

# Markscheme

November 2020

Physics

Higher level

Paper 3

28 pages

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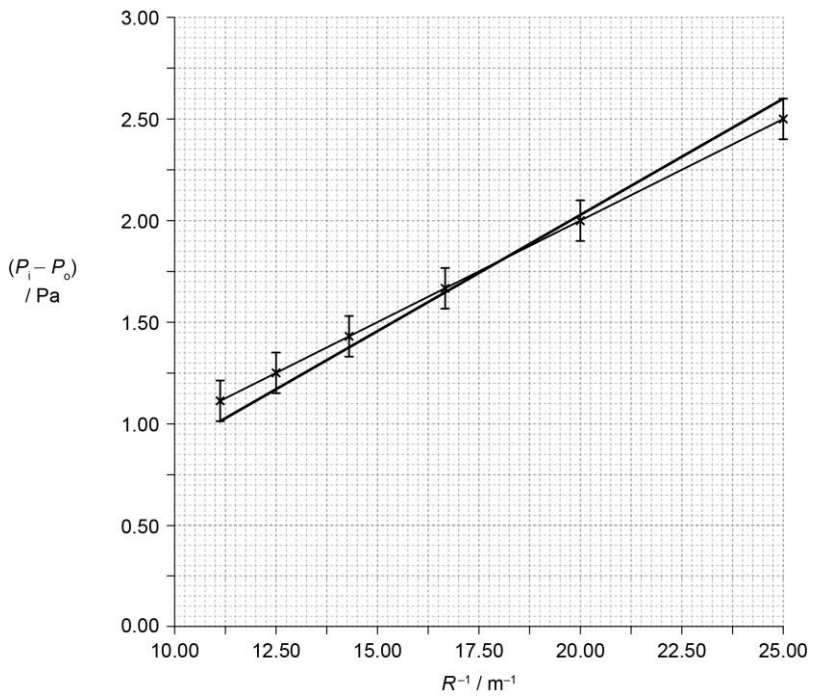
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**Section A**

Question			Answers	Notes	Total
1.	a		<p>«theory suggests» <math>P_1 - P_0</math> is proportional to <math>\frac{1}{R}</math> ✓</p> <p>graph/line of best fit is straight/linear «so yes»</p> <p><b>OR</b></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 = «<math>4\gamma</math>» = 0.10</p> <p><b>OR</b></p> <p>use of equation with coordinates of a point ✓</p> <p><math>\gamma = 0.025</math> ✓</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 <math>\gamma</math></i></p>	2
1	b	ii	<p><math>\text{kg s}^{-2}</math> ✓</p>	<p>Accept <math>\frac{\text{kg}}{\text{s}^2}</math></p>	1

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

Question			Answers	Notes	Total
1	b	iv	«15% of 0.025» = 0.00375 <b>OR</b> «15% of 0.030» = 0.0045 ✓  rounds uncertainty to 1sf ±0.004 <b>OR</b> ±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 ✓ <b>OR</b> 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 <math>W</math> versus <math>\frac{1}{T^2}</math> »</p> <p><b>OR</b></p> <p>to confirm proportionality between « <math>W</math> and <math>T^{-2}</math> »</p> <p><b>OR</b></p> <p>to confirm relationship between « <math>W</math> and <math>T</math> »</p> <p><b>OR</b></p> <p>because <math>W</math> is the independent variable in the experiment ✓</p>	OWTTE.	1
2	b	<p><b>ALTERNATIVE 1</b></p> <p><math>W + \text{friction} = \frac{4\pi^2 mr}{T^2}</math></p> <p><b>OR</b></p> <p>centripetal force is larger «than <math>W</math>» / <math>W</math> is smaller «than centripetal» ✓</p> <p>«so» experimental <math>mr</math> is smaller «than calculated value» ✓</p> <p><b>ALTERNATIVE 2</b> (refers to graph)</p> <p>reference to «friction force is» a systematic error «and does not affect gradient» ✓</p> <p>«so» <math>mr</math> 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  <b>OR</b>  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

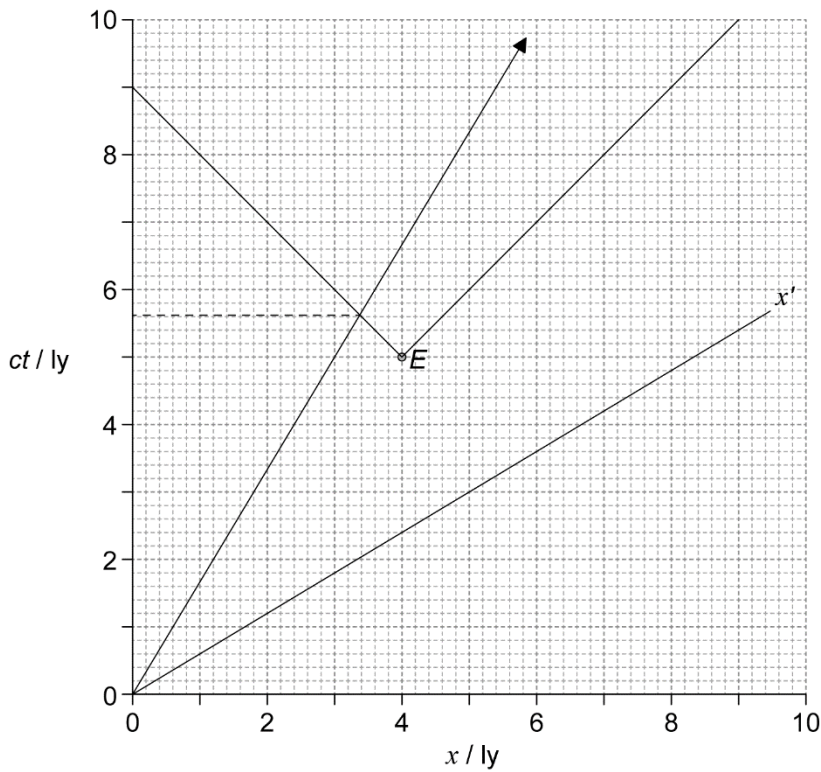
**Section B**

**Option A — Relativity**

Question			Answers	Notes	Total
3.	a		mention of electric <b>AND</b> magnetic fields ✓ <b>OR</b> 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 ✓	<i>OWTTE</i>	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» ✓	<i>OWTTE</i>	3



Question			Answers	Notes	Total
4.	a		constancy of time <b>OR</b> 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 $\gamma$  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 <b>all</b> negative signs for velocities  Award [2] marks for a bald correct answer	2

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

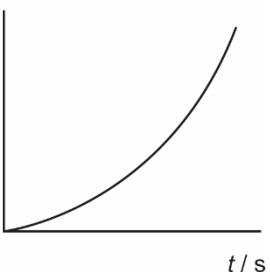
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(Question 5 continued)

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 <b>OR</b> mass of object when not in motion/in object's rest frame ✓		1
6	b		«rest energy $\Rightarrow$ (2.014 x 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» $\lambda$ reduced so frequency increases ✓	Award <b>[1 max]</b> 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 $\checkmark$ $\theta / \text{rad}$  $t / \text{s}$		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><b>OR</b></p> $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \quad \checkmark$ <p>using <math>I = \frac{2}{5}mr^2</math> <b>AND</b> <math>\omega = \frac{v}{r}</math> ✓</p> <p>with <b>correct manipulation</b> to find the requested relationship ✓</p>		3
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Question			Answers	Notes	Total
11.	a	i	«-» $3 \times 10^3$ «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» <b>OR</b> 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 = $6\pi\eta r v + \rho V g$  <b>OR</b>  $v = \frac{(1.26 \times 10^{-2} - 915 \times 7.24 \times 10^{-6}) \times 9.81}{6\pi \times 37.9 \times 10^{-3} \times 1.2 \times 10^{-2}} \checkmark$  $v = 6.84 \text{ «m s}^{-1}\text{»} \checkmark$	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

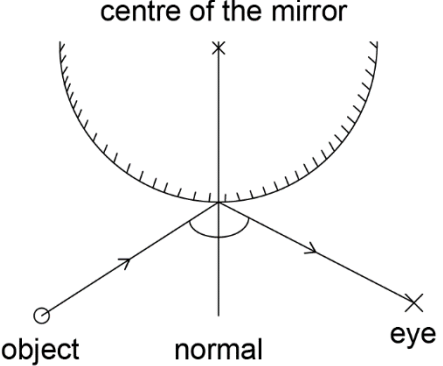
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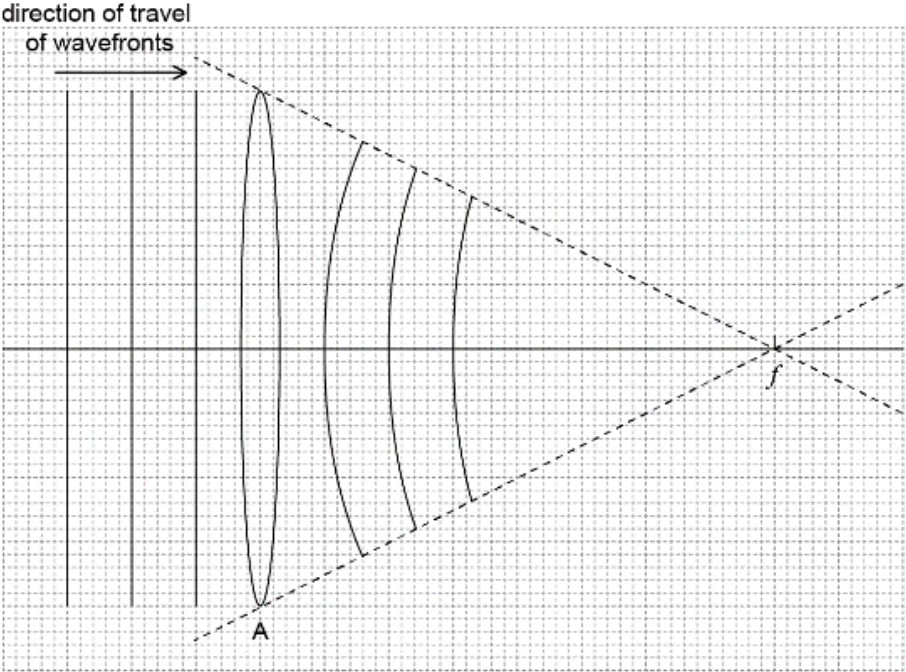


(Question 12 continued)

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

Option C — Imaging

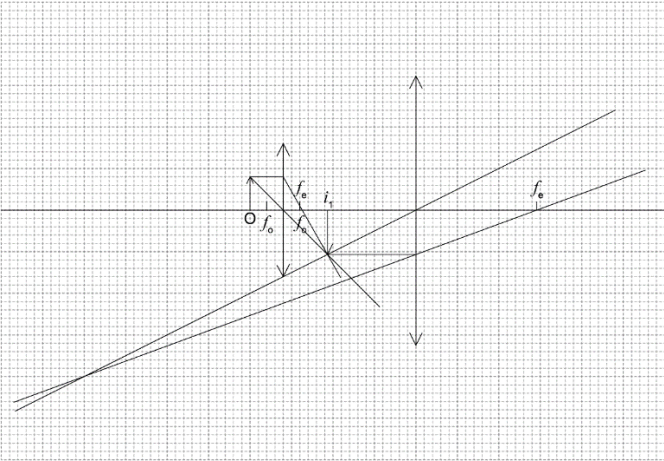
Question		Answers	Notes	Total
13.	a	<p>attempt to connect object and eye with ray showing equal angles of reflection such that reflection occurs within 1 hatch mark of position shown ✓</p> <p>construction showing normal at point of reflection ✓</p>  <p>centre of the mirror</p> <p>object      normal      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><b>OR</b></p> <p>do not form an image on a screen</p> <p><b>OR</b></p> <p>appear to have come from a point</p> <p><b>OR</b></p> <p>formed by extension of rays ✓</p>	<p><i>OWTTE.</i></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 <math>f</math> ✓</p>  <p>direction of travel of wavefronts</p>	<p><i>By eye.</i>  <i>Dotted construction lines are not required, allow wavefronts to extend beyond or be inside the dotted lines here.</i>                      Allow <b>[1max]</b> if only two wavefronts drawn.</p>	<p>2</p>
<p>14 b</p>	$\frac{1}{v} = \frac{1}{4.00} - \frac{1}{4.50} \quad \checkmark$ $v = 36.0 \text{ «cm»} \quad \checkmark$		<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 <b>[2 max]</b> 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 <b>[2]</b> 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 ✓</p> <p>forming an intermediate image at approximate position shown</p> <p><b>OR</b></p> <p>use of image from objective lens as object for eyepiece lens ✓</p> <p>any 2 correct rays for eyepiece lens from intermediate image ✓</p> <p>ray extension to form a final image ✓</p> 	<p>Allow ECF for MP2, MP3 &amp; MP4 for badly drawn rays.</p> <p>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 ✓	<i>Answer may be indicated on the photograph.</i>	1
20.	a		substitution of $L = \sigma AT^4$ into $b = \frac{L}{4\pi d^2}$ giving $b = \frac{\sigma AT^4}{4\pi d^2}$ ✓	<i>Removal of constants <math>\sigma</math> and <math>4\pi</math> is optional</i>	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» ✓	<i>OWTTE</i>	2



Question		Answers	Notes	Total
21.	a	<p>« <math>\frac{R_0}{R} =</math> »</p> <p><math>\frac{1}{1.11}</math> <b>OR</b> 0.90 <b>OR</b> 90% ✓</p>		1
21	b	<p>«Hubble's » measure of v/recessional speed uses redshift which is z</p> <p><b>OR</b></p> <p>redshift (z) of galaxies is proportional to distance «from earth»</p> <p><b>OR</b></p> <p>combines <math>v = Hd</math> <b>AND</b> <math>z = \frac{v}{c}</math> into one expression, e.g. <math>z = \frac{Hd}{c}</math> ✓</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 (<math>2630 L_{\odot}</math>) is very different «so it is not main sequence» <math>\checkmark</math></p>	<p>Allow calculation of <math>L^{\frac{1}{3.5}}</math> to give <math>M = 9.5 M_{\odot}</math> 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 <math>d = \sqrt{\frac{L}{4\pi b}} \checkmark</math></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 <b>[3]</b> 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 $\theta$ ✓ 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 <b>OR</b> star more massive and mass related to time in main sequence <b>OR</b> 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>	<b>2 max</b>

24	a	the temperature/«peak» wavelength/intensity «of the CMBR» varies «slightly» / is not constant in different directions ✓		<b>1</b>
	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» ✓		<b>2 max</b>