Diploma Programme
Programme du diplôme
Programa del Diploma

# Markscheme

## May 2019

## Physics

## Higher level

## Paper 3

27 pages



International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

**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 <u>underlined</u> 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 | i | error in $m_1 + m_2$ is 1 % ***OR*** error in $m_1 - m_2$ is 40 % ***OR*** error in *a* is 1 % ✓<br>adds percentage errors ✓<br>so error in *g* is 42 % ***OR*** 40 % ***OR*** 41.8% ✓ | *Allow answer 0.42 or 0.4 or 0.418.*<br>*Award [0] for comparing the average value with a known value, e.g. 9.81* m s$^{-2}$. | **3** |
| 1. | a | ii | $g = 9.996$ «$\text{m s}^{-2}$» ***OR*** $\Delta g = 4.20$ «$\text{m s}^{-2}$» ✓<br>$g = (10 \pm 4)$«$\text{m s}^{-2}$»<br>***OR***<br>$g = (10.0 \pm 4.2)$«$\text{m s}^{-2}$» ✓ | *Award **[1]** max for not proper significant digits or decimals use, such as: 9.996±4.178 or 10±4.2 or 10.0±4 or 10.0±4.18* « *m s*$^{-2}$ » *.* | **2** |
| 1. | b | i | the acceleration would be small/the time of fall would be large ✓<br>easier to measure /a longer time of fall reduces the % error in the time of fall and « hence acceleration » ✓ | *Do not accept ideas related to the mass/moment of inertia of the pulley.* | **2** |
| 1. | b | ii | the percentage error in the difference of the masses is large ✓<br>leading to a large percentage error/uncertainty in *g*/of the experiment ✓ | *Do not accept ideas related to the mass/moment of inertia of the pulley.* | **2** |

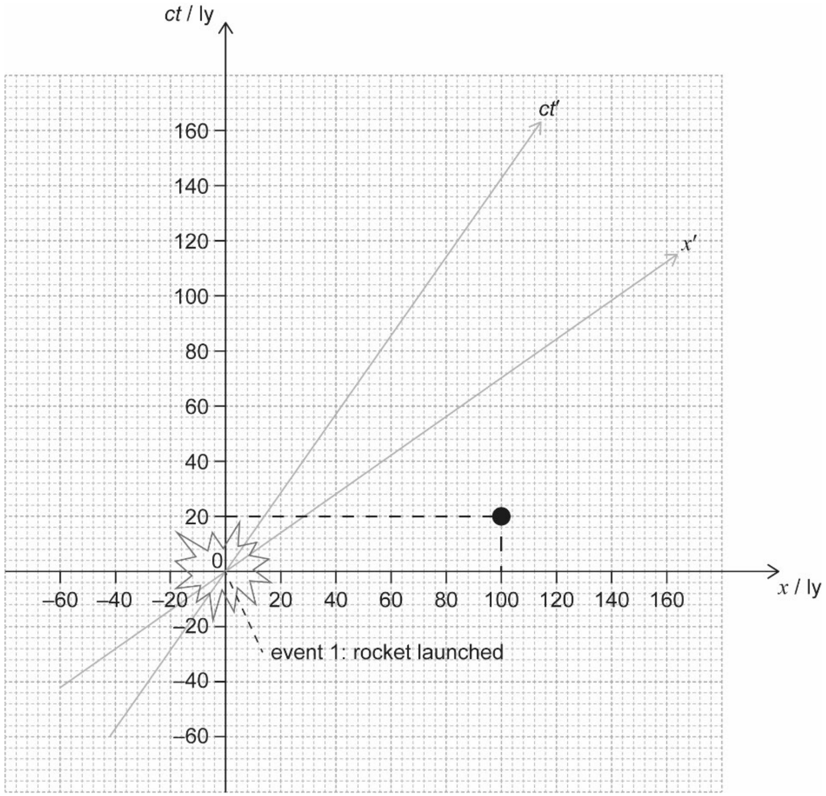
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 2. | a | | theory « $H = cD^{\left(\frac{2}{3}\right)}$ » predicts that $H^3 \propto D^2$ ✓<br>graph « of $H^3$ vs $D^2$ » is a straight line through the origin/graph of proportionality ✓ | *Allow $H = cD^{\left(\frac{2}{3}\right)}$ gives $H^3 = c^3D^2$ for MP1.*<br>*Do not award MP2 for "the graph is linear" without mention of origin.* | **2** |
| 2. | b | | evidence of gradient calculation to give gradient $= 3.0$ ✓<br>$c^3 = 3.0 \Rightarrow c = 1.4$ ✓<br>$m^{\frac{1}{3}}$ ✓ | | **3** |
| 2. | c | | the load/the thickness of paper/the type of paper/ the number of times the paper is rolled to form a cylinder ✓ | | **1** |

## Section B

**Option A — Relativity**

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 3. | a | | $c-v$ ✓ | | 1 |
| 3. | b | | $c$ ✓ | | 1 |
| 3. | c | | $c$ ✓ | | 1 |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 4. | a | i | time of travel is «$\frac{3230}{0.98\times3.0\times10^{8}}$» $=1.10\times10^{-5}$ «s» ✓<br>which is «$\frac{1.10\times10^{-5}}{2.20\times10^{-6}}$» $=5.0$ half-lives ✓<br>so fraction arriving as muons is «$\frac{1}{2^{5}}$» $=\frac{1}{32}$<br>***OR***<br>3 % ✓ | *Award **[3]** for a bald correct answer.* | **3** |
| 4. | a | ii | time of travel corresponds to «$\frac{1.10\times10^{-5}}{5.0\times2.20\times10^{-6}}$» $=1.0$ half-life ✓<br>so fraction arriving as muons is $\frac{1}{2}$<br>***OR***<br>50 % ✓ | *Award **[2]** for a bald correct answer.* | **2** |
| 4. | b | | observer measures the distance to the surface to be shorter « by a factor of 5.0 » / length contraction occurs ✓<br>so time of travel again corresponds to «$\frac{\left(\frac{\frac{3230}{5.0}}{0.98\times3.0\times10^{8}}\right)}{\left(2.20\times10^{-6}\right)}$»= 1.0 half-life ✓ | | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 5. | a | | <br>point as shown ✓ | | 1 |

*(continued…)*

*(Question 5 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 5. | b | | ***ALTERNATIVE 1***<br>the rocket would have to travel faster than the speed of light ✓<br>so impossible ✓<br><br>***ALTERNATIVE 2***<br>drawing of future lightcone at origin ✓<br>and seeing that the asteroid explodes outside the lightcone so impossible ✓<br><br>***ALTERNATIVE 3***<br>the event was observed at +20 years, but its distance (stationary) is 100 ly ✓<br>so the asteroid event happened 80 years before t = 0 for the galactic observer ✓ | | **2** |
| 5. | c | | $100^2 - 20^2 = 9600$ «$ly^2$» ✓ | *Also accept 98 (the square root of 9600).*<br>*Allow negative value.* | **1** |
| 5. | d | i | $9600 = 120^2 - c^2t^2$ ✓<br>$ct =$ «–» 69.3 «ly» / $t =$ «–» 69.3 «y» ✓ | *Allow approach with Lorentz transformation.* | **2** |

*(continued…)*

*(Question 5 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **5.** | **d** | **ii** | line from event 2 parallel to $x'$ axis intersects $ct'$ axis at a negative value ✓<br>event 2 occurred first ✓ | | **2** |
| **5.** | **e** | | use of $\tan\theta = \frac{v}{c}$ with the angle between the time axes ✓<br>to get $(0.70 \pm 0.02)c$ ✓ | | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 6. | a | | momentum of xi baryon is also $289.7$ «MeV $c^{-1}$» ✓<br>total energy of xi baryon and pion is $\sqrt{289.7^2+1321^2}+\sqrt{289.7^2+135.0^2}=1672$ «MeV» ✓<br>which equals the rest energy of the omega ✓ | *Allow a backwards argument, assuming the energy is equal.* | 3 |
| 6. | b | | $\gamma$ «$=\frac{\sqrt{289.7^2+135.0^2}}{135.0}$» $=2.367$ ✓<br>$v$ «$=\sqrt{1-\frac{1}{2.367^2}}c$» $=0.906c$ ✓ | *Award **[2]** for bald correct answer.* | 2 |

| | | | | | |
|---|---|---|---|---|---|
| 7. | a | | a freely falling frame in a gravitational field is equivalent to an inertial frame<br>***OR***<br>a frame accelerating in free space is equivalent to a frame at rest in a gravitational field ✓ | | 1 |
| 7. | b | i | X is in an inertial frame ✓<br>so light will follow a straight line path « parallel to the floor of the box » ✓ | | 2 |
| 7. | b | ii | ***ALTERNATIVE 1***<br>light must hit right wall of box at same place as determined by X ✓<br>« but box is accelerating » so path must be curved downward ✓<br>***ALTERNATIVE 2***<br>light is affected by gravity « for the observer at rest to the ground » ✓<br>so the path is curved downward/toward the ground ✓ | | 2 |

**Option B — Engineering physics**

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 8. | a | i | equations of motion are: $TR = \frac{1}{2}MR^2\alpha$ and $\frac{Mg}{4} - T = \frac{M}{4}a$<br>***OR***<br>$\frac{M}{4}gR = \frac{1}{2}MR^2\alpha + \frac{M}{4}Ra$ ✓<br>use of $a = \alpha R$ ✓<br>combine equations to get result ✓ | *Allow energy conservation use.*<br>*This is a show that question, so look for correct working.*<br>*Do not allow direct use of tension from a ii).* | **3** |
| 8. | a | ii | use of $T = \frac{1}{2}MR\alpha$ to find $T = \frac{1}{2}MR \times \frac{g}{3R}$ ✓<br>« cancelling to show final answer » | | **1** |
| 8. | b | | $a = 3.27$ «$\text{m s}^{-2}$» / $a = g/3$ ✓<br>$t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 0.50}{3.27}}$ ✓<br>$= 0.55$ «s» | *Do not apply ECF from MP1 to MP2 if for a=g, giving answer 0.32 s.* | **2** |

*(continued…)*

*(Question 8 continued)*

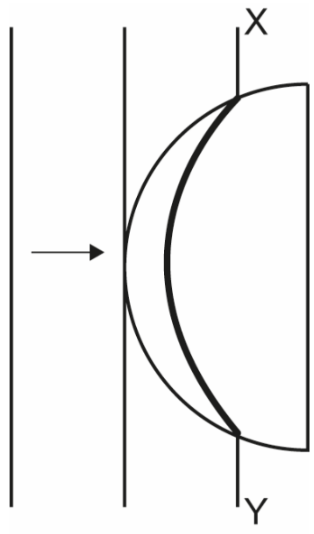
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 8. | c | i | ***ALTERNATIVE 1***<br>$\Delta L$ «$= \Gamma\Delta t = TR\Delta t$» $= \dfrac{12 \times 9.81 \times 0.20 \times 0.55}{6}$ ✓<br>$\Delta L = 2.2$ «Js» ✓<br>***ALTERNATIVE 2***<br>$\omega =< \alpha\Delta t = \dfrac{g}{3R}\Delta t = \dfrac{9.81 \times 0.55}{3 \times 0.20} => 8.99$ «$\text{rad s}^{-1}$» ✓<br>$\Delta L$ «$= I\omega$» $= \dfrac{1}{2} \times 12 \times 0.20^2 \times 8.99 = 2.2$ «Js» ✓ | *Award **[2]** for a bald correct answer.* | 2 |
| 8. | c | ii | $\omega =< \alpha\Delta t = \dfrac{g}{3R}\Delta t = \dfrac{9.81 \times 0.55}{3 \times 0.20} => 8.99$ «$\text{rad s}^{-1}$» ✓<br>$E_K =$ «$\dfrac{1}{2}I\omega^2 = \dfrac{1}{4}MR^2\omega^2 = \dfrac{1}{4} \times 12 \times 0.20^2 \times 8.99^2 =$» $9.7$ «J» ✓ | *Award **[2]** for a bald correct answer.* | 2 |

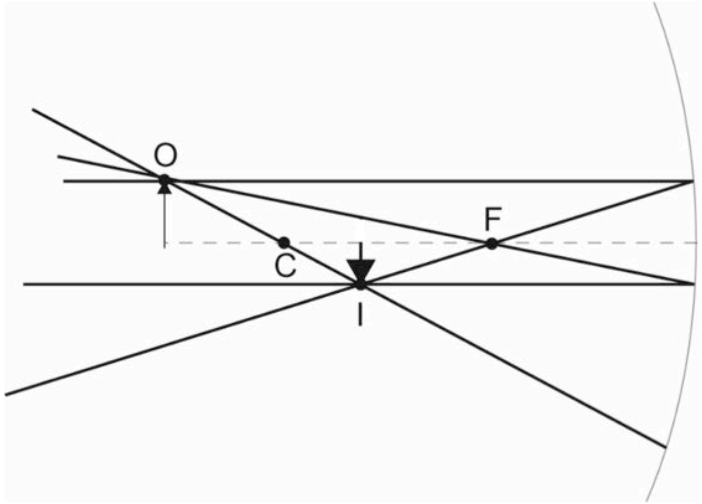
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 9. | a | | substitution of $P=\frac{nRT}{V}$ in $P_X V_X^{\frac{5}{3}} = P_Y V_Y^{\frac{5}{3}}$ ✓<br>manipulation to get result ✓ | | 2 |
| 9. | b | i | $e$ «$=1-\frac{T_c}{T_h}=1-\frac{340}{620}$» $=0.45$ ✓ | | 1 |
| 9. | b | ii | heat into gas « is along AB » and equals<br>$Q_{in}$ «$=\Delta U + W = 0+540$» $=540$ «J» ✓<br>heat out is $(1-e)Q_{in}=(1-0.45)\times 540 = 297$ «J» $\approx 3.0\times 10^2$ «J» ✓ | *Award **[2]** for bald correct answer.* | 2 |
| 9. | b | iii | $T_B V_B^{\frac{2}{3}} = T_C V_C^{\frac{2}{3}} \Rightarrow \frac{V_C}{V_B} = \left(\frac{T_B}{T_C}\right)^{\frac{3}{2}}$ ✓<br>$\frac{V_C}{V_B} = \left(\frac{620}{340}\right)^{\frac{3}{2}} = 2.5$ ✓ | *Award **[2]** for bald correct answer.* | 2 |
| 9. | c | i | $\Delta S$ «$=\frac{Q}{T}=\frac{540}{620}$» $=0.87$ «$JK^{-1}$» ✓ | | 1 |
| 9. | c | ii | the Carnot cycle has the maximum efficiency « for heat engines operating between two given temperatures » ✓<br>real engine can not work at Carnot cycle/ideal cycle ✓<br>the second law of thermodynamics says that it is impossible to convert all the input heat into mechanical work ✓<br>a real engine would have additional losses due to friction *etc* ✓ | | 2 max |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 10. | a | | flow must be laminar/steady/not turbulent ✓<br>fluid must be incompressible/have constant density ✓<br>fluid must be non viscous ✓ | | **1 max** |
| 10. | b | i | « continuity equation says » $Av = \text{constant}$ « and the areas are the same » ✓ | | **1** |
| 10. | b | ii | Bernoulli: «$\frac{1}{2}\rho v_X^2 + 0 + P_X = \frac{1}{2}\rho v_Y^2 + \rho gH + P_Y$» gives $P_X - P_Y = \rho gH$ ✓<br>$P_X - P_Y = 720 \times 9.81 \times 1.2 = 8.5$ «kPa» ✓ | *Award **[2]** for bald correct answer.*<br>*Watch for POT mistakes.* | **2** |
| 10. | b | iii | the fluid speed at Y will be greater « than that at X » ✓<br><br>reducing the pressure at Y<br>***OR***<br>the formula used to show that the difference is increased ✓ | | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **11.** | **a** | | ***ALTERNATIVE 1***<br>$«Q = 2\pi\frac{E_0}{E_0 - E_1}» \Rightarrow E_1 = \left(1 - \frac{2\pi}{Q}\right)E_0$ ✓<br>$E_1 «= \left(1 - \frac{2\pi}{25}\right) \times 12» = 9.0 «\text{mJ}»$ ✓<br>reading off the graph, period is 0.48 « s » ✓<br>***ALTERNATIVE 2***<br>use of $Q = 2\pi f \frac{\text{energy stored}}{\text{power loss}}$ ✓<br>energy stored=12 « mJ » ***AND*** power loss = 5.6 « mJ/s » ✓<br>« $f = 1.86$ s so » period is 0.54 « s » ✓ | *Award **[3]** for bald correct answer.*<br>*Allow correct use of any value of $E_0$, not only at the time = 0.*<br>*Allow answer from interval 0.42–0.55 s*<br>*Allow answer from interval 0.42–0.55 s.* | **3** |
| **11.** | **b** | | similar shape graph starting at 12 mJ and above the original ✓ | | **1** |

**Option C — Imaging**

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **12.** | | | smooth curve of correct curvature continuous at the boundary as shown ✓<br>wavelength must be half the one in air; judge by eye ✓ |  | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 13. | a | i | F half-way between C and mirror vertex and on the principal axis ✓ | | 1 |
| 13. | a | ii | <br>one correct ray ✓<br>second correct ray that allows the image to be located ✓<br>image drawn ✓ | | 3 |
| 13. | a | iii | image will be less bright / dimmer ✓ | | 1 |

*(continued…)*

*(Question 13 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **13.** | **b** | | «image distance is $\frac{1}{v}=\frac{1}{1.5}-\frac{1}{3.8\times10^{8}}$ *ie*» $v=1.5$ «m» ✓<br>$m=-\frac{1.5}{3.8\times10^{8}}$ ✓<br>image diameter is $\frac{1.5}{3.8\times10^{8}}\times3.5\times10^{6}=1.4$ «cm» ✓ | *Award **[3]** for bald correct answer.* | **3** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **14.** | **a** | **i** | «$\sin\theta_c = \frac{n_1}{n_2}$» $\sin\theta_c = \frac{1.276}{1.620}$ ✓<br>$\theta_c = 51.97^\circ$ ✓ | *Award **[2]** for bald correct answer.* | **2** |
| **14.** | **a** | **ii** | angle of refraction at air-core boundary is 90°–$\theta_c$<br>« $= 90.00^\circ - 51.97^\circ = 38.03^\circ$ » ✓<br>$1.000 \times \sin\theta_{max} = 1.620 \times \sin 38.03^\circ$ ✓<br>$\theta_{max} = 86.41^\circ$ ✓ | | **3** |
| **14.** | **a** | **iii** | « $\theta_{max}$ is almost $90^\circ$ which means that » a ray entering the core almost at any angle will be totally internally reflected/will not escape ✓ | | **1** |
| **14.** | **a** | **iv** | rays will follow very different paths in the core ✓<br>leading to waveguide dispersion/different arrival times/pulse overlap ✓ | | **2** |
| **14.** | **b** | | *Reference to 2 of:*<br>secure/encrypted transfer of data ✓<br>high bandwidth/volume of data transferred ✓<br>high quality/minimal noise in transmission ✓<br>free from cross talk ✓<br>low « specific » attenuation ✓ | | **2 max** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 15. | a | | mention of AC voltage ***OR*** to piezo-electric crystal ✓<br>crystal vibrates « at its resonant frequency » ✓ | | **2** |
| 15. | b | | 1 MHz waves have shorter wavelength than 0.1 MHz ✓<br>can probe smaller size areas of organs/have higher resolution ✓ | | **2** |
| 15. | c | | a B scan is a computer generated combination of a large number of A scans ✓<br>allowing a measurement in different directions/two dimensional image ✓ | | **2** |

| | | | | | |
|---|---|---|---|---|---|
| 16. | a | | $I_0 e^{-0.24 \times 7.8}$ ✓<br>$0.15 I_0$ ✓ | *Award **[2]** for bald correct answer.* | **2** |
| 16. | b | | to produce an X-ray image there must be contrast/a difference in the intensity of the beam transmitted through tissue and the bowel ✓<br>introduction of air will produce contrast ✓ | | **2** |

**Option D — Astrophysics**

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **17.** | **a** | **i** | $L_X = 5.0^{3.5} L_{\odot} = 279.5 L_{\odot}$ ✓ | *Correct working or answer to 4 sig figs required.* | **1** |
| **17.** | **a** | **ii** | $\frac{L_X}{L_{\odot}} = 280 = \frac{R_X^2}{R_{\odot}^2}\frac{T_X^4}{T_{\odot}^4}$ ✓<br>$\frac{T_X}{T_{\odot}}$ «$= \sqrt[4]{\frac{280}{3.2^2}}$» $= 2.3$ ✓ | *Award **[2]** for bald correct answer.* | **2** |
| **17.** | **b** | **i** | the position of the star is recorded 6 months apart<br>***OR***<br>the radius/diameter of the Earth orbit clearly labelled on a diagram ✓<br><br>the parallax is measured from the shift of the star relative to the background of the distant stars ✓ | *For MP2 accept a correctly labelled parallax angle on a diagram.*<br>*Award MP2 only if background distance stars are mentioned.* | **2** |
| **17.** | **b** | **ii** | $d = \frac{1}{0.125} = 8.0$ «pc» ✓<br>$d = 8.0 \times 3.26 \times \frac{9.46 \times 10^{15}}{1.5 \times 10^{11}}$ «AU» ✓<br>«$= 1.64 \times 10^{6}$ AU» | | **2** |

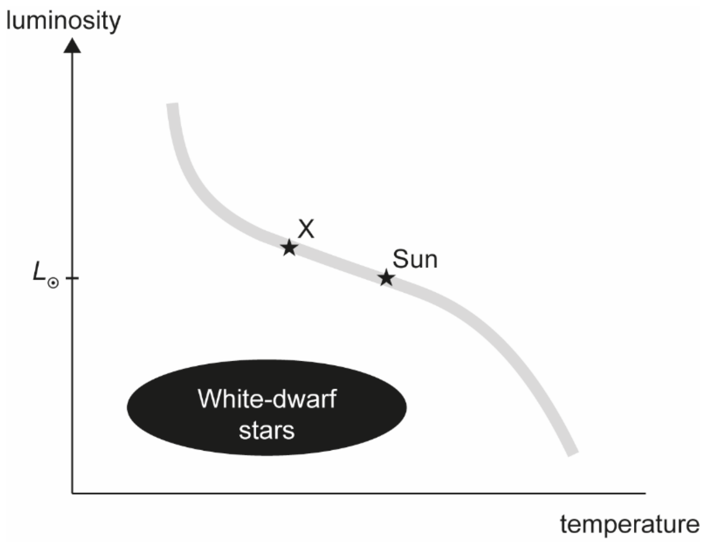
*(continued…)*

*(Question 17 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 17. | b | iii | ***ALTERNATIVE 1***<br>$\frac{b_x}{1400} = \frac{\frac{280}{4\pi(1.6\times10^6)^2}}{\frac{1}{4\pi(1)^2}}$<br>***OR***<br>$b_x = \frac{279.5}{4\pi\times(1.6\times10^6\times1.5\times10^{11})^2}$ and $b_\odot = \frac{L_\odot}{4\pi\times(1.5\times10^{11})^2}$ ✓<br><br>$b_x = 1.5\times10^{-7}$ «$\text{W m}^{-2}$» ✓<br><br>***ALTERNATIVE 2***<br>$\frac{b_x}{b_\odot} = \frac{L_x}{L_\odot}\times\left(\frac{d_\odot^{\ 2}}{d_x^{\ 2}}\right)$ ***OR*** $\frac{b_x}{b_\odot} = \frac{280}{(1.6\times10^6)^2}$ ***OR*** $\frac{b_x}{b_\odot} = 1.094\times10^{-10}\ Wm^{-2}$ ✓<br>$b_x = 1.09375\times10^{-10}\times1400$ $b_x = 1.5\times10^{-7}\ Wm^{-2}$ ✓ | *Award **[2]** for bald correct answer.*<br><br>*Allow ECF from MP1 to MP2* | **2** |

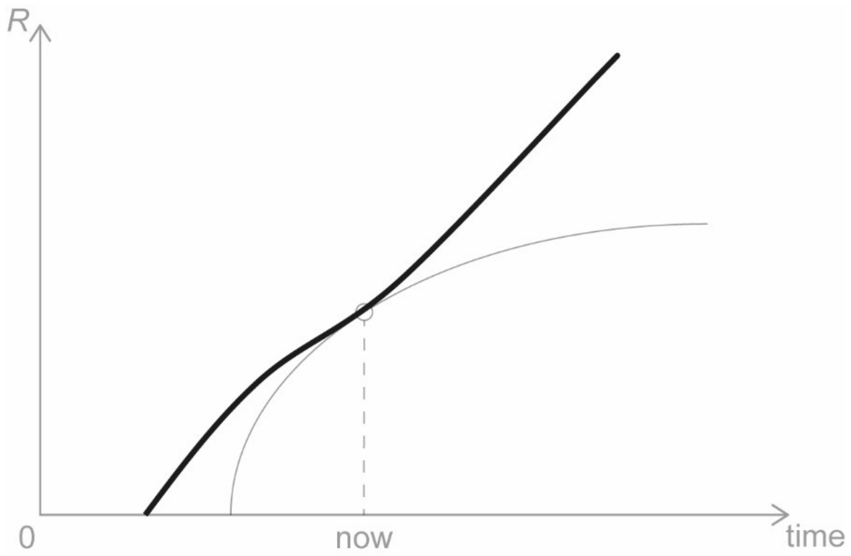
*(continued…)*

*(Question 17 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **17.** | **c** | **i** |   ✓ | *Allow any region with L below Sun and left to the main sequence.* | **1** |
| **17.** | **c** | **ii** | an electron degeneracy « pressure develops that opposes gravitation » /reference to Pauli principle ✓ | | **1** |
| **17.** | **c** | **iii** | thermal energy/internal energy ✓ | | **1** |
| **17.** | **c** | **iv** | « temperature decreases so » luminosity decreases ✓ | | **1** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 18. | a | i | « the received » wavelength is longer than that emitted ✓ | *Allow context of Doppler redshift as well as cosmological redshift.* | **1** |
| 18. | a | ii | $v = zc = 0.15 \times 3.0 \times 10^5 = 4.5 \times 10^4$ «km s$^{-1}$» ✓<br>$d = \frac{v}{H_0} = \frac{4.5 \times 10^4}{72} = 625$ «Mpc» ✓ | *Award **[2]** for bald correct answer.*<br>*Accept in other units, eg, 1.95 x $10^{25}$m.* | **2** |
| 18. | b | i | the radiation has a black body spectrum/it is black body radiation ✓<br>the radiation is highly isotropic/uniform ✓<br>matched the « predicted » wavelength/temperature if the Big Bang had increased/cooled by expansion ✓ | | **2 max** |
| 18. | b | ii | peak wavelength read off graph as $(1.1 \pm 0.05)$ «mm» ✓<br>substitution into Wien's law to get $T = (2.5 \text{ to } 2.8)$ «K» ✓ | | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 19. | a | i | ***ALTERNATIVE 1***<br>a white dwarf star in a binary system accretes mass from the companion star ✓<br>when the white dwarf star mass reaches the Chandrasekhar limit the star explodes « due to fusion reactions » ✓<br>***ALTERNATIVE 2***<br>it can be formed in the collision of two white dwarf stars ✓<br>where shock waves from the collision rip both stars apart ✓ | | **2** |
| 19. | a | ii | a red supergiant star explodes when its core collapses ✓ | | **1** |
| 19. | b | | « it was necessary » to measure the distance « of very distant objects more accurately » ✓<br>type I a are standard candles/objects of known luminosity ✓ | | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 20. | a | | « according to general relativity » space expands stretching distances between far away objects ✓<br>wavelengths of photons « received a long time after they were emitted » are thus longer leading to the observed redshift ✓ | *Do not accept references to the Doppler effect.* | 2 |
| 20. | b | i |  ✓ | | 1 |
| 20. | b | ii | « since $T \propto \frac{1}{R}$ » the temperature drops for both models ✓<br>but in the accelerating model $R$ increases faster and so the temperature drops faster ✓ | | 2 |