Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

November 2016

Physics

Higher level

Paper 3

28 pages

General Marking Instructions

1. Follow the markscheme provided, award only whole marks and mark only in **RED**.

2. Make sure that the question you are about to mark is highlighted in the mark panel on the right-hand side of the screen.

3. Where a mark is awarded, a tick/check (✓) **must** be placed in the text at the **precise point** where it becomes clear that the candidate deserves the mark. **One tick to be shown for each mark awarded.**

4. Sometimes, careful consideration is required to decide whether or not to award a mark. In these cases use RM™ Assessor annotations to support your decision. You are encouraged to write comments where it helps clarity, especially for re-marking purposes. Use a text box for these additional comments. It should be remembered that the script may be returned to the candidate. Please do not allow these annotations to obscure the written material. Try to keep these to the margin of the scan as far as possible. (Ticks should however be at the point of award, cf 4.)

5. Personal codes/notations are unacceptable.

6. Where an answer to a part question is worth no marks but the candidate has attempted the part question, use the "ZERO" annotation to award zero marks. Where a candidate has not attempted the part question, use the "SEEN" annotation to show you have looked at the question. RM™ Assessor will apply "NR" once you click complete.

7. If a candidate has attempted more than the required number of questions within a paper or section of a paper, mark all the answers. RM™ Assessor will only award the highest mark or marks in line with the rubric.

8. Ensure that you have viewed **every** page including any additional sheets. Please ensure that you stamp "SEEN" on any additional pages that are blank or where the candidate has crossed out his/her work.

9. There is no need to stamp an annotation when a candidate has not chosen an option. RM™ Assessor will apply "NR" once you click complete.

10. Mark positively. Give candidates credit for what they have achieved and for what they have got correct, rather than penalizing them for what they have got wrong. However, a mark should not be awarded where there is contradiction within an answer. Make a comment to this effect using a text box or the "CON" stamp.

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.

15. Allow reasonable substitutions where in common usage, eg ^{c} for rad.

Section A

Question			Answers	Notes	Total
1.	a	i	OY always smaller than OX ***AND*** uncertainties are the same/0.1 « so fraction $\frac{0.1}{OY} > \frac{0.1}{OX}$ » ✓		1
	a	ii	$\frac{0.1}{1.3}$ ***AND*** $\frac{0.1}{1.8}$ ✓ $= 0.13$ ***OR*** 13 % ✓	*Watch for correct answer even if calculation continues to the absolute uncertainty.*	2
	b	i	total length of bar = 0.2 cm ✓	*Accept correct error bar in one of the points: OX = 1.8 cm* ***OR*** *OY = 5.8 cm (which is not a measured point but is a point on the interpolated line)* ***OR*** *OX = 5.8 cm.* *Ignore error bar of OX.* *Allow range from 0.2 to 0.3 cm, by eye.*	1
	b	ii	suitable line drawn extending at least up to 6 cm ***OR*** gradient calculated using two out of the first three data points ✓ inverse of gradient used ✓ value between 1.30 and 1.60 ✓	*If using one value of OX and OY from the graph for any of the first three data points award* ***[2 max]****.* *Award* ***[3]*** *for correct value for each of the three data points and average.* *If gradient used, award* ***[1 max]****.*	3

Question			Answers	Notes	Total
	b	iii	«the equation $n = \frac{OX}{OY}$» involves a tan approximation/is true only for small θ «when sinθ = tanθ» ***OR*** «the equation $n = \frac{OX}{OY}$» uses OI instead of the hypotenuse of the ΔIOX or IOY ✓	*OWTTE*	**1**

2.	**a**		$kg\,m^{-1}\,s^{-2}\,K^{-1}$ ✓		**1**
	b	**i**	any straight line that either goes or would go, if extended, through the origin ✓		**1**
	b	**ii**	for ideal gas *p* is proportional to *T* / P= nRT/V ✓ gradient is constant /graph is a straight line ✓ line passes through origin / 0,0 ✓		**2max**

Question			Answers	Notes	Total
3.	**a**	**i**	18 «s» ✓	*Allow answer in the range of 17 «s» to 19 «s».* *Ignore wrong unit.*	**1**
	a	**ii**	36 «s» ✓	*Allow answer in the range of 35 «s» to 37 «s».*	**1**
	b		radioactive/nuclear decay ***OR*** capacitor discharge ***OR*** cooling ✓	*Accept any relevant situation, eg: critically damping, approaching terminal velocity.*	**1**

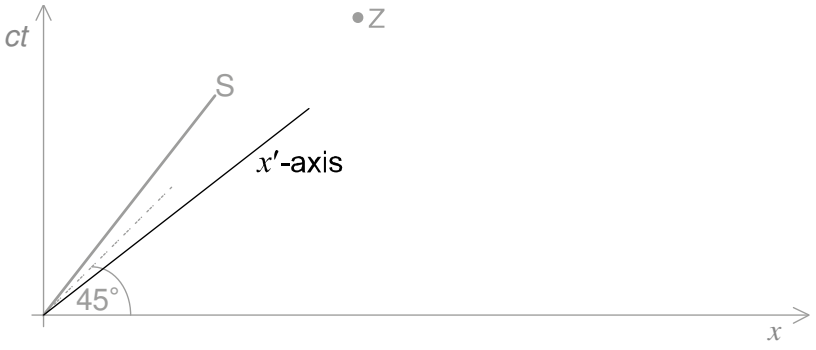
Section B

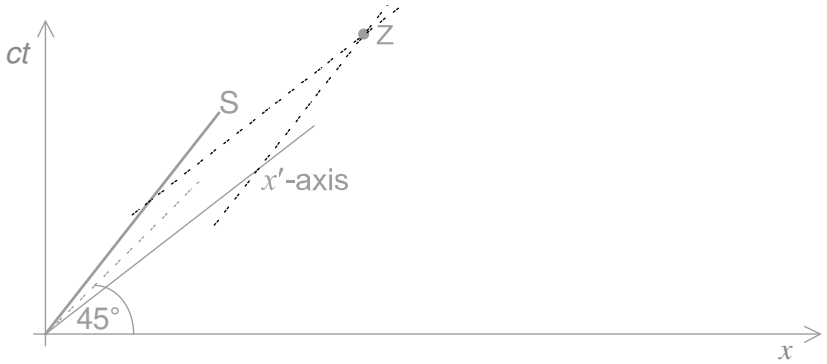
Option A — Relativity

Question			Answers	Notes	Total
4.	a		a coordinate system ***OR*** a system of clocks and measures providing time and position relative to an observer ✓	*OWTTE*	1
	b	i	electric ***OR*** electrostatic ✓		1
	b	ii	«as the positive ions are moving with respect to the charge,» there is a length contraction ✓ therefore the charge density on ions is larger than on electrons ✓ so net positive charge on wire attracts X ✓	*For candidates who clearly interpret the question to mean that X is now at rest in the Earth frame accept this alternative MS for bii* *the magnetic force on a charge exists only if the charge is moving* ✓ *an electric force on X , if stationary, only exists if it is in an electric field* ✓ *no electric field exists in the Earth frame due to the wire* ✓ *and look back at b i, and award mark for* *there is no electric or magnetic force on X*✓	3

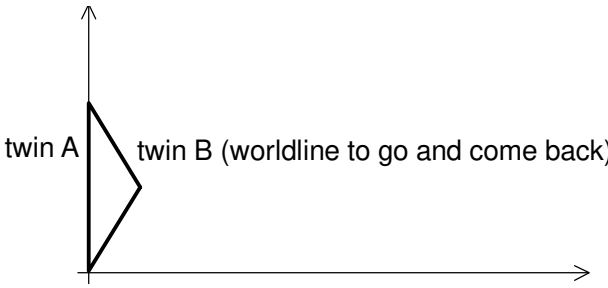
Question			Answers	Notes	Total
5.	**a**		the length of an object in its rest frame ✓		**1**
	b		$\frac{1}{\sqrt{(1-0.96^2)}}$ ***OR*** $\gamma = 3.6$ ✓ 93 «ns» ✓	*ECF for wrong* γ *Award **[2]** for a bald correct answer.*	**2**

Question			Answers	Notes	Total
	c		«X is» 7.5 «m» in frame on pion ✓ «Y is» 26.8 «m» in frame on Earth ✓ identifies proper length as the Earth measurement ***OR*** identifies Earth distance according to pion as contracted length ***OR*** a statement explaining that one of the length is shorter than the other one ✓		**3**

6.	**a**		angle $= \tan^{-1}$ «$\frac{0.8}{1}$» $= 39$ «°» ***OR*** 0.67 «rad» ✓		**1**
	b		adds x'-axis as shown ✓  	*Approximate same angle to $v = c$ as for ct'. Ignore labelling of that axis.*	**1**

Question			Answers	Notes	Total
	c		adds two lines parallel to ct' and x' as shown indicating coordinates ✓  		1

7.	a		«0.6 $ct = 6$ ly» so $t = 10$ «years» ✓	*Accept: If the 6 ly are considered to be measured from B, then the answer is 12.5 years.*	1
	b		***ALTERNATIVE 1*** $10^2 - 6^2 = t^2 - 0^2$ ✓ so t is 8 «years» ✓ ***ALTERNATIVE 2*** gamma is $\frac{5}{4}$ ✓ $10 \times \frac{4}{5} = 8$ «years» ✓	*Accept: If the 6 ly are considered to be measured from B, then the answer is 10 years.* *Allow ECF from a* *Allow ECF for incorrect γ in mp1*	2

Question			Answers	Notes	Total
	c		three world lines as shown ✓  	*Award mark only if axes **OR** world lines are labelled.*	**1**
	d		according to both twins, it is the other one who is moving fast therefore clock should run slow ✓ «it is not considered a paradox as» twin B is not always in the same inertial frame of reference ***OR*** twin B is actually accelerating «and decelerating» ✓	*Allow explanation in terms of spacetime diagram.*	**2**

Question			Answers	Notes	Total
8.	**a**		as the total initial momentum is zero, it must be zero after the collision ✓		**1**
	b		$2 = (\gamma - 1) m_0 c^2 = (\gamma - 1)\ 0.511$ ✓ $\gamma = 4.91$ ✓ $v = 0.978c$ ✓		**3**
	c		«$2 + 2 + 2 \times 0.511 = 5.02$ MeV» so each photon is 2.51« MeV »✓ $p = \frac{E}{c} = 2.51$ «MeV c^{-1}» ✓		**2**

9.	**a**		$\frac{\Delta f}{f} = \frac{gh}{c^2}$ so $\Delta f = \frac{0.6 \times 20000000}{(3 \times 10^8)^2} = 1.3 \times 10^{-10}$ ✓ $\frac{\Delta f}{f} = \frac{\Delta t}{t}$ ✓ $1.3 \times 10^{-10} \times 24 \times 3600 = 1.15$ x10 $^{-5}$ «s» «running fast» ✓	*Award **[3 max]** if for g 0.6 **OR** 9.8 **OR** average of 0.6 and 9.8 is used.*	**3**
	b		***ALTERNATIVE 1*** *g* is not constant through Δh so value determined should be larger ✓ ***ALTERNATIVE 2*** the satellite clock is affected by time dilation due to special relativity/its motion ✓	*Use ECF from (a)* *Accept under or overestimate for SR argument.*	**1**

Option B — Engineering physics

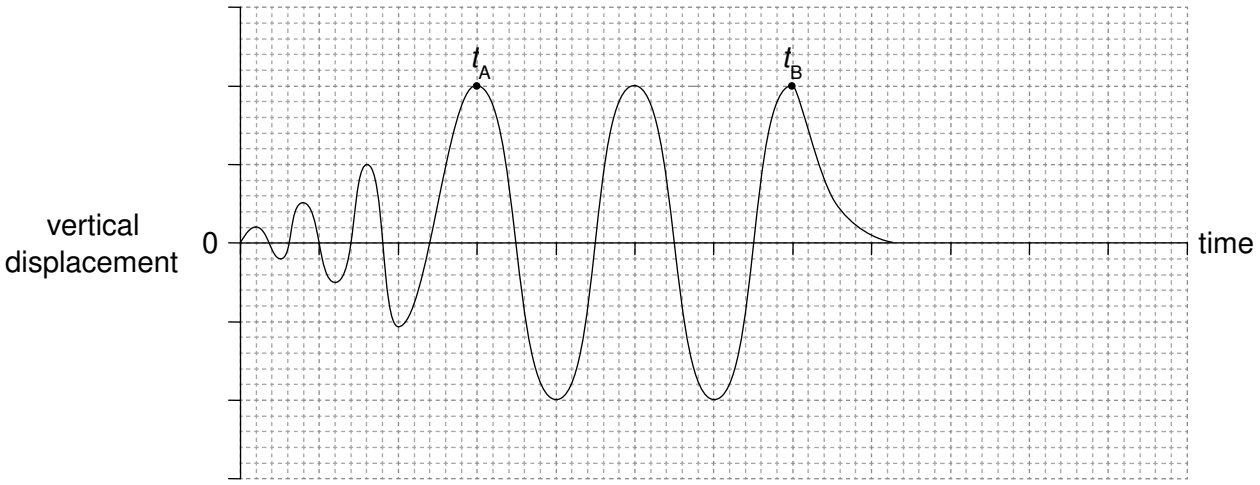
Question			Answers	Notes	Total
10.	**a**		***ALTERNATIVE 1*** $\omega_{\text{final}} = \frac{v}{r} = 31.5$ «rad s^{-1}» ✓ «$\omega = \omega_o + \alpha t$ so» $\alpha = \frac{\omega}{t} = \frac{31.5}{3.98} = 7.91$ «rad s^{-2}» ✓ ***ALTERNATIVE 2*** $a = \frac{1.89}{3.98} = 0.4749$ «m s^{-2}» ✓ $\alpha = \frac{a}{r} = \frac{0.4749}{0.060} = 7.91$ «rad s^{-2}» ✓	*Award **[1 max]** for $r = 0.24$ mm used giving $\alpha = 1.98$ «rad s^{-2}».*	**2**
	b		$\Gamma = \frac{1}{2}MR^2$ $\alpha = \frac{1}{2} \times 1.22 \times 0.240^2 \times 7.91$ ✓ $= 0.278$ «Nm» ✓	*At least two significant figures required for MP2, as question is a "Show".*	**2**
	c	**i**	$F_T = \frac{\Gamma}{r}$ ✓ $F_T = 4.63$ «N» ✓	*Allow 5 «N» if $\Gamma = 0.3$ Nm is used.*	**2**
	c	**ii**	$F_T = mg - ma$ so $m = \frac{4.63}{9.81 - 0.475}$ ✓ $m = 0.496$ «kg» ✓	*Allow ECF*	**2**

Question			Answers	Notes	Total
11.			in method 1 the perpendicular distance varies from 0 to a maximum value, in method 2 this distance is constant at the maximum value ***OR*** angle between F and r is 90° in method 2 and less in method 1 ***OR*** $\Gamma = F \times$ perpendicular distance ✓ perpendicular distance/ torque is greater in method 2 ✓		**2**

12.	**a**		correct conversion to K «622 K cold, 885 K hot» ✓ $\eta_{\text{Carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}} = 1 - \frac{622}{885} = 0.297$ ***or*** 29.7% ✓	*Award **[1 max]** if temperatures are not converted to K, giving result 0.430.*	**2**
	b		the Carnot efficiency is the maximum possible ✓ the Carnot cycle is theoretical/reversible/impossible/infinitely slow✓ energy losses to surroundings «friction, electrical losses, heat losses, sound energy» ✓	*OWTTE*	**2 max**
	c		$0.71 \times 0.297 = 0.211$ ✓ $1.33/0.211 \times 0.789 = 4.97$ «GW»✓ $4.97 \times 3600 = 1.79 \times 10^{13}$ «J» ✓	*Allow solution utilizing wasted power «78.9 %».* *Award **[2 max]** if 71 % used as the overall efficiency giving an answer of 1.96×10^{12} J.* *Award **[3]** for a bald correct answer.* *Watch for ECF from (a).*	**3**

Question			Answers	Notes	Total
	d		Law 1: net thermal energy flow is $Q_{IN} - Q_{OUT}$ ✓ Law 1: $Q_{IN} - Q_{OUT} = \Delta Q = \Delta W$ as ΔU is zero ✓ Law 1: does not forbid $Q_{OUT} = 0$ ✓ Law 2: no power plant can cover 100 % of Q_{IN} into work ✓ Law 2: total entropy must increase so some Q must enter surroundings ✓	Q_{OUT} *refers to "waste heat"* *OWTTE*	**3 max**

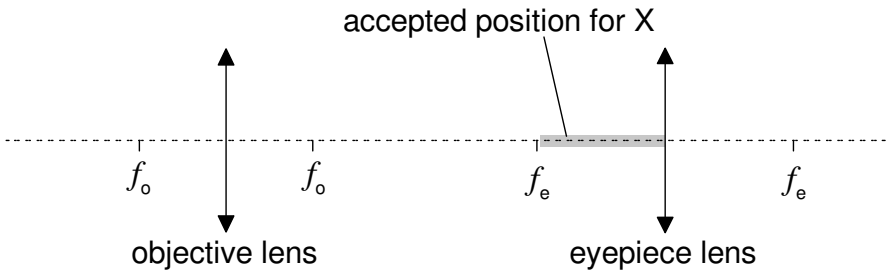
13.	**a**	**i**	$F_{weight} = \ll \rho g V_{cube} = 210 \times 9.81 \times 0.15^3 = \gg 6.95$ «N» ✓		**1**
	a	**ii**	$F_{buoyancy} = 6.95 = \rho g V$ gives $V = 9.8 \times 10^{-4}$ ✓ $\frac{9.8 \times 10^{-4}}{(0.15)^3} = 0.29$ so 0.71 ***or*** 71 % of the cube is above the gasoline ✓	*Award **[2]** for a bald correct answer.*	**2**
	b		«from continuity equation» v is greater at B ***OR*** area at B is smaller thus «from continuity equation» velocity at B is greater ✓ increase in speed leads to reduction in pressure «through Bernoulli effect» ✓ pressure related to height of column ***OR*** $p = \rho g h$ ✓		**3**

Question			Answers	Notes	Total
14.	**a**	**i**	amplitude is increasing as energy is added ✓		**1**
	a	**ii**	energy input = energy lost due to damping ✓		**1**
	b		curve from time t_B reaching zero displacement ✓ in no more than one cycle ✓  	*Award zero if displacement after t_B goes to negative values.*	**2**

Option C — Imaging

Question			Answers	Notes	Total
15.	**a**		***ALTERNATIVE 1*** for incident ray, normal drawn which pass through C ✓ reflected ray drawn such as $i = r$ ✓ ***ALTERNATIVE 2*** drawn second ray through C, parallel to incident ray ✓ adds focal plane and draws reflected ray so that it meets 2nd ray at focal plane ✓	*$i = r$ by eye* *If normal is not visibly constructed using C, do not award MP1.* *If no normal is drawn then grazing angles must be equal for MP2.* *Focal plane position by eye, half-way between C and mirror*	**2**
	b	**i**	spherical «aberration» ✓		**1**
	b	**ii**	using parabolic mirror ***OR*** reducing the aperture ✓		**1**

Question			Answers	Notes	Total
16.	**a**		converging/positive/biconvex/plane convex ✓	*Do not accept convex.*	**1**
	b		$\frac{v}{u} = 4$ ✓ $v + u = 6$ ✓ so lens is 1.2 «m» from object ***or*** $u = 1.2$ «m» ✓	*Award **[3]** for a bald correct answer.* *Allow **[1]** if the answer is 4.8 «m».*	**3**
	c		«$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$, so $\frac{1}{1.2} + \frac{1}{4.8} = \frac{1}{f}$, so» $f =$ 0.96 «m» ***or*** 1 «m» ✓	*Watch for ECF from (b)*	**1**
	d		real ***AND*** inverted ✓ smaller ***OR*** diminished ✓		**2**

Question			Answers	Notes	Total
17.	a		$f_{\text{OBJECTIVE}}$ for telescope $>$ $f_{\text{OBJECTIVE}}$ for microscope ***OR*** $f_{\text{OBJECTIVE}}$ for telescope $>$ f_{EYEPIECE} for telescope but $f_{\text{OBJECTIVE}}$ for microscope $<$ f_{EYEPIECE} for microscope ✓		**1**
	b		$\frac{500}{5}$ ***OR*** 100 times ✓		**1**
	c	i	RF photons have smaller energy, so signal requires larger dish ✓ RF waves have greater wavelength, good resolution requires larger dish ✓	*Must see both, reason and explanation.*	**1 max**
	c	ii	use of an array of dishes/many mutually connected antennas «so the effective diameter equals to the distance between the furthest antennas» ✓		**1**
	d		between f_e and eyepiece lens, on its left ✓ 	*Accept any clear indication of the image (eg: X, arrow, dot).* *Accept positions which are slightly off axis.*	**1**
	e		resolution improves as wavelength decreases ***AND*** wavelength of UV is smaller ***OR*** gives resolution formula ***AND*** adds that λ is smaller for UV ✓		**1**

Question			Answers	Notes	Total
18.	**a**		step-index fibres have constant «core» refracting index, graded index fibres have refracting index that reduces/decreases/gets smaller away from axis ✓	*OWTTE but refractive index is variable is not enough for the mark.* *Award the mark if these ideas are evident in the answer to 18(b).*	**1**
	b		«in graded index fibres» rays travelling longer paths travel faster ✓ so that rays travelling different paths arrive at same/similar time ✓	*Ignore statements about different colours/wavelengths.*	**2**

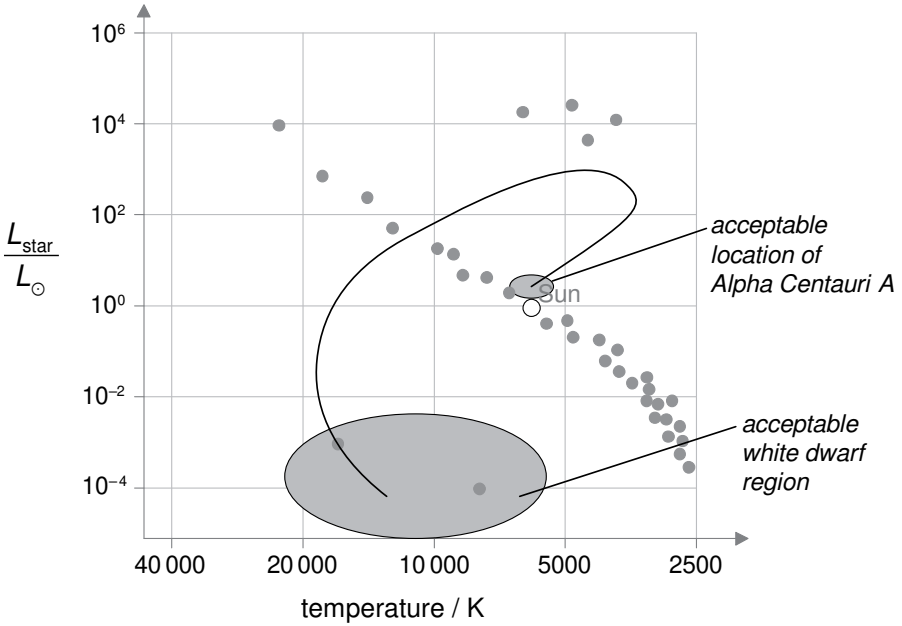
19.	**a**		reads value on graph at 20 keV as $4\ «\text{cm}^2\ \text{g}^{-1}»$ ✓ $«4\ \text{cm}^2\ \text{g}^{-1} \times 1800\ \text{kg m}^{-3} \times \frac{1000}{1000000} =» 7.2\ «\text{cm}^{-1}»$ ✓	*Ensure that the calculation has right POT conversion.* *Answer must be to at least two significant figures.*	**2**

Question			Answers	Notes	Total
	b		***ALTERNATIVE 1*** *(finds intensity ratios for muscle and bone separately)* for muscle: obtains $\mu = 0.96\ \text{cm}^{-1}$ ✓ $\frac{I}{I_0} = e^{-\mu x}$ so for muscle 0.38 ✓ for bone: $\frac{I}{I_0} = 7.5 \times 10^{-4}$ «if $\mu = 7.2$ is used» ***OR*** 9.1×10^{-4} «if $\mu = 7$ is used» ✓ ***ALTERNATIVE 2*** for muscle: obtains $\mu = 0.96\ \text{cm}^{-1}$ ✓ $\frac{I_{\text{MUSCLE}}}{I_{\text{BONE}}} = \frac{e^{-0.96}}{e^{-7.2}}$ ✓ ratio is about 500 «513» ✓	*Watch for ECF* *Allow answers in the range of 0.90 to 1.02 cm^{-1}.* *Allow answers in the range of 0.36 to 0.41.* *Allow answers in dB. Muscle -4dB, Bone -30 or -31dB* *Allow answers in the range of 0.90 to 1.02 cm^{-1}.* *Frequently the POT will be incorrect for MP1. Allow ECF from MP1 to MP2.* *Allow +/- 26 or 27dB* *Award **[2 max]** if $\mu = 960$ as they will get $\frac{I_{\text{MUSCLE}}}{I_{\text{BONE}}} = 0$.* *Allow range 395 to 546* *If 7 used, ratio is about 420, if 7.2 is used, ratio is about 510* *Allow answer I_{BONE}/I_{MUSCLE} from a range 0.0017 to 0.0026.*	**3**
	c		similar absorption so poor contrast ✓		**1**

Question			Answers	Notes	Total
20.	**a**		«proton» spin ✓		**1**
	b		strong B field applied to align proton spins ✓ cross-field applied to give gradient field ***OR*** each point in a plane has a unique B ✓ RF field excites spins ✓ protons emit RF at resonant/Larmor frequency dependent on Total B field ✓ RF detected shows position in the plane / is used to form 2D images✓	*OWTTE* *Allow features to be mentioned in any order.*	**3 max**

Option D — Astrophysics

Question			Answers	Notes	Total
21.	**a**		two stars orbiting about a common centre «of mass/gravity» ✓	*Do not accept two stars orbiting each other.*	**1**
	b	**i**	stars are roughly at the same distance from Earth ***OR*** *d* is constant for binaries ✓ $\frac{L_A}{L_B} = \frac{1.5}{0.5} = 3.0$ ✓	*Award **[2]** for a bald correct answer.*	**2**
	b	**ii**	$r = \sqrt{\frac{1.5 \times 3.8 \times 10^{26}}{5.67 \times 10^{-8} \times 4\pi \times 5800^4}}$ ✓ $= 8.4 \times 10^8$ «m» ✓	*Award **[2]** for a bald correct answer.*	**2**
	c		«$A = \frac{L}{\sigma T^4}$» B and A have similar temperatures ✓ so areas are in ratio of luminosities ✓ «so B radius is less than A»		**2**
	d		radiation pressure/force outwards ✓ gravitational pressure/force inwards ✓ forces/pressures balance ✓		**3**

Question			Answers	Notes	Total
	e		Alpha Centauri A within allowable region ✓ some indication of star moving right and up then left and down ending in white dwarf region as indicated ✓  		**2**

Question			Answers	Notes	Total
22.			from first graph period $= 5.7$ «days» ± 0.3 «days» ✓ from second graph $\frac{L}{L_{SUN}} = 2300$ «± 200» ✓ $d = \text{«}\sqrt{\frac{2500 \times 3.8 \times 10^{26}}{4\pi \times 1.1 \times 10^{-9}}} = 8.3 \times 10^{18}$ m» =250 «pc» ✓	*Accept answer from interval 240 to 270 pc If unit omitted, assume pc* *Watch for ECF from mp1*	**3**

Question			Answers	Notes	Total
23.	**a**		isotropic/appears the same from every viewing angle ✓ homogenous/same throughout the universe ✓ black-body radiation ✓		**2 max**
	b		23 100 «cm» ***OR*** 231 «m» ✓		**1**

24.	**a**		white dwarf must have companion «in binary system» ✓ white dwarf gains material «from companion» ✓ when dwarf reaches and exceeds the Chandrasekhar limit/1.4 M_{SUN} supernova can occur ✓		**3**
	b		a standard candle represents a «stellar object» with a known luminosity ✓ this supernova occurs at an certain/known/exact mass so luminosity/energy released is also known ✓	*OWTTE* *MP1 for indication of known luminosity, MP2 for any relevant supportive argument.*	**2**
	c		distant supernovae were dimmer/further away than expected ✓ hence universe is accelerating ✓ dark energy «is a hypothesis to» explain this ✓		**3**

Question			Answers	Notes	Total
25.	**a**		$v = \text{«}\sqrt{\frac{4\pi G\rho}{3}}\, r \text{»} = \sqrt{\frac{4}{3}\times\pi\times 6.67\times10^{-11}\times 5.0\times10^{-21}}\times(4000\times3.1\times10^{16})$ ✓ v is about 146 000 «m s^{-1}» ***or*** 146 «km s^{-1}» ✓	*Accept answer in the range of 140 000 to 160 000 «m s^{-1}».*	**2**
	b		rotation curves/velocity of stars were expected to decrease outside core of galaxy ✓ flat curve suggests existence of matter/mass that cannot be seen – now called dark matter ✓		**2**