 \times 16.0 = (1.44 \times 10^4 + 4.80 \times 10^3) \times \omega$ ✓ $\omega = 12.0$ « s^{-1} » ✓	Allow ECF from (b).	2
	c	ii	initial KE $\frac{1}{2} \times 1.44 \times 10^4 \times 16.0^2 = 1.843 \times 10^6$ «J» ✓ final KE $\frac{1}{2} \times (1.44 \times 10^4 + 4.80 \times 10^3) \times 12.0^2 = 1.382 \times 10^6$ «J» ✓ loss of KE = 4.6×10^5 «J» ✓	Allow ECF from part (c)(i).	3

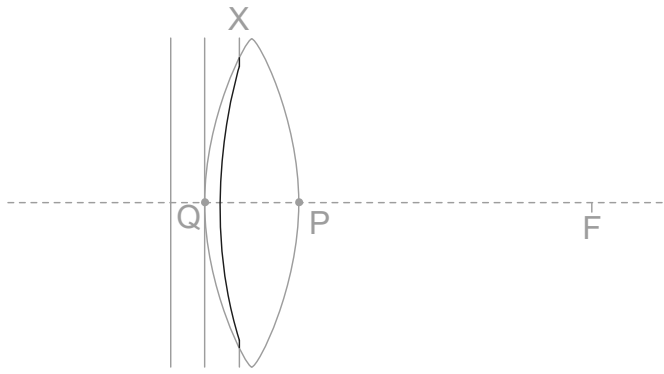
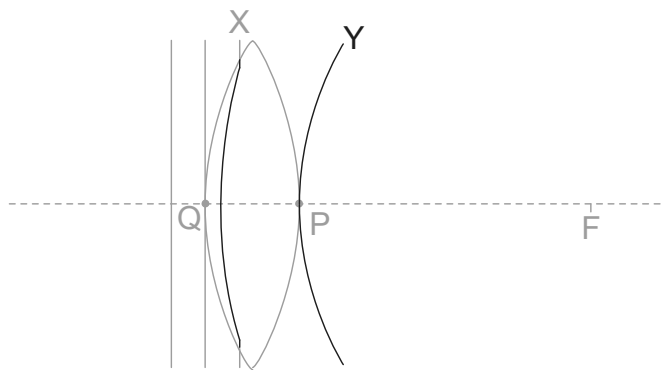
Question			Answers	Notes	Total
7.	a	i	$\Delta U = 0$ so $Q = \Delta U + W = 0 + 416 = 416$ «J» ✓	<i>Answer given, mark is for the proof.</i>	1
	a	ii	<p>ALTERNATIVE 1</p> <p>use $pV^{\frac{5}{3}} = c$ to get $TV^{\frac{2}{3}} = c$ ✓</p> <p>hence $T_C = T_A \left(\frac{V_A}{V_C}\right)^{\frac{2}{3}} = 612 \times 0.5^{\frac{2}{3}} = 385.54$ ✓</p> <p>«$T_C \approx 386\text{K}$»</p> <p>ALTERNATIVE 2</p> <p>$P_C V_C^\gamma = P_A V_A^\gamma$ giving $P_C = 1.26 \times 10^6$ «Pa» ✓</p> <p>$\frac{P_C V_C}{T_C} = \frac{P_A V_A}{T_A}$ giving $T_C = 1.26 \times \frac{612}{2} = 385.54$ «K» ✓</p> <p>«$T_C \approx 386\text{K}$»</p>	<p><i>Answer of 386K is given. Look carefully for correct working if answers are to 3 SF.</i></p> <p><i>There are other methods:</i></p> <p><i>Allow use of $P_B = 2 \times 10^6$ «Pa» and $\frac{P}{T}$ is constant for BC.</i></p> <p><i>Allow use of $n = 0.118$ and $T_C = \frac{P_C V_C}{nR}$.</i></p>	2
	a	iii	<p>$Q = \Delta U + W = \frac{3 P_A V_A}{2 T_A} \Delta T + 0$ ✓</p> <p>$Q = \frac{3}{2} \times \frac{4.00 \times 10^6 \times 1.50 \times 10^{-4}}{612} \times (386 - 612)$ ✓</p> <p>«-332 J»</p>	<p><i>Answer of 330 J given in the question.</i></p> <p><i>Look for correct working or more than 2 SF.</i></p>	2

(continued...)

(Question 7 continued)

Question		Answers	Notes	Total
a	iv	$e = \frac{Q_{in} - Q_{out}}{Q_{in}} = \frac{416 - 332}{416} \checkmark$ $e = 0.20 \checkmark$	Allow $\frac{416 - 330}{416}$. Allow $e = 0.21$.	2
b		entropy is largest at B \checkmark entropy increases from A to B because $T = \text{constant}$ but volume increases so more disorder or $\Delta S = \frac{Q}{T}$ and $Q > 0$ so $\Delta S > 0 \checkmark$ entropy is constant along CA because it is adiabatic, $Q = 0$ and so $\Delta S = 0$ OR entropy decreases along BC since energy has been removed, $\Delta Q < 0$ so $\Delta S < 0 \checkmark$		3

Option C — Imaging

Question			Answers	Notes	Total
8.	a	i	line of correct curvature as shown ✓ 		1
	a	ii	line of approximately correct curvature as shown ✓ 	Judged by eye. Allow second wavefront Y, to have “passed” P as this is how this question is being interpreted by some. Ignore any waves beyond Y.	1

(continued...)

(Question 8 continued)

Question		Answers	Notes	Total
	b	wave travels slower in glass than in air OR RI greater for glass ✓ wavelength less in glass than air ✓ hence wave from Q will cover a shorter distance «than in air» causing the curvature shown ✓	OWTTE	2 max
	c	realization that the two lenses must have a common focal point ✓ distance is $12 - 4.0 = 8.0$ «cm» ✓	Accept MP1 from a separate diagram or a sketch on the original diagram. A valid reason from MP1 is expected. Award [1 max] for a bald answer of $12 - 4 = 8$ «cm».	2

9.	a	states $f_o + f_e = 90$ AND $\frac{f_o}{f_e} = 17$ ✓ solves to give $f_o = 85$ AND $f_e = 5$ «cm» ✓	Both needed. Both needed.	2
	b	angle subtended by Moon is $\frac{0.16}{17} = 0.0094$ «rad» ✓ $0.0094 = \frac{D}{3.8 \times 10^8}$ ✓ $D = 3.6 \times 10^6$ «m» ✓	Allow ECF from MP1. Allow [2] for an answer of 6.1×10^7 «m» if the factor of 17 is missing in MP1.	3
	c	operation day and night ✓ operation at all wavelengths/no atmospheric absorption ✓ operation without atmospheric turbulence/light pollution ✓	Accept any other sensible advantages.	2 max

Question		Answers	Notes	Total	
10.	a	calculation of critical angle at core–cladding boundary $\llcorner 1.52 \times \sin \theta_c = 1.48 \gg \theta_c = 76.8^\circ \checkmark$ refraction angle at air–core boundary $90^\circ - 76.8^\circ = 13.2^\circ \checkmark$ $\llcorner 1.52 \times \sin 13.2^\circ = \sin A \gg A = 20.3^\circ \checkmark$	Allow ECF from MP1 to MP2 to MP3.	3	
	b	i	<i>attenuation</i> : output signal has smaller area \checkmark <i>dispersion</i> : output signal is wider than input signal \checkmark	OWTTE OWTTE	2
	b	ii	attenuation = $\llcorner 10 \log \frac{I}{I_0} = 10 \log \frac{77}{320} = \gg \llcorner - \gg 6.2 \llcorner \text{dB} \gg \checkmark$ $\frac{-6.2}{5.1} = \llcorner - \gg 1.2 \llcorner \text{dB km}^{-1} \gg \checkmark$	Allow intensity ratio to be inverted. Allow ECF from MP1 to MP2.	2

Option D — Astrophysics

Question		Answers	Notes	Total	
11.	a	core: helium ✓ outer layer: hydrogen ✓	Accept no other elements.	2	
	b	ratio of masses is $\left(\frac{10^4}{10^{-3}}\right)^{\frac{1}{3.5}} = 10^2$ ✓ ratio of volumes is $\left(\frac{10}{10^{-1}}\right)^3 = 10^6$ ✓ so ratio of densities is $\frac{10^2}{10^6} = 10^{-4}$ ✓	Allow ECF for MP3 from earlier MPs	3	
	c	i	line to the right of X, possibly undulating, very roughly horizontal ✓	Ignore any paths beyond this as the star disappears from diagram.	1
	c	ii	gravitation is balanced by a pressure/force due to neutrons/neutron degeneracy/pauli exclusion principle ✓	Do not accept electron degeneracy.	1
	c	iii	$L = \sigma AT^4 = 5.67 \times 10^{-8} \times 4\pi \times (2.0 \times 10^4)^2 \times (10^6)^4$ ✓ $L = 3 \times 10^{26}$ «W» OR $L = 2.85 \times 10^{26}$ «W» ✓	Allow ECF for [1 max] if πr^2 used (gives 7×10^{25} «W») Allow ECF for a POT error in MP1.	2
	c	iv	$\lambda = \frac{2.9 \times 10^{-3}}{10^6} = 2.9 \times 10^{-9}$ «m» ✓ this is an X-ray wavelength ✓		2

Question		Answers	Notes	Total
12.	a	theory in which all space/time/energy/matter were created at a point/singularity ✓ at enormous temperature ✓ with the volume of the universe increasing ever since or the universe expanding ✓	OWTTE	2 max
	b	CMB has a black-body spectrum ✓ wavelength stretched by expansion ✓ is highly isotropic/homogenous ✓ but has minor anisotropies predicted by BB model ✓ $T \ll 2.7 \text{ K}$ is close to predicted value ✓	For MP4 and MP5 idea of "prediction" is needed	2 max
	c	i $\frac{v}{c} = z \Rightarrow v = 0.084 \times 3 \times 10^5 = 2.52 \times 10^4 \text{ «kms}^{-1}\text{»} \checkmark$ $d = \frac{v}{H_0} = \frac{2.52 \times 10^4}{68} = 370.6 \approx 370 \text{ «Mpc»} \checkmark$	Allow ECF from MP1 to MP2.	2
	c	ii type Ia have a known luminosity/are standard candles ✓ measure apparent brightness ✓ determine distance from $d = \sqrt{\frac{L}{4\pi b}} \checkmark$	Must refer to type Ia. Do not accept other methods (parallax, Cepheids)	3