

Markscheme

May 2018

Physics

Higher level

Paper 3

30 pages

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Section A

Question		Answers	Notes	Total
1.	a	<p>distance fallen = $654 - 12 = 642$ «mm» ✓</p> <p>absolute uncertainty = $2 + 0.1$ «mm» $\approx 2 \times 10^{-3}$ «m» or $= 2.1 \times 10^{-3}$ «m» or 2.0×10^{-3} «m» ✓</p>	Accept answers in mm or m	2
1.	b	<p>$\llbracket a = \frac{2s}{t^2} = \frac{2 \times 0.642}{0.363^2} \rrbracket = 9.744$ «ms⁻²» ✓</p> <p>fractional uncertainty in distance = $\frac{2}{642}$ AND fractional uncertainty in time = $\frac{0.002}{0.363}$ ✓</p> <p>total fractional uncertainty = $\frac{\Delta s}{s} + 2 \frac{\Delta t}{t}$ «= 0.00311 + 2 × 0.00551» ✓</p> <p>total absolute uncertainty = 0.1 or 0.14 AND same number of decimal places in value and uncertainty, ie: 9.7 ± 0.1 or 9.74 ± 0.14 ✓</p>	<p>Accept working in % for MP2 and MP3</p> <p>Final uncertainty must be the absolute uncertainty</p>	4

Question			Answers	Notes	Total
2.	a		<p>combines the two equations to obtain result</p> <p>«for example $\frac{1}{I} = K^2 (C + x)^2 = \frac{4\pi}{P} (C + x)^2$» ✓</p> <p>OR</p> <p>reverse engineered solution – substitute $K = 2\sqrt{\frac{\pi}{P}}$ into $\frac{1}{I} = K^2 (C + x)^2$ to get</p> <p>$I = \frac{P}{4\pi(C + x)^2}$ ✓</p>	<p><i>There are many ways to answer the question, look for a combination of two equations to obtain the third one</i></p>	1
2.	b	i	<p>extrapolating line to cross x-axis / use of x-intercept</p> <p>OR</p> <p>Use $C = \frac{y\text{-intercept}}{\text{gradient}}$</p> <p>OR</p> <p>use of gradient and one point, correctly substituted in one of the formulae ✓</p> <p>accept answers between 3.0 and 4.5 «cm» ✓</p>	<p><i>Award [1 max] for negative answers</i></p>	2

(continued...)

(Question 2 continued)

Question			Answers	Notes	Total
2.	b	ii	<p>ALTERNATIVE 1</p> <p>Evidence of finding gradient using two points <u>on the line</u> at least 10 cm apart ✓</p> <p>Gradient found in range: 115–135 or 1.15–1.35 ✓</p> <p>Using $P = \frac{4\pi}{K^2}$ to get value between 6.9×10^{-4} and 9.5×10^{-4} «W» and POT correct ✓</p> <p>Correct unit, W and answer to 1, 2 or 3 significant figures ✓</p> <p>ALTERNATIVE 2</p> <p>Finds $I\left(\frac{1}{y^2}\right)$ from use of one point (x and y) on the line with $x > 6\text{cm}$ and C from (b)(i) to use in $I = \frac{P}{4\pi(C+x)^2}$ or</p> $\frac{1}{\sqrt{I}} = Kx + KC \quad \checkmark$ <p>Correct re-arrangement to get P between 6.9×10^{-4} and 9.5×10^{-4} «W» and POT correct ✓</p> <p>Correct unit, W and answer to 1, 2 or 3 significant figures ✓</p>	<p><i>For 3rd marking point if no unit given, assume answer is in W</i></p> <p><i>Award [3 max] for an answer between 6.9W and 9.5W (POT penalized in 3rd marking point)</i></p> <p><i>Alternative 2 is worth [3 max]</i></p>	4

(continued...)

(Question 2 continued)

Question		Answers	Notes	Total
2.	c	this graph will be a curve / not be a straight line ✓ more difficult to determine value of K OR more difficult to determine value of C OR suitable mathematical argument ✓	OWTTE	2

Section B

Option A — Relativity

Question			Answers	Notes	Total
3.	a	i	1.25c ✓		1
3.	a	ii	<p>ALTERNATIVE 1</p> $u' = \frac{(0.50 + 0.75)}{1 + 0.5 \times 0.75} c \quad \checkmark$ <p>0.91c ✓</p> <p>ALTERNATIVE 2</p> $u' = \frac{-0.50 - 0.75}{1 - (-0.5 \times 0.75)} c \quad \checkmark$ <p>-0.91c ✓</p>		2
3.	b		nothing can travel faster than the speed of light (therefore (a)(ii) is the valid answer) ✓	OWTTE	1

Question		Answers	Notes	Total
4.	a	<p>0.60c OR $1.8 \times 10^8 \text{ «m s}^{-1}\text{»} \checkmark$</p>		1
4.	b	<p>ALTERNATIVE 1 time interval in the Earth frame = $90 \times \gamma = 112.5$ minutes \checkmark «in Earth frame it takes 112.5 minutes for ship to reach station» so distance = $112.5 \times 60 \times 0.60c \checkmark$ $1.2 \times 10^{12} \text{ «m»} \checkmark$</p> <p>ALTERNATIVE 2 Distance travelled according in the spaceship frame = $90 \times 60 \times 0.6c \checkmark$ = $9.72 \times 10^{11} \text{ «m»} \checkmark$ Distance in the Earth frame «= $9.72 \times 10^{11} \times 1.25$» = $1.2 \times 10^{12} \text{ «m»} \checkmark$</p>		3

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	c		signal will take « $112.5 \times 0.60 \Rightarrow 67.5$ «minutes» to reach Earth «as it travels at c » OR signal will take « $\frac{1.2 \times 10^{12}}{3 \times 10^8} \Rightarrow 4000$ «s» ✓ total time « $= 67.5 + 112.5$ » = 180 minutes or 3.00 h or 3:00am ✓		2
4.	d	i	line from event E to A, upward and to left with A on ct axis (approx correct) ✓ line from event A to B, upward and to right with B on ct' axis (approx correct) ✓ both lines drawn with ruler at 45 (judge by eye) ✓	eg: 	3

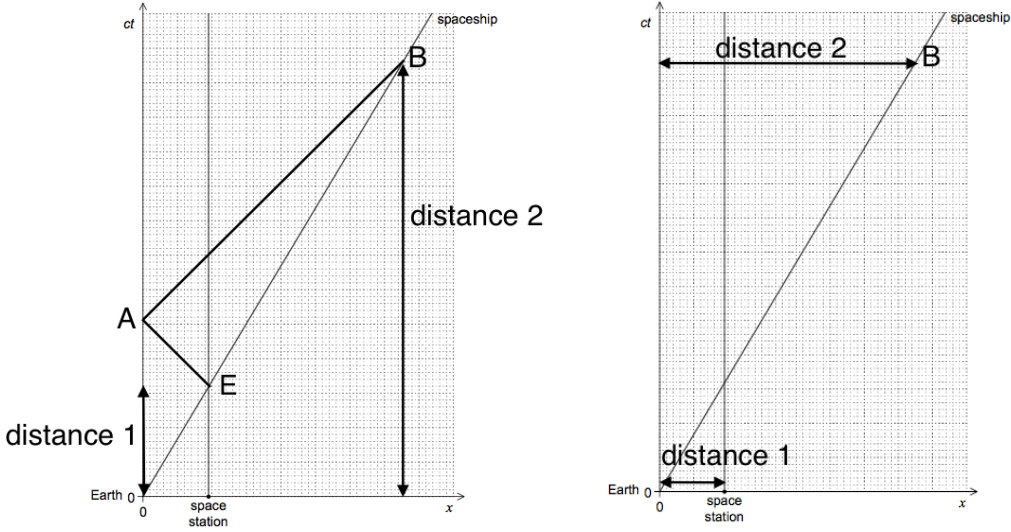
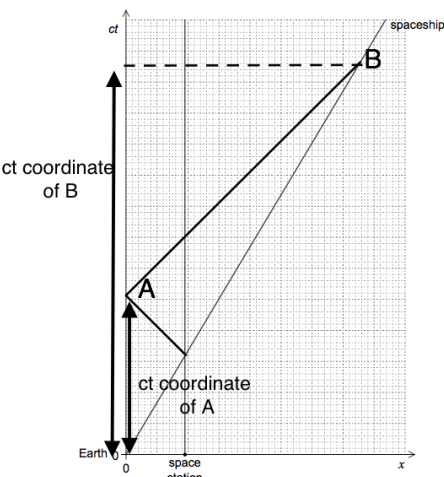
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(Question 4 continued)

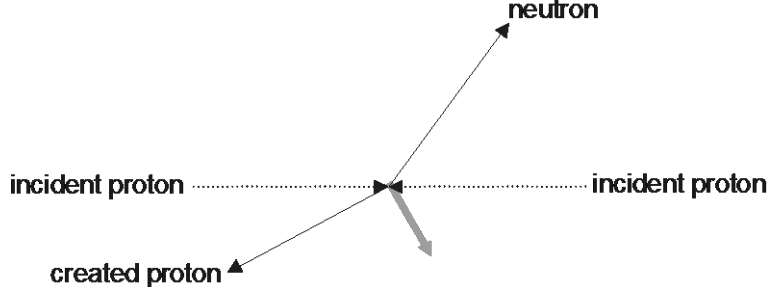
Question			Answers	Notes	Total
4.	d	ii	<p>ALTERNATIVE 1</p> <p>«In spaceship frame»</p> <p>Finds the ratio $\frac{OB}{OE}$ (or by similar triangles on x or ct axes), value is approximately 4 ✓</p> <p>hence time elapsed $\approx 4 \times 90\text{mins} \approx 6\text{h}$ «so clock time is $\approx 6:00$» ✓</p>	<p>Alternative 1:</p> <p>Allow similar triangles using x-axis or ct-axis, such as $\frac{\text{distance 2}}{\text{distance 1}}$ from diagrams below</p>	2

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	d	ii	<p>ALTERNATIVE 2</p> <p>«In Earth frame»</p> <p>Finds the ratio $\frac{ct \text{ coordinate of B}}{ct \text{ coordinate of A}}$, value is approximately 2.5 ✓</p> <p>hence time elapsed $\approx \frac{2.5 \times 3h}{1.25} \approx 6h$</p> <p>«so clock time is $\approx 6:00$» ✓</p>	 <p>ALTERNATIVE 2:</p> 	

Question			Answers	Notes	Total
5.	a		quantity that is the same/constant in all inertial frames ✓		1
5.	b	i	spacetime interval = $27^2 - 15^2 = 504$ «m ² » ✓		1
5.	b	ii	<p>ALTERNATIVE 1</p> <p>Evidence of $x' = 0$ ✓</p> $t' \text{ «} = \frac{\sqrt{504}}{c} \text{»} = 7.5 \times 10^{-8} \text{ «s»} \checkmark$ <p>ALTERNATIVE 2</p> <p>$\gamma = 1.2$ ✓</p> $t' \text{ «} = \frac{9 \times 10^{-8}}{1.2} \text{»} = 7.5 \times 10^{-8} \text{ «s»} \checkmark$		2
5.	c		<p>observer B measures the proper time and this is the shortest time measured</p> <p>OR</p> <p>time dilation occurs «for B's journey» according to A</p> <p>OR</p> <p>observer B is stationary relative to the particle, observer A is not ✓</p>		1

Question			Answers	Notes	Total
6.	a		$\gamma \ll \frac{3350}{938} \gg = 3.57 \checkmark$		1
6.	b	i	energy of pion = $(3350 \times 2) - 6200 = 500 \ll \text{MeV} \gg \checkmark$ $500^2 = p^2 c^2 + 140^2 \checkmark$ $p = 480 \ll \text{MeV c}^{-1} \gg \checkmark$		3
6.	b	ii	path of pion constructed in direction around 4–5 o'clock by eye \checkmark	eg: 	1

Question			Answers	Notes	Total
7.	a	i	boundary inside which events cannot be communicated to an outside observer OR distance/surface at which escape velocity = c ✓	OWTTE	1
7.	a	ii	mass of black hole = 7.2×10^{36} «kg» ✓ $\left\langle \frac{2GM}{c^2} \right\rangle = 1 \times 10^{10}$ «m» ✓		2
7.	b		wherever S-2 is in orbit, time observed is longer than 5.0 s ✓ when closest to the star S-2 periodic time dilated more than when at greatest distance ✓ Justification using formula or time is more dilated in stronger gravitational fields ✓		2 max

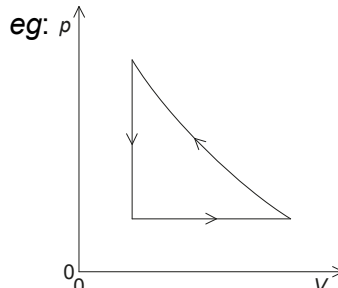
Option B — Engineering physics

Question			Answers	Notes	Total
8.	a	i	an object's resistance to change in rotational motion OR equivalent of mass in rotational equations ✓	OWTTE	1
8.	a	ii	$\Delta KE + \Delta \text{rotational KE} = \Delta GPE$ OR $\frac{1}{2}mv^2 + \frac{1}{2}I\frac{v^2}{r^2} = mgh$ ✓ $\frac{1}{2} \times 0.250 \times v^2 + \frac{1}{2} \times 1.3 \times 10^{-4} \times \frac{v^2}{1.44 \times 10^{-4}} = 0.250 \times 9.81 \times 0.36$ ✓ $v = 1.2 \text{ « m s}^{-1} \text{ »}$ ✓		3
8.	a	iii	$\omega \ll = \frac{1.2}{0.012} \gg = 100 \text{ « rad s}^{-1} \text{ »}$ ✓		1
8.	b	i	force in direction of motion ✓ so linear speed increases ✓		2
8.	b	ii	force gives rise to anticlockwise/opposing torque on wheel ✓ so angular speed decreases ✓	OWTTE	2

Question		Answers	Notes	Total
9.	a	<p>ALTERNATIVE 1</p> <p>«Using $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ »</p> $V_2 = \frac{47.1 \times (273 + 19)}{(273 - 12)} \checkmark$ $V_2 = 52.7 \text{ «m}^3\text{»} \checkmark$ <p>ALTERNATIVE 2</p> <p>«Using $PV = nRT$ »</p> $V = \frac{243 \times 8.31 \times (273 + 19)}{11.2 \times 10^3} \checkmark$ $V = 52.6 \text{ «m}^3\text{»} \checkmark$		2
9.	b	$W \text{ «} = P\Delta V \text{»} = 11.2 \times 10^3 \times (52.7 - 47.1) \checkmark$ $W = 62.7 \times 10^3 \text{ «J»} \checkmark$	<p>Accept $66.1 \times 10^3 \text{ J}$ if 53 used</p> <p>Accept $61.6 \times 10^3 \text{ J}$ if 52.6 used</p>	2
9.	c	$\Delta U \text{ «} = \frac{3}{2} nR\Delta T \text{»} = 1.5 \times 243 \times 8.31 \times (19 - (-12)) = 9.39 \times 10^4 \checkmark$ $Q \text{ «} = \Delta U + W \text{»} = 9.39 \times 10^4 + 6.27 \times 10^4 \checkmark$ $Q = 1.57 \times 10^5 \text{ «J»} \checkmark$	<p>Accept 1.60×10^5 if $66.1 \times 10^3 \text{ J}$ used</p> <p>Accept 1.55×10^5 if $61.6 \times 10^3 \text{ J}$ used</p>	3

(continued...)

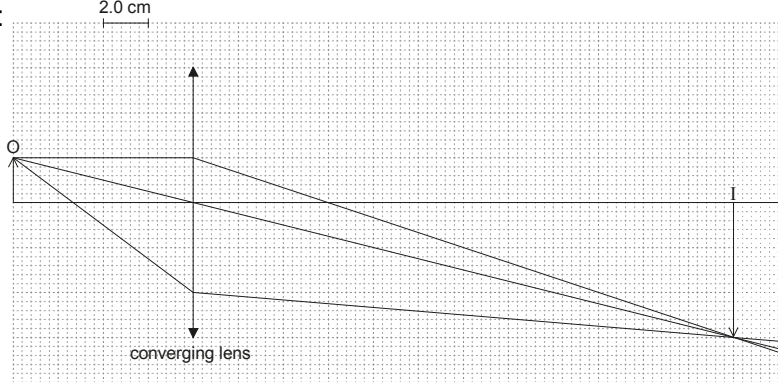
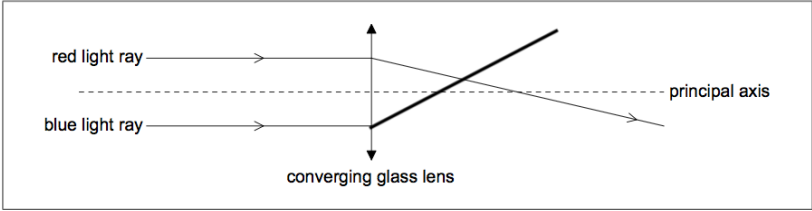
(Question 9 continued)

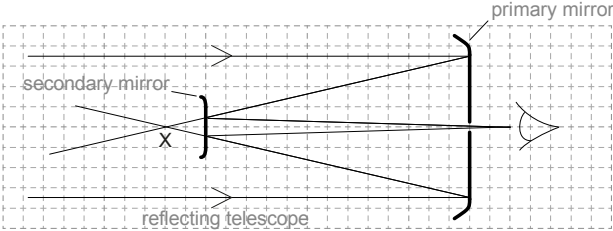
Question			Answers	Notes	Total
9.	d	i	concave curve from RHS of present line to point above LHS of present line ✓ vertical line from previous curve to the beginning ✓	eg: p 	2
9.	d	ii	energy is removed from the gas and so entropy decreases OR temperature decreases «at constant volume (less disorder)» so entropy decreases ✓	OWTTE	1
9.	e		different paradigms/ways of thinking/modelling/views ✓ allows testing in different ways ✓ laws can be applied different situations ✓	OWTTE	1 max

Question		Answers	Notes	Total	
10.	a	$\frac{1}{2} \rho v_x^2 = p_Y - p_X = \rho g \Delta h \checkmark$ $v_x = \sqrt{2 \times 9.8 \times (0.32 - 0.10)} \checkmark$ $v_x = 2.08 \text{ «ms}^{-1}\text{»} \checkmark$		3	
10.	b	i	$R = \left\langle \frac{vr\rho}{\eta} = \frac{2.1 \times 0.25 \times 10^3}{8.9 \times 10^{-4}} \right\rangle 5.9 \times 10^5 \checkmark$	1	
10.	b	ii	$(R > 1000)$ flow is not laminar, so assumption is invalid \checkmark	OWTTE	1

Question		Answers	Notes	Total
11.	a	general shape as shown \checkmark peak at 6 kHz \checkmark graph does not touch the f axis \checkmark		3
11.	b	peak broadens \checkmark reduced maximum amplitude / graph shifted down \checkmark resonant frequency decreases / graph shifted to the left \checkmark		2 max

Option C — Imaging

Question			Answers	Notes	Total
12.	a	i	<p>constructs ray parallel to principal axis and then to image position</p> <p>OR</p> <p>$u = 8\text{cm}$ and $v = 24\text{cm}$ and lens formula ✓</p> <p>6 «cm» ✓</p>	<p>eg:</p>  <p>converging lens</p> <p>Allow answers in the range of 5.6 to 6.4 cm</p>	2
12.	a	ii	<p>$m = \text{«-»}3.0$ ✓</p>		1
12.	b		<p>completes diagram with blue focal point closer to lens ✓</p> <p>blue light/rays refracted/deviated more</p> <p>OR</p> <p>speed of blue light is less than speed of red light ✓</p> <p>OR</p> <p>different colors/wavelengths have different focal points/converge at different points ✓</p>	<p>First marking point can be explained in words or seen on diagram</p>  <p>converging glass lens</p>	2

Question		Answers	Notes	Total
13.	a	where the extensions of the reflected rays from the primary mirror would meet, with construction lines ✓	eg: 	1
13.	b	greater magnification ✓		1
13.	c	«use of $\frac{1.22\lambda}{d}$ to get» resolution of 6.7×10^{-9} «rad» ✓ $\frac{5.8 \times 10^{-7}}{6.7 \times 10^{-9}} = 87$ «m» ✓ some reference to difficulty in making optical mirrors/lenses of this size ✓	Allow $\frac{5.8 \times 10^{-7}}{5.5 \times 10^{-9}} = 105$ «m»	3

Question			Answers	Notes	Total
14.	a		$\text{sinc} = \frac{1.4444}{1.4475}$ <i>or</i> $\text{sinc} = 0.9978$ ✓ critical angle = 86.2° » ✓ with cladding only rays travelling nearly parallel to fibre axis are transmitted OR pulse broadening/dispersion will be reduced ✓	OWTTE	3
14.	b	i	$\text{attenuation} = \ll 10 \log \frac{I}{I_0} \gg = 10 \log \frac{2.0 \times 10^{-6}}{400 \times 10^{-6}}$ ✓ $\text{attenuation} = \ll - \gg 23 \ll \text{dB} \gg$ ✓	Accept $10 \log \frac{400}{2.0}$ for first marking point	2
14.	b	ii	$185 \times 0.200 = 37$ loss over length of cable ✓ $\ll \frac{37 - 23}{12} = 1.17 \gg$ so two amplifiers are sufficient ✓		2
14.	b	iii	mention of material dispersion ✓ mention that rays become separated in time OR mention that ray A travels slower/arrives later than ray B ✓		2

(continued...)

(Question 14 continued)

Question		Answers	Notes	Total
14.	c	high bandwidth/data transfer rates ✓ low distortion/Low noise/Faithful reproduction ✓ high security ✓ fast «fibre» broadband/internet ✓ high quality optical audio ✓ medical endoscopy ✓	<i>Allow any other verifiable sensible advantage</i>	1 max
15.	a	many/array of transducers send ultrasound through body/object ✓ B scan made from many A scans in different directions ✓ the reflection from organ boundaries gives rise to position ✓ the amplitude/size gives brightness to the B scan ✓ 2D/3D image formed «by computer» ✓		3 max

(continued...)

(Question 15 continued)

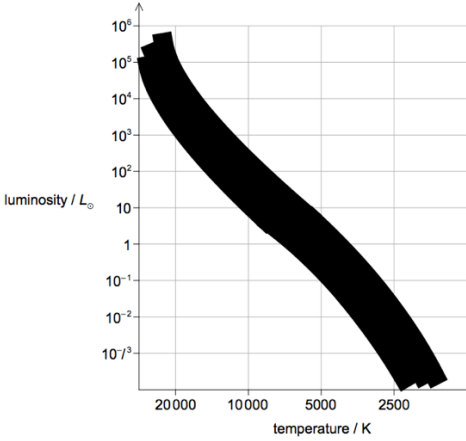
Question			Answers	Notes	Total
15.	b	i	the thickness of tissue that reduces the intensity «of the X-rays» by a half OR $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$ where $x_{\frac{1}{2}}$ is the half value thickness and μ is attenuation coefficient ✓	<i>Symbols must be defined for mark to be awarded</i>	1
15.	b	ii	after fat layer, $I_{\text{fat}} = I_0 e^{-0.4499 \times 5.00}$ ✓ after muscle layer, $I = I_{\text{fat}} e^{-0.8490 \times 4.00}$ ✓ $I = 0.003533 I_0$ or 0.35% ✓		3
15.	b	iii	«high energies factors:» less attenuation/more penetration ✓ more damage to the body ✓ «so» stronger signal leaves the body OR «so» used in «most» medical imaging techniques ✓ «low energy factors:» must be used with enhancement techniques ✓ greater attenuation/less penetration ✓ «so» more damage to the body «on surface layers» OR «so» unwanted in «most» medical imaging techniques ✓		3 max

Option D — Astrophysics

Question			Answers	Notes	Total
16.	a		photon/fusion/radiation force/pressure balances gravitational force/pressure ✓ gives both directions correctly (outwards radiation, inwards gravity) ✓	OWTTE	2
16.	b		« $L \propto M^{3.5}$ for main sequence » luminosity of $P = 2.5$ «luminosity of the Sun» ✓		1
16.	c	i	$L_{Gacrux} = 5.67 \times 10^{-8} \times 4\pi \times (58.5 \times 10^9)^2 \times 3600^4$ ✓ $L_{Gacrux} = 4.1 \times 10^{29}$ «W» ✓ $\frac{L_{Gacrux}}{L_{\odot}} \ll = \frac{4.1 \times 10^{29}}{3.85 \times 10^{26}} \gg = 1.1 \times 10^3$ ✓		3
16.	c	ii	if the star is too far then the parallax angle is too small to be measured OR stellar parallax is limited to closer stars ✓	OWTTE	1

(continued...)

(Question 16 continued)

Question			Answers	Notes	Total
16.	d	i	line or area roughly inside shape shown – judge by eye ✓	<p><i>Accept straight line or straight area at roughly 45°</i></p> 	1
16.	d	ii	P between $1 L_{\odot}$ and $10^1 L_{\odot}$ on main sequence drawn ✓		1

(continued...)

(Question 16 continued)

Question			Answers	Notes	Total
16.	d	iii	at $10^3 L_{\odot}$, further to right than 5000 K and to the left of 2500 K (see shaded region)✓	<p>The figure is a log-log plot of luminosity relative to the Sun (L_{\odot}) on the vertical axis versus temperature in Kelvin (K) on the horizontal axis. The vertical axis has major ticks at 10^{-3}, 10^{-2}, 10^{-1}, 1, 10^2, 10^3, 10^4, 10^5, and 10^6. The horizontal axis has major ticks at 20000, 10000, 5000, and 2500. A shaded rectangular region is located between 5000 K and 2500 K on the x-axis and between 10^3 and 10^4 on the y-axis.</p>	1

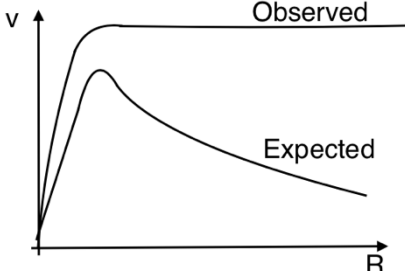
(continued...)

(Question 16 continued)

Question		Answers	Notes	Total
16.	e	<p>ALTERNATIVE 1</p> <p>Main sequence to red giant ✓</p> <p><u>planetary nebula</u> with <u>mass</u> reduction/loss</p> <p>OR</p> <p><u>planetary nebula</u> with mention of remnant <u>mass</u> ✓</p> <p>white dwarf ✓</p> <p>ALTERNATIVE 2</p> <p>Main sequence to red supergiant region ✓</p> <p><u>Supernova</u> with <u>mass</u> reduction/loss</p> <p>OR</p> <p><u>Supernova</u> with mention of remnant <u>mass</u> ✓</p> <p>neutron star</p> <p>OR</p> <p>Black hole ✓</p>	OWTTE for both alternatives	3

Question		Answers	Notes	Total
17.	a	<p>use of gradient or any coordinate pair to find $H_0 \llcorner \frac{v}{d} \llcorner$ or $\frac{1}{H_0} \llcorner \frac{d}{v} \llcorner \checkmark$</p> <p>convert Mpc to m and km to m «for example $\frac{82 \times 10^3}{10^6 \times 3.26 \times 9.46 \times 10^{15}} \llcorner \llcorner \checkmark$</p> <p>age of universe $\llcorner \frac{1}{H_0} \llcorner = 3.8 \times 10^{17} \llcorner \llcorner \llcorner \llcorner \checkmark$</p>	<p>Allow final answers between 3.7×10^{17} and $3.9 \times 10^{17} \llcorner \llcorner \llcorner \llcorner$ or $4 \times 10^{17} \llcorner \llcorner \llcorner \llcorner$</p>	3
17.	b	<p>non-accelerated/uniform rate of expansion</p> <p>OR</p> <p>H_0 constant over time \checkmark</p>	OWTTE	1
17.	c	<p>$z \llcorner \frac{v}{c} \llcorner = \frac{4.6 \times 10^4 \times 10^3}{3.00 \times 10^8} = 0.15 \checkmark$</p> <p>$\frac{R}{R_0} = \llcorner z + 1 \llcorner = 1.15 \checkmark$</p> <p>$\frac{R_0}{R} = \llcorner \frac{1}{1.15} \llcorner = 0.87$</p> <p>OR</p> <p>87 % of the present size \checkmark</p>		3

Question		Answers	Notes	Total
18.	a	<p>«For a star to form»: magnitude of PE of gas cloud > KE of gas cloud OR Mass of cloud > Jean's mass OR Jean's criterion is the critical mass ✓ hence a hot diffuse cloud could have KE which is too large/PE too small OR hence a cold dense cloud will have low KE/high PE OR a cold dense cloud is more likely to exceed Jeans mass OR a hot diffuse cloud is less likely to exceed the Jeans mass ✓</p>	Accept $E_p + E_k < 0$	2
18.	b	<p>Neutron capture creates heavier isotopes / heavier nuclei / more unstable nucleus ✓ <u>β^- decay</u> of heavy elements/iron increases atomic number «by 1» ✓</p>	OWTTE	2

Question		Answers	Notes	Total
19.	a	<p>«rotational» velocity of stars are expected to decrease as distance from centre of galaxy increases ✓</p> <p>the observed velocity of outer stars is constant/greater than predicted ✓</p> <p>implying large mass on the edge «which is dark matter» ✓</p>	<p>OWTTE</p> <p>1st and 2nd marking points can be awarded from an annotated sketch with similar shape as the one below</p> 	3
19.	b	<p>data from <u>type 1a supernovae</u> shows universe expanding at an accelerated rate ✓</p> <p>gravity was expected to slow down the expansion of the universe</p> <p>OR</p> <p>this did not fit the hypotheses at that time ✓</p> <p>dark energy counteracts/opposes gravity</p> <p>OR</p> <p>dark energy causes the acceleration ✓</p>	OWTTE	3