

# Markscheme

**May 2017**

**Physics**

**Higher level**

**Paper 3**

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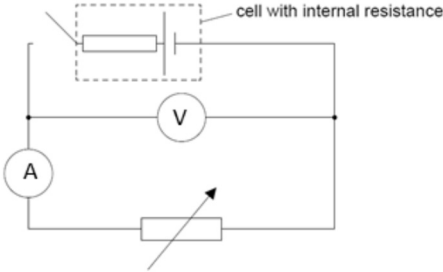
**Section A**

Question			Answers	Notes	Total
1.	a		it is not possible to draw a straight line through all the error bars <b>OR</b> 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	$d = 0.35 \pm 0.01$ <b>AND</b> $\Delta d = 0.05 \pm 0.01$ «cm» ✓ $\left\langle \frac{\Delta d}{d} = \frac{0.05}{0.35} \right\rangle = 0.14$ <b>OR</b> $\frac{1}{7}$ <b>or</b> 14 % <b>or</b> 0.1 ✓	Allow final answers in the range of 0.11 to 0.18. Allow [1 max] for 0.03 to 0.04 if $\times = \lambda 5 \cdot 10^6$ 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	<p><b>ALTERNATIVE 1</b> – if graph on page 4 is used</p> <p><math>d^2 = 0.040 \times 10^{-4} \text{ «m}^2 \text{»} \checkmark</math></p> <p><math>d = 0.20 \times 10^{-2} \text{ «m»} \checkmark</math></p> <p><b>ALTERNATIVE 2</b> – if graph on page 2 is used</p> <p>any evidence that <math>d</math> intercept has been determined <math>\checkmark</math></p> <p><math>d = 0.20 \pm 0.05 \text{ «cm»} \checkmark</math></p>	<p><i>For MP1 accept answers in range of 0.020 to 0.060 « cm<sub>2</sub> » if they fail to use given value of “a”.</i></p> <p><i>For MP2 accept answers in range 0.14 to 0.25 « cm » .</i></p>	2

Question		Answers	Notes	Total
2.	a	correct labelling of both instruments ✓	 <p>The diagram shows a circuit with a cell (labeled 'cell with internal resistance') connected in series with an ammeter (A) and a variable resistor. A voltmeter (V) is connected in parallel across the variable resistor.</p>	1
	b	$V = E - Ir$ ✓ large triangle to find gradient and correct read-offs from the line <b>OR</b> use of intercept $E = 1.5\text{ V}$ and another correct data point ✓ internal resistance = $0.60\ \Omega$ ✓	<p><i>For MP1 – do not award if only <math>R = \frac{V}{I}</math> is used.</i></p> <p><i>For MP2 points at least 1A apart must be used.</i></p> <p><i>For MP3 accept final answers in the range of <math>0.55\ \Omega</math> to <math>0.65\ \Omega</math>.</i></p>	3

(continued...)

(Question 2 continued)

Question		Answers	Notes	Total
	<b>c</b>	<b>i</b>	a non-zero reading when a zero reading is expected/no current is flowing <b>OR</b> a calibration error ✓	OWTTE Do not accept just “systematic error”.  <b>1</b>
	<b>c</b>	<b>ii</b>	the error causes «all» measurements to be high/different/incorrect ✓  effect on calculations/gradient will cancel out <b>OR</b> effect is that value for $r$ is unchanged ✓	Award [ <b>1 max</b> ] for statement of “no effect” without valid argument.  OWTTE  <b>2</b>

**Section B**

**Option A — Relativity**

Question		Answers	Notes	Total
3.	a	the speed of light is a universal constant/invariant <b>OR</b> 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 <b>[2 max]</b> 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.	<p><b>ALTERNATIVE 1</b> — for answers in terms of time</p> <p>overall idea that more muons are detected at the ground than expected «without time dilation» ✓</p> <p>« Earth frame transit time = <math>\frac{2000}{0.98c}</math> » = 6.8 « μs » ✓</p> <p>« Earth frame dilation of proper half-life = <math>2.2 \mu\text{s} \times 5</math> » = 11 « μs »</p> <p><b>OR</b></p> <p>« muon's proper transit time = <math>\frac{6.8 \mu\text{s}}{5}</math> » = 1.4 « μs » ✓</p> <p><b>ALTERNATIVE 2</b> – for answers in terms of distance</p> <p>overall idea that more muons are detected at the ground than expected «without time dilation» ✓</p> <p>« distance muons can travel in a proper lifetime = <math>2.2 \mu\text{s} \times 0.98c</math> » = 650 « m » ✓</p> <p>« Earth frame lifetime distance due to time dilation = <math>650 \text{ m} \times 5</math> » = 3250 « m »</p> <p><b>OR</b></p> <p>« muon frame distance travelled = <math>\frac{2000}{5}</math> » = 400 « m » ✓</p>	<p>Accept answers from <b>one</b> of the alternatives.</p>	<p>3</p>



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

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

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

(continued...)

(Question 7 continued)

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

Option B — Engineering physics

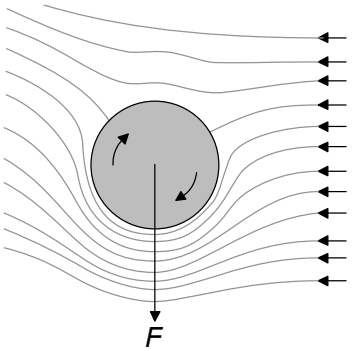
Question			Answers	Notes	Total
8.	a	i	zero ✓		1
	a	ii	the torque of each force is $9.60 \times 10^3 \times 6.0 = 5.76 \times 10^4$ «Nm» ✓ so the net torque is $2 \times 5.76 \times 10^4 = 1.15 \times 10^5$ «Nm» ✓	Allow a one-step solution.	2
	b		the angular acceleration is given by $\frac{1.15 \times 10^5}{1.44 \times 10^4}$ «=8.0 s <sup>-2</sup> » ✓ $\omega = \alpha t = 8.0 \times 2.00 = 16$ « s <sup>-1</sup> » ✓		2
	c	i	$1.44 \times 10^4 \times 16.0 = (1.44 \times 10^4 + 4.80 \times 10^3) \times \omega$ ✓ $\omega = 12.0$ «s <sup>-1</sup> » ✓	Allow ECF from (b).	2
	c	ii	initial KE $\frac{1}{2} \times 1.44 \times 10^4 \times 16.0^2 = 1.843 \times 10^6$ «J» ✓ final KE $\frac{1}{2} \times (1.44 \times 10^4 + 4.80 \times 10^3) \times 12.0^2 = 1.382 \times 10^6$ «J» ✓ loss of KE = $4.6 \times 10^5$ «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» ✓	<i>Answer given, mark is for the proof.</i>	1
	a	ii	<p><b>ALTERNATIVE 1</b></p> <p>use <math>pV^{\frac{5}{3}} = c</math> to get <math>TV^{\frac{2}{3}} = c</math> ✓</p> <p>hence <math>T_C = T_A \left(\frac{V_A}{V_C}\right)^{\frac{2}{3}} = 612 \times 0.5^{\frac{2}{3}} = 385.54</math> ✓</p> <p>«<math>T_C \approx 386</math>K»</p> <p><b>ALTERNATIVE 2</b></p> <p><math>P_C V_C^\gamma = P_A V_A^\gamma</math> giving <math>P_C = 1.26 \times 10^6</math> «Pa» ✓</p> <p><math>\frac{P_C V_C}{T_C} = \frac{P_A V_A}{T_A}</math> giving <math>T_C = 1.26 \times \frac{612}{2} = 385.54</math> «K» ✓</p> <p>«<math>T_C \approx 386</math>K»</p>	<p><i>Answer of 386K is given. Look carefully for correct working if answers are to 3 SF.</i></p> <p><i>There are other methods:</i></p> <p><i>Allow use of <math>P_B = 2 \times 10^6</math> «Pa» and <math>\frac{P}{T}</math> is constant for BC.</i></p> <p><i>Allow use of <math>n = 0.118</math> and <math>T_C = \frac{P_C V_C}{nR}</math>.</i></p>	2
	a	iii	<p><math>Q = \Delta U + W = \frac{3 P_A V_A}{2 T_A} \Delta T + 0</math> ✓</p> <p><math>Q = \frac{3}{2} \times \frac{4.00 \times 10^6 \times 1.50 \times 10^{-4}}{612} \times (386 - 612)</math> ✓</p> <p>«-332 J»</p>	<p><i>Answer of 330 J given in the question.</i></p> <p><i>Look for correct working or more than 2 SF.</i></p>	2

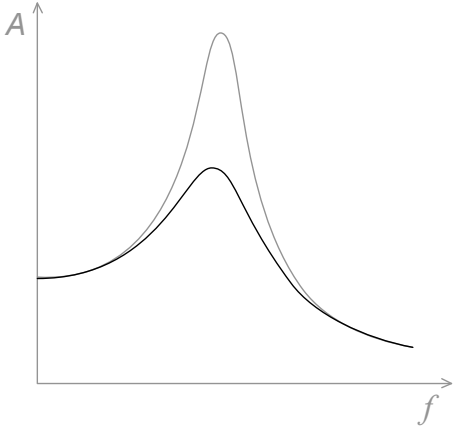
(continued...)

(Question 9 continued)

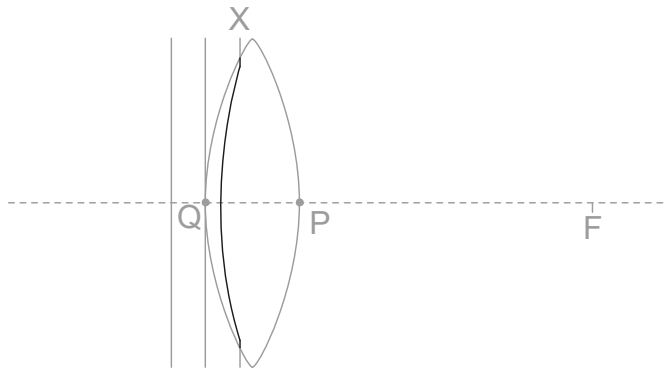
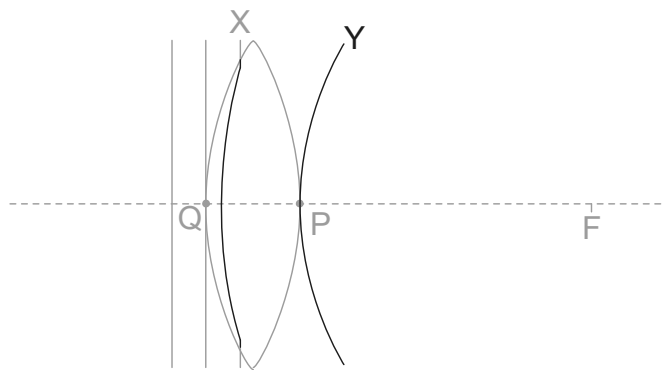
Question		Answers	Notes	Total
a	iv	$e = \frac{Q_{in} - Q_{out}}{Q_{in}} = \frac{416 - 332}{416} \checkmark$ $e = 0.20 \checkmark$	Allow $\frac{416 - 330}{416}$ . Allow $e = 0.21$ .	2
b		entropy is largest at B $\checkmark$ entropy increases from A to B because $T = \text{constant}$ but volume increases so more disorder <b>or</b> $\Delta S = \frac{Q}{T}$ and $Q > 0$ so $\Delta S > 0 \checkmark$ entropy is constant along CA because it is adiabatic, $Q = 0$ and so $\Delta S = 0$ <b>OR</b> entropy decreases along BC since energy has been removed, $\Delta Q < 0$ so $\Delta S < 0 \checkmark$		3

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



Question		Answers	Notes	Total	
11.	a	<p>lower peak ✓</p> <p>identical behaviour to original curve at extremes ✓</p> <p>peak frequency shifted to the left ✓</p> 	<p>Award [0] if peak is higher.</p> <p>For MP2 do not accept curves which cross.</p>	2 max	
	b	i	<p>displacement of vibrator is 0 ✓</p> <p>because phase difference is <math>\frac{\pi}{2}</math> or <math>90^\circ</math> or <math>\frac{1}{4}</math> period ✓</p>	<p>Do not penalize sign of phase difference.</p> <p>Do not accept <math>\frac{\lambda}{4}</math> for MP2</p>	2
	b	ii	<p>resonant <math>f = 0.125</math> « Hz » ✓</p> <p><math>\frac{25}{(2\pi \times 0.125)} = 32</math> « s » ✓</p>	<p>Watch for ECF from MP1 to MP2.</p>	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>b</b>	wave travels slower in glass than in air <b>OR</b> 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	<b>2 max</b>
	<b>c</b>	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 <b>[1 max]</b> for a bald answer of $12 - 4 = 8$ «cm».	<b>2</b>

<b>13.</b>	<b>a</b>	states $f_o + f_e = 90$ <b>AND</b> $\frac{f_o}{f_e} = 17$ ✓  solves to give $f_o = 85$ <b>AND</b> $f_e = 5$ «cm» ✓	Both needed.  Both needed.	<b>2</b>
	<b>b</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 <b>[2]</b> for an answer of $6.1 \times 10^7$ «m» if the factor of 17 is missing in MP1.	<b>3</b>
	<b>c</b>	operation day and night ✓ operation at all wavelengths/no atmospheric absorption ✓ operation without atmospheric turbulence/light pollution ✓	Accept any other sensible advantages.	<b>2 max</b>

Question		Answers	Notes	Total	
14.	a	calculation of critical angle at core–cladding boundary $\llcorner 1.52 \times \sin \theta_c = 1.48 \gg \theta_c = 76.8^\circ \checkmark$  refraction angle at air–core boundary $90^\circ - 76.8^\circ = 13.2^\circ \checkmark$ $\llcorner 1.52 \times \sin 13.2^\circ = \sin A \gg A = 20.3^\circ \checkmark$	Allow ECF from MP1 to MP2 to MP3.	3	
	b	i	<i>attenuation</i> : output signal has smaller area $\checkmark$  <i>dispersion</i> : output signal is wider than input signal $\checkmark$	OWTTE  OWTTE	2
	b	ii	attenuation = $\llcorner 10 \log \frac{I}{I_0} = 10 \log \frac{77}{320} = \gg \llcorner - \gg 6.2 \llcorner \text{dB} \gg \checkmark$  $\frac{-6.2}{5.1} = \llcorner - \gg 1.2 \llcorner \text{dB km}^{-1} \gg \checkmark$	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	$Z_{\text{muscle}} = 1.71 \times 10^6 \text{ « kg m}^{-2} \text{ s}^{-1} \text{ » } \checkmark$	1
	c	ii	$\checkmark \left\langle \frac{I_2}{I_1} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} \right\rangle = 4.3 \times 10^{-3} \checkmark$  $I_2 = \checkmark \langle 0.012 \times (4.3 \times 10^{-3}) \rangle = \checkmark 5.1 \times 10^{-5} \text{ « W cm}^{-2} \text{ » } \checkmark$	2

*Allow ECF from (c)(i).*  
*Allow ECF from MP1 to MP2.*

Question	Answers	Notes	Total
16.	<p>a «strong» magnetic field aligns proton «spins» ✓</p> <p>an RF signal is applied to excite protons</p> <p><b>OR</b></p> <p>change spin up to spin down state ✓</p> <p>protons de-excite/return to lower energy state</p> <p><b>OR</b></p> <p>proton relaxation occurs ✓</p> <p>with emission of RF radiation «that is detected» ✓</p>	<p>OWTTE</p> <p><i>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</i></p>	<p><b>3 max</b></p>

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	$L = \sigma AT^4 = 5.67 \times 10^{-8} \times 4\pi \times (2.0 \times 10^4)^2 \times (10^6)^4$ ✓ $L = 3 \times 10^{26}$ «W» OR $L = 2.85 \times 10^{26}$ «W» ✓	Allow ECF for [1 max] if $\pi r^2$ used (gives $7 \times 10^{25}$ «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 <b>or</b> 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 ✓ $T \ll 2.7 \text{ K}$ is close to predicted value ✓	For MP4 and MP5 idea of "prediction" is needed	2 max
	c	i $\frac{v}{c} = z \Rightarrow v = 0.084 \times 3 \times 10^5 = 2.52 \times 10^4 \text{ «kms}^{-1}\text{»} \checkmark$ $d = \frac{v}{H_0} = \frac{2.52 \times 10^4}{68} = 370.6 \approx 370 \text{ «Mpc»} \checkmark$	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	<p>the cosmological origin of redshift implies that the wavelength is proportional to the scale factor: <math>\lambda \propto R</math> ✓</p> <p>combining this with Wien's law <math>\lambda \propto \frac{1}{T}</math></p> <p><b>OR</b></p> <p>use of <math>kT \propto \frac{hc}{\lambda}</math> ✓</p> <p>«gives the result»</p>	<p><i>Evidence of correct algebra is needed as relationship <math>T = \frac{k}{R}</math> is given.</i></p>	2
	a	ii	<p>use of <math>T \propto \frac{1}{R}</math> ✓</p> <p>= <math>2.8 \times 1100 = 3080 \approx 3100</math> «K» ✓</p>		2
	b		<p>CMB anisotropies are related to fluctuations in density which are the cause for the formation of structures/nebulae/stars/galaxies ✓</p>	OWTTE	1

Question		Answers	Notes	Total
20.	a	dark matter is invisible/cannot be seen directly <b>OR</b> does not interact with EM force/radiate light/reflect light ✓  interacts with gravitational force <b>OR</b> accounts for galactic rotation curves <b>OR</b> 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 $\rho$ 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 <b>OR</b> more mass in the form of dark matter ✓	OWTTE	2