M17/4/PHYSI/HP3/ENG/TZ2/XX/M

Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

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Physics

Higher level

Paper 3

26 pages

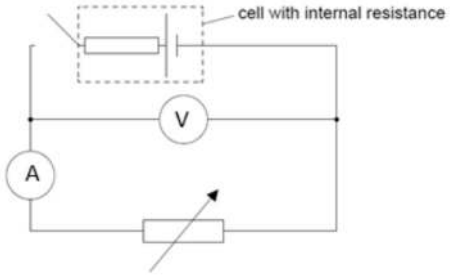
Section A

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 ✓	*Treat as neutral any reference to the origin.* *Allow "linear" for "straight line".*	**1**
	b	i	$d = 0.35 \pm 0.01$ ***AND*** $\Delta d = 0.05 \pm 0.01$ **«**cm**»** ✓ **«**$\frac{\Delta d}{d} = \frac{0.05}{0.35}$**»** $= 0.14$ ***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* $\times = \lambda 5 \quad 10^6$ *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	***ALTERNATIVE 1*** – if graph on page 4 is used $d^2 = 0.040 \times 10^{-4}$ «m^2» ✓ $d = 0.20 \times 10^{-2}$ «m» ✓ ***ALTERNATIVE 2*** – if graph on page 2 is used any evidence that *d* intercept has been determined ✓ $d = 0.20 \pm 0.05$ «cm» ✓	*For MP1 accept answers in range of 0.020 to 0.060 «cm_2» if they fail to use given value of "a".* *For MP2 accept answers in range 0.14 to 0.25 «cm».*	**2**

Question			Answers	Notes	Total
2.	a		correct labelling of both instruments ✓		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 $= 0.60\,\Omega$ ✓	*For MP1 – do not award if only* $R = \frac{V}{I}$ *is used.* *For MP2 points at least 1A apart must be used.* *For MP3 accept final answers in the range of* $0.55\,\Omega$ *to* $0.65\,\Omega$.	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

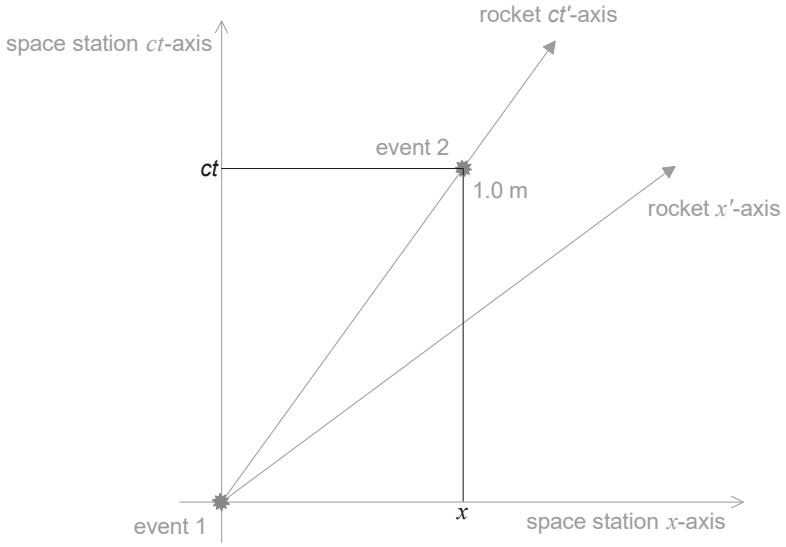
Question			Answers	Notes	Total
3.	a		the speed of light is a universal constant/invariant ***OR*** *c* does not depend on velocity of source/observer ✓ electric and magnetic fields/forces unified/frame of reference dependant ✓		**1 max**
	b		observer X will measure zero «magnetic or electric» force ✓ 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.			***ALTERNATIVE 1*** *— for answers in terms of time* overall idea that more muons are detected at the ground than expected «without time dilation» ✓ «Earth frame transit time $= \frac{2000}{0.98c}$» $= 6.8$ «μs» ✓ «Earth frame dilation of proper half-life $= 2.2\ \mu s \times 5$» $= 11$ «μs» ***OR*** «muon's proper transit time $= \frac{6.8\ \mu s}{5}$» $= 1.4$ «μs» ✓ ***ALTERNATIVE 2*** *– for answers in terms of distance* overall idea that more muons are detected at the ground than expected «without time dilation» ✓ «distance muons can travel in a proper lifetime $= 2.2\ \mu s \times 0.98c$» $= 650$ «m» ✓ «Earth frame lifetime distance due to time dilation $= 650\ m \times 5$» $= 3250$ «m» ***OR*** «muon frame distance travelled $= \frac{2000}{5}$» $= 400$ «m» ✓	*Accept answers from **one** of the alternatives.*	**3**

Question			Answers	Notes	Total
5.	**a**	**i**	the gamma factor is $\frac{5}{3}$ ***or*** 1.67 ✓ $L = \frac{450}{\frac{5}{3}} = 270$ «m» ✓	*Allow ECF from MP1 to MP2.*	**2**
	a	**ii**	$u' = \text{«}\frac{u-v}{1-\frac{uv}{c^2}} = \text{»} \frac{0.20c - 0.80c}{1 - 0.20 \times 0.80}$ ***OR*** $0.2c = \frac{0.80c + u'}{1 + 0.80u'}$ ✓ $u' = \text{«} - \text{»} 0.71c$ ✓	*Check signs and values carefully.*	**2**
	b	**i**	$\Delta t' = \text{«}\gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right) = \text{»} \frac{5}{3} \times \left(0 - \frac{(0.80c \times 9000)}{c^2}\right)$ ✓ $\Delta t' = \text{«} - \text{»} 4.0 \times 10^{-5}$ «s» ✓	*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	x coordinate as shown ✓ *ct* coordinate as shown ✓  	*Labels must be clear and unambiguous.* *Construction lines are optional.*	**2**
	c	ii	«in any other frame» *ct* is greater ✓ the interval $ct' = 1.0$ «m» is proper time ***OR*** *ct* is a dilated time ***OR*** $ct = \gamma ct'$ «$= \gamma$» ✓	*MP1 is a statement* *MP2 is an explanation*	**2**
	c	iii	use of $c^2t^2 - x^2 = c^2t'^2 - x'^2$ ✓ $c^2t^2 - x^2 = 1^2 - 0^2 = 1$ «m^2» ✓	*For MP1 equation must be used.* *Award **[2]** for correct answer that first finds x (1.33 m) and ct (1.66 m)*	**2**

Question			Answers	Notes	Total
6.			pion momentum is $\gamma mv = 1.2265 \times 140 \times 0.579 = 99.4$ **«**MeV c^{-1}**»** ✓ use of momentum conservation to realize that produced particles have equal and opposite momenta ✓ so for proton $\gamma v = \frac{99.4}{938} = 0.106c$ ✓ solving to get $v = 0.105c$ ✓	*Accept pion momentum calculation using* $E^2 = p^2c^2 + m^2c^4$. *Award* ***[2 max]*** *for a non-relativistic answer of* $v = 0.0864c$.	**4**

7.	**a**	**i**	the surface at which the escape speed is the speed for light ***OR*** the surface from which nothing/not even light can escape to the outside ***OR*** the surface of a sphere whose radius is the Schwarzschild radius ✓	*Accept distance as alternative to surface.*	**1**
	a	**ii**	use of $A = 4\pi R^2$ and $R = \frac{2GM}{c^2}$ ✓ **«**to get $A = \frac{16\pi G^2 M^2}{c^4}$**»**		**1**

(continued…)

(Question 7 continued)

Question			Answers	Notes	Total
	a	iii	since mass and energy can never leave a black hole and $A = \frac{16\pi G^2 M^2}{c^4}$ ***OR*** some statement that area is increasing with mass ✓ «the area cannot decrease»		**1**
	b		***ALTERNATIVE 1 —*** *(student/planet frame):* photon energy/frequency decreases with height ***OR*** there is a gravitational redshift ✓ detector in ceiling is approaching photons so Doppler blue shift ✓ two effects cancel/frequency unchanged ✓ ***ALTERNATIVE 2*** *– (box frame):* by equivalence principle box is an inertial frame ✓ so no force on photons ✓ so no redshift/frequency unchanged ✓		**3**

Option B — Engineering physics

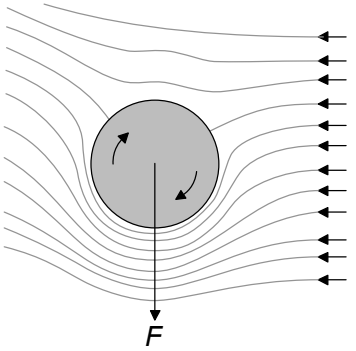
Question			Answers	Notes	Total
8.	**a**	**i**	zero ✓		**1**
	a	**ii**	the torque of each force is $9.60\times10^{3}\times6.0=5.76\times10^{4}$ **«**Nm**»** ✓ so the net torque is $2\times5.76\times10^{4}=1.15\times10^{5}$ **«**Nm**»** ✓	*Allow a one-step solution.*	**2**
	b		the angular acceleration is given by $\frac{1.15\times10^{5}}{1.44\times10^{4}}$ **«**$=8.0\,\text{s}^{-2}$**»** ✓ $\omega=\alpha t=8.0\times2.00=16$ **«** s^{-1} **»** ✓		**2**
	c	**i**	$1.44\times10^{4}\times16.0=(1.44\times10^{4}+4.80\times10^{3})\times\omega$ ✓ $\omega=12.0$**«**s^{-1}**»** ✓	*Allow ECF from (b).*	**2**
	c	**ii**	initial KE $\frac{1}{2}\times1.44\times10^{4}\times16.0^{2}=1.843\times10^{6}$ **«**J**»** ✓ final KE $\frac{1}{2}\times(1.44\times10^{4}+4.80\times10^{3})\times12.0^{2}=1.382\times10^{6}$ **«**J**»** ✓ loss of KE $=4.6\times10^{5}$ **«**J**»** ✓	*Allow ECF from part (c)(i).*	**3**

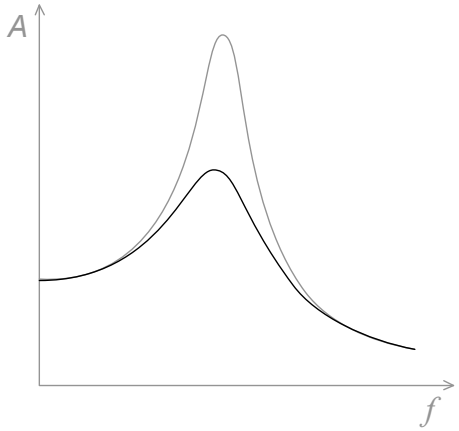
Question			Answers	Notes	Total
9.	a	i	$\Delta U = 0$ so $Q = \Delta U + W = 0 + 416 = 416$ **«J»** ✓	*Answer given, mark is for the proof.*	1
	a	ii	***ALTERNATIVE 1*** use $pV^{\frac{5}{3}} = c$ to get $TV^{\frac{2}{3}} = c$ ✓ hence $T_C = T_A\left(\frac{V_A}{V_C}\right)^{\frac{2}{3}} = 612 \times 0.5^{\frac{2}{3}}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

(continued…)

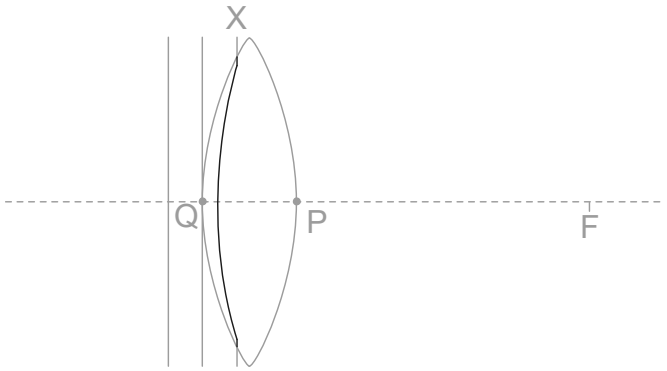
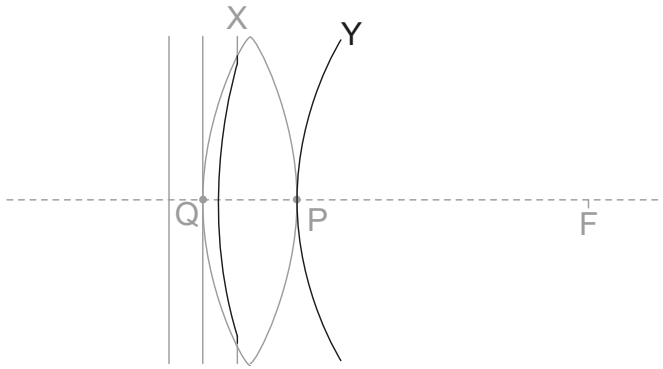
(Question 9 continued)

Question			Answers	Notes	Total
	a	**iv**	$e = \frac{Q_{in} - Q_{out}}{Q_{in}} = \frac{416 - 332}{416}$ ✓ $e = 0.20$ ✓	*Allow* $\frac{416 - 330}{416}$. *Allow e = 0.21.*	**2**
	b		entropy is largest at B ✓ entropy increases from A to B because T = constant but volume increases so more disorder **or** $\Delta S = \frac{Q}{T}$ and $Q > 0$ so $\Delta S > 0$ ✓ 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 $\Delta S < 0$ ✓		**3**

Question			Answers	Notes	Total
10.	**a**	**i**	$\Delta p = \text{«}\frac{1}{2}\rho({v_T}^2 - {v_L}^2) = \frac{1}{2}\times 1.20\times(28.4^2 - 16.6^2) = \text{»}\ 318.6\ \text{«Pa»}$ ✓ $F = \text{«}318.6\times\frac{2.50\times10^{-2}}{4} = \text{»}\ 1.99\ \text{«N»}$ ✓	*Allow ECF from MP1.*	**2**
	a	**ii**	downward arrow of any length or position ✓	*Accept any downward arrow not just vertical.*  	**1**
	b		flow is laminar/non-turbulent ***OR*** Bernoulli's equation holds ***OR*** pressure is uniform on each hemisphere ***OR*** diameter of ball can be ignored / ρgz = constant ✓		**1**

Question			Answers	Notes	Total
11.	**a**		lower peak ✓ identical behaviour to original curve at extremes ✓ peak frequency shifted to the left ✓  	*Award **[0]** if peak is higher.* *For MP2 do not accept curves which cross.*	**2 max**
	b	**i**	displacement of vibrator is 0 ✓ because phase difference is $\frac{\pi}{2}$ ***or*** 90° ***or*** $\frac{1}{4}$ period ✓	*Do not penalize sign of phase difference.* *Do not accept $\frac{\lambda}{4}$ for MP2*	**2**
	b	**ii**	resonant $f = 0.125$ **« Hz »** ✓ $\frac{25}{(2\pi \times 0.125)} = 32$ **« s »** ✓	*Watch for ECF from MP1 to MP2.*	**2**

Option C — Imaging

Question			Answers	Notes	Total
12.	**a**	**i**	line of correct curvature as shown ✓ 		**1**
	a	**ii**	line of approximately correct curvature as shown ✓ 		**1**

(continued…)

(Question 12 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**

13.	**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
14.	**a**		calculation of critical angle at core–cladding boundary «$1.52 \times \sin\theta_C = 1.48$» $\theta_C = 76.8^\circ$ ✓ refraction angle at air–core boundary $90^\circ - 76.8^\circ = 13.2^\circ$ ✓ «$1.52 \times \sin 13.2^\circ = \sin A$» $A = 20.3^\circ$ ✓	*Allow ECF from MP1 to MP2 to MP3.*	**3**
	b	**i**	*attenuation*: output signal has smaller area ✓ *dispersion*: output signal is wider than input signal ✓	*OWTTE* *OWTTE*	**2**
	b	**ii**	attenuation = «$10 \log \frac{I}{I_0} = 10 \log \frac{77}{320}$» «–» 6.2 «dB» ✓ $\frac{-6.2}{5.1}$ = «–» 1.2 «dB km^{-1}» ✓	*Allow intensity ratio to be inverted.* *Allow ECF from MP1 to MP2.*	**2**

Question			Answers	Notes	Total
15.	**a**		accept any value between 1 MHz to 20 MHz ✓		**1**
	b		an alternating electrical signal is applied to a crystal ✓ crystal vibrates emitting sound ✓ frequency of vibration of crystal is the same as the frequency of the ac ✓ mention of piezoelectric effect/crystal ✓		**3 max**
	c	**i**	$Z_{\text{muscle}} = 1.71 \times 10^{6}$ **«** $\text{kg m}^{-2}\,\text{s}^{-1}$ **»** ✓		**1**
	c	**ii**	**«** $\frac{I_2}{I_1} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$ **»** $= 4.3 \times 10^{-3}$ ✓ $I_2 =$ **«** $0.012 \times (4.3 \times 10^{-3}) =$ **»** 5.1×10^{-5} **«** W cm^{-2} **»** ✓	*Allow ECF from (c)(i).* *Allow ECF from MP1 to MP2.*	**2**

Question			Answers	Notes	Total
16.			a «strong» magnetic field aligns proton «spins» ✓ an RF signal is applied to excite protons ***OR*** change spin up to spin down state ✓ protons de-excite/return to lower energy state ***OR*** proton relaxation occurs ✓ with emission of RF radiation «that is detected» ✓	*OWTTE* *Treat any mention of the following as neutral as they are not strictly relevant to the question: gradient field, Larmor frequency, precession, resonance, 3-D image*	**3 max**

Option D — Astrophysics

Question			Answers	Notes	Total
17.	**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**	$L = \sigma A T^4 = 5.67 \times 10^{-8} \times 4\pi \times (2.0 \times 10^4)^2 \times (10^6)^4$ ✓ $L = 3 \times 10^{26}$ **«** 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
18.	**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 **«**$= 2.7\,\text{K}$**»** is close to predicted value ✓	*For MP4 and MP5 idea of "prediction" is needed*	**2 max**
	c	**i**	$\frac{v}{c} = z \Rightarrow v = 0.084 \times 3 \times 10^5 = 2.52 \times 10^4$ **«**km s^{-1}**»** ✓ $d = \frac{v}{H_0} = \frac{2.52 \times 10^4}{68} = 370.6 \approx 370$ **«**Mpc**»** ✓	*Allow ECF from MP1 to MP2.*	**2**
	c	**ii**	type Ia have a known luminosity/are standard candles ✓ measure apparent brightness ✓ determine distance from $d = \sqrt{\frac{L}{4\pi b}}$ ✓	*Must refer to type Ia. Do not accept other methods (parallax, Cepheids)*	**3**

Question			Answers	Notes	Total
19.	**a**	**i**	the cosmological origin of redshift implies that the wavelength is proportional to the scale factor: $\lambda \propto R$ ✓ combining this with Wien's law $\lambda \propto \frac{1}{T}$ ***OR*** use of $kT \propto \frac{hc}{\lambda}$ ✓ **«**gives the result**»**	*Evidence of correct algebra is needed as relationship* $T = \frac{k}{R}$ *is given.*	**2**
	a	**ii**	use of $T \propto \frac{1}{R}$ ✓ $= 2.8 \times 1100 = 3080 \approx 3100$ **«**K**»** ✓		**2**
	b		CMB anisotropies are related to fluctuations in density which are the cause for the formation of structures/nebulae/stars/galaxies ✓	*OWTTE*	**1**

Question			Answers	Notes	Total
20.	**a**		dark matter is invisible/cannot be seen directly ***OR*** does not interact with EM force/radiate light/reflect light ✓ interacts with gravitational force ***OR*** accounts for galactic rotation curves ***OR*** accounts for some of the “missing” mass/energy of galaxies/the universe ✓	*OWTTE*	**2**
	b		«from data booklet formula» $v = \sqrt{\frac{4\pi G\rho}{3}}\, r$ substitute to get $v = \sqrt{\frac{4\pi Gk}{3}}$ ✓	*Substitution of ρ must be seen.*	**1**
	c		curve A shows that the outer regions of the galaxy are rotating faster than predicted ✓ this suggests that there is more mass in the outer regions that is not visible ***OR*** more mass in the form of dark matter ✓	*OWTTE*	**2**