Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2018

Physics

Higher level

Paper 3

30 pages

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*** $= 2.1 \times 10^{-3}$ «m» ***or*** 2.0×10^{-3} «m» ✓	*Accept answers in mm or m*	**2**
1.	b		«$a = \frac{2s}{t^2} = \frac{2 \times 0.642}{0.363^2}$» $= 9.744$ «m s^{-2}» ✓ fractional uncertainty in distance $= \frac{2}{642}$ ***AND*** fractional uncertainty in time $= \frac{0.002}{0.363}$ ✓ total fractional uncertainty $= \frac{\Delta s}{s} + 2\frac{\Delta t}{t}$ «$= 0.00311 + 2 \times 0.00551$» ✓ 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

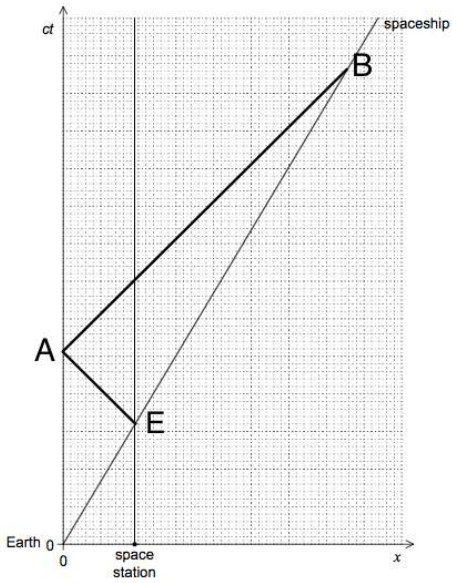
Option A — Relativity

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*** 1.8×10^{8} **«**m s^{-1}**»** ✓		**1**
4.	b		***ALTERNATIVE 1*** time interval in the Earth frame $=90\times\gamma=112.5$ minutes ✓ **«**in Earth frame it takes 112.5 minutes for ship to reach station**»** so distance $=112.5\times60\times0.60c$ ✓ 1.2×10^{12} **«**m**»** ✓ ***ALTERNATIVE 2*** Distance travelled according in the spaceship frame $=90\times60\times0.6c$ ✓ $=9.72\times10^{11}$ **«**m**»** ✓ Distance in the Earth frame **«**$=9.72\times10^{11}\times1.25$**»** $=1.2\times10^{12}$ **«**m**»** ✓		**3**

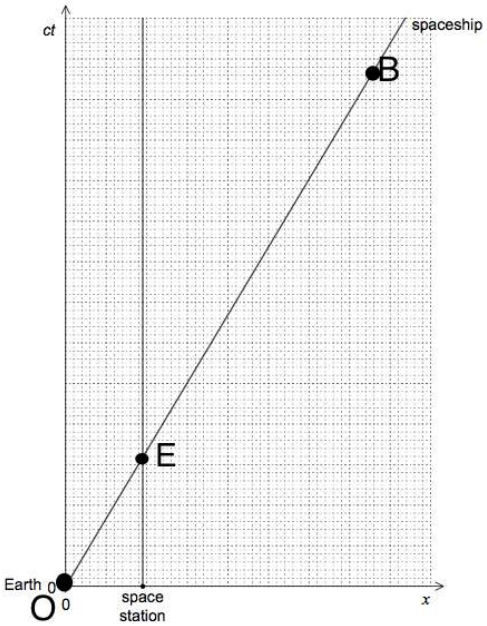
(continued…)

(Question 4 continued)

Question			Answers	Notes	Total
4.	**c**		signal will take **«**$112.5 \times 0.60 =$**»** 67.5 **«**minutes**»** to reach Earth **«**as it travels at *c***»** **OR** signal will take **«**$\frac{1.2 \times 10^{12}}{3 \times 10^{8}} =$**»** 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**

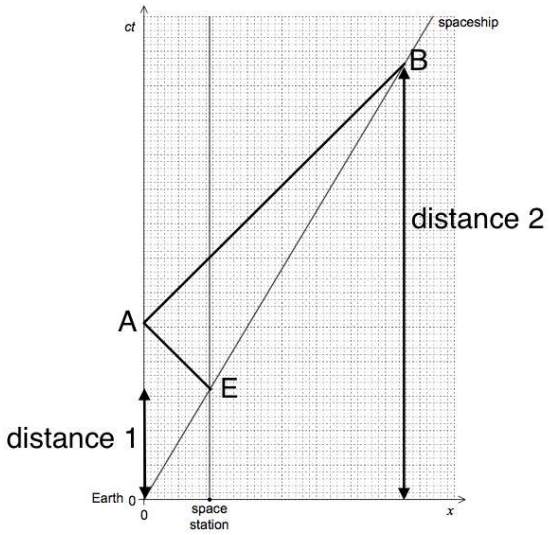
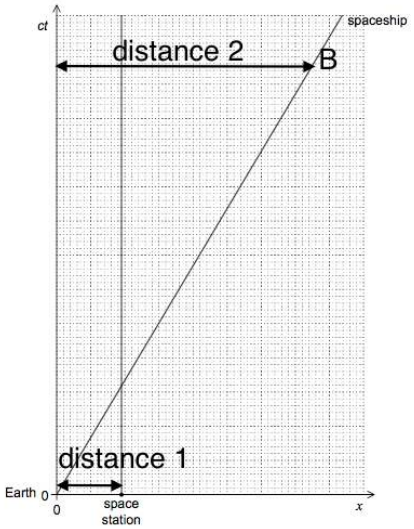
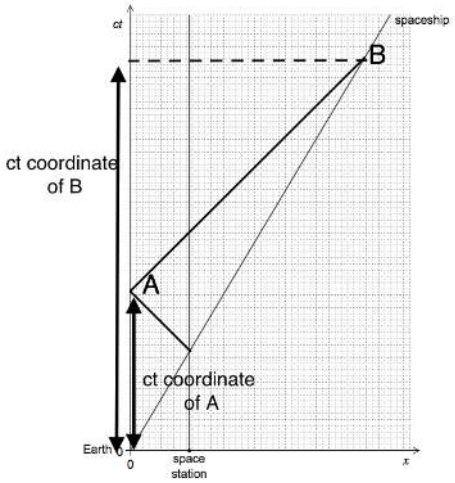
(continued…)

(Question 4 continued)

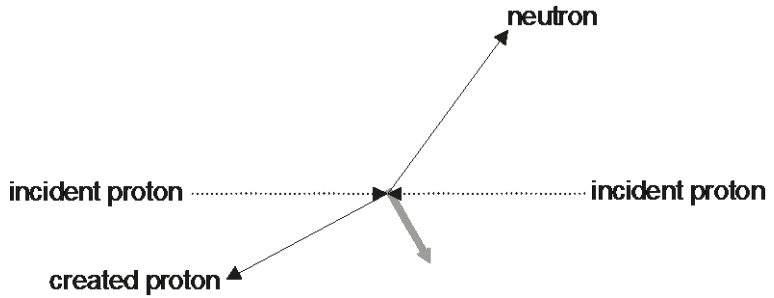
Question			Answers	Notes	Total
4.	d	ii	***ALTERNATIVE 1*** «In spaceship frame» Finds the ratio $\frac{OB}{OE}$ (or by similar triangles on x or *ct* axes), value is approximately 4 ✓ hence time elapsed $\approx 4 \times 90\text{mins} \approx 6\text{h}$ «so clock time is $\approx 6{:}00$» ✓	***Alternative 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 $\approx \frac{2.5 \times 3\text{h}}{1.25} \approx 6\text{h}$ «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 $= 27^2 - 15^2 = 504$ «m^2» ✓		1
5.	b	ii	***ALTERNATIVE 1*** Evidence of $x' = 0$ ✓ t' «$= \frac{\sqrt{504}}{c}$» $= 7.5 \times 10^{-8}$ «s» ✓ ***ALTERNATIVE 2*** $\gamma = 1.2$ ✓ t' «$= \frac{9 \times 10^{-8}}{1.2}$» $= 7.5 \times 10^{-8}$ «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		γ «$= \frac{3350}{938}$» $= 3.57$ ✓		1
6.	b	i	energy of pion $= (3350 \times 2) - 6200 = 500$ «MeV» ✓ $500^2 = p^2c^2 + 140^2$ ✓ $p = 480$ «MeV c^{-1}» ✓		3
6.	b	ii	path of pion constructed in direction around 4–5 o'clock by eye ✓	*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 $= 7.2 \times 10^{36}$ «kg» ✓ «$\frac{2GM}{c^2} =$» 1×10^{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**

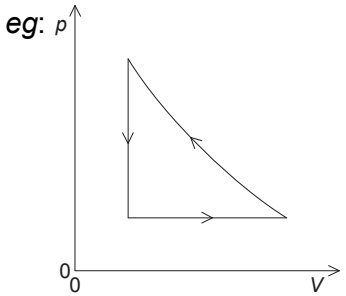
Option B — Engineering physics

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	$\Delta\text{KE} + \Delta\text{rotational KE} = \Delta\text{GPE}$ ***OR*** $\frac{1}{2}mv^2 + \frac{1}{2}I\frac{v^2}{r^2} = mgh$ ✓ $\frac{1}{2}\times 0.250\times v^2 + \frac{1}{2}\times 1.3\times 10^{-4}\times\frac{v^2}{1.44\times 10^{-4}} = 0.250\times 9.81\times 0.36$ ✓ $v = 1.2$ «m s^{-1}» ✓		**3**
8.	a	iii	ω «$= \frac{1.2}{0.012}$» $= 100$ «rad s^{-1}» ✓		**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**

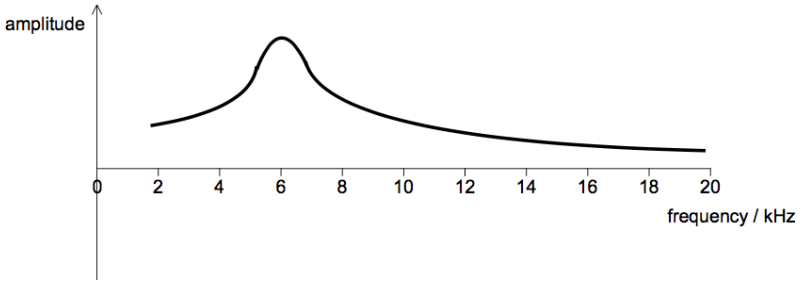
Question			Answers	Notes	Total
9.	a		***ALTERNATIVE 1*** «Using $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ » $V_2 = \frac{47.1 \times (273 + 19)}{(273 - 12)}$ ✓ $V_2 = 52.7$ «m^3» ✓ ***ALTERNATIVE 2*** «Using $PV = nRT$ » $V = \frac{243 \times 8.31 \times (273 + 19)}{11.2 \times 10^3}$ ✓ $V = 52.6$ «m^3» ✓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

(continued…)

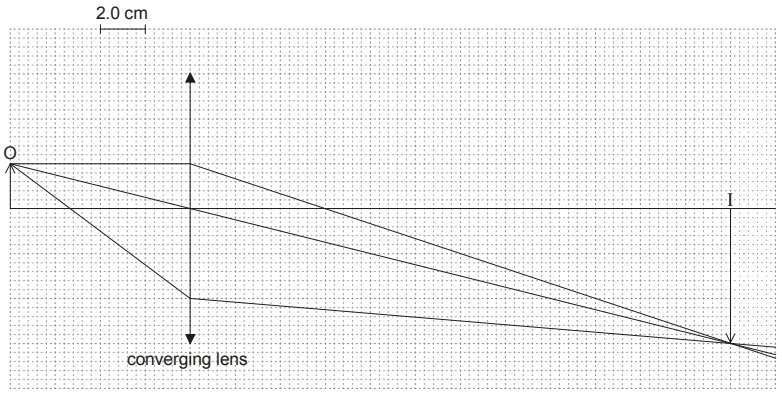
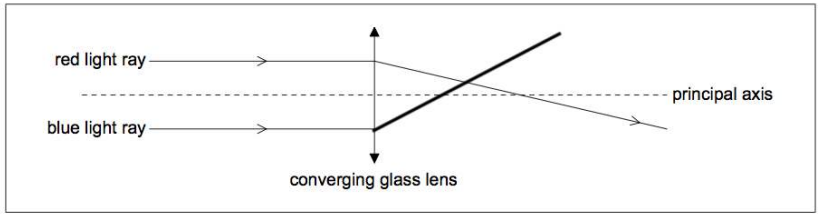
(Question 9 continued)

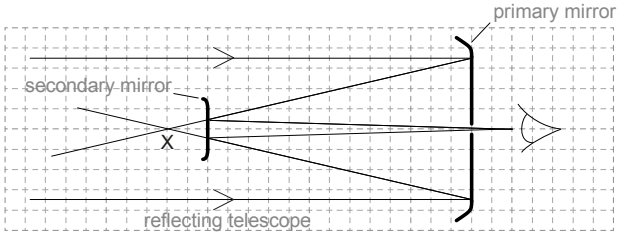
Question			Answers	Notes	Total
9.	**d**	**i**	concave curve from RHS of present line to point above LHS of present line ✓ vertical line from previous curve to the beginning ✓	*eg*: 	**2**
9.	**d**	**ii**	energy is removed from the gas and so entropy decreases ***OR*** temperature decreases «at constant 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		$\frac{1}{2}\rho v_X^2 = p_Y - p_X = \rho g \Delta h$ ✓ $v_X = \sqrt{2 \times 9.8 \times (0.32 - 0.10)}$ ✓ $v_X = 2.08$ «ms^{-1}» ✓		3
10.	b	i	$R = «\frac{vr\rho}{\eta} = \frac{2.1 \times 0.25 \times 10^3}{8.9 \times 10^{-4}}» 5.9 \times 10^5$ ✓		1
10.	b	ii	$(R > 1000)$ flow is not laminar, so assumption is invalid ✓	*OWTTE*	1

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

Option C — Imaging

Question			Answers	Notes	Total
12.	a	i	constructs ray parallel to principal axis and then to image position ***OR*** $u = 8\,cm$ and $v = 24\,cm$ and lens formula ✓ 6 «cm» ✓	*eg*:  *Allow answers in the range of 5.6 to 6.4 cm*	**2**
12.	a	ii	m = «–»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*  	**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» ✓ $\frac{5.8\times10^{-7}}{6.7\times10^{-9}} = 87$ «m» ✓ some reference to difficulty in making optical mirrors/lenses of this size ✓	*Allow* $\frac{5.8\times10^{-7}}{5.5\times10^{-9}} = 105$ *«m»*	3

Question			Answers	Notes	Total
14.	**a**		$\sin c = \frac{1.4444}{1.4475}$ ***or*** $\sin c = 0.9978$ ✓ 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**	attenuation $=$ **«**$10 \log \frac{I}{I_0}$**»** $= 10 \log \frac{2.0 \times 10^{-6}}{400 \times 10^{-6}}$ ✓ attenuation $=$ **«**$-$**»**23 **«**dB**»** ✓	*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 ✓ **«**$\frac{37-23}{12} = 1.17$**»** 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 ✓	*Allow any other verifiable sensible advantage*	**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)

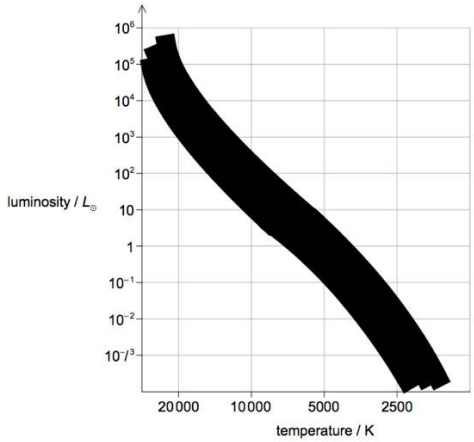
Question			Answers	Notes	Total
15.	**b**	**i**	the thickness of tissue that reduces the intensity «of the X-rays» by a half ***OR*** $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$ where $x_{\frac{1}{2}}$ is the half value thickness and μ is attenuation coefficient ✓	*Symbols must be defined for mark to be awarded*	**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» ✓ $\frac{L_{Gacrux}}{L_{\odot}}$ «$= \frac{4.1 \times 10^{29}}{3.85 \times 10^{26}}$» $= 1.1 \times 10^{3}$ ✓		**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**

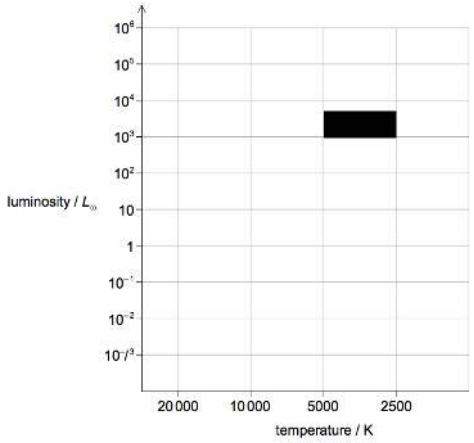
(continued…)

(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)✓		**1**

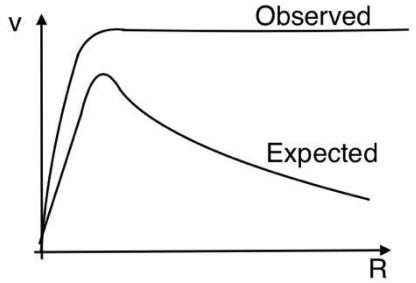
(continued…)

(Question 16 continued)

Question			Answers	Notes	Total
16.	**e**		***ALTERNATIVE 1*** Main sequence to red giant ✓ planetary nebula with mass reduction/loss ***OR*** planetary nebula with mention of remnant mass ✓ white dwarf ✓ ***ALTERNATIVE 2*** Main sequence to red supergiant region ✓ Supernova with mass reduction/loss ***OR*** Supernova with mention of remnant mass ✓ 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 «$= \frac{v}{d}$» or $\frac{1}{H_0}$ «$= \frac{d}{v}$» ✓ convert Mpc to m and km to m «for example $\frac{82 \times 10^3}{10^6 \times 3.26 \times 9.46 \times 10^{15}}$» ✓ age of universe «$= \frac{1}{H_0}$» $= 3.8 \times 10^{17}$ «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 «$= \frac{v}{c}$» $= \frac{4.6 \times 10^4 \times 10^3}{3.00 \times 10^8} = 0.15$ ✓ $\frac{R}{R_0}$ «$= z + 1$» $= 1.15$ ✓ $\frac{R_0}{R}$ «$= \frac{1}{1.15}$» $= 0.87$ ***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 ✓ β^- decay 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 type 1a supernovae 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