

Markscheme

November 2020

Physics

Higher level

Paper 3

28 pages

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Section A

Question			Answers	Notes	Total
1.	a		<p>«theory suggests» $P_1 - P_0$ is proportional to $\frac{1}{R}$ ✓</p> <p>graph/line of best fit is straight/linear «so yes»</p> <p>OR</p> <p>graph/line of best fit passes through the origin «so yes» ✓</p>	<p><i>MP1: Accept 'linear'</i></p> <p><i>MP2 do not award if there is any contradiction eg: graph not proportional, does not pass through origin.</i></p>	2
1	b	i	<p>gradient = «4γ» = 0.10</p> <p>OR</p> <p>use of equation with coordinates of a point ✓</p> <p>$\gamma = 0.025$ ✓</p>	<p><i>MP1 allow gradients in range 0.098 to 0.102</i></p> <p><i>MP2 allow a range 0.024 to 0.026 for γ</i></p>	2
1	b	ii	<p>kg s^{-2} ✓</p>	<p>Accept $\frac{\text{kg}}{\text{s}^2}$</p>	1

Question			Answers	Notes	Total
1	b	iii	straight line, gradient greater than line of best fit, and within the error bars ✓ 		1

Question			Answers	Notes	Total
1	b	iv	«15% of 0.025» = 0.00375 OR «15% of 0.030» = 0.0045 ✓ rounds uncertainty to 1sf ±0.004 OR ±0.005 ✓	Allow ECF from (b)(i) Award [2] marks for a bald correct answer	2
1	b	v	Experimental value matches this/correct, as expected value within the range ✓ OR experimental value does not match/incorrect, as it is not within range ✓		1

Question		Answers	Notes	Total
2.	a	<p>In order to draw a graph « of W versus $\frac{1}{T^2}$ »</p> <p>OR</p> <p>to confirm proportionality between « W and T^{-2} »</p> <p>OR</p> <p>to confirm relationship between « W and T »</p> <p>OR</p> <p>because W is the independent variable in the experiment ✓</p>	OWTTE.	1
2	b	<p>ALTERNATIVE 1</p> <p>$W + \text{friction} = \frac{4\pi^2 mr}{T^2}$</p> <p>OR</p> <p>centripetal force is larger «than W» / W is smaller «than centripetal» ✓</p> <p>«so» experimental mr is smaller «than calculated value» ✓</p> <p>ALTERNATIVE 2 (refers to graph)</p> <p>reference to «friction force is» a systematic error «and does not affect gradient» ✓</p> <p>«so» mr is the same ✓</p>	<p><i>MP2 awarded only with correct justification. Candidates can gain zero, MP1 alone or full marks.</i></p> <p>OWTTE</p>	2

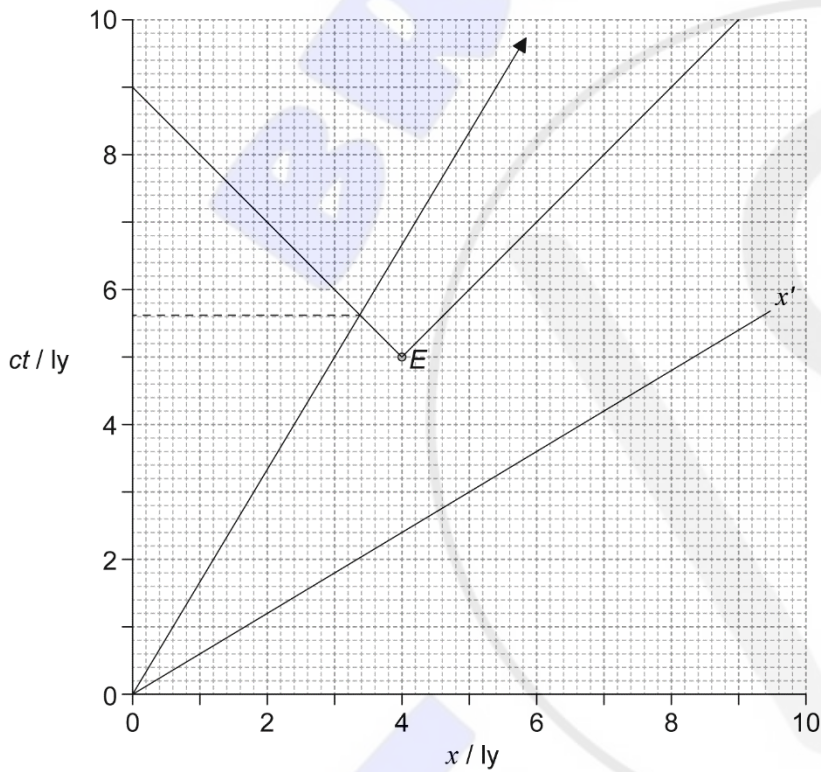
Question			Answers	Notes	Total
2	c	i	mention of mean/average value «of T » ✓ this reduces uncertainty in T / result OR more accurate/precise ✓	Reference to “random errors average out” scores MP1 Accept “closer to true value”, “more reliable value” OWTTE for MP2	2
2	c	ii	systematic errors «usually» constant/always present/not influenced by repetition ✓	OWTTE	1

Section B

Option A — Relativity

Question			Answers	Notes	Total
3.	a		mention of electric AND magnetic fields ✓ OR mention of electromagnetic radiation/wave/fields ✓		1
3	b		the laws of physics are the same in all «inertial» frames of reference/for all «inertial» observers ✓	OWTTE	1
3	c	i	magnetic ✓		1
3	c	ii	«In observer frame» protons «in the two wires» move in same/parallel direction ✓ these moving protons produce magnetic attraction ✓ there is also a smaller electrostatic repulsion due to wires appearing positive due to length contraction «of proton spacing» ✓	OWTTE	3

Question			Answers	Notes	Total
4.	a		constancy of time OR speed of light > c is possible ✓	OWTTE.	1
4	b	i	$\gamma = 1.15$ ✓ length = 6.9 «m» ✓	Allow length in the range 6.7 to 7.0 m. Allow ECF from wrong γ Award [2] marks for a bald correct answer in the range indicated above.	2
4	b	ii	8.0 m / measurement made on the probe ✓ the measurement made by an observer at rest in the frame of the probe ✓		2
4	c		$u = \frac{0.5c + 0.8c}{1 + \frac{0.5c \times 0.8c}{c^2}}$ ✓ $u = 0.93c$ ✓	Allow all negative signs for velocities Award [2] marks for a bald correct answer	2

Question			Answers	Notes	Total
5.	a	i	0.6c ✓	Accept $1.8 \times 10^8 \text{ ms}^{-1}$ if unit given.	1
5	a	ii	line through origin and through (5, 3) ± one small square at this coordinate ✓ 	Answers shown for 5(a)(ii) and (b)(i) and (b)(ii).	1
5	b	i	X value of E at 4 «ly» ✓ Y value of E at 5 «y» ✓		2

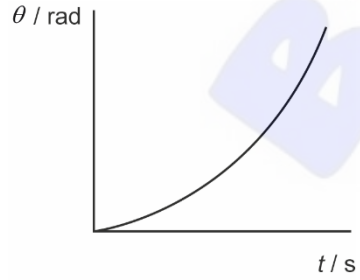
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(Question 5 continued)

Question			Answers	Notes	Total
5.	b	ii	light cone from E «crosses ct at 9 so» intersection on $ct' = 5.6 \pm 0.2$ y «on ct scale» ✓ $\gamma = 1.25$ ✓ so $t' = \frac{5.6}{1.25} \Rightarrow 4.5$ «y after leaving Earth» ✓	MP1 accept use of linear equations to find $t = 5.625$ Allow ECF from (b)(i) and (a)	3
6.	a		invariant mass OR mass of object when not in motion/in object's rest frame ✓		1
6	b		«rest energy =» (2.014×931.5) «MeV» ✓ « $E_T = KE + \text{rest energy} = 270.0 + (2.014 \times 931.5) \Rightarrow 2146$ «MeV» ✓	Final answer accept $3.443 \times 10^{-10} \text{J}$ if unit given Award [2] marks for a bald correct answer.	2
6	c		is converted to energy ✓ as kinetic energy of the products ✓		2

Question			Answers	Notes	Total
7.	a		« $\frac{\Delta f}{f} = \frac{g\Delta h}{c^2} = \frac{9.81 \times 22.6}{c^2}$ » $\frac{\Delta f}{f} = 2.46 \times 10^{-15}$ ✓		1
7	b	i	GPE gained by photons so E increases ✓ $E = hf$, so frequency increases ✓		2
7	b	ii	gamma rays travel at c ✓ detector accelerates towards source so «by Doppler effect» λ reduced so frequency increases ✓	Award [1 max] for reference to principle of equivalence without further explanation.	2

Option B — Engineering

Question		Answers	Notes	Total
8.	a	$\omega_f^2 = 0 + 2 \times 0.110 \times 6 \times 2\pi \checkmark$ $\omega_f = 2.88 \text{ «rad s}^{-1}\text{»} \checkmark$	Other methods are possible. At least 2 sig figs for MP2.	2
8	b	concave up from origin \checkmark 		1
8	c	$\Gamma = \alpha I$ so $\Gamma = 0.110 \times 0.0216 \Rightarrow 2.38 \times 10^{-3} \text{ «N m»} \checkmark$		1
8	d	$\alpha = \frac{2.9^2}{2 \times 2\pi \times 30} = \text{OR } -0.022 \text{ «rad s}^{-2}\text{} \checkmark$ $t \text{ «} = \frac{\omega_f - \omega_i}{\alpha} = \frac{-2.9}{-0.0220} \text{»} = 130 \text{ «s»} \checkmark$	Other methods are possible. Award [2] marks for a bald correct answer	2

Question		Answers	Notes	Total
9.	a	<p>«person rotates» anticlockwise ✓</p> <p>the person gains angular momentum «in the opposite direction to the new wheel motion» ✓</p> <p>so that the total angular momentum is conserved ✓</p>	<p>OWTTE</p> <p>Award [1 max] for a bald statement of conservation of angular momentum.</p>	3
9	b	<p>the rotational kinetic energy has increased ✓</p> <p>energy is provided by the person doing work «flipping the wheel» ✓</p>	OWTTE	2
10.		<p>conservation of rotational and linear energy</p> <p>OR</p> $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \quad \checkmark$ <p>using $I = \frac{2}{5}mr^2$ AND $\omega = \frac{v}{r} \quad \checkmark$</p> <p>with correct manipulation to find the requested relationship ✓</p>		3

Question			Answers	Notes	Total
11.	a	i	«-» 3×10^3 «J» ✓		1
11	a	ii	0 «J» ✓	OWTTE	1
11	b	i	use of $PV^{\frac{5}{3}}$ is constant « $4.0 \times 10^5 \times (2.0 \times 10^{-2})^{\frac{5}{3}} = P_2 \times (5.0 \times 10^{-2})^{\frac{5}{3}}$ » ✓ $P_2 = 8.7 \times 10^4$ «Pa» OR 87 «kPa» ✓	Award [2] marks for a bald correct answer	2
11	b	ii	adiabatic means no transfer of heat in or out of the system ✓ should be fast ✓ «can be slow if» the system is insulated ✓	OWTTE	2 max

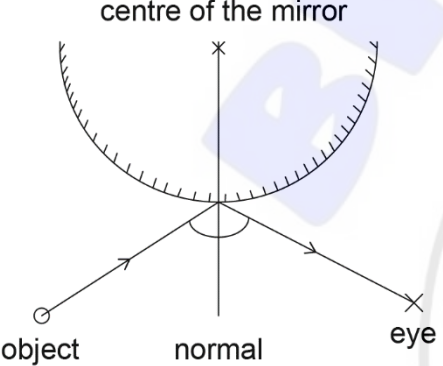
Question		Answers	Notes	Total
12.	a	incompressible ✓ non-viscous ✓ laminar/streamlined flow ✓		2 max
12	b	radius of sphere = 0.012 «m» ✓ weight of sphere = $6\pi\eta r v + \rho V g$ OR $v = \frac{(1.26 \times 10^{-2} - 915 \times 7.24 \times 10^{-6}) \times 9.81}{6\pi \times 37.9 \times 10^{-3} \times 1.2 \times 10^{-2}} \checkmark$ $v = 6.84 \text{ «m s}^{-1}\text{»}$ ✓	Accept use of $g = 10$ leading to $v = 7.0 \text{ «m s}^{-1}\text{»}$ Allow implicit calculation of radius for MP1 Do not allow ECF for MP3 if buoyant force omitted.	3

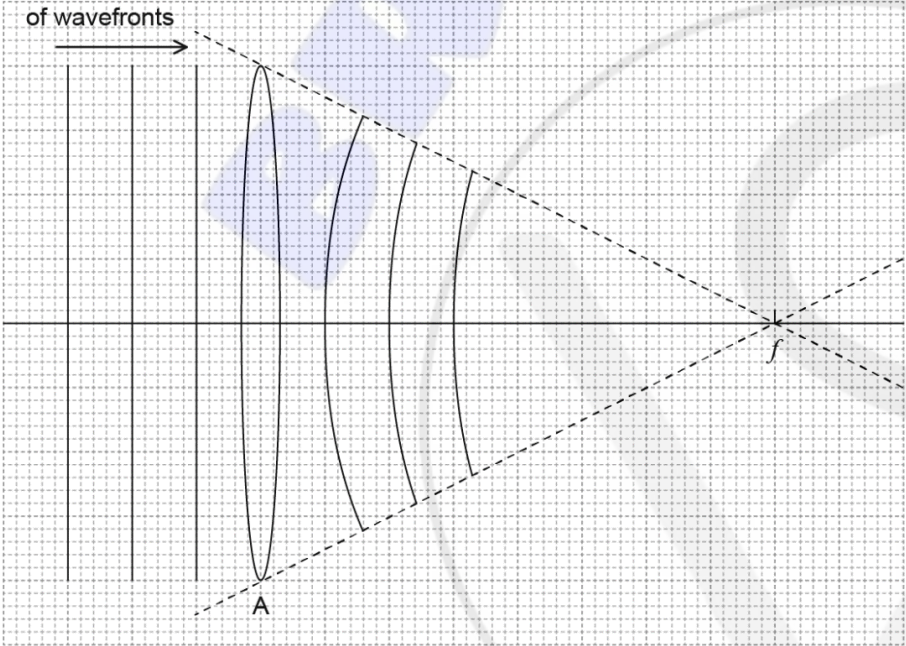
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(Question 12 continued)

Question			Answers	Notes	Total
12.	c	i	$F = mg - \rho Vg$ OR $F = (0.0126 \times 9.81) - (915 \times 7.24 \times 10^{-6} \times 9.81) \checkmark$ $F = 5.86 \times 10^{-2} \text{ «N» } \checkmark$	Accept use of $g = 10$ leading to $F = 6.0 \times 10^{-2} \text{ N}$	2
12	c	ii	$Q = \left\langle 2\pi \times \frac{\text{energy stored}}{\text{energy lost}} = 2\pi \times \frac{100}{10} = \right\rangle 63 \checkmark$		1
12	c	iii	drag force increases OR damping increases OR more energy lost per cycle \checkmark Q will decrease \checkmark		2

Option C — Imaging

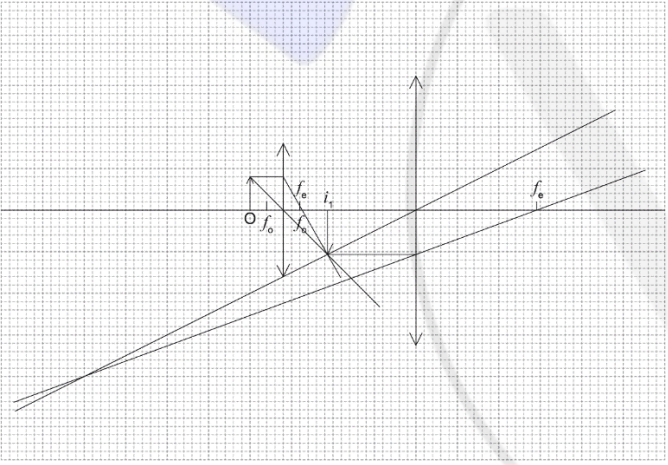
Question		Answers	Notes	Total
13.	a	<p>attempt to connect object and eye with ray showing equal angles of reflection such that reflection occurs within 1 hatch mark of position shown ✓</p> <p>construction showing normal at point of reflection ✓</p>  <p>object normal eye</p>	<p><i>Allow rays that are drawn freehand without a ruler - use judgement.</i></p>	2
13	b	<p>light rays do not pass through the image</p> <p>OR</p> <p>do not form an image on a screen</p> <p>OR</p> <p>appear to have come from a point</p> <p>OR</p> <p>formed by extension of rays ✓</p>	<p>OWTTE.</p>	1

Question	Answers	Notes	Total
<p>14. a</p>	<p>wavefront separation identical and equal to separation before the lens ✓ wavefronts converging, approximately centered on f ✓</p> <p>direction of travel of wavefronts</p> 	<p>By eye. Dotted construction lines are not required, allow wavefronts to extend beyond or be inside the dotted lines here. Allow [1max] if only two wavefronts drawn.</p>	<p>2</p>
<p>14 b</p>	$\frac{1}{v} = \frac{1}{4.00} - \frac{1}{4.50} \checkmark$ $v = 36.0 \text{ «cm» } \checkmark$		<p>2</p>

(continued...)

(Question 14 continued)

Question		Answers	Notes	Total
14.	c	$A: \frac{1}{-2.0} = \frac{1}{8} + \frac{1}{u} \checkmark$ $u = -1.6 \text{ «cm» } \checkmark$ distance necessary = «36.0-1.6 => 34.4 «cm» \checkmark	Allow [2 max] for ECF for no negative in MP1. Gives $u=2.7$ and distance of 38.7«cm» Allow ECF from (b) in MP3.EG use of 0.4m / 40cm.	3
14	d	$\text{« } m = -\frac{i}{o} = \frac{-36}{4.5} \text{ for A or } \frac{-8}{-1.6} \text{ for B »}$ $m_A = \text{«-» } 8 \text{ OR } m_B = \text{«+» } 5 \checkmark$ total magnification = «-» 40 \checkmark	Allow [2] marks for a bald correct answer Allow ECF from (b) and (c). Eg if $u=2.7\text{cm}$ in (c) then $m_B = 3$ and total $m=24$	2

Question		Answers	Notes	Total
15.	a	the final image lies at the near point «often assumed to be 25 cm» ✓		1
15	b	<p>any 2 correct rays from O for objective lens ✓ forming an intermediate image at approximate position shown OR use of image from objective lens as object for eyepiece lens ✓ any 2 correct rays for eyepiece lens from intermediate image ✓ ray extension to form a final image ✓</p> 	<p>Allow ECF for MP2, MP3 & MP4 for badly drawn rays. MP4 allow final image to be off the page</p>	4

Question		Answers	Notes	Total
16.		mention of attenuation ✓ mention of dispersion or pulse broadening ✓ gives explanation for at least one of above ✓		3
17.	a	bone «denser so» absorb rays «and appear white in the negative» ✓ larger attenuation for bone ✓ muscles have less attenuation, so rays pass through «and appear darker» ✓	<i>Accept the reversed argument</i>	3
17	b	collimation✓ fluorescent screens «each side of photographic plate» ✓ barium/magnesium meal ✓		1 max

Question		Answers	Notes	Total
18.	a	use of strong magnetic field ✓ protons are aligned ✓ radio wave at «nuclear» resonant frequency flips «some of» them into higher energy state ✓ proton de-excites emitting energy at known «radio» wavelength/frequency/Larmor frequency ✓ «which can be located and detected»		3 max
18	b	mention of gradient field «added to the NMR uniform magnetic field» ✓ reference to «the total field that determines» the output «Larmor» frequency from the de-excitation ✓ different positions «in the body» give rise to different frequencies ✓ «and this can be mapped»		2 max
18	c	NMR higher resolution ✓ NMR less attenuation ✓	<i>Accept the reverse argument</i>	1 max

Option D — Astrophysics

Question			Answers	Notes	Total
19.	a		AU: «average» distance from the Earth to the Sun ✓ ly: distance light travels in one year ✓		2
19	b	i	made of ice «and dust» ✓ «highly» eccentric/elliptical orbit around the Sun ✓ formed in the Oort Cloud ✓		1 max
19	b	ii	star / named star / stellar cluster/ galaxy/ constellation ✓	Answer may be indicated on the photograph.	1
20.	a		substitution of $L = \sigma AT^4$ into $b = \frac{L}{4\pi d^2}$ giving $b = \frac{\sigma AT^4}{4\pi d^2}$ ✓	Removal of constants σ and 4π is optional	1
20	b		equation applies to Sirius/stars that are luminous/emit light «from fusion» ✓ but Venus reflects the Sun's light/does not emit light «from fusion» ✓	OWTTE	2

Question		Answers	Notes	Total
21.	a	<p>« $\frac{R_0}{R} =$ »</p> <p>$\frac{1}{1.11}$ OR 0.90 OR 90% ✓</p>		1
21	b	<p>«Hubble's » measure of v/recessional speed uses redshift which is z</p> <p>OR</p> <p>redshift (z) of galaxies is proportional to distance «from earth»</p> <p>OR</p> <p>combines $v = Hd$ AND $z = \frac{v}{c}$ into one expression, e.g. $z = \frac{Hd}{c}$ ✓</p>	OWTTE	1
21	c	<p>reference to «redshift due to» expansion of the universe, «not recessional speed» ✓</p> <p>expansion of universe stretches spacetime / increases distance between objects ✓</p> <p>«so» wavelength stretches / increases leading to observed redshift ✓</p>		3

Question		Answers	Notes	Total
22.	a	$\left\langle \frac{L}{L_{\odot}} = \frac{M^{3.5}}{M_{\odot}^{3.5}} = 5.70^{3.5} \right\rangle = 442 \checkmark$ <p>the luminosity of Eta ($2630 L_{\odot}$) is very different «so it is not main sequence» \checkmark</p>	<p>Allow calculation of $L^{\frac{1}{3.5}}$ to give $M = 9.5 M_{\odot}$ so not main sequence</p> <p>OWTTE</p>	2
22	b i	$d \left\langle = \frac{1}{2.36 \times 10^{-3}} \right\rangle = 424 \text{ «pc»} \checkmark$		1
22	b ii	<p>Use of $d = \sqrt{\frac{L}{4\pi b}}$ \checkmark</p> $= \sqrt{\frac{2630 \times 3.83 \times 10^{26}}{4\pi \times 7.20 \times 10^{-10}}} \checkmark$ $\left\langle = \frac{1.055 \times 10^{19}}{3.26 \times 9.46 \times 10^{15}} \right\rangle = 342 \text{ «pc»} \checkmark ($	<p>Award [3] marks for a bald correct answer between 340 and 344 «pc»</p>	3

(continued...)

(Question 22 continued)

Question		Answers	Notes	Total
22.	c	parallax angle in milliarc seconds/very small/at the limits of measurement ✓ uncertainties/error in measuring L or b or θ ✓ values same order of magnitude, so not significantly different ✓	Accept answers where MP1 and MP2 both refer to parallax angle OWTTE	2 max
22	d	reference to change in size ✓ reference to change in temperature ✓ reference to periodicity of the process ✓ reference to transparency / opaqueness ✓		3 max
22	e	shorter time ✓ star more massive and mass related to luminosity OR star more massive and mass related to time in main sequence OR position on HR diagram to the left and above shows that will reach red giant region sooner ✓		2

Question		Answers	Notes	Total
23.		higher atomic number than iron ✓ excess of neutrons ✓ radioactive/undergoing beta decay ✓	<i>Allow heavier than iron for MP1</i>	2 max
24	a	the temperature/«peak» wavelength/intensity «of the CMBR» varies «slightly» / is not constant in different directions ✓		1
	b	quantum fluctuations «that have expanded» ✓ density perturbations «that resulted in galaxies and clusters of galaxies» ✓ dipole distortion «due to the motion of the Earth» ✓		2 max