

Markscheme

May 2018

Physics

Higher level

Paper 3

30 pages

This markscheme is the property of the International Baccalaureate and must **not** be reproduced or distributed to any other person without the authorization of the IB Global Centre, Cardiff.

Section A

Question			Answers	Notes	Total
1.	a		distance fallen = $654 - 12 = 642$ «mm» ✓ absolute uncertainty = $2 + 0.1$ «mm» $\approx 2 \times 10^{-3}$ «m» or 2.1×10^{-3} «m» or 2.0×10^{-3} «m» ✓	Accept answers in mm or m	2
1.	b		$\ll a = \frac{2s}{t^2} = \frac{2 \times 0.642}{0.363^2} \gg = 9.744$ «ms⁻²» ✓ fractional uncertainty in distance = $\frac{2}{642}$ AND fractional uncertainty in time = $\frac{0.002}{0.363}$ ✓ total fractional uncertainty = $\frac{\Delta s}{s} + 2 \frac{\Delta t}{t}$ «= 0.00311 + 2 × 0.00551» ✓ 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 ✓	Accept working in % for MP2 and MP3 Final uncertainty must be the absolute uncertainty	4

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

(continued...)

(Question 2 continued)

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

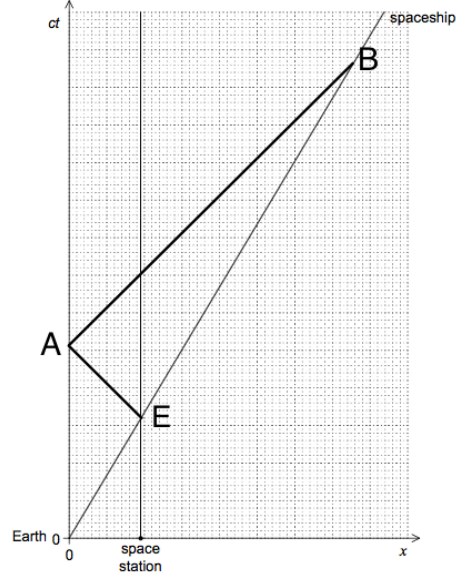
Option A — Relativity

Question			Answers	Notes	Total
3.	a	i	$1.25c$ ✓		1
3.	a	ii	ALTERNATIVE 1 $u' = \frac{(0.50 + 0.75)}{1 + 0.5 \times 0.75} c$ ✓ $0.91c$ ✓ ALTERNATIVE 2 $u' = \frac{-0.50 - 0.75}{1 - (-0.5 \times 0.75)} c$ ✓ $-0.91c$ ✓		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		$0.60c$ OR $1.8 \times 10^8 \text{ «m s}^{-1}\text{»} \checkmark$		1
4.	b		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 = $112.5 \times 60 \times 0.60c \checkmark$ $1.2 \times 10^{12} \text{ «m»} \checkmark$ 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 «= $9.72 \times 10^{11} \times 1.25$ » = $1.2 \times 10^{12} \text{ «m»} \checkmark$		3

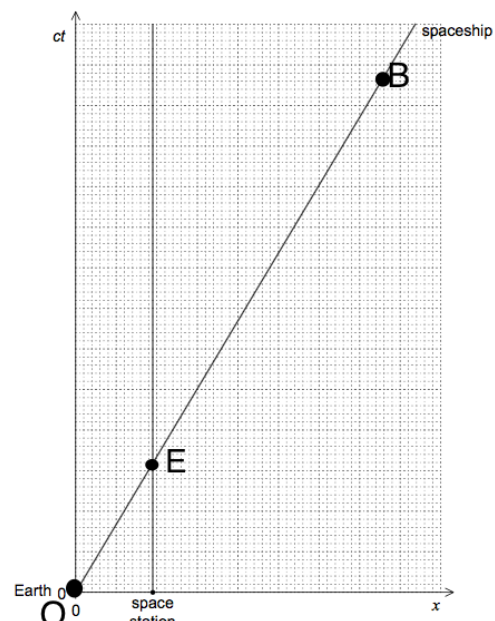
(continued...)

(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

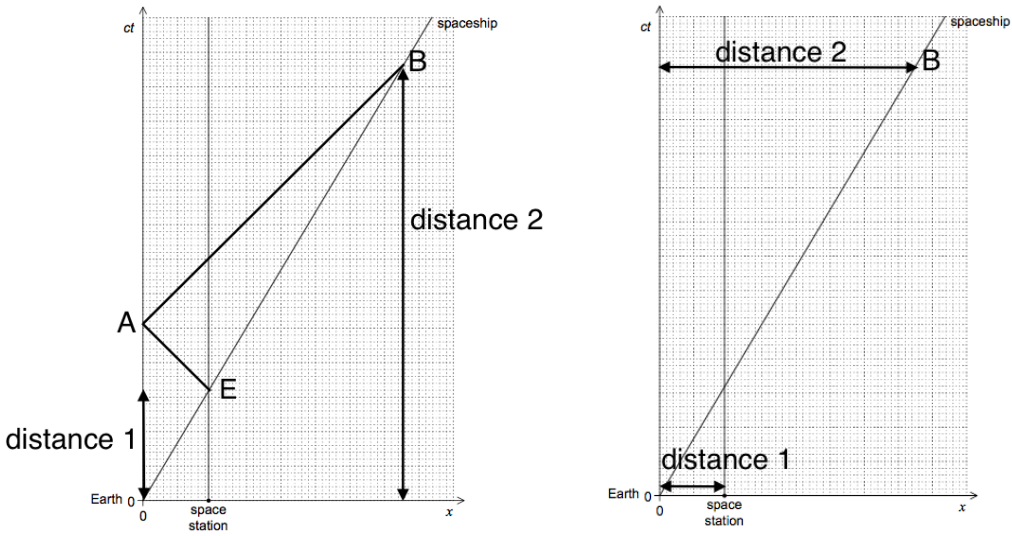
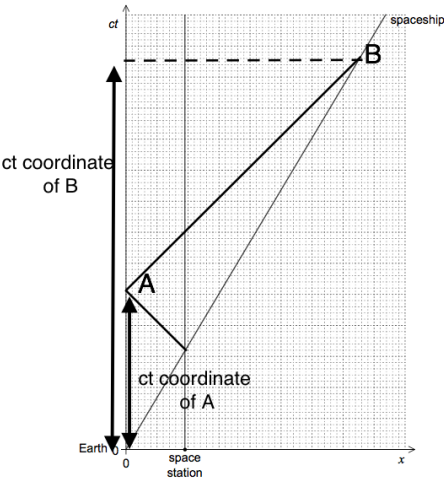
(continued...)

(Question 4 continued)

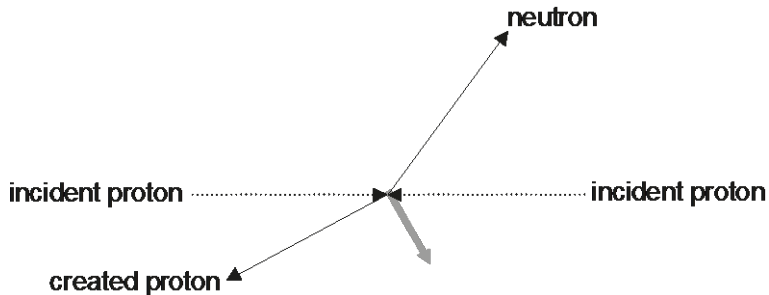
Question			Answers	Notes	Total
4.	d	ii	ALTERNATIVE 1 «In spaceship frame» Finds the ratio $\frac{OB}{OE}$ (or by similar triangles on x or ct axes), value is approximately 4 ✓ hence time elapsed $\approx 4 \times 90\text{mins} \approx 6\text{h}$ «so clock time is $\approx 6:00$ » ✓	Alternative 1:  Allow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

(continued...)

(Question 4 continued)

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

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

Question			Answers	Notes	Total
6.	a		$\gamma \ll \frac{3350}{938} \gg = 3.57 \checkmark$		1
6.	b	i	energy of pion = $(3350 \times 2) - 6200 = 500 \text{ «MeV»} \checkmark$ $500^2 = p^2 c^2 + 140^2 \checkmark$ $p = 480 \text{ «MeV c}^{-1}\text{»} \checkmark$		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» ✓ $\ll \frac{2GM}{c^2} = \gg 1 \times 10^{10}$ «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

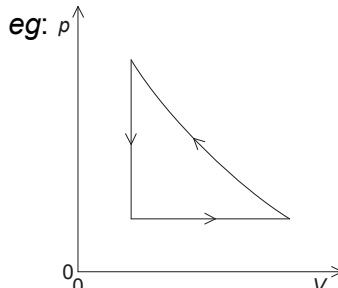
Option B — Engineering physics

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	$\omega \text{ «} = \frac{1.2}{0.012} \text{»} = 100 \text{ «rad s}^{-1}\text{»}$ ✓		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

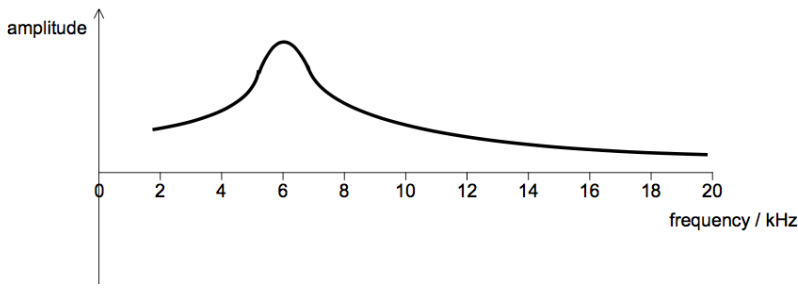
Question			Answers	Notes	Total
9.	a		ALTERNATIVE 1 «Using $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ » $V_2 = \frac{47.1 \times (273 + 19)}{(273 - 12)} \checkmark$ $V_2 = 52.7 \text{ «m}^3\text{»} \checkmark$ ALTERNATIVE 2 «Using $PV = nRT$ » $V = \frac{243 \times 8.31 \times (273 + 19)}{11.2 \times 10^3} \checkmark$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

(continued...)

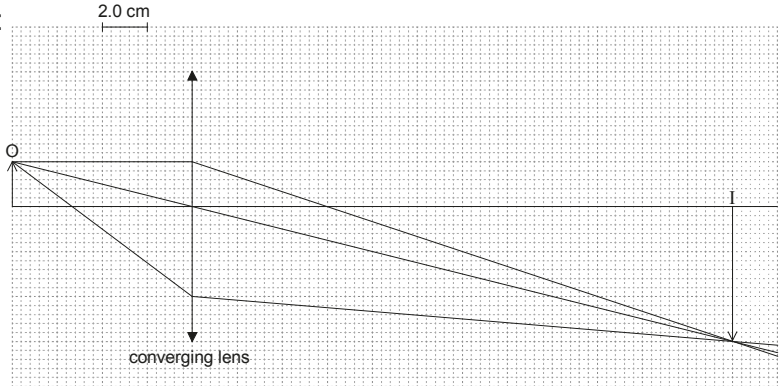
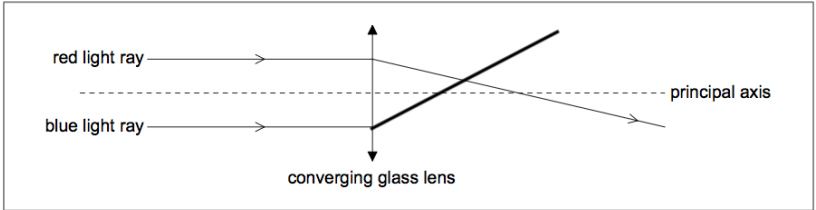
(Question 9 continued)

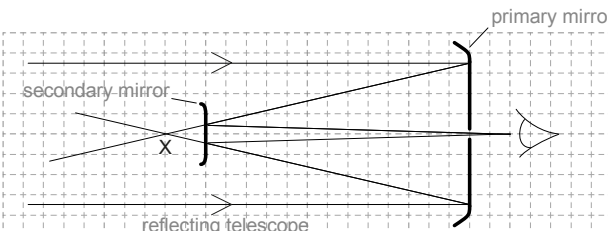
Question			Answers	Notes	Total
9.	d	i	concave curve from RHS of present line to point above LHS of present line ✓ vertical line from previous curve to the beginning ✓	eg: 	2
9.	d	ii	energy is removed from the gas and so entropy decreases OR temperature decreases «at constant volume (less disorder)» so 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	constructs ray parallel to principal axis and then to image position OR $u = 8\text{cm}$ and $v = 24\text{cm}$ and lens formula ✓ 6 «cm» ✓	eg:  converging lens Allow answers in the range of 5.6 to 6.4 cm	2
12.	a	ii	$m = \text{«-»}3.0$ ✓		1
12.	b		completes diagram with blue focal point closer to lens ✓ blue light/rays refracted/deviated more OR speed of blue light is less than speed of red light ✓ OR different colors/wavelengths have different focal points/converge at different points ✓	First marking point can be explained in words or seen on diagram  converging glass lens	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		$\text{sinc} = \frac{1.4444}{1.4475}$ or $\text{sinc} = 0.9978$ ✓ 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	$\text{attenuation} = \ll 10 \log \frac{I}{I_0} \gg = 10 \log \frac{2.0 \times 10^{-6}}{400 \times 10^{-6}}$ ✓ $\text{attenuation} = \ll - \gg 23 \text{ dB} \gg$ ✓	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)

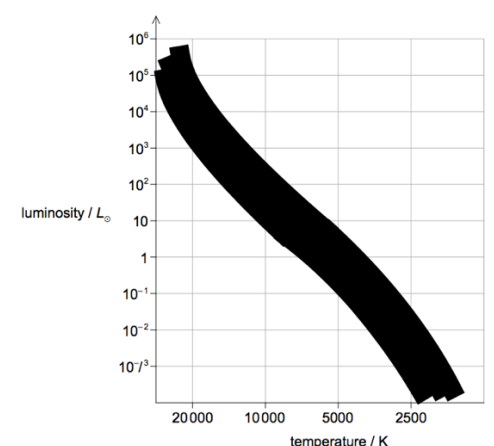
Question			Answers	Notes	Total
15.	b	i	the thickness of tissue that reduces the intensity «of the X-rays» by a half OR $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$ where $x_{\frac{1}{2}}$ is the half value thickness and μ is attenuation coefficient ✓	<i>Symbols must be defined for mark to be awarded</i>	1
15.	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	$L_{\text{Gacrux}} = 5.67 \times 10^{-8} \times 4\pi \times (58.5 \times 10^9)^2 \times 3600^4$ ✓ $L_{\text{Gacrux}} = 4.1 \times 10^{29}$ «W» ✓ $\frac{L_{\text{Gacrux}}}{L_{\odot}} \ll \frac{4.1 \times 10^{29}}{3.85 \times 10^{26}} = 1.1 \times 10^3$ ✓		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

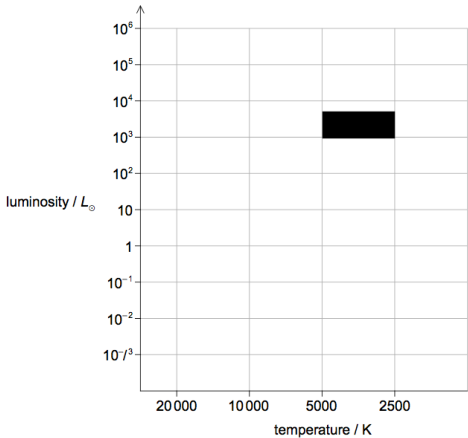
(continued...)

(Question 16 continued)

Question			Answers	Notes	Total
16.	d	i	line or area roughly inside shape shown – judge by eye ✓	Accept straight line or straight area at roughly 45° 	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)✓	 luminosity / $L_{\odot}$ temperature / K	1

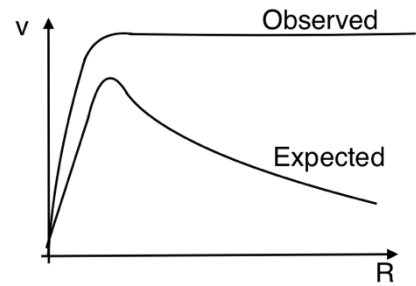
(continued...)

(Question 16 continued)

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

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

Question			Answers	Notes	Total
18.	a		«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 ✓	Accept $E_p + E_k < 0$	2
18.	b		Neutron capture creates heavier isotopes / heavier nuclei / more unstable nucleus ✓ <u>β^- decay</u> of heavy elements/iron increases atomic number «by 1» ✓	OWTTE	2

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