

Markscheme

November 2018

Physics

Higher level

Paper 3

26 pages

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Section A

Question			Answers	Notes	Total
1.	a		$m^{\frac{3}{2}}$ ✓	Accept other power of tens multiples of $m^{\frac{3}{2}}$, eg: $cm^{\frac{3}{2}}$.	1
1.	b		<p>measured uncertainties «for one oscillation and for 20 oscillations» are the same/similar/OWTTE</p> <p>OR</p> <p>% uncertainty is less for 20 oscillations than for one ✓</p> <p>dividing «by 20» / finding mean reduces the random error ✓</p>		2

(continued...)

(Question 1 continued)

Question			Answers	Notes	Total
1.	c	i	<p>Straight line touching at least 3 points drawn across the range ✓</p> <p style="text-align: center;">$\frac{1}{d} / \text{m}^{-1}$</p>	<p><i>It is not required to extend the line to pass through the origin.</i></p>	1
1.	c	ii	<p>theory predicts proportional relation «$T \propto \frac{1}{d}$», slope = $Td = \frac{c}{\sqrt{g}}$ = constant » ✓</p> <p>the graph is «straight» line <u>through the origin</u> ✓</p>		2

(continued...)

(Question 1 continued)

[illegible]

Question			Answers	Notes	Total
2.	a		to provide a constant heating rate / power OR to have m proportional to t ✓		1
2.	b		due to heat losses « V/t is larger than heat into liquid» ✓ L_v calculated will be larger ✓		2
2.	c		heat losses will be similar / the same for both experiments OR heat loss presents systematic error ✓ taking the difference cancels/eliminates the effect of these losses OR use a graph to eliminate the effect ✓		2

Section B

Option A — Relativity

Question			Answers	Notes	Total
3.	a		a set of rulers and clocks / set of coordinates to record the position and time of events ✓		1
3.	b	i	<p>ALTERNATIVE 1:</p> <p>the time in frame S' is $t' = \frac{L}{c}$ ✓</p> <p>but time is absolute in Galilean relativity so is the same in S ✓</p> <p>ALTERNATIVE 2:</p> <p>In frame S, light rays travel at $c + v$ ✓</p> <p>so $t = \frac{L}{(c+v)-v} = \frac{L}{c}$ ✓</p>	<i>In Alternative 1, they must refer to S'</i>	2
3.	b	ii	<p>$x = x' + vt$ and $x' = L$ ✓</p> <p>«substitution to get answer»</p>		1

Question			Answers	Notes	Total
4.	a		$\frac{0.82c + 0.40c}{1 + \frac{0.82c \times 0.40c}{c^2}} \checkmark$ $0.92c \checkmark$		2
4.	b	i	$\Delta t' = \frac{120}{0.40c} \checkmark$ $\Delta t' = 1.0 \times 10^{-6} \text{ « s » } \checkmark$		2
4.	b	ii	$\gamma = \frac{1}{\sqrt{1 - 0.82^2}} = 1.747 \checkmark$ $\Delta t = \gamma \left(\Delta t' + \frac{v \Delta x'}{c^2} \right) = 1.747 \times \left(1.0 \times 10^{-6} + \frac{0.82c \times 120}{c^2} \right)$ <p>OR</p> $\Delta t = \frac{120}{1.747 \times (0.92 - 0.82)c} \checkmark$ $2.3 \times 10^{-6} \text{ « s » } \checkmark$		3

Question			Answers	Notes	Total
5.	a	i	$\gamma = \frac{1}{\sqrt{1-0.745^2}} = 1.499 \checkmark$ $x' = \gamma(x - vt) = 1.499 \times (1.0 - 0) \checkmark$ $\ll x' = 1.5 \text{ m} \gg$		2
5.	a	ii	$t' = \gamma \left(t - \frac{vx}{c^2} \right) = 1.499 \times \left(0 - \frac{0.745c \times 1}{c^2} \right) = -\frac{1.11}{c} \gg$ $\ll ct' = -1.1 \text{ m} \gg$ <p>OR</p> <p>using spacetime interval $0 - 1^2 = (ct')^2 - 1.5^2 \Rightarrow \ll ct' = -1.11 \gg \checkmark$</p>		1

(continued...)

(Question 5 continued)

Question			Answers	Notes	Total
5.	b	i	line through event E parallel to ct' axis meeting x' axis and labelled P ✓		1
5.	b	ii	point on x' axis about $\frac{2}{3}$ of the way to P labelled Q ✓		1

(continued...)

(Question 5 continued)

Question			Answers	Notes	Total
5.	c	i	<p>ends of rod must be recorded at the same time in frame S' ✓</p> <p>any vertical line from E crossing x', no label required ✓</p> <p>right-hand end of rod intersects at R «whose co-ordinate is less than 1.0 m» ✓</p>		3
5.	c	ii	0.7 m ✓		1

Question			Answers	Notes	Total
6.	a		$pc = \sqrt{E^2 - (mc^2)^2} = \sqrt{1.50^2 - 0.511^2} \llcorner = 1.410 \text{ MeV} \llcorner \checkmark$		1
6.	b	i	first equation is due to momentum conservation \checkmark second equation is due to total energy conservation \checkmark		2
6.	b	ii	adding $2p_1 = 3.42 \text{ MeV c}^{-1} \Rightarrow p_1 = 1.71 \text{ MeV c}^{-1} \checkmark$ $p_2 = 0.30 \text{ MeV c}^{-1} \checkmark$		2

Question			Answers	Notes	Total
7.	a	i	the distance from the black hole at which the escape speed is the speed of light \checkmark		1
7.	a	ii	$R_s = \llcorner \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 4.0 \times 10^{36}}{9.0 \times 10^{16}} = \llcorner 5.9 \times 10^9 \llcorner \text{ «m» } \checkmark$		1
7.	b		$2 = \frac{1}{\sqrt{1 - \frac{5.9 \times 10^9}{r}}} \checkmark$ rearranged to give r OR $r = 1.33 \times 5.9 \times 10^9 \llcorner \text{ «m» } \checkmark$ $r = 7.9 \times 10^9 \llcorner \text{ «m» } \checkmark$		3

Option B — Engineering physics

Question			Answers	Notes	Total
8.	a		taking torques about the pivot $R \times 4.00 = 36.0 \times 2.5$ ✓ $R = 22.5$ «N» ✓		2
8.	b	i	$36.0 \times 2.50 = 30.6 \times \alpha$ ✓ $\alpha = 2.94$ «rad s ⁻² » ✓		2
8.	b	ii	the equation can be applied only when the angular acceleration is constant ✓ any reasonable argument that explains torque is not constant, giving non constant acceleration ✓	<i>eg weight is no longer perpendicular to the rod</i>	2
8.	c	i	«from conservation of energy» Change in GPE = Change in rotational KE ✓ $W \frac{L}{2} = \frac{1}{2} I \omega^2$ ✓ $\omega = \sqrt{\frac{36.0 \times 5.00}{30.6}}$ ✓ « $\omega = 2.4254$ rad s ⁻¹ »		3
8.	c	ii	$L = 30.6 \times 2.43 = 74.4$ «Js» ✓		1

Question			Answers	Notes	Total
9.	a	i	<p>ALTERNATIVE 1:</p> $P_c = P_B = \frac{P_A V_A}{V_B} \checkmark$ $= \frac{2.8 \times 10^6 \times 1 \times 10^{-4}}{2.8 \times 10^{-4}} \llcorner = 1.00 \times 10^6 \text{ Pa} \llcorner \checkmark$ <p>ALTERNATIVE 2</p> $2.80 \times 10^6 \times 1.00^{\frac{5}{3}} = P_c \times 1.85^{\frac{5}{3}} \checkmark$ $P_c = 2.80 \times 10^6 \times \frac{1.00^{\frac{5}{3}}}{1.85^{\frac{5}{3}}} \llcorner = 1.00 \times 10^6 \text{ Pa} \llcorner \checkmark$		2
9.	a	ii	<p>ALTERNATIVE 1:</p> <p>Since $T_B = T_A$ then $T_C = \frac{V_C T_B}{V_B} \checkmark$</p> $= \frac{1.85 \times 385}{2.8} \llcorner = 254.4 \text{ K} \llcorner \checkmark$ <p>ALTERNATIVE 2:</p> $\frac{2.80 \times 1.00}{385} = \frac{1.00 \times 1.85}{T_c} \llcorner \text{K} \llcorner \checkmark$ $T_c = 385 \times \frac{1.00 \times 1.85}{2.80} \llcorner = 254.4 \text{ K} \llcorner \checkmark$		2

(continued...)

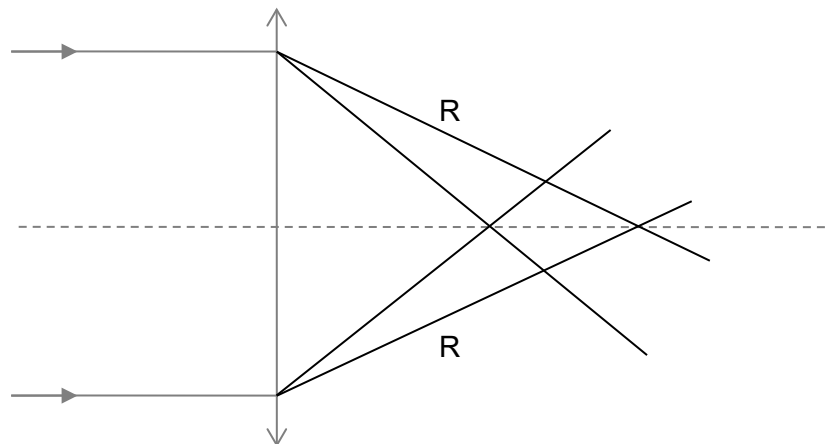
(Question 9 continued)

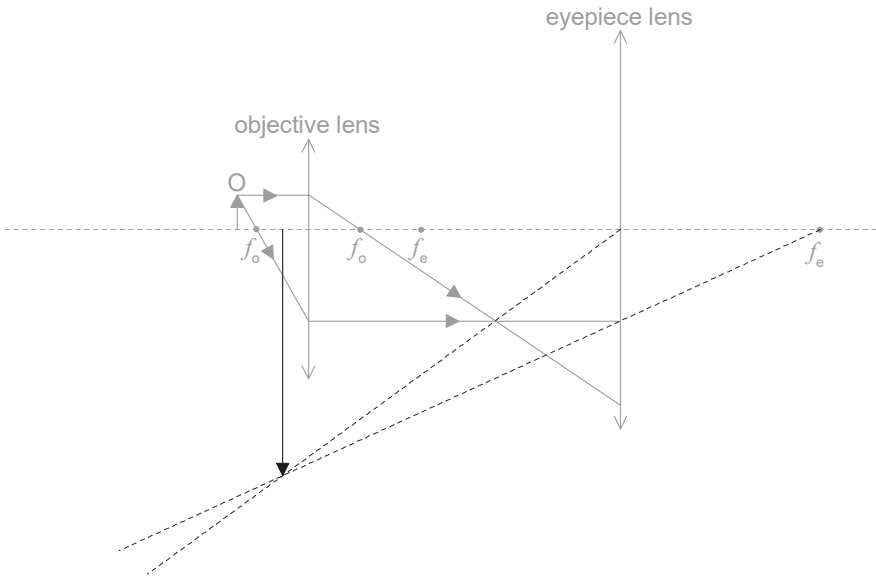
Question			Answers	Notes	Total
9.	b		<p>work done = « $p\Delta V = 1.00 \times 10^6 \times (1.85 \times 10^{-4} - 2.80 \times 10^{-4}) = \rangle -95 \text{ « J} \rangle \checkmark$</p> <p>change in internal energy = « $\frac{3}{2}p\Delta V = -\frac{3}{2} \times 95 = \rangle -142.5 \text{ « J} \rangle \checkmark$</p> <p>$Q = -95 - 142.5 \checkmark$</p> <p>« $-238 \text{ J} \rangle$</p>	Allow positive values.	3
9.	c	i	<p>net work is $288 - 238 = 50 \text{ « J} \rangle \checkmark$</p> <p>efficiency = « $\frac{288 - 238}{288} = \rangle 0.17 \checkmark$</p>		2
9.	c	ii	along B → C \checkmark		1

Question			Answers	Notes	Total
10.	a		ice displaces its own weight of water / OWTTE OR melted ice volume equals original volume displaced / OWTTE ✓ no change will take place ✓		2
10.	b	i	continuity equation says $v \times A_1 = u \times A_2$ ✓ «and» $A_1 = 4A_2$ ✓ «giving result»		2
10.	b	ii	<i>Bernoulli:</i> $\left\langle \frac{1}{2} \rho v^2 + \rho g H + P_{\text{atm}} = \frac{1}{2} \rho u^2 + 0 + P_{\text{atm}} \right\rangle$ gives $\frac{1}{2} \times 1000 \times \frac{u^2}{16} + 1000 \times 9.8 \times 5.0 = \frac{1}{2} \times 1000 \times u^2$ ✓ $u = 10.2 \text{ «m s}^{-1}\text{»}$ ✓	<i>Accept solving directly via conservation of energy.</i>	2

Question			Answers	Notes	Total
11.	a		because the mass and the driver are out of phase «by π » ✓ so upwards ✓	<i>Justification needed for MP2</i>	2
11.	b		<p>ALTERNATIVE 1:</p> $\left\langle Q = 2\pi \frac{A_0^2}{A_0^2 - A_1^2} \right\rangle \Rightarrow \frac{A_1^2}{A_0^2} = 1 - \frac{2\pi}{Q} \quad \checkmark$ $\frac{A_1}{A_0} = \left\langle \sqrt{1 - \frac{2\pi}{22}} \right\rangle \Rightarrow A_1 = 8.5 \text{ « cm »} \quad \checkmark$ <p>ALTERNATIVE 2:</p> <p>driver amplitude is constant ✓</p> <p>so mass amplitude is unchanged at 10 cm ✓</p>		2

Option C — Imaging

Question			Answers	Notes	Total
12.	a		<p>each incident ray shown splitting into two ✓</p> <p>each pair symmetrically intersecting each other on principal axis ✓</p> <p>for red, intersection further to the right ✓</p>	 <p><i>For MP3, at least one of the rays must be labelled.</i></p>	3
12.	b	i	<p>rays diverge after passing through lens</p> <p>OR</p> <p>the extension of the rays will intersect the principal axis on the side of incident rays/as if they were coming from the focal point/points in the left side/OWTTE ✓</p>		1
12.	b	ii	<p>by placing a diverging lens next to the converging lens</p> <p>OR</p> <p>make an achromatic doublet ✓</p>	Further details are not required.	1

Question			Answers	Notes	Total
13.	a		<p>proper construction lines ✓</p> <p>image at intersection of proper construction lines ✓</p>	 <p>The diagram illustrates a telescope setup. It features two lenses: an objective lens on the left and an eyepiece lens on the right. A horizontal dashed line represents the optical axis. The objective lens has a focal point f_o marked on the axis. An object, labeled 'O', is positioned at this focal point. The eyepiece lens has a focal point f_e marked on the axis. Three rays are shown originating from the top of the object 'O': one ray is parallel to the optical axis and passes through the focal point of the objective lens; another ray passes through the optical center of the objective lens; and a third ray passes through the focal point of the eyepiece lens. These rays are extended as dashed lines to show their intersection, which determines the position of the image. Labels 'objective lens' and 'eyepiece lens' are placed above their respective lenses.</p>	2

(continued...)

(Question 13 continued)

Question			Answers	Notes	Total
13.	b	i	<p>distance of intermediate image from objective is</p> $\frac{1}{v} = \frac{1}{20} - \frac{1}{24} \text{ ie: } v = 120 \text{ «mm» } \checkmark$ <p>distance of intermediate image from eyepiece is</p> $\frac{1}{u} = \frac{1}{60} - \left(-\frac{1}{240}\right) \text{ ie: } u = 48 \text{ «mm» } \checkmark$ <p>lens separation 168 «mm» \checkmark</p>		3
13.	b	ii	<p>ALTERNATIVE 1:</p> <p>eyepiece: $m = \frac{-v}{u} = \frac{240}{48} = 5$</p> <p>AND</p> <p>objective $m = \frac{-v}{u} = \frac{-120}{24} = -5 \checkmark$</p> <p>Total $m = -5 \times 5 = -25 \checkmark$</p> <p>ALTERNATIVE 2:</p> <p>$m = \left(\frac{240}{60} + 1\right) \times \left(-\frac{120}{24}\right) \checkmark$</p> <p>$m = -25 \checkmark$</p>		2

Question			Answers	Notes	Total
14.	a	i	$\llcorner \sin \theta_c = \frac{n_1}{n_2} \gg n_1 = 1.52 \times \sin 84.0^\circ \checkmark$ $n_1 = 1.51 \checkmark$		2
14.	a	ii	to have a critical angle close to $90^\circ \checkmark$ so only rays parallel to the axis are transmitted \checkmark to reduce waveguide/modal dispersion \checkmark	Do not accept “so that most rays are reflected”.	1 max
14.	b	i	long path is $\frac{12 \times 10^3}{\sin 84^\circ} \checkmark$ $= 12066 \text{ «m» } \checkmark$ «so 66 m longer»		2
14.	b	ii	speed of light in core is $\frac{3.0 \times 10^8}{1.52} = 1.97 \times 10^8 \text{ «m s}^{-1}\gg \checkmark$ time delay is $\frac{66}{1.97 \times 10^8} = 3.35 \times 10^{-7} \text{ «s» } \checkmark$		2
14.	b	iii	no, period of signal is $1 \times 10^{-8} \text{ «s»}$ which is smaller than the time delay/OWTTE \checkmark		1

Question			Answers	Notes	Total
15.	a		protons spin direction changes OR proton energy state changes ✓		1
15.	b		Relaxation time «of signal/proton spin» ✓ Location/time delay of the emitted RF signal ✓		2
15.	c		Relaxation time gives information on tissue type/density/health/OWTTE✓ Location information provides 3D image/OWTTE✓		2

Question			Answers	Notes	Total
16.	a		$I_0 e^{-23 \times 0.041}$ ✓ $= 0.39 I_0$ ✓		2
16.	b		$R = \left(\frac{6.3 \times 10^6 - 1.7 \times 10^6}{6.3 \times 10^6 + 1.7 \times 10^6} \right)^2 = 0.33$ ✓ so reflected intensity is $0.33 \times 0.39 I_0 = 0.13 I_0$ ✓		2
16.	c		$0.13 I_0 \times 0.39 = 0.05 I_0$ ✓		1

Option D — Astrophysics

Question			Answers	Notes	Total
17.	a		<p>In cluster, stars are gravitationally bound OR constellation not ✓</p> <p>In cluster, stars are the same/similar age OR in constellation not ✓</p> <p>Stars in cluster are close in space/the same distance</p> <p>OR</p> <p>in constellation not ✓</p> <p>Cluster stars appear closer in night sky than constellation ✓</p> <p>Clusters originate from same gas cloud OR constellation does not ✓</p>		2 max
17.	b	i	$d = 275$ «pc» ✓		1
17.	b	ii	because of the difficulty of measuring very small angles ✓		1
17.	c		<p>mass of gas cloud > Jeans mass ✓</p> <p>«magnitude of» gravitational potential energy > E_k of particles ✓</p> <p>cloud collapses/coalesces «to form a protostar» ✓</p>		2 max

Question			Answers	Notes	Total
18.	a	i	$\lambda = \ll \frac{2.9 \times 10^{-3}}{4600} = \gg 630 \text{ nm} \gg \checkmark$		1
18.	a	ii	black body curve shape \checkmark peaked at a value from range 600 to 660 nm \checkmark		2
18.	a	iii	$\frac{L}{L_{\odot}} = \left(\frac{0.73 R_{\odot}}{R_{\odot}} \right)^2 \times \left(\frac{4600}{5800} \right)^4 \checkmark$ $L = 0.211 L_{\odot} \checkmark$		2
18.	b		$M = \ll 0.21^{\frac{1}{3.5}} M_{\odot} = \gg 0.640 M_{\odot} \checkmark$	Accept reverse argument $0.64^{3.5} = 0.21$	1
18.	c		$\frac{T_E}{T_{\odot}} = \ll \frac{\frac{M_E}{L_E}}{\frac{M_{\odot}}{L_{\odot}}} = \frac{0.64}{0.21} = \gg 3.0 \checkmark$ $T \approx 27 \text{ billion years} \checkmark$		2
18.	d		red giant \checkmark planetary nebula \checkmark white dwarf \checkmark	do NOT accept supernova, red supergiant, neutron star or black hole as stages	3

Question			Answers	Notes	Total
19.	a		measured redshift «z» of star ✓ use of Doppler formula OR $z \sim v/c$ OR $v = \frac{c\Delta\lambda}{\lambda}$ to find v ✓	OWTTE	2
19.	b		use of gradient or any point on the line to obtain any expression for either $H = \frac{v}{d}$ or $t = \frac{d}{v}$ ✓ correct conversion of d to m and v to m/s ✓ $= 4.6 \times 10^{17}$ «s» ✓		3

Question			Answers	Notes	Total
20.	a		energy filling all space ✓ resulting in a repulsive force/force opposing gravity ✓ accounts for the accelerating universe ✓ makes up about 70% of «the energy» of universe ✓		2 max
20.	b		black hole ✓ brown dwarf ✓ massive compact halo object /MACHO ✓ neutrinos ✓ weakly interacting massive particle /WIMP ✓		2 max

Question			Answers	Notes	Total
21.	a		<p>«wavelength of light/CBR» $\lambda \propto R$ ✓</p> <p>reference to Wien's law showing that $\lambda \propto \frac{1}{T}$ ✓</p> <p>combine to get result ✓</p>	OWTTE	3
21.	b		$\frac{R_{\text{past}}}{R_{\text{now}}} = \frac{3}{300} = 0.01$ ✓		1