Markscheme

November 2020

Physics

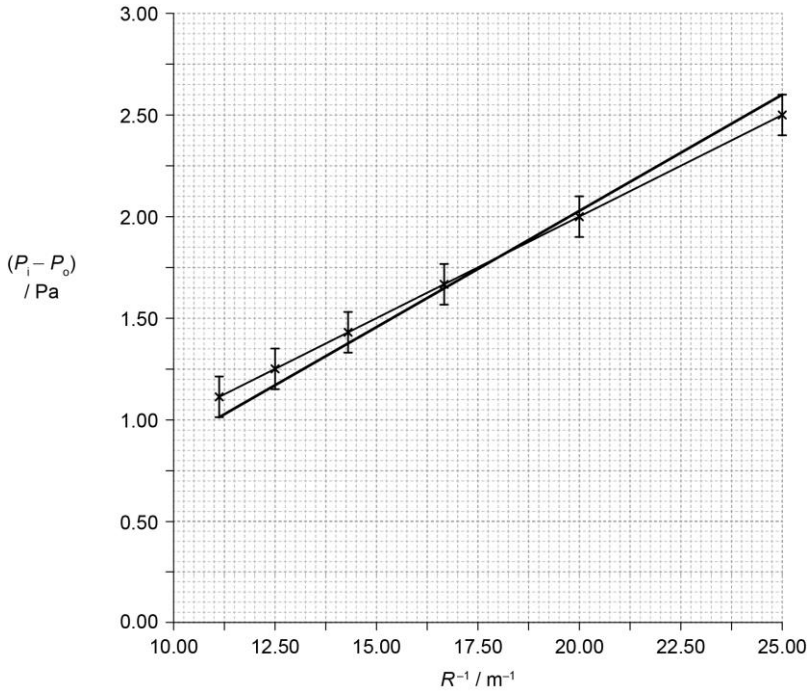
Higher level

Paper 3

28 pages

Section A

Question			Answers	Notes	Total
1.	**a**		«theory suggests» P_i-P_o is proportional to $\frac{1}{R}$ ✓ graph/line of best fit is straight/linear «so yes» ***OR*** graph/line of best fit passes through the origin «so yes» ✓	*MP1: Accept 'linear'* *MP2 do not award if there is any contradiction eg: graph not proportional, does not pass through origin.*	**2**
1	**b**	**i**	gradient = «4γ» = 0.10 ***OR*** use of equation with coordinates of a point✓ γ = 0.025 ✓	*MP1 allow gradients in range 0.098 to 0.102* *MP2 allow a range 0.024 to 0.026 for* γ	**2**
1	**b**	**ii**	kg s^{-2} ✓	*Accept* $\frac{kg}{s^2}$	**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		In order to draw a graph« of *W* versus $\frac{1}{T^2}$» ***OR*** to confirm proportionality between «*W* and T^{-2}» ***OR*** to confirm relationship between «*W* and *T*» ***OR*** because *W* is the independent variable in the experiment ✓	*OWTTE.*	1
2	b		**ALTERNATIVE 1** W + friction $= \frac{4\pi^2 mr}{T^2}$ ***OR*** centripetal force is larger «than W» / W is smaller «than centripetal» ✓ «so» experimental *mr* is smaller «than calculated value» ✓ **ALTERNATIVE 2** (refers to graph) reference to «friction force is» a systematic error «and does not affect gradient» ✓ «so» *mr* is the same ✓	*MP2 awarded only with correct justification. Candidates can gain zero, MP1 alone or full marks.* *OWTTE*	**2**

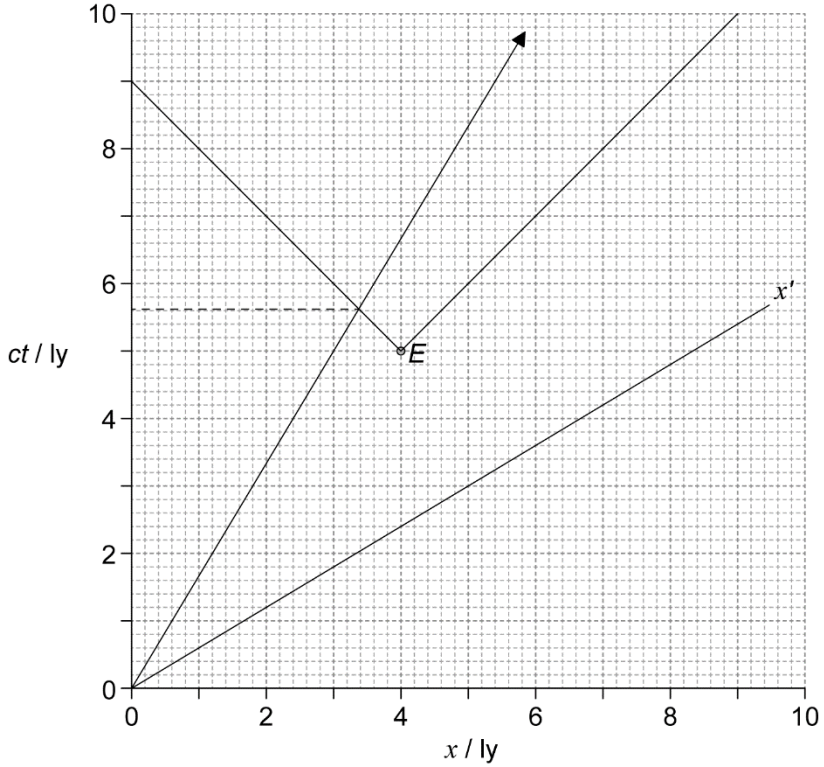
Question			Answers	Notes	Total
2	c	i	mention of mean/average value «of *T*» ✓ this reduces uncertainty in *T* / result ***OR*** more accurate/precise ✓	*Reference to "random errors average out" scores MP1* *Accept "closer to true value", "more reliable value" OWTTE for MP2*	**2**
2	c	ii	systematic errors «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**	γ = 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 x10^{8} 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**

(continued…)

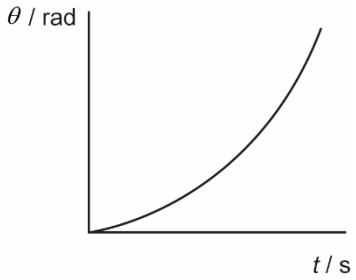
(Question 5 continued)

Question			Answers	Notes	Total
5.	**b**	**ii**	light cone from E «crosses *ct* at 9 so» intersection on *ct'*= 5.6 ± 0.2 y «on *ct* scale» ✓ γ = 1.25 ✓ so *t'*=**«** $\frac{5.6}{1.25}$ =»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 x 931.5) **«**MeV**»** ✓ **«***E*$_T$ = KE + rest energy = 270.0 + (2.014 x 931.5) =**»** 2146 **«**MeV**»** ✓	*Final answer accept 3.443x10^{-10}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**		$\omega_f^2 = 0 + 2 \times 0.110 \times 6 \times 2\pi$ ✓ $\omega_f = 2.88$ «rad s^{-1}»✓	*Other methods are possible.* *At least 2 sig figs for MP2.*	**2**
8	**b**		concave up from origin ✓ 		**1**
8	**c**		Γ=**«** I α so Γ=0.110 x 0.0216 =**»** 2.38 x 10^{-3} «N m» ✓		**1**
8	**d**		$\alpha = \frac{2.9^2}{2 \times 2\pi \times 30} =$ ***OR*** -0.022 «rad s^{-2} ✓ t **«** $= \frac{\omega_f - \omega_i}{\alpha} = \frac{-2.9}{-0.0220}$ **»** = 130 «s» ✓	*Other methods are possible.* *Award **[2]** marks for a bald correct answer*	**2**

Question			Answers	Notes	Total
9.	**a**		«person rotates» anticlockwise ✓ the person gains angular momentum «in the opposite direction to the new wheel motion**»** ✓ so that the total angular momentum is conserved ✓	*OWTTE* *Award **[1 max]** for a bald statement of conservation of angular momentum.*	**3**
9	**b**		the rotational kinetic energy has increased ✓ energy is provided by the person doing work **«**flipping the wheel**»** ✓	*OWTTE*	**2**

10.			conservation of rotational and linear energy ***OR*** $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$ ✓ using $I = \frac{2}{5}mr^2$ ***AND*** $\omega = \frac{v}{r}$ ✓ with **correct manipulation** to find the requested relationship ✓		**3**

Question			Answers	Notes	Total
11.	**a**	**i**	**«–»** 3x10^3 «J» ✓		**1**
11	**a**	**ii**	0 «J» ✓	*OWTTE*	**1**
11	**b**	**i**	use of $PV^{\frac{5}{3}}$ is constant « $4.0\times10^5\times(2.0\times10^{-2})^{\frac{5}{3}}=P_2\times(5.0\times10^{-2})^{\frac{5}{3}}$ » ✓ P_2 = 8.7x10^4 «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**

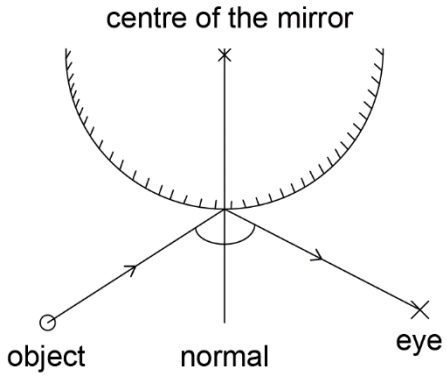
Question			Answers	Notes	Total
12.	**a**		incompressible ✓ non-viscous ✓ laminar/streamlined flow ✓		**2 max**
12	**b**		radius of sphere = 0.012 **«**m**»** ✓ weight of sphere = $6\pi\eta rv + \rho Vg$ ***OR*** $v = \frac{\left(1.26\times10^{-2} - 915\times7.24\times10^{-6}\right)\times9.81}{6\pi\times37.9\times10^{-3}\times1.2\times10^{-2}}$ ✓ v = 6.84 **«**m s^{-1}**»** ✓	*Accept use of g = 10 leading to v = 7.0* **«**m s^{-1}**»** *Allow implicit calculation of radius for MP1* *Do not allow ECF for MP3 if buoyant force omitted.*	**3**

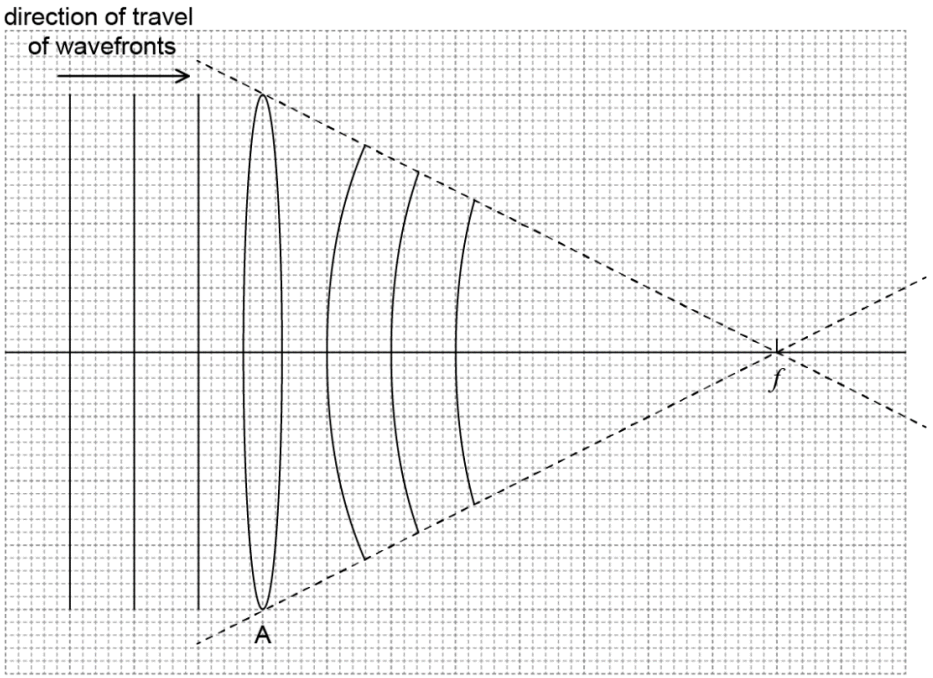
(continued…)

(Question 12 continued)

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

Option C — Imaging

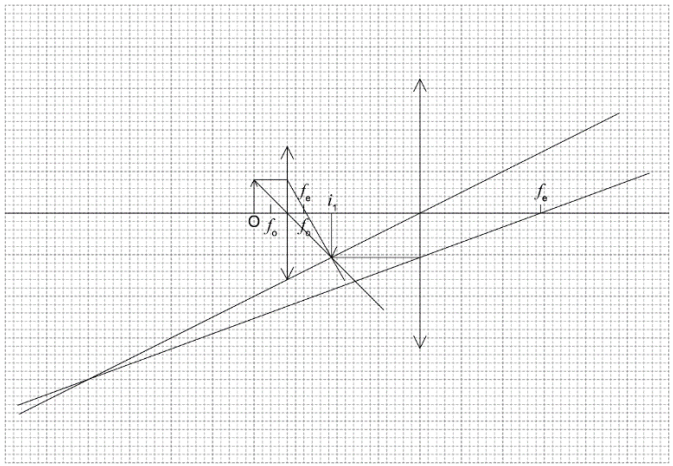
Question			Answers	Notes	Total
13.	**a**		attempt to connect object and eye with ray showing equal angles of reflection such that reflection occurs within 1 hatch mark of position shown ✓ construction showing normal at point of reflection ✓  	*Allow rays that are drawn freehand without a ruler - use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

Question			Answers	Notes	Total
14.	**a**		wavefront separation identical and equal to separation before the lens ✓ wavefronts converging, approximately centered on f ✓  	*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.*	**2**
14	**b**		$\frac{1}{v} = \frac{1}{4.00} - \frac{1}{4.50}$ ✓ v = 36.0 «cm» ✓		**2**

(continued…)

(Question 14 continued)

Question			Answers	Notes	Total
14.	**c**		A: $\frac{1}{-2.0}=\frac{1}{8}+\frac{1}{u}$ ✓ u = – 1.6 **«**cm**»** ✓ distance necessary= **«**36.0–1.6 =**»** 34.4 **«**cm**»** ✓	*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 0.4*m */ 40*cm.	**3**
14	**d**		**«** $m=-\frac{i}{o}=\frac{-36}{4.5}$ for A or $\frac{-8}{-1.6}$ for B**»** m_A = **«–»** 8 ***OR*** m_B = **«+»** 5 ✓ total magnification = **«–»** 40 ✓	*Allow **[2]** marks for a bald correct answer* *Allow ECF from (b) and (c).* *Eg if u=2.7*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**		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 ✓  	*Allow ECF for MP2, MP3 & MP4 for badly drawn rays.* *MP4 allow final image to be off the page*	**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**»** ✓	*Accept the reversed argument*	**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 ✓	*Accept the reverse argument*	**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 $L = \sigma A T^4$ into $b = \frac{L}{4\pi d^2}$ giving $b = \frac{\sigma A T^4}{4\pi d^2}$ ✓	*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**		« $\frac{R_0}{R} =$ **»** $\frac{1}{1.11}$ ***OR*** 0.90 ***OR*** 90% ✓		**1**
21	**b**		«Hubble's » measure of v/recessional speed uses redshift which is *z* ***OR*** redshift (*z*) of galaxies is proportional to distance «from earth» ***OR*** combines $v = Hd$ ***AND*** $z = \frac{v}{c}$ into one expression, e.g. $z = \frac{Hd}{c}$ ✓	*OWTTE*	**1**
21	**c**		reference to «redshift due to» expansion of the universe, «not recessional speed» ✓ expansion of universe stretches spacetime / increases distance between objects ✓ «so» wavelength stretches / increases leading to observed redshift ✓		**3**

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

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(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 ✓	*Allow heavier than iron for MP1*	**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**