Markscheme

May 2019

Physics

Higher level

Paper 3

33 pages

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**		ΔI is too small to be shown/seen **OR** Error bar of negligible size compared to error bar in V ✔		1
1.	**b**		evidence that ε can be determined from the y-intercept of the line of best-fit or lines of min and max gradient ✔ states $\varepsilon = 1.59$ **OR** 1.60 **OR** 1.61 «V» ✔ states uncertainty in ε is 0.02 «V» **OR** 0.03«V» ✔		3
1.	**c**		determine the gradient «of the line of best-fit» ✔ *r* is the negative of this gradient ✔		2

Question			Answers	Notes	Total
2.	**a**		Any curve that passes through ALL the error bars ✓		**1**
2.	**b**	**i**	$kg^{-1}\,m^{-1}$ ✓		**1**
2.	**b**	**ii**	f^2 AND T **OR** f AND $\sqrt{T}$ **OR** $\log f$ AND $\log T$ **OR** $\ln f$ AND $\ln T$ ✓		**1**
2.	**b**	**iii**	graph would be a straight line/constant gradient/linear ✓ passing through the origin ✓		**2**

Question			Answers	Notes	Total
3.	**a**		Evidence of $\dfrac{\Delta s}{s}$ AND $\dfrac{\Delta D}{D}$ used ✔ «add fractional/% uncertainties» obtains 11 % (or 0.11) **OR** 10 % (or 0.1) ✔		**2**
3.	**b**		**ALTERNATIVE 1:** measure the combined width for several fringes **OR** repeat measurements ✔ take the average **OR** so the «percentage» uncertainties are reduced ✔ **ALTERNATIVE 2:** increase D «hence s» **OR** Decrease d ✔ so the «percentage» uncertainties are reduced ✔	*Do not accept answers which suggest using different apparatus.*	**2**

Section B

Option A — Relativity

Question			Answers	Notes	Total
4.	**a**	**i**	a coordinate system which is not accelerating/has constant velocity/Newtons 1st law applies ✓	OWTTE *Both "inertial" and "reference frame" need to be defined*	**1**
4.	**a**	**ii**	1.5*c* ✓		**1**
4.	**b**		*c* is the same in all frames **OR** c is maximum velocity possible ✓ velocity addition frame dependent ✓ length/time/mass/fields relative measurements ✓ Newtonian/Galilean mechanics valid only at low speed ✓		**2 max**

Question			Answers	Notes	Total
5.	**a**		moving charges give rise to magnetic fields ***OR*** magnetic attraction between parallel currents ✓	5.	**1**
5.	**b**		protons at rest produce no magnetic field ***OR*** mention of $F = Bev$ where B and/or $v = 0$ ✓	5.	**1**
5.	**c**		there is a repulsive electric/electrostatic force «in both frames» ✓ the attractive magnetic force «in the lab frame» is smaller than the repulsive electric force ✓ in all frames the net force is repulsive as all must agree that protons move apart ***OR*** mention of the first postulate of relativity ✓	5.	**2 max**

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	Question		Answers	Notes	Total
6.	**a**		the length measured «in a reference frame» where the object is at rest ✔		**1**
6.	**b**	**i**	$\Delta t = «\dfrac{85}{0.5\times 3\times 10^{8}} =»5.7\times 10^{-7}$ «s» ✔		**1**
6.	**b**	**ii**	*ALTERNATIVE 1:* «for $v=0.6c$ » $\gamma = 1.25$ ✔ «uses LT with Δt' from 6(b)(i)» $\Delta t = 1.25\left(5.7\times 10^{-7} + \dfrac{0.6\times 85}{3\times 10^{8}}\right)$ ✔ 9.2×10^{-7} «s» *OR* 9.3×10^{-7} «s» ✔ *ALTERNATIVE 2:* v of ball is $0.846c$ for platform ✔ length of train is 68m for platform ✔ time = «$\dfrac{68}{0.846c - 0.6c} =$» 9.2×10^{-7} «s» *OR* 9.3×10^{-7} «s» ✔ *ALTERNATIVE 3:* « $\gamma = 1.154$ for ball in train, so proper time for ball» $\Delta t_{0} = «\dfrac{5.7\times 10^{-7}}{1.154} =$» 4.9×10^{-7} «s» ✔ v of ball is $0.846c$ for platform *OR* $\gamma = 1.876$ ✔ $\Delta t = «\gamma \Delta t_{0} = 1.876\times 4.9\times 10^{-7} =$» 9.2×10^{-7} «s» *OR* 9.3×10^{-7} «s» ✔		**3**

Question			Answers	Notes	Total
7.	**a**		*Evidence of finding 1/gradient such as:* use of any correct coordinate pair to find *v* - *eg* $\dfrac{4}{5}$ or $\dfrac{6}{7.5}$ **OR** measures tan of angle between *ct* and *ct'* as about 39° **AND** $\tan 39 \approx 0.8$ ✔	*Answer 0.8c given, so check coordinate values carefully.*	1
7.	**b**		E labelled at $x = 4$, $ct = 5$ ✔	*Check that E is placed on the worldline of S.*	1
7.	**c**	**i**	$\gamma = \dfrac{5}{3} = 1.67$ ✔ $t' = \dfrac{5}{\gamma} = 3\,\text{years}$ **OR** $ct' = 3\,\text{ly}$ ✔	*Allow solutions involving the use of Lorentz equations.*	2
7.	**c**	**ii**	$t = 5$ years **OR** $ct = 5\,\text{ly}$ ✔		1

(continued…)

(Question 7 continued)

	Question		Answers	Notes	Total
7.	d		On return to Earth the astronaut will have aged less than Earthlings «by 4 years» **OR** time passed on Earth is greater than time passed for the astronaut «by 4 years» ✓ astronaut accelerated/changed frames but Earth did not **OR** for astronaut the Earth clock jumps forward at turn- around ✓	*OWTTE* *Treat as neutral any mention of both the Earth and astronaut seeing each other's clock as running slow.*	**2**

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	Question		Answers	Notes	Total
8.	**a**		total energy is the sum of the rest energy and the kinetic energy ✓		**1**
8.	**b**	**i**	«$p^2c^2 = 1050^2 - 938^2$ therefore» $p = 472$ «$MeVc^{-1}$» ✓		**1**
8.	**b**	**ii**	$\gamma = \dfrac{1050}{938} = 1.12$ ✓ $v = 0.45c$ **OR** $V = 1.35 \times 10^8$ «ms^{-1}» ✓		**2**
8.	**b**	**iii**	$V = 112$ «MV» ✓		**1**

Question			Answers	Notes	Total
9.	a		**ALTERNATIVE 1** detector accelerates/moves away from point of photon emission ✓ so Doppler effect / redshift ✓ so f decreases ✓ **ALTERNATIVE 2** equivalent to stationary rocket on earth's surface ✓ photons lose «gravitational» energy as they move upwards ✓ hf **OR** f decreases ✓		**3**
9.	b		«Using $E = hf$» $f = \dfrac{14.4 \times 10^3 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 3.48 \times 10^{18}$ «Hz» ✓ «$\Delta f = f\dfrac{g\Delta h}{c^2}$» $\Delta f = 3.48 \times 10^{18}\dfrac{9.81 \times 52}{\left(3 \times 10^8\right)^2} = 1.97 \times 10^4$ «Hz» ✓		**2**

Option B — Engineering physics

Question			Answers	Notes	Total
10.	**a**		«translational equilibrium demands that the» resultant force in the <u>horizontal</u> direction must be zero✓ «hence $N_W = F$»	*Equality of forces is given, look for reason why.*	**1**
10.	**b**		«clockwise moments = anticlockwise moments» $50 \times 2\cos 60 = N_W \times 4\sin 60$ ✓ «$N_W = F = \dfrac{50 \times 2\cos 60}{4\sin 60}$» $F = 14.4$ «N» ✓		**2**
10.	**c**		maximum friction force $= $ «$0.4 \times 50\text{N}$» $= 20$ «N» ✓ $14.4 < 20$ ***AND*** so will not slip ✓		**2**

Question			Answers	Notes	Total
11.	**a**		$E_k = E_k$ linear $+ E_k$ rotational **OR** $E_k = \dfrac{1}{2}mv^2 + \dfrac{1}{2}I\omega^2$ ✔ $= \dfrac{1}{2}mv^2 + \dfrac{1}{2} \times \dfrac{2}{5}mr^2 \times \left(\dfrac{v}{r}\right)^2$ ✔ $\text{«} = \dfrac{7}{10}mv^2 \text{»}$	*Answer is given in the question so check working is correct at each stage.*	**2**
11.	**b**		Initial $E_K = \dfrac{7}{10} \times 1.50 \times 0.5^2$ «$= 0.26\,$J» ✔ Final $E_K = 0.26 + 1.5 \times 9.81 \times 0.45$ «$= 6.88\,$J» ✔ $v = \text{«} \sqrt{\dfrac{10}{7} \times \dfrac{6.88}{1.5}} =\text{»}\ 2.56$ «m s^{-1}» ✔	*Other solution methods are possible.*	**3**
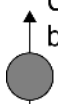
	Question		Answers	Notes	Total
12.	**a**		evidence of work done equals area between AC and the Volume axis ✓ reasonable method to estimate area giving a value 425 to 450 J ✓	*Answer 440 J is given, check for valid working.* *Examples of acceptable methods for MP2:* *- estimates 17to18 small squares x 25J per square = 425 to 450 J.* *- 250 J for area below BC plus a triangle of dimensions 5 × 3, 3 × 5, or 4 × 4 small square edges giving 250J + 187.5 J or 250 J + 200 J.* *Accurate integration value is 438 J - if method seen award* **[2]**.	**2**
12.	**b**	**i**	«use of $U = \frac{3}{2}nRT$ and $pV = nRT$ to give» $\Delta U = \frac{3}{2}\Delta pV$ ✓ «$= \frac{3}{2} \times -2.5 \times 10^5 \times 1 \times 10^{-3}$» $= $ «−»375«J» ✓	*Another method is possible: eg realisation that ΔU for BC has same magnitude, so ΔU = 3/2 PΔV.*	**2**
12.	**b**	**ii**	$T_A = 816$«K» ***OR*** 543«°C» ✓		**1**

(continued…)

(Question 12 continued)

	Question		Answers	Notes	Total
12.	**c**		for CA $\Delta U = 0$ so $Q = W = -440$ «J» ✓ for AB $W = 0$ so $Q = \Delta U = -375$ «J» ✓ 815 «J» transferred to the building ✓	*Must use the first law of thermodynamics for MP1 and MP2.*	
		3			**3**
12.	**d**		the temperature changes in the cycle are too large ✓ the cycle takes too long «because it contains an isothermal stage» ✓ energy/power output would be too small ✓		**12.** **2 max**

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Question			Answers	Notes	Total
13.	**a**		U **OR** upthrust **OR** buoyant force **OR** buoyancy force **OR** buoyancy **OR** B W **OR** weight **OR** mg **OR** force of gravity	*Both forces must be suitably labeled.* *Do not accept just 'gravity'* *Award [0] if a third force is shown.*	**1**
13.	**b**		«as the ball falls» there is a drag force ✔ when drag force + buoyant force/upthrust = «-» weight **OR** When net/resultant force = 0 ✔ «terminal speed occurs»	*OWTTE* *Terminal speed is mentioned in the question, so no additional marks for reference to it.*	**2**
13.	**c**		any evidence (numerical or algebraic) of a realisation that $6\pi\eta rv + \rho gV = W$ ✔ $«\eta = \dfrac{6.16\times10^{-3} - 4.366\times10^{-3}}{6\pi\times0.005\times0.280}»$ $\eta = 0.0680$ «Pas» ✔		**2**

Question			Answers	Notes	Total
14.	**a**		time period $T = «\dfrac{25}{10}» = 2.5\,\text{s}$ **AND** $f = \dfrac{1}{T}$ **OR** evidence of $f = \dfrac{10}{25}$ ✔	*Answer 0.4 Hz is given, check correct working is shown.*	1
14.	**b**		$30\,\text{m s}^{-1}$ corresponds to $f = 1.2\,\text{Hz}$ ✔ the amplitude of vibration is a maximum for this speed **OR** corresponds to the resonant frequency ✔		2
14.	**c**		similar shape with lower amplitude ✔ maximum shifted slightly to left of the original curve ✔	*Amplitude must be lower than the original, but allow the amplitude to be equal at the extremes.*	2

Option C — Imaging

	Question		Answers	Notes	Total
15.	**a**	**i**	any two correct rays with extensions ✓ extensions converging to locate an upward virtual image labelled I with position within shaded region around focal point on diagram ✓		**2**
15.	**a**	**ii**	$v = «-» 10 «\text{cm}»$ ✓ $M «= -\left(\dfrac{v}{u}\right) = -\left(\dfrac{-10}{5}\right)» = «+» 2$ ✓		**2**
15.	**a**	**iii**	magnifying glass **OR** Simple microscope **OR** eyepiece lens ✓		**1**

(continued…)

(Question 15 continued)

	Question		Answers	Notes	Total
15.	**b**	**i**	I labelled at 25 cm mark ✓		**1**
15.	**b**	**ii**	the second lens has f «$= \dfrac{10}{5}$» $= 2$ «cm» ✓ «so for telescope image to be at infinity» the second lens is placed at 27 «cm» **OR** separation becomes 12 «cm» ✓		**2**
15.	**b**	**iii**	image formed by 10 cm lens is greater than 10 cm/further to the right of the first lens ✓ so second lens must also move to the right **OR** lens separation increases ✓	Award *[1 max]* for bald "separation increases".	**2**

Question			Answers	Notes	Total
16.	**a**		refractive index of step index fibre is constant ✔ refractive index of graded index fibre decreases with distance from axis/centre ✔ graded index fibres have less dispersion ✔ step index fibre: path of rays is in a zig-zag manner ✔ graded index fibre: path of rays is in curved path ✔	*For MP2 do not accept vague statements such as "index increases/varies with distance from centre".*	**2 max**
16.	**b**	**i**	$v = \dfrac{c}{n} = v_{1299} = \dfrac{2.99792 \times 10^8}{1.45061} = 2.06666 \times 10^8$ «m s^{-1}» **AND** $v_{1301} = \dfrac{2.99792 \times 10^8}{1.45059} = 2.06669 \times 10^8$ «m s^{-1}» **OR** $\Delta v = \left(\dfrac{1}{1.45059} - \dfrac{1}{1.45061} \right) \times 2.99792 \times 10^8$ ✔ $\Delta v = 2.85 \times 10^3$ **OR** 3×10^3 «m s^{-1}» ✔		**2**

(continued…)

(Question 16 continued)

Question			Answers	Notes	Total
16.	**b**	**ii**	pulse wider ✓ pulse area smaller ✓	*For MP2 do not accept lower amplitude unless pulse area is also smaller.*	**2**
16.	**b**	**iii**	reference to dispersion ***OR*** reference to time/speed/path difference ✓ reference to power loss/energy loss/scattering/attenuation ✓		**2**
16.	**b**	**iv**	longer cables give wider pulses ✓ which overlap/interfere if T too small/f too high ✓	*OWTTE*	**2**

Question			Answers	Notes	Total
17.	**a**	**i**	***Advantage of ultrasound compared to X-rays:*** no exposure to radiation **OR** relatively harmless **OR** can be performed in a doctor's office **OR** can be used to measure blood flow rate **OR** Video image possible <<eg heart, foetus>> ✓ ***Disadvantage:*** limited resolution **OR** difficulty imaging lungs or gastrointestinal system **OR** difficulty imaging any body part with a gas in it ✓	*Accept any reasonable advantage.* *Accept any reasonable disadvantage.* *Do not allow answers that contradict each other.*	**2**
17.	**a**	**ii**	gel has similar Z to skin **OR** gel prevents acoustic mismatch ✓ without gel much ultrasound is reflected at skin **OR** gel increases ultrasound transmission ✓	*OWTTE*	**2**

(continued…)

(Question 17 continued)

Question			Answers	Notes	Total
17.	**a**	**iii**	$IL = «10\log\left(\dfrac{10}{40}\right) =» -6\,«\mathrm{dB}»$ ✔		**1**
17.	**b**	**i**	$c = «\dfrac{Z}{\rho} = \dfrac{1.65\times10^{6}}{1090\,\mathrm{kg\,m^{-3}}} =»\,1514\,«\mathrm{ms^{-1}}»$ ✔ $«\approx 1500\,\mathrm{ms^{-1}}»$	*Answer 1500 is given, check working or look for at least 3 significant figures.*	**1**
17.	**b**	**ii**	$4.5\times10^{-2}\,«\mathrm{m}»$ ✔		**1**

(continued…)

(Question 17 continued)

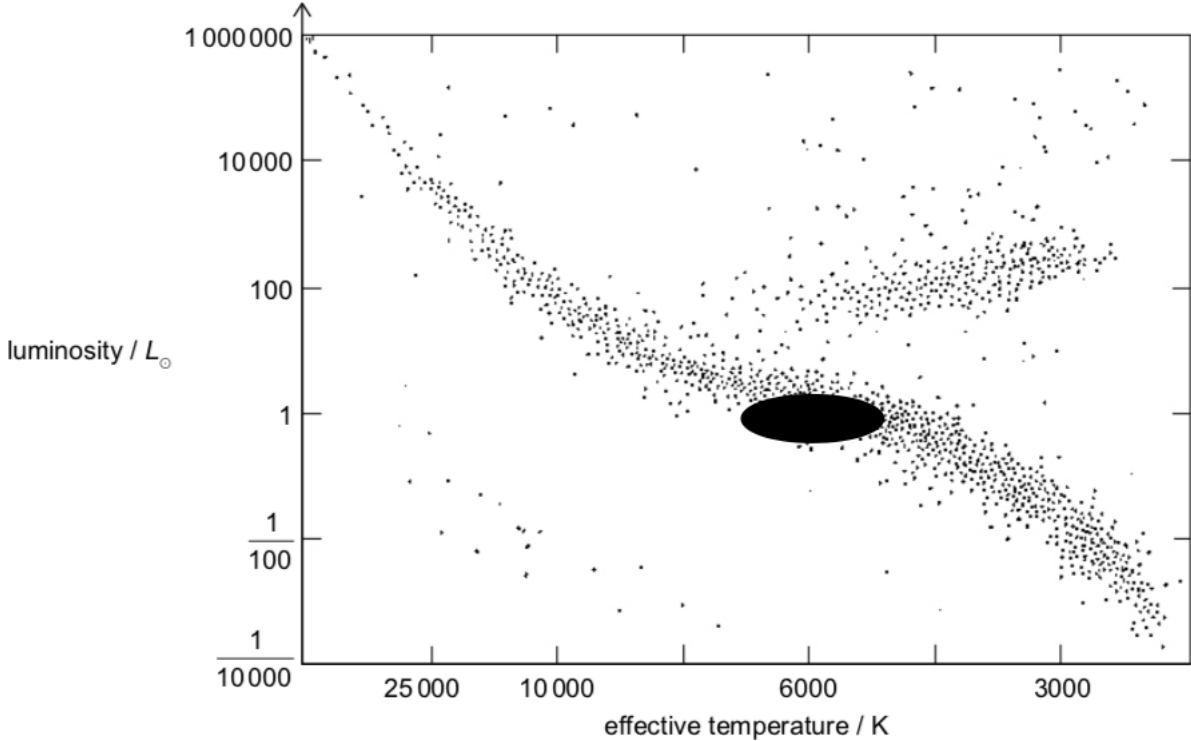| Question			Answers	Notes	Total
17.	**b**	**iii**	$\lambda = \dfrac{4.5 \times 10^{-2}}{200} = 2.25 \times 10^{-4}$ «m» ✔ $f = \dfrac{v}{\lambda} = \dfrac{1500}{2.25 \times 10^{-4}} = 6.7 \times 10^{6}$ «Hz» ✔		**2**
17.	**b**	**iv**	«compared to lower frequencies, higher frequencies» have better resolution ✔ have greater attenuation ✔ used for superficial structures/organs ✔ have greater heating effect ✔	*OWTTE* *Award **[0]** for contradictory comments or for any incorrect comment*	**1 max**

Option D — Astrophysics

	Question		Answers	Notes	Total
18.	**a**	**i**	Cepheid variables expand and contract *OR* Radius increases and decreases *OR* Surface area increases and decreases ✓ Surface temperature decreases then increases✓ Surface becomes transparent then opaque ✓	*OWTTE* *Do not reward 'change in luminosity/brightness' as this is given in the question.* *Accept changes in reverse order*	**2 max**
18.	**a**	**ii**	the «peak» luminosity/actual brightness depends on the period *OR* More luminous Cepheid variables have greater period✓ measurements of apparent brightness allow distance determination *OR* Mention of $b = \dfrac{L}{4\pi d^2}$ ✓	*OWTTE*	**2**

(continued…)

(Question 18 continued)

Question			Answers	Notes	Total
18.	**b**	**i**	$d = $«$273 \times 3.26 \times 9.46 \times 10^{15} =$» 8.42×10^{18} «m» ✔ $b = $«$\dfrac{L}{4\pi d^2} = \dfrac{7.70 \times 10^{29}}{4\pi\left(8.42 \times 10^{18}\right)^2} =$» 8.6×10^{-10} «Wm^{-2}» ✔		**2**
18.	**b**	**ii**	«$T = \dfrac{2.9 \times 10^{-3}}{4.29 \times 10^{-7}}$» $= 6800$ «K» ✔		**1**
18.	**c**		Data subject to peer review/checks by others ✔ Compare light from stars with Earth based light sources ✔ measurements are corroborated by different instruments/methods from different teams ✔	*OWTTE*	**1max**

	Question		Answers	Notes	Total
19.	**a**	**i**	$d = $ «$1.6 \times 10^8 \times 9.46 \times 10^{15} = $» 1.51×10^{24} «m» ✓ $v = $ «$H_0 d = 2.3 \times 10^{-18} \times 1.51 \times 10^{24} = $» 3.48×10^6 «ms^{-1}» ✓	*Answer given, correct working required or at least 3sf needed for MP2.*	**2**
19.	**a**	**ii**	$\Delta\lambda = $ «$\dfrac{\lambda_0 v}{c} = \dfrac{4.86 \times 10^{-7} \times 3.48 \times 10^6}{3 \times 10^8} = $» 5.64 «nm» ✓ observed $\lambda = $ «$486 + 5.64 = $» 492 «nm» ✓		**2**
19.	**b**		all distant galaxies exhibit red-shift ✓	OWTTE	**1**

Question			Answers	Notes	Total
20.	**a**		the letter S should be in the region of the shaded area ✓		**1**

(Question 20 continued)

	Question		Answers	Notes	Total
20.	**b**		the fusion of hydrogen in the core eventually stops **OR** core contracts ✓ the hydrogen in a layer around the core will begin to fuse ✓ Sun expands AND the surface cools ✓ helium fusion begins in the core ✓ Sun becomes more luminous/brighter✓	*Ignore any mention of the evolution past the red giant stage*	**3max**
20.	**c**		electron degeneracy <<prevents further compression>> ✓	*Ignore mention of the Chandrasekhar limit.* *Award [0] for answer mentioning radiation pressure or fusion reactions.*	**1**
20.	**d**		«use of $L = \sigma AT^4$ » $\dfrac{10^{-4}}{10^{4}} = \left(\dfrac{R_{\mathrm{D}}}{R_{\mathrm{G}}}\right)^2 \times \left(\dfrac{10\,000}{3000}\right)^4$ ✓ $\dfrac{R_{\mathrm{D}}}{R_{\mathrm{G}}} = 9 \times 10^{-6}$ ✓		**2**

Question			Answers	Notes	Total
21.	**a**		white dwarf attracts mass from another star ✓ explodes/becomes supernova when mass equals/exceeds the Chandrasekhar limit / $1.4M_{SUN}$ ✓ hence luminosity of all type I a supernova is the same ✓	*OWTTE*	**3**
21.	**b**		«successive» rapid neutron capture ✓ faster than «β» decay can occur ✓ results in formation of heavier/neutron rich isotopes ✓	*OWTTE*	**2 max**

Question			Answers	Notes	Total
22.	**a**		total energy $=$ kinetic energy $+$ potential energy **OR** total energy $= \dfrac{1}{2}mv^2 - \dfrac{GMm}{r}$ ✔ substitution of $M = \dfrac{4}{3}\pi r^3 \rho$ ✔ «Hence answer given»	Answer given so for MP2 look for clear evidence that $M_{Universe}$ ($\dfrac{4}{3}\pi r^3 \rho$) is stated and substituted.	**2**
22.	**b**		substitutes $H_0 r$ for v ✔ «total energy $= 0$» $\dfrac{1}{2}mH_0^2 r^2 = \dfrac{4}{3}\pi G\rho r^2 m$ ✔ «hence $\rho_c = \dfrac{3H_0^2}{8\pi G}$ »	*Answer given, check working carefully.*	**2**
22.	**c**		9.5×10^{-27} « kgm^{-3}» ✔		**1**