Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2023

Physics

Standard level

Paper 3

22 pages

The following are the annotations available to use when marking responses.

Annotation	Explanation	Shortcut	Annotation	Explanation	Shortcut
	Correct point – 1 mark will be added to the score for each tick placed up to the maximum for the question part. Please make sure that the number of ticks = the number of marks			Text box for comments – used for additional marking comments, it can be used in conjunction with a specific tick if that is appropriate. You might like to have a word document of regularly used comments that can be copied and pasted into the text box	
	Unclear			Answer acceptable	
	Omission mark			Indicates that the point has been noted, but no credit has been given **or** to confirm that an examiner has checked a sub-part of a question that has not been answered.	
	Arithmetic error			Power of 10 error	
	Alternative solution			Dynamic; can be sized to highlight area	
	Benefit of the doubt			Dynamic; horizontal line that can be expanded	
	Contradiction			Award 0 marks. 0 marks will be added to the marks panel when this annotation is stamped on the script.	
	Error carried forward			Does not answer question	

You **must** make sure you have looked at all pages. Please put the  annotation on any blank page, to indicate that you have seen it.

General Marking Instructions

Assistant Examiners (AEs) will be contacted by their team leader (TL) through RM™ Assessor, by e-mail or telephone – if through RM™ Assessor or by e-mail, please reply to confirm that you have downloaded the markscheme from IBIS. The purpose of this initial contact is to allow AEs to raise any queries they have regarding the markscheme and its interpretation. AEs should contact their team leader through RM™ Assessor or by e-mail at any time if they have any problems/queries regarding marking. For any queries regarding the use of RM™ Assessor, please contact emarking@ibo.org.

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 SL Paper 3 Markscheme

Candidates are required to answer **all** questions in Section A and **all** questions from **one** option in Section B. Maximum total = **35 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		$[\mu] = \text{«}\frac{\text{kg} \times \text{m}\,\text{s}^{-2}}{\text{s}^{-2} \times \text{m}^2} = \text{»} \text{kg} \times \text{m}^{-1}$ ✓	*Accept* kg/m . *Do **not** accept* g m^{-1}.	1
1.	b	i	straight line through all error bars✓	*Accept line that is straight with no ruler, but no obvious deviation.*	1
1.	b	ii	line does not go through the origin «and all error bars»✓		1
1.	b	iii	mass of tray of weights neglected/friction at pulley/friction at slider/thickness of slider/change in wire length/calibration error/zero off-set error ✓	*Do **not** allow vague answers like friction neglected / error in length measurement*	1
1.	b	iv	large enough triangle $\Delta m \geq 50$ g✓ answer in range $0.210 - 0.240 \text{«kg m}^{-2}\text{»}$ ✓	*Accept answers in* g m^{-2}. *Do **not** allow **ECF** from **MP1***	2
1.	c		$\mu = \text{«}\frac{g \times \text{gradient}}{f^2}\text{»} = 6.229 \times 10^{-4} \text{«kg} \times \text{m}^{-1}\text{»}$ ✓ percentage uncertainty $= 6.0 + 2 \times 2.0 = 10\%$ ✓	*Accept μ in the range 5.7 to 6.6.* *Allow answer in* g m^{-1} *Allow **ECF** from **(b).***	2

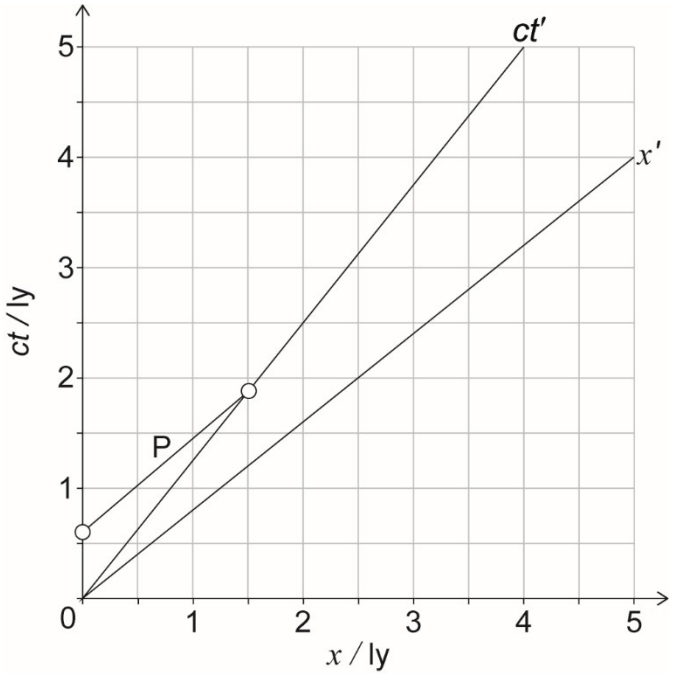
Question			Answers	Notes	Total
2.	**a**	**i**	mass ***OR*** diameter ***OR*** material of bob ***OR*** « initial » amplitude/angle ✓	*Do **not** allow statements about rulers, stopwatches, string, number of oscillations, constant gravity.*	**1**
2.	**a**	**ii**	student's reaction time «in starting and stopping stopwatch» / starting/stopping stopwatch✓	*Allow human error / **OWTTE.***	**1**
2.	**b**		it reduces «the random» error/uncertainty✓ by a factor of 20 «compared to that in a single period measurement» ✓	*Ignore any mention of systematic error.* *For **MP1**, allow increasing accuracy/precision.* ***Award [0]** for answers related to number of trials, 20 measurements of one period.*	**2**
2.	**c**	**i**	T^2 ✓		**1**
2.	**c**	**ii**	$g = 9.7$ **«**$\mathrm{m\,s^{-2}}$**»** ✓ $\Delta g = 0.8$ **«**$\mathrm{m\,s^{-2}}$**»** ✓		**2**

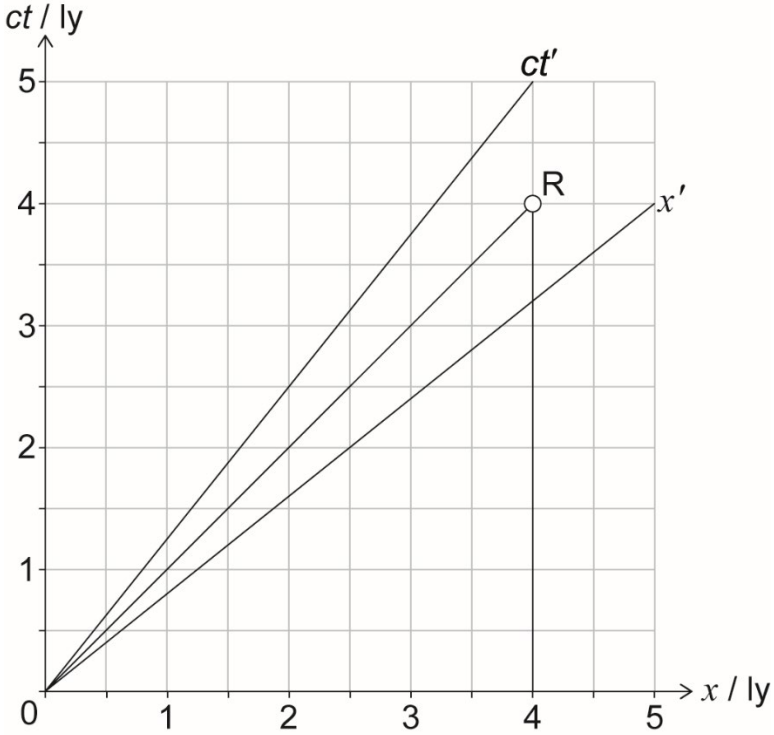
Section B

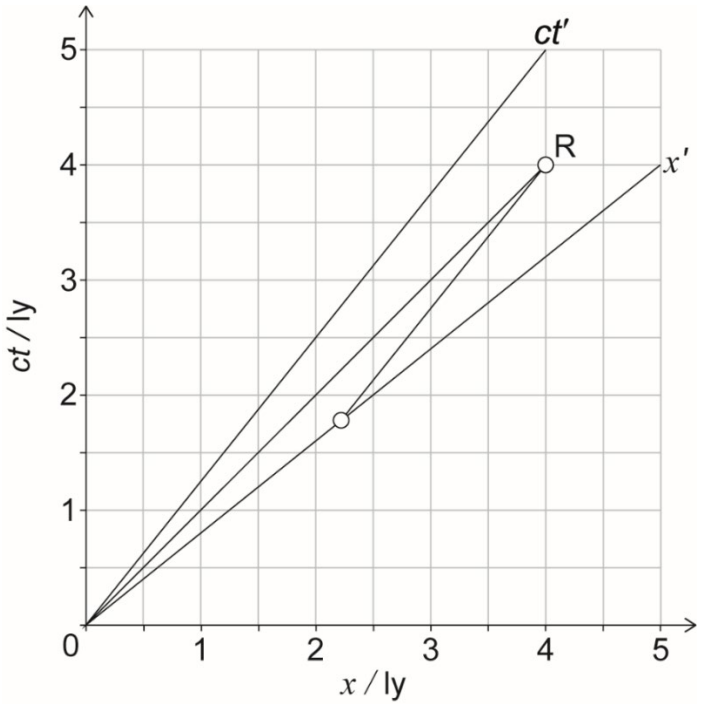
Option A — Relativity

Question			Answers	Notes	Total
3.	**a**		«in the proton rest frame » the speed of the proton is zero so force is zero ✓		**1**
3.	**b**		the proton sees an electric field / experiences electric force✓ upward force✓		**2**

Question			Answers	Notes	Total
4.	**a**		moves 4 ly in 5 years **OR** slope of angle with time axis is 0.8✓	*Allow evidence for mark on the graph.*	**1**
4.	**b**	**i**	$\gamma = 1.67$ ***OR*** $\frac{5}{3}$ ***OR*** $\frac{1}{\sqrt{(1-0.8^2)}}$ ✓ $ct' = \text{«}\gamma(ct - \frac{vx}{c})\text{»} = \frac{5}{3} \times (0.60 + 0)$ ✓ «=1.00 ly»	*For **MP2**, working should be seen.* ***Award [2]** for answer 1.67x0.6 = 1*	**2**

Question			Answers	Notes	Total
4.	b	ii	identifies point with coordinates $x = 0$, $ct = 0.60$ on vertical axis ✓ draws line parallel to the x prime axis until it intersects the prime c*t* axis ✓  	***Award [2]*** *for correct position of P without working shown.*	**2**

Question			Answers	Notes	Total
4.	c	i	 R located at (4,4) ✓ «as intersection of» vertical line through 4 ly and photon worldline at 45 degrees✓	*Allow **MP2** even if one of the lines is not drawn.*	**2**

Question			Answers	Notes	Total
4.	c	ii	***ALTERNATIVE 1*** *Using diagram:* line from R parallel to prime ct axis until it intersects space axis ✓ use of scale from (b) to estimate coordinate to $x' = (1.3 \pm 0.2)$ ly ✓  ***ALTERNATIVE 2*** *Using Lorentz transformation:* event R has coordinates $x = ct = 4.00$ ly in S ✓ so $x' = \text{«}\gamma(x - vt) = \frac{5}{3} \times (4.00 - 0.80 \times 4.00)\text{»} = 1.33$ ly ✓	***ECF** from **c{i)***	**2**

Question			Answers	Notes	Total
5.	**a**		$T_{\frac{1}{2}} = 2.00 \times 1.56 \times 10^{-6}$ or 3.12×10^{-6} s ✓ $D = «3.12 \times 10^{-6} \times 0.866 \times 3 \times 10^{8} =» 811\,\text{m}$ ✓	***Award [2]*** *for* ***BCA*** *811* m ***OR*** *810* m*.*	**2**
5.	**b**	**i**	$0.866c \times \text{half life} = 0.866c \times 1.56 \times 10^{-6} =$ **«**405 m**»** ***OR*** distance travelled by detector $= \frac{D}{y} = \frac{D}{2}$ = «405m» ✓	*Working must be seen.*	**1**
5.	**b**	**ii**	transit time $= \frac{405}{0.866c} = 1.56 \mu s$ ✓	***Award [1]*** *for* ***BCA.***	**1**
5.	**c**		transit time is one half life ✓ so ratio has to be $\frac{1}{2}$ ✓	***Award [2]*** *for* ***BCA.***	**2**
5.	**d**		the answers are the same✓ count rates cannot vary from frame to frame /**OWTTE**✓	*Do* ***not*** *allow* ***ECF*** *from* ***(c)****.* ***Award [2]*** *for "count rates cannot vary" if student made a mistake* ***OR*** *no answer in* ***(c)*** *and well discussed here.* *For* ***MP2****, allow any good explanation why answers are the same.*	**2**

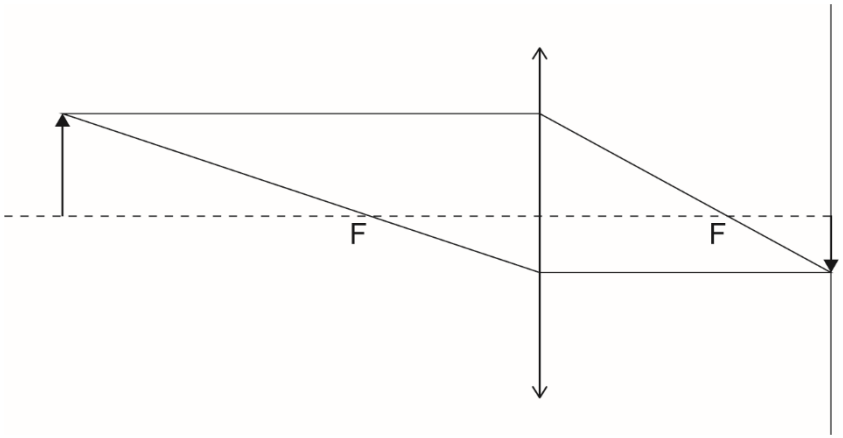
Option B – Engineering physics

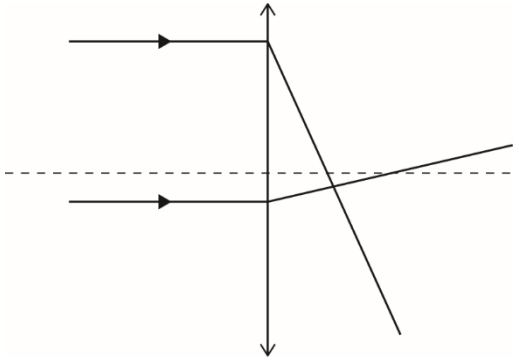
Question			Answers	Notes	Total
6.	**a**		$0.180 + 0.200 \times 0.60^2$ **«**$= 0.252$ kg m^2**»**		**1**
6.	**b**		angular speed of particle = «12/0.6 = » 20 « rad s^{-1} » ***OR*** angular momentum of particle **«**$0.200 \times 12.0 \times 0.60$**»** $= 1.44$ **«**J s**»** ✓ «angular momentum of rod-particle system $0.252\ \omega$ » equating $\omega =$ **«**$\frac{1.44}{0.252}$**»** $= 5.71\,\text{rad}\,\text{s}^{-1}$ ✓	*For **MP2**, working or answer to at least 3 SF should be seen.*	**2**
6.	**c**		$\frac{1}{2} \times 0.200 \times 12.0^2 - \frac{1}{2}(0.252) \times 5.71^2$ ✓ 10.3 J ✓	***Award [1]** for answer 11.5* J *that neglects moment of inertia of particle but do not penalize this omission in **(d)(i).***	**2**
6.	**d**	**i**	$\alpha = \frac{0.152}{0.252} = 0.603\,\text{rad}\,\text{s}^{-2}$ ✓	*Accept 0.6 **OR** 0.844 **OR** 0.8.* *Accept negative values.*	**1**
6.	**d**	**ii**	$\theta = \frac{5.71^2}{2 \times 0.603} = 27.0$ rad ✓ $N = \frac{27.0}{2 \times \pi} = 4.3$ ✓	*Allow **ECF** from parts **(b)** and **(d)(i).***	**2**
6.	**e**		the rod will rotate «about centre of mass»✓ «centre of mass» will move along straight line «parallel to the particle's initial velocity»✓	*For **MP2**, mention of translational motion is not enough.*	**2**

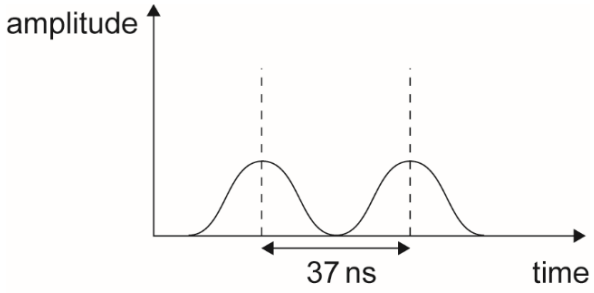
Question			Answers	Notes	Total
7.	a		***ALTERNATIVE 1*** «considering expansions from A» an adiabatic process will reduce/change temperature✓ and so curve AC must be the steeper ✓ ***ALTERNATIVE 2*** temperature drop occurs for BC ✓ therefore CA must increase temperature «via adiabatic process». ✓		**2**
7.	b		***ALTERNATIVE 1*** Use of adiabatic formula $\text{«}p_A V_A^{\frac{5}{3}} = p_C V_C^{\frac{5}{3}} \Rightarrow\text{»} V_C = \left(\frac{p_A}{p_C}\right)^{\frac{3}{5}} V_A$ ✓ $V_C = \left(\frac{5.00\times10^5}{4.60\times10^3}\right)^{\frac{3}{5}} \times 2.00\times10^{-3}$ **«**$= 3.333\times10^{-2}$ m^3**»** ✓ ***ALTERNATIVE 2*** $V_C = V_B$ ***AND*** $p_A V_A = p_B V_B$ ✓ $V_C = \frac{5\times10^5 \times 2\times10^{-3}}{3\times10^4}$ ✓ ***ALTERNATIVE 3*** $V_C = V_B$ ***AND*** n=0.2 mol ✓ V_C= (0.2 x 8.31 x 602) / 4 x 10^4 ✓	*For **MP2**, working or answer to at least 4 SF must be seen.*	**2**

Question			Answers	Notes	Total
7.	c		Increasing ✓ because thermal energy/heat is being provided to the gas « and temperature is constant, $\Delta S = \frac{\Delta Q}{T}$ » ✓	*Allow answer in common symbols Q, W, U.*	**2**
7.	d		***ALTERNATIVE 1*** $Q = \Delta U = \frac{3}{2} V_C \Delta P$ ✓ $Q = \text{«}\frac{3}{2} \times 3.33 \times 10^{-2} \times (3.00 \times 10^4 - 4.60 \times 10^3)\text{»} = 1268.7 \approx 1270$ **«J»** ✓ ***ALTERNATIVE 2*** $Rn = \frac{5 \times 10^5 \times 2 \times 10^{-3}}{602} = 1.66$ ***OR*** $T_c = 4.6 \times 10^3 \times 3.33 \times 10^{-2} \times 1.66 = 92.2$ ✓ $\Delta U = \frac{3}{2} \times 1.661 \times (602 - 92.21) = 1270$ **«J»** ✓	***Award [2]*** *for* ***BCA.*** *Accept negative values.* *Award* ***MP1*** *if* T_c **=** *92 taken from* ***(e)***	**2**
7.	e		$e_C = 1 - \frac{92}{602} = 0.847$ ✓ this engine has $e < e_C$ as it should✓	***Award [0]*** *if no calculation shown.*	**2**

Option C - Imaging

Question			Answers	Notes	Total
8.	a		 one of the two rays above✓		1
8.	b		$-\frac{v}{u}=-\frac{1}{2}$ ***OR*** $v=\frac{u}{2}$ ✓ $\frac{1}{u}+\frac{2}{u}=\frac{1}{4.0}$ ✓ u=12«cm» ✓	*Diagram is **not** to scale so **award [0]** if answer obtained by measurement.* *Allow **MP1** if mistake in negative sign.* *Do **not** allow **ECF** from **MP1**.* ***Award [3]** for **BCA.***	3

Question			Answers	Notes	Total
8.	**c**	**i**	 the extreme ray crosses principal axis closer than paraxial ray✓		**1**
8.	**c**	**ii**	image is curved / blurred / distorted / poorly focused✓		**1**
8.	**c**	**iii**	block non-paraxial rays/ reduce aperture/use rays closer to axis/***OWTTE*** ***OR*** use aspherical lens ✓	*Allow parabolic lens.* *Allow use of additional lens **OR** compensation plates.*	**1**
8.	**d**	**i**	angular magnification is $\frac{75}{4.0} = 18.75$ ✓ angle = **«**$18.75 \times 0.51^\circ$**»** $= 9.6^\circ$ ✓		**2**
8.	**d**	**ii**	It would be «much» smaller ✓		**1**

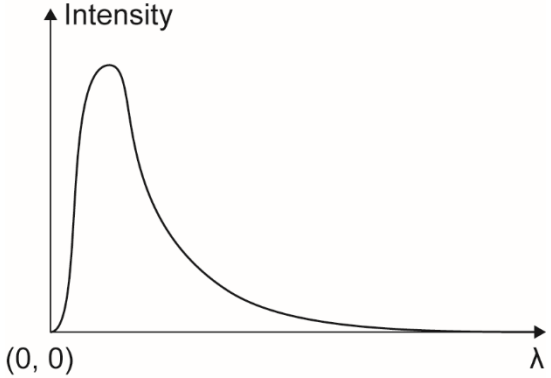
Question			Answers	Notes	Total
9.	**a**	**i**	$1.500 \times \sin\theta_c = 1.489 \times 1$ ✓ $\theta_c = 83.06^\circ$ ✓	*Allow* 83° ***OR*** *1.45 rad.*	**2**
9.	**a**	**ii**	$1.00 \times \sin\theta_{max} = 1.500 \times \sin(90^\circ - 83.06^\circ)$ ✓ $\theta_{max} = 10.4^\circ$ ✓	*Allow* 11° *Allow* ***ECF*** *from* ***(a)(i).***	**2**
9.	**b**		« when ray 1 travels a distance 1.00 km » ray 2 travels a distance $\frac{1}{\sin\theta_c} = 1.0074$ km✓ speed is $\frac{c}{1.500} = 2.0 \times 10^8$ **«**m s^{-1}**»** ✓ hence $\Delta t =$ **«**$0.0074 \times \frac{10^3}{2 \times 10^8}$ **=»**36.67**«**ns**»** ✓	*Allow* ***ECF*** *from* ***(a)(i).*** *Time for ray 1 is 5000 ns , time for ray 2 is 5036.9 ns.* *Do* ***not*** *allow* ***ECF*** *from* ***MP2****.* *For* ***MP3****, working or answer to at least 3 SF should be seen.*	**3**
9.	**c**	**i**	 pulses rounded and of lower amplitude, symmetrical about dotted lines. ✓ just starting to overlap✓		**2**
9.	**c**	**ii**	the pulses would overlap/the signal will be lost/***OWTTE*** ✓		**1**

Option D - Astrophysics

Question			Answers	Notes	Total
10.			open clusters are irregular in shape ***OR*** globular clusters are spherical✓ open clusters have few stars ***OR*** globular clusters have many✓ open clusters have young stars ***OR*** globular clusters have old stars✓ open clusters have active stars ***OR*** globular clusters have mostly dead stars✓ open clusters are less dense ***OR*** globular clusters are more dense/tightly packed✓	*Open clusters are bigger / have stars further apart is not enough to award the mark.* *Globular clusters are round is not enough to award the mark.*	**1 max**

Question			Answers	Notes	Total
11.	**a**		$L = L_{\odot} \times 52^{3.5} = 1.01 \times 10^{6} L_{\odot}$ ✓	*Accept back working.* *Working should be seen.*	**1**
11.	**b**		$L_B = L_A = 10^6 L_{sun}$ ✓ $\frac{L_B}{L_{\odot}} = (\frac{4\pi R_B^{\ 2}}{4\pi R_{\odot}^{\ 2}})(\frac{3.0}{6.0})^4$ ***OR*** $1.0 \times 10^6 = (\frac{R_B}{R_{\odot}})^2 \frac{1}{16}$ ✓ $\frac{R_B}{R_{\odot}} = \sqrt{1.0 \times 10^6 \times 16} = 4 \times 10^3$ ✓	***Award [3]*** *for* ***BCA*** *Do* ***not*** *allow* ***ECF*** *from* ***MP2*** *to* ***MP3.***	**3**
11.	**c**		«star A will evolve into a» red supergiant/giant star✓ will then explode/supernova ✓ creating a neutron star or black hole✓ « neutron star if core/remnant mass < the Oppenheimer–Volkoff limit/ a black hole if core more massive »	*For* ***MP3****, award the mark if only one of neutron star* ***OR*** *black hole is mentioned.*	**3**
11.	**d**		$d = \sqrt{\frac{L}{4\pi b}}$ ✓ $d = \sqrt{\frac{2.4 \times 10^{23}}{4\pi \times 4.1 \times 10^{-14}}}$ **«**$= \frac{6.8 \times 10^{17}}{3.09 \times 10^{16}}$**»** $\approx 22\,\text{pc}$ ✓	***Award [2]*** *for* ***BCA.*** *For* ***MP1****, allow answer in unit m, value 6.8 x* 10^{17} *m.*	**2**
11.	**e**		the distance is well within the limit of about 1000 pc for stellar parallax, so yes it can✓	*Accept 100* pc ***OR*** *similar distance in other units.* *Allow* ***ECF*** *from* ***(d)*** *(also converse argument).* ***Award [0]*** *for Yes with no reason*	**1**

Question			Answers	Notes	Total
12.	**a**		$\frac{v}{c} = \frac{512 - 486}{486}$ ✓ $\Rightarrow v = 1.6 \times 10^4$ **«**km s^{-1}**»** ✓	*Accept 0.053 c.* *Accept answer in* m s^{-1} *.* ***Award [2]** for **BCA.*** ***Award [1]** for 1.5 x 10^4 **OR** 0.051c*	**2**
12.	**b**		$d = \frac{v}{H} = \frac{1.6 \times 10^4}{72} = 222 \approx 220$**«**Mpc**»** ✓	***ECF** from **(a).***	**1**
12.	**c**		it is important because it is related to the age of the universe✓ it is important in testing models of the universe✓ it is important for determining distances✓		**1 max**

Question			Answers	Notes	Total
13.	a		the radiation filling the early universe was at a very high temperature✓· the observed CMB at 3K shows cooling of this radiation✓· that came about due to the expansion/stretching of the universe✓· homogeneous and isotropic✓· predicted by the BB theory✓·		3 max
13.	b	i	standard black body curve✓  	*Do **not** accept bell curves.* *Right hand asymptote should not intersect with horizontal axis*	1
13.	b	ii	identify the peak wavelength ***AND*** use Wien's law✓·		1