

Markscheme

November 2019

Physics

Higher level

Paper 3

30 pages

No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without written permission from the IB.

Additionally, the license tied with this product prohibits commercial use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, is not permitted and is subject to the IB's prior written consent via a license. More information on how to request a license can be obtained from <http://www.ibo.org/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite de l'IB.

De plus, la licence associée à ce produit interdit toute utilisation commerciale de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, n'est pas autorisée et est soumise au consentement écrit préalable de l'IB par l'intermédiaire d'une licence. Pour plus d'informations sur la procédure à suivre pour demander une licence, rendez-vous à l'adresse <http://www.ibo.org/fr/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin que medie la autorización escrita del IB.

Además, la licencia vinculada a este producto prohíbe el uso con fines comerciales de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales— no está permitido y estará sujeto al otorgamiento previo de una licencia escrita por parte del IB. En este enlace encontrará más información sobre cómo solicitar una licencia: <http://www.ibo.org/es/contact-the-ib/media-inquiries/for-publishers/guidance-for-third-party-publishers-and-providers/how-to-apply-for-a-license>.

Subject Details: Physics HL Paper 3 Markscheme

Candidates are required to answer **all** questions in Section A and **all** questions from **one** option in Section B. Maximum total = **45 marks**.

1. Each row in the “Question” column relates to the smallest subpart of the question.
2. The maximum mark for each question subpart is indicated in the “Total” column.
3. Each marking point in the “Answers” column is shown by means of a tick (✓) at the end of the marking point.
4. A question subpart may have more marking points than the total allows. This will be indicated by “**max**” written after the mark in the “Total” column. The related rubric, if necessary, will be outlined in the “Notes” column.
5. An alternative wording is indicated in the “Answers” column by a slash (/). Either wording can be accepted.
6. An alternative answer is indicated in the “Answers” column by “**OR**”. Either answer can be accepted.
7. An alternative markscheme is indicated in the “Answers” column under heading **ALTERNATIVE 1** etc. Either alternative can be accepted.
8. Words inside chevrons « » in the “Answers” column are not necessary to gain the mark.
9. Words that are underlined are essential for the mark.
10. The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.
11. If the candidate’s answer has the same “meaning” or can be clearly interpreted as being of equivalent significance, detail and validity as that in the “Answers” column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by **OWTTE** (or words to that effect) in the “Notes” column.
12. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.
13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script. “ECF acceptable” will be displayed in the “Notes” column.
14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the “Notes” column.

Section A

Question		Answers	Notes	Total
1.	a	a straight line cannot be drawn through all error bars OR the graph/line of best fit is /curved/not straight/parabolic etc. OR graph has increasing/variable gradient ✓	<i>Do not allow “a line cannot be drawn through all error bars” without specifying “straight”.</i>	1
1.	b	$v = 1.15 \text{ «ms}^{-1}\text{» AND } \Delta v = 0.05 \text{ «ms}^{-1}\text{» ✓}$ $\text{«} \frac{0.05}{1.15} \text{»} \Rightarrow 0.04 \text{ ✓}$	Accept 4 %	2

(continued...)

(Question 1 continued)

Question		Answers	Notes	Total
1.	c	use of 2 correct points on the line with $\Delta v^2 > 2$ ✓ b in range 0.012 to 0.013 ✓ $s^3 m^{-2}$ ✓		3
1.	d	$a_{\max} = 2.101 \text{ «s»} \pm 0.001 \text{ «s»}$ AND $a_{\min} = 2.095 \text{ «s»} \pm 0.001 \text{ «s»}$ ✓ $\text{«} \frac{2.101 - 2.095}{2} \text{ »} = 0.003 \text{ «s»}$ ✓		2

Question			Answers	Notes	Total
2.	a	i	evidence of use of $\rho = \text{given gradient} \times \text{wire area}$ OR substitution of values from a single data point with wire area ✓ $\rho = \ll = 6.30 \times \pi \times \left(\frac{0.500 \times 10^{-3}}{2} \right)^2 = \gg 1.24 \times 10^{-6} \ll \Omega \text{ m} \gg \checkmark$	Check POT is correct. MP2 must be correct to exactly 3 s.f.	2
2.	a	ii	measurement should be performed at a constant temperature OR resistance of wire changes with temperature ✓ series resistance prevents the wire from overheating OR reduces power dissipated in the wire ✓ by reducing voltage across/current through the wire ✓		3
2.	b		ANY straight line going through the origin if extrapolated ✓ ANY straight line below existing line with smaller gradient ✓		2

Section B

Option A — Relativity

Question			Answers	Notes	Total
3.	a		laws of physics are the same for all observers OR laws of physics are the same in all «inertial» frames ✓	<i>OWTTE</i>	1
3.	b	i	magnetic ✓		1
3.	b	ii	«from 3a» force must still be repulsive ✓ for P there is no magnetic force AND force is electric/electrostatic OR since P is at rest the force is electric/electrostatic ✓		2
3.	b	iii	protons and electrons in the wire move with different velocities «relative to P» OR speed of electrons is greater ✓ «for P» the density of protons and electrons in wire will be different «due to length contraction» OR «for P» the wire appears to have negative charge «due to length contraction» ✓ «hence electric force arises»	<i>Do not award mark for mention of length contraction without details.</i>	2

(continued...)

(Question 3 continued)

Question			Answers	Notes	Total
3.	b	iv	$u' = \frac{0.80 + 0.30}{1 + 0.80 \times 0.30} c \checkmark$ $= 0.89c \checkmark$	Accept 0.89c if all negative values used. Accept - 0.89c even though speed is required.	2

4.	a	i	$\gamma = 1.09 \checkmark$ $L_A = \left\langle \frac{2.0}{1.09} \right\rangle = 1.8 \text{ «km»} \checkmark$		2
4.	a	ii	<p>ALTERNATIVE 1</p> $\text{time} = \frac{1.8 \times 10^3}{1.2 \times 10^8} \checkmark$ $1.5 \times 10^{-5} \text{ «s»} \checkmark$ <p>ALTERNATIVE 2</p> $t_B = \frac{2 \times 10^3}{1.2 \times 10^8} = 1.66 \times 10^{-5} \text{ «s»} \checkmark$ $t_A = \frac{t_B}{\gamma} = 1.5 \times 10^{-5} \text{ «s»} \checkmark$		2

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	b		L_B is the length/measurement «by observer B» made in the reference frame in which the bridge is at rest ✓	Idea of rest frame or frame in which bridge is not moving is required.	1
4.	c	i	<p>x' axis drawn with correct gradient of 0.4 ✓</p>	<p>Line must be 1 square below Y, allow ± 0.5 square.</p> <p>Allow line drawn without a ruler.</p>	1

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	c	ii	<p>lines parallel to the x' axis through X and Y intersecting the worldline ct' at points shown ✓ so Y/lamp at the end of the bridge turned on first ✓</p>	<p><i>Allow lines drawn without a ruler</i></p> <p><i>Do not allow MP2 without supporting argument or correct diagram.</i></p>	2

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	c	iii	<p>light worldlines at 45° from X AND Y intersecting the worldline ct' ✓ so light from lamp X is observed first ✓</p>	<p><i>Allow lines drawn without a ruler.</i></p> <p><i>Do not allow MP2 without supporting argument or correct diagram.</i></p>	2

(continued...)

(Question 4 continued)

Question			Answers	Notes	Total
4.	c	iv	<p>ALTERNATIVE 1</p> $\Delta t' = 1.09 \times \left(0 - \frac{0.4 \times 2.0 \times 10^3}{3.0 \times 10^8} \right) \checkmark$ $= \llcorner - \gg 2.9 \times 10^{-6} \llcorner \text{s} \gg \checkmark$ <p>ALTERNATIVE 2</p> <p>equating spacetime intervals between X and Y relies on realization that $\Delta x' = \gamma(\Delta x - 0)$ eg:</p> $(c\Delta t')^2 - (1.09 \times 2000)^2 = 0^2 - 2000^2 \checkmark$ $\Delta t' = \llcorner \pm \gg \frac{\sqrt{(1.09 \times 2000)^2 - 2000^2}}{3.0 \times 10^8} = \llcorner \pm \gg 2.9 \times 10^{-6} \llcorner \text{s} \gg \checkmark$ <p>ALTERNATIVE 3</p> <p>use of diagram from answer to 4(c)(ii) (1 small square = 200 m) counts 4.5 to 5 small squares (allow 900 – 1000 m) between events for A seen on B's ct axis \checkmark</p> $\frac{950}{\gamma c} = 2.9 \times 10^{-6} \pm 0.2 \times 10^{-6} \llcorner \text{s} \gg \checkmark$		2

Question			Answers	Notes	Total
5.	a	i	neutron energy = $\sqrt{185^2 + 940^2} = 958$ «MeV» ✓	Allow 1.5×10^{-10} «J»	1
5.	a	ii	<p>ALTERNATIVE 1 « use of $E = \gamma E_0$ » « 958 = 940γ so» $\gamma = 1.019$ ✓ $v = 0.193c$ ✓</p> <p>ALTERNATIVE 2 « use of $p = \gamma mv$ » $185 = 940 \frac{\frac{v}{c}}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \checkmark$ $v = 0.193c$ ✓</p> <p>ALTERNATIVE 3 « use of $p = \gamma mv$ » $v = \frac{pc}{E} \checkmark$ $v = \frac{185}{958} = 0.193c \checkmark$</p>	Allow $v = 5.8 \times 10^7$ «ms ⁻¹ »	2
5.	b		<p>momentum of X = 185 «MeV c⁻¹» ✓ energy of X = 1190 – 958 = 232 «MeV» ✓ $m_0 = \llcorner \sqrt{232^2 - 185^2} \llcorner = 140$ «MeV c⁻²» ✓</p>	Allow mass in kg - gives 2.5×10^{-28} «kg»	3

Question		Answers	Notes	Total
6.	a	<p>ALTERNATIVE 1</p> <p>as the photons move away from the black hole, they lose energy in the gravitational field ✓</p> <p>since $E = hf$ «the detected frequency is lower than the emitted frequency» ✓</p> <p>ALTERNATIVE 2</p> <p>if the observer was accelerating away from the probe, radio waves would undergo Doppler shift towards lower frequency ✓</p> <p>by the equivalence principle, the gravitational field has the same effect as acceleration ✓</p> <p>ALTERNATIVE 3</p> <p>due to gravitational time dilation, time between arrivals of wavefronts is greater for the observer ✓</p> <p>since $f = \frac{1}{T}$, «the detected frequency is lower than the emitted frequency» ✓</p>	<p><i>The question states that received frequency is lower so take care not to award a mark for simply re-stating this, a valid explanation must be given.</i></p>	2
6.	b	<p>time between pulses = 3 s according to the probe ✓</p> $\Delta t = \left\langle \frac{3}{\sqrt{1 - \frac{1}{1.5}}} \right\rangle = 5.2 \text{ «s» } \checkmark$		2

Option B — Engineering physics

Question			Answers	Notes	Total
7.	a		zero ✓		1
7.	b	i	«change in» angular momentum ✓	<i>Allow angular impulse.</i>	1
7.	b	ii	use of $L = I\omega = \text{area under graph} = 1.80 \text{ «kg m}^2 \text{ s}^{-1}\text{»} \checkmark$ rearranges «to give $\omega = \text{area}/I$ » $1.80 = 0.5 \times 5.00 \times 0.060^2 \times \omega \checkmark$ «to get $\omega = 200 \text{ rad s}^{-1}$ »		2
7.	b	iii	« $\frac{0.40}{0.012} =$ » $33.3 \text{ N} \checkmark$		1
7.	c	i	translational equilibrium is when the sum of all the forces on a body is zero ✓ rotational equilibrium is when the sum of all the torques on a body is zero ✓		2
7.	c	ii	ALTERNATIVE 1 $0 = 200^2 + 2 \times \alpha \times 2\pi \times 8000 \checkmark$ $\alpha = \text{«-» } 0.398 \text{ «rad s}^{-2}\text{»} \checkmark$ torque = $\alpha I = 0.398 \times (0.5 \times 5.00 \times 0.060^2) = 3.58 \times 10^{-3} \text{ «N m»} \checkmark$ ALTERNATIVE 2 change in kinetic energy = «-» $0.5 \times (0.5 \times 5.00 \times 0.060^2) \times 200^2 = \text{«-» } 180 \text{ «J»} \checkmark$ identifies work done = change in KE ✓ torque = $\frac{W}{\theta} = \frac{180}{2\pi \times 8000} = 3.58 \times 10^{-3} \text{ «N m»} \checkmark$		3

Question			Answers	Notes	Total
8.	a	i	$P_B = \frac{250 \times 10^3}{1.5^{\frac{5}{3}}} \llcorner \text{from } P_B (1.5 V_A)^{\frac{5}{3}} = 250 \times 10^3 \times V_A^{\frac{5}{3}} \llcorner \checkmark$ $= 127 \text{ kPa } \checkmark$		2
8.	a	ii	$\llcorner 127 \times 10^3 \times 1.5 V_A = 250 \times 10^3 V_C \llcorner$ $1.31 \checkmark$		1
8.	b	i	<p>ALTERNATIVE 1</p> <p>work done $\Delta W = \llcorner - \llcorner 250 \times 10^3 \times 1.5 \times 10^{-3} = \llcorner - \llcorner 375 \llcorner \text{J} \llcorner \checkmark$</p> <p>change in internal energy $\Delta U = \frac{3}{2} \times 0.300 \times 8.31 \times (-150) = \llcorner - \llcorner 561 \llcorner \text{J} \llcorner$</p> <p>OR</p> $\Delta U = \frac{3}{2} P \Delta V = \frac{3}{2} \times 375 = \llcorner - \llcorner 563 \llcorner \text{J} \llcorner \checkmark$ <p>thermal energy removed $\Delta Q = 375 + 561 = 936 \llcorner \text{J} \llcorner$</p> <p>OR</p> $\Delta Q = 375 + 563 = 938 \llcorner \text{J} \llcorner \checkmark$ <p>ALTERNATIVE 2</p> $\Delta Q = \llcorner n C_p \Delta T = \llcorner \frac{5}{2} \times n R T \llcorner \checkmark$ <p>thermal energy removed $\Delta Q = 0.300 \times 2.5 \times 8.31 \times 150 \checkmark$</p> $= 935 \llcorner \text{J} \llcorner \checkmark$		3

(continued...)

(Question 8 continued)

Question			Answers	Notes	Total
8.	b	ii	<p>ALTERNATIVE 1 «from (b)(i)» ΔQ is negative ✓ $\Delta S = \frac{\Delta Q}{T}$ AND so ΔS is negative ✓</p> <p>ALTERNATIVE 2 T and/or V decreases ✓ less disorder/more order «so S decreases» ✓</p> <p>ALTERNATIVE 3 T decreases ✓ $\Delta S = K \times \ln\left(\frac{T_2}{T_1}\right) < 0$ ✓</p>	<p><i>Answer given, look for a valid reason that S decreases.</i></p>	2
8.	b	iii	<p>not violated ✓</p> <p>the entropy of the surroundings must have increased OR the overall entropy of the system and the surroundings is the same or increased ✓</p>		2

Question		Answers	Notes	Total
9.	a	air speed at A greater than at B/speed at B is zero OR total/stagnation pressure « P_B » – static pressure « P_A » = dynamic pressure ✓ so P_A is less than at P_B (or <i>vice versa</i>) «by Bernoulli effect» ✓ height of the liquid column is related to «dynamic» pressure difference «hence lower height in arm B» ✓		3
9.	b	« $\rho_{\text{liquid}} gh = 0.5 \times \rho_{\text{air}} v^2$ » difference in pressure $P_B - P_A = 8.7 \times 10^2 \times 9.8 \times 0.06 = 510$ «Pa» ✓ correct substitution into the Bernoulli equation, eg: $\frac{1}{2} \times 1.2 v^2 = 510$ ✓ $v = 29$ «ms ⁻¹ » ✓		3

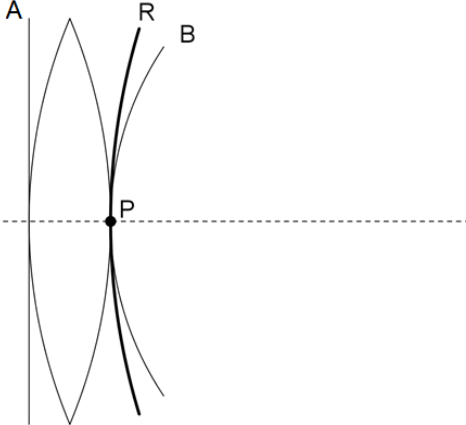
10.	a	a situation in which a resistive force opposes the motion OR amplitude/energy decreases with time ✓		1
10.	b	$Q = 2\pi \times \frac{30}{30 - 28} = 94.25 \approx 94$ ✓		1
10.	c	$94 = 2\pi \times 0.80 \times \frac{0.020}{\text{power loss}}$ ✓ Power added = 1.1×10^{-3} «W» ✓		2

Option C — Imaging

Question			Answers	Notes	Total
11.	a	i	<p>correctly draws any 2 of the 4 conventional rays from the object tip ✓ correctly extends reflections to form virtual upright image I in approximate position shown ✓</p>	<p>No ECF for incorrect rays in MP1.</p> <p>Award [0] for rays of converging lens or diverging mirror.</p>	2
11.	a	ii	1.5 ✓	For "correct" image position in (a)(i) allow 1.3 to 1.7.	1

(continued...)

(Question 11 continued)

Question			Answers	Notes	Total
11.	a	iii	Any two of: virtual OR upright OR larger than the object ✓		1
11.	b	i	 <p>“circular” wave front through P: symmetric about the principal axis AND of greater radius than B ✓</p>		1
11.	b	ii	red and blue wave fronts have different curvature/radius OR red and blue waves are refracted differently/have different speeds ✓ so different colors have different foci/do not focus to one point OR so image is multi-coloured/blurred ✓	MP1 is for the reason for the aberration, MP2 is for the effect.	2

(continued...)

(Question 11 continued)

Question			Answers	Notes	Total
11.	b	iii	mention combination of converging and diverging lenses ✓ of different refractive index/material ✓	<i>Achromatic doublet is in the question, so no marks for mentioning this.</i>	2
12.	a		«the final» image is formed at the near point of the eye ✓		1
12.	b		«image is virtual so» $v = -24$ «cm» ✓ $\left\langle \frac{1}{u} = \frac{1}{3.0} + \frac{1}{24} \right\rangle$ so $u = 2.7$ «cm» ✓		2
12.	c		$M_e = \frac{v}{u} = \frac{24}{2.66} = 9.0$ AND $M_o = \frac{70}{9.0} = 7.8$ ✓ $v_o = 2.0 \times 7.8 = 15.6$ «cm» ✓ $\left\langle \frac{1}{f} = \frac{1}{2} + \frac{1}{16} \right\rangle$ so $f_o = 1.8$ «cm» ✓	<i>MP1 allow $M_e = \frac{D}{f} + 1 = 9$</i>	3

Question			Answers	Notes	Total
13.	a		fibres have broader bandwidth than cables ✓ therefore can carry multiple signals simultaneously ✓		2
13.	b	i	absorption/scattering of light OR impurities in the «glass core of the» fibre ✓		1
13.	b	ii	attenuation = $10 \log (2 \times 10^{-4}) = -37$ «dB» ✓ amplification required after $\frac{37}{0.4} = 92$ or 93 «km» ✓	Allow ECF from mp1 for wrong dB value. (eg: 42 km if % symbol ignored).	2

Question			Answers	Notes	Total
14.	a	i	$\mu_t = 0.379 \times 1.1 \times 10^3 \times \frac{10^3}{10^6} = 0.417 \text{ « cm}^{-1} \text{ » AND } \mu_b = 0.408 \text{ « cm}^{-1} \text{ » } \checkmark$ $\frac{I_b}{I_t} = \frac{I_0 e^{-\mu_b x}}{I_0 e^{-\mu_t x}} = e^{-(0.408 - 0.417) \times 0.5} \checkmark$ $\frac{I_b}{I_t} = 1.004 \checkmark$		3

(continued...)

(Question 14 continued)

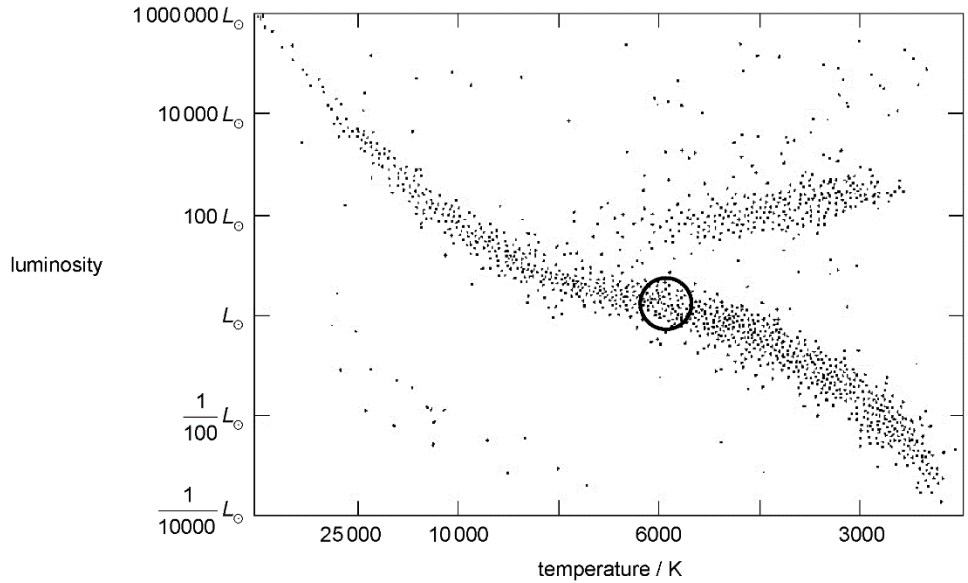
Question			Answers	Notes	Total
14.	a	ii	the difference between intensities is negligible so no contrast ✓ modifying the blood is easier than modifying the soft tissue ✓ increase absorption of X-rays in the blood ✓ by injecting/introducing a liquid/chemical/contrast medium ✓ with large mass absorption coefficient/nontoxic/higher density ✓		4 max
14.	b		«a uniform» magnetic field is applied to align proton spins ✓ proton spins are excited by an «external» radio frequency signal/field OR protons change from spin-up to spin-down state due to «external» RF signal/field ✓ «radio frequency» radiation is emitted as the protons relax ✓	For MP3 do not allow simplistic “protons emit RF radiation” as this is given in the question	3

Option D — Astrophysics

Question		Answers	Notes	Total	
15.	a	<p>stars in a cluster are gravitationally bound OR in constellation are not ✓</p> <p>stars in a cluster are the same/similar age OR in constellation are not ✓</p> <p>stars in a cluster are close in space/the same distance away OR in constellation are not ✓</p> <p>stars in a cluster originate from same gas cloud OR in constellation do not ✓</p> <p>stars in a cluster-appear much closer in night sky than in a constellation ✓</p>	<p>Take care to reward only 1 comment from a given marking point for MP1 to MP5.</p>	2 max	
15.	b	i	<p>«$T = \frac{2.9 \times 10^{-3}}{490 \times 10^{-9}}$»</p> <p>5900 K ✓</p>	<p>Answer 6000 K is given in the question.</p> <p>Answer must be to at least 2 s.f. OR correct working.</p>	1
15.	b	ii	<p>«from $b \propto L \propto R^2 T^4$»</p> <p>realization that $R^2 \propto \frac{b}{T^4}$ «for binary stars which are same distance away» ✓</p> $\frac{R_A}{R_B} = \sqrt{\frac{\left(\frac{1.1 \times 10^{-9}}{5.4 \times 10^{-11}}\right)}{\left(\frac{5900}{4100}\right)^4}} \checkmark$ $\frac{R_A}{R_B} = 2.2 \checkmark$	<p>Award [2] for answer 0.46 from inverted ratio.</p>	3

(continued...)

(Question 15 continued)

Question			Answers	Notes	Total
15.	b	iii	<p>«use of $L = 4\pi d^2 b$»</p> <p>$L = 4\pi \times (1.8 \times 10^{17})^2 \times 1.1 \times 10^{-9}$ « = 4.48×10^{26} W » ✓</p> <p>$L = 1.2L_{\odot}$ ✓</p>		2
15.	c	i	 <p>approximately correct position on the main sequence as shown, within highlighted region ✓</p>		1

(continued...)

(Question 15 continued)

Question			Answers	Notes	Total
15.	c	ii	main sequence star OR type F or G star ✓		1
15.	c	iii	$\frac{M}{M_{\odot}} = 1.2^{\frac{1}{3.5}} = 1.05$ ✓		1
15.	c	iv	mass of the «remnant» star $< 1.4M_{\odot}$ OR Chandrasekhar limit OR mass OR luminosity similar to the Sun ✓ the final stage is white dwarf ✓		2

Question			Answers	Notes	Total
16.	a	i	<p>spectra of galaxies are redshifted «compared to spectra on Earth» ✓ redshift/longer wavelength implies galaxies recede/ move away from us OR redshift is interpreted as cosmological expansion of space ✓ «hence universe expands»</p>	<p><i>Universe expansion is given, so no mark for repeating this.</i></p> <p><i>Do not accept answers based on CMB radiation.</i></p>	2
16.	a	ii	<p>ALTERNATIVE 1</p> $z = \frac{392 - 122}{122} = 2.21 \checkmark$ $\frac{R}{R_0} = \text{«}2.21+1\text{»} = 3.21 \checkmark$ <p>ALTERNATIVE 2</p> $\frac{R}{R_0} = \frac{392}{122} \checkmark$ $= 3.21 \checkmark$		2
16.	b	i	<p>density of flat/Euclidean universe OR density for which universe has zero curvature OR density resulting in universe expansion rate tending to zero ✓</p>		1

(continued...)

(Question 16 continued)

Question			Answers	Notes	Total
16.	b	ii	$H = \left\langle \frac{70 \times 10^3}{(10^6 \times 3.26 \times 9.46 \times 10^{15})} \right\rangle = 2.27 \times 10^{-18} \text{ «s}^{-1}\text{» } \checkmark$ $\rho = 0.32 \times \frac{3 \times (2.27 \times 10^{-18})^2}{8\pi \times 6.67 \times 10^{-11}} \checkmark$ $3.0 \times 10^{-27} \text{ «kg m}^{-3}\text{» } \checkmark$	MP1 for conversion of H to base units. Allow ECF from MP1, but NOT if H is left as 70.	3
16.	b	iii	rotation speed of galaxies is larger than expected away from the centre \checkmark there must be more mass «at the edges» than is visually observable «indicating the presence of dark matter» \checkmark		2

Question		Answers	Notes	Total
17.	a	realization that lifetime $T \propto \frac{\text{mass}}{\text{luminosity}} \checkmark$ $\frac{T}{T_{\odot}} = \left(\frac{M}{M_{\odot}} \right)^{-2.5} = 0.12^{-2.5} = 200 \checkmark$		2
17.	b	the binding energy per nucleon is a maximum for iron \checkmark formation of heavier elements than iron by fusion is not energetically possible \checkmark	<i>For MP2 some reference to energy is needed</i>	2
17.	c	<p>ALTERNATIVE 1 — s-process</p> s-process involves «slow» neutron capture \checkmark in s-process beta decay occurs before another neutron is captured \checkmark s-process occurs in giant stars «AGB stars» \checkmark s-process terminates at bismuth/lead/polonium \checkmark <p>ALTERNATIVE 2 — r-process</p> r-process involves «rapid» neutron capture \checkmark in r-process further neutrons are captured before the beta decay occurs \checkmark r-process occurs in type II supernovae \checkmark r-process can lead to elements heavier than bismuth/lead/polonium \checkmark	<i>If the type of the process (r or s/rapid or slow) is not mentioned, award [2 max].</i>	3 max