Diploma Programme
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Markscheme

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Physics

Higher level

Paper 3

29 pages

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Subject Details: Physics HL Paper 3 Markscheme

Mark Allocation

Candidates are required to answer ALL questions in Section A [15 marks] and all questions from ONE option in Section B [30 marks]. 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.

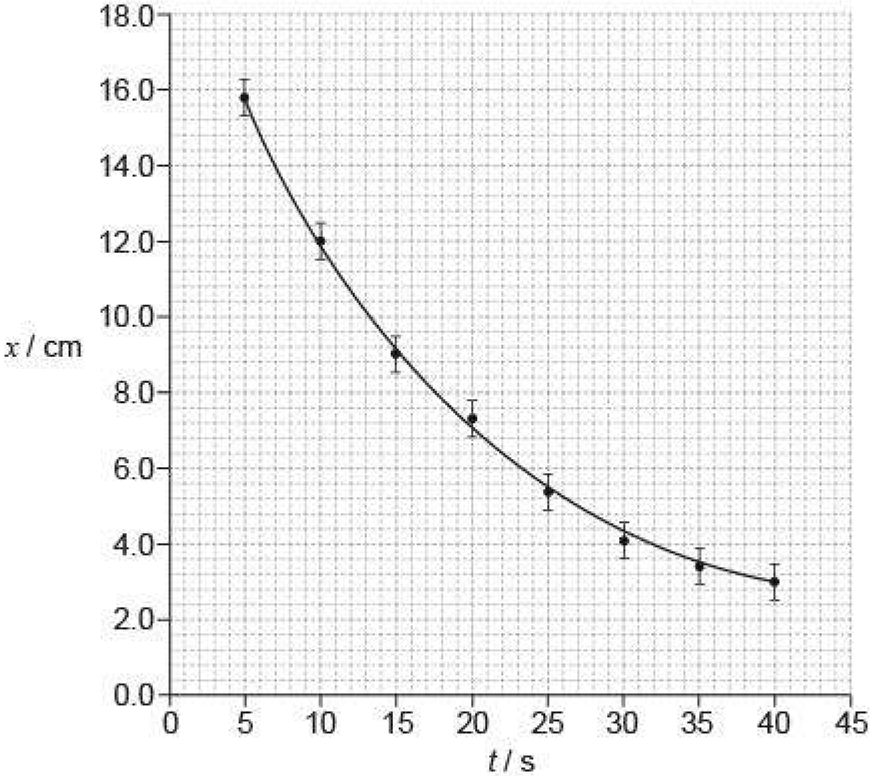
6. An alternative answer is indicated in the “Answers” column by “***OR***” between the alternatives. Either answer can be accepted.

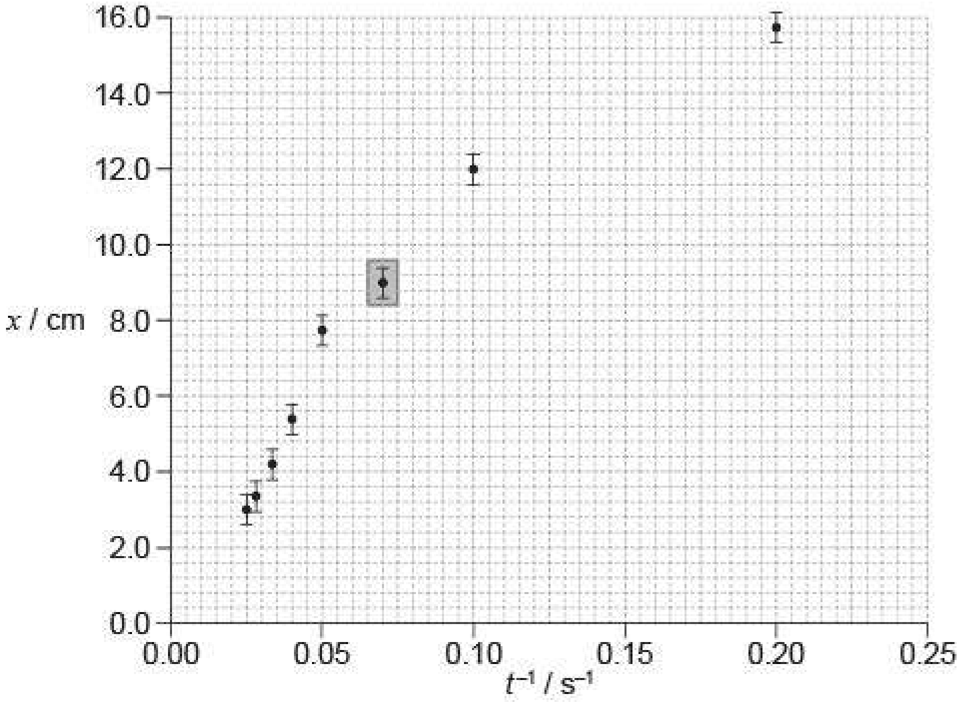
7. Words in angled brackets « » in the “Answers” column are not necessary to gain the mark.

8. Words that are <u>underlined</u> are essential for the mark.

9. The order of marking points does not have to be as in the “Answers” column, unless stated otherwise in the “Notes” column.

Section A

Question			Answers	Notes	Total
1	a		smooth curve passing through all error bars ✓ 		1
	b		$x = 2.5$ «cm» ± 0.2 cm ***AND*** $\Delta x = 0.5$ cm ± 0.1 cm ✓ «$\frac{0.5}{2.5} =$» 20% ✓	*Accept correctly calculated value from interval 15 % to 25 %.*	2

Question			Answers	Notes	Total
1	c	i	plotted point (0.07, 9.0) as shown ✓ 	*Allow any point within the grey square. The error bar is not required.*	1

Question			Answers	Notes	Total
1	c	ii	***ALTERNATIVE 1*** t^{-1} from 0.025 s^{-1} to 0.04 s^{-1} ✓ giving *t* from 25 to 40 ✓ ***ALTERNATIVE 2*** the data do not support the hypothesis ✓ any relevant support for the suggestion, *eg* straight line cannot be fitted through the error bars and the origin ✓	*Do not allow ECF from MP1 to MP2.*	**2**

Question			Answers	Notes	Total
2	**a**	**i**	refractive index = 1.5 ✓	*Both correct value and 2SF required for* ***[1]****.*	**1**
	a	**ii**	fractional uncertainty $x_3 - x_1 = \frac{0.04}{1.15} = 0.035$ ***AND*** $x_3 - x_2 = \frac{0.04}{0.76} = 0.053$ ✓ sum of fractional uncertainty = 0.088 ✓ «uncertainty = their RI × 0.088» = 0.1 ✓	*Accept correct calculation using maximum and minimum values giving the same answer.*	**3**
	b	**i**	systematic error ✓	*Accept "zero error/offset".*	**1**
	b	**ii**	calculated refractive index is unchanged ✓ because both numerator and denominator are unchanged ✓	*Accept calculation of refractive index with 0.05 subtracted to each x value.*	**2**
	c		numerator and denominator will be 10 times larger so refractive index is unchanged ✓ relative/absolute uncertainty will be smaller ✓	*"Constant material" is not enough for MP1.*	**2**

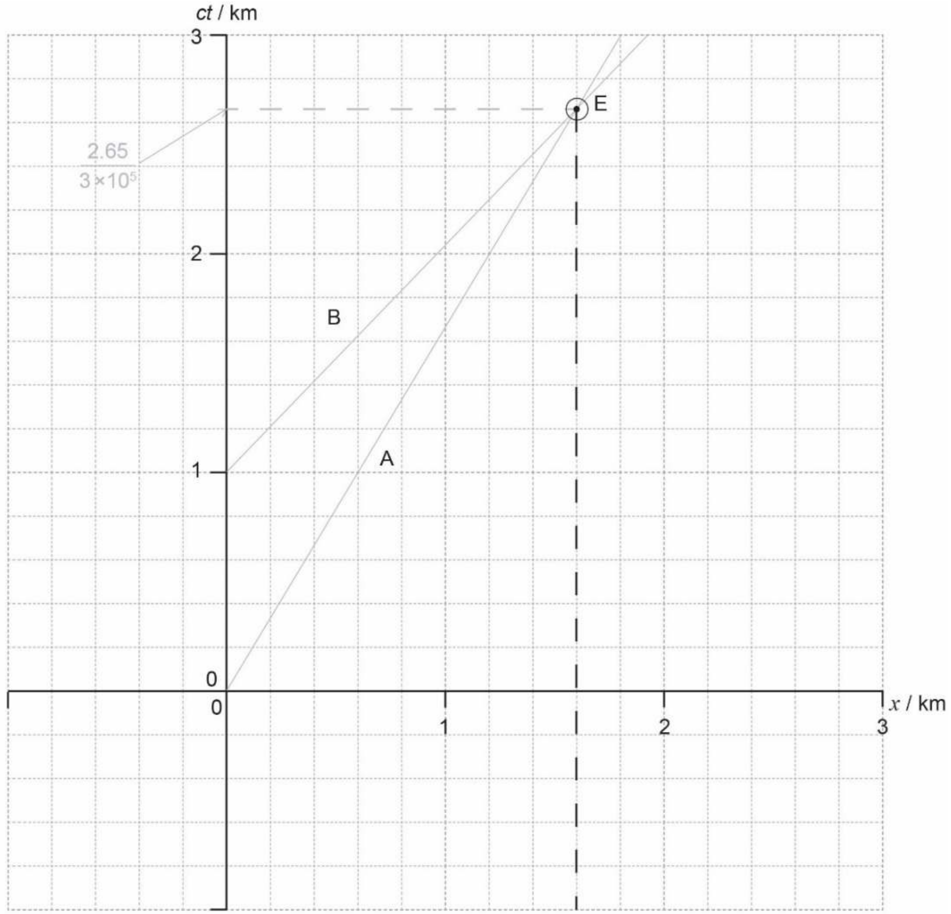
Section B

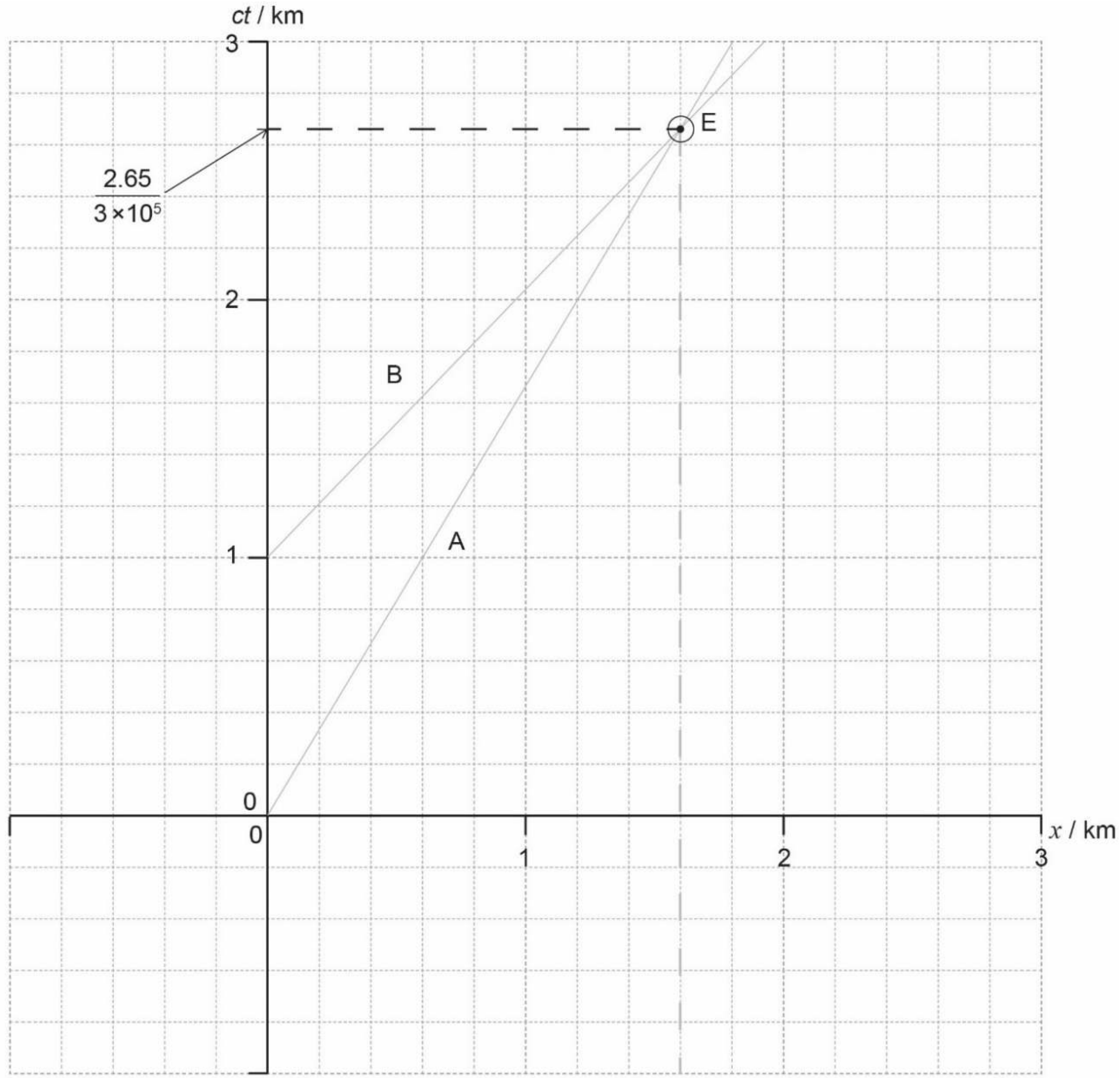
Option A — Relativity					
Question			**Answers**	**Notes**	**Total**
3	**a**		not being accelerated ***OR*** not subject to an unbalanced force ***OR*** where Newton’s laws apply ✓		**1**
	b	**i**	c ✓		**1**
	b	**ii**	$c+v$ ✓		**1**

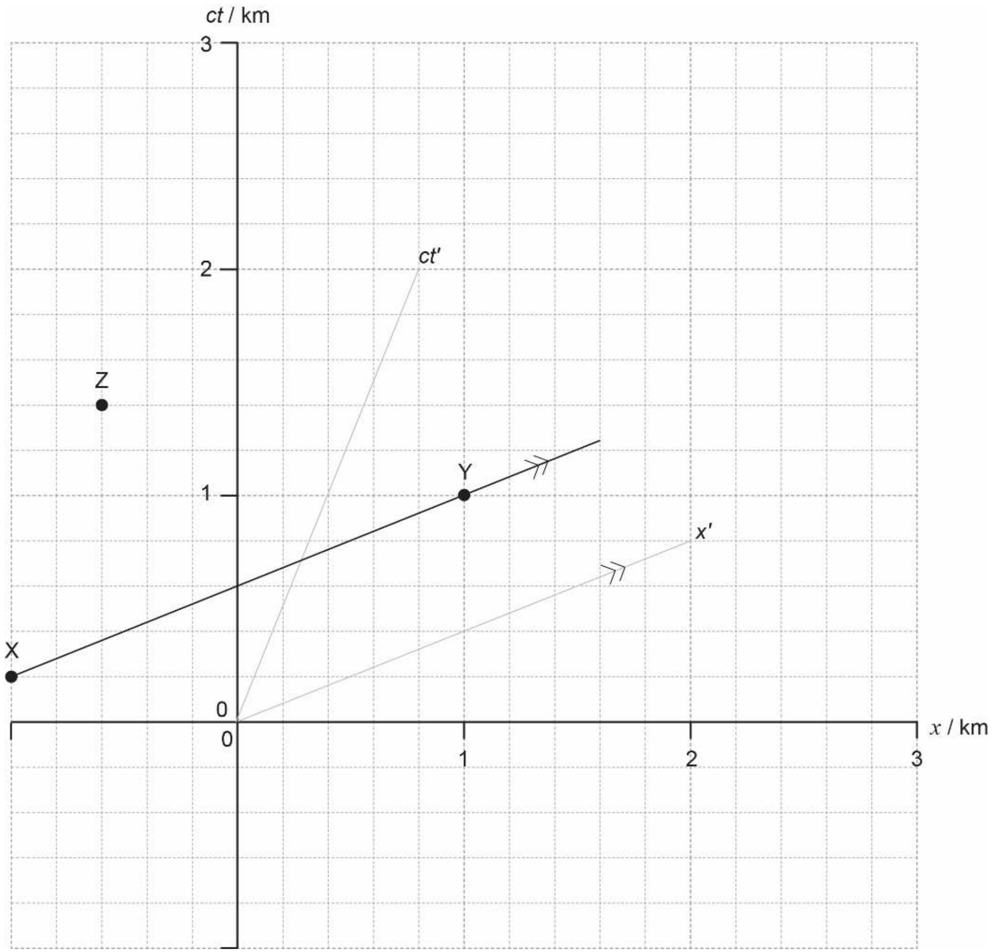
4			Y measures electrostatic repulsion only ✓ protons are moving relative to X «but not Y» ***OR*** protons are stationary relative to Y ✓ moving protons create magnetic fields around them according to X ✓ X also measures an attractive magnetic force ***OR*** relativistic/Lorentz effects also present ✓		**4**

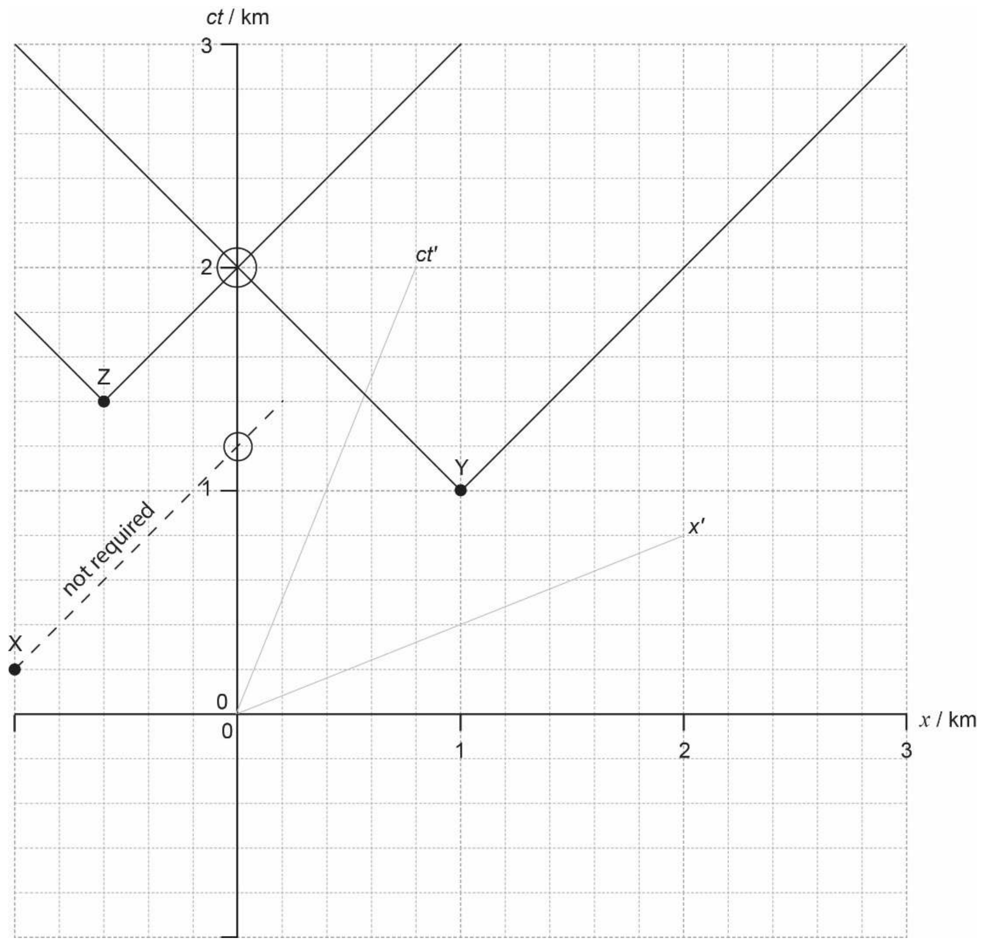
Question			Answers	Notes	Total
5	a		***ALTERNATIVE 1*** «rest mass = 0.511 MeV c^{-2}» $\gamma = \frac{2.30}{0.511} = 4.50$ ✓ $v = c\sqrt{\frac{\gamma^2 - 1}{\gamma^2}}$ ***OR*** $3 \times 10^8 \times \left(\frac{4.50^2 - 1}{4.50^2}\right)^{\frac{1}{2}}$ ✓ $0.9750c$ ✓ ***ALTERNATIVE 2*** $\gamma =$ «$\frac{1}{\sqrt{1 - 0.98^2}} =$» 5.0 ✓ $E =$ «$\gamma m_0 c^2 =$» 4.1×10^{-13} J ✓ $E = 2.6$ MeV ✓	*Must see answer to at least 3SF.*	**3**
	b	i	distance $= \frac{0.800}{\gamma}$ ✓ 0.178 m ✓	*Accept 0.159 for $\gamma = 5.0$.*	**2**

Question			Answers	Notes	Total
5	b	ii	time $= \dfrac{0.800}{2.94\times10^{8}}$ ✓ 2.74 ns ✓		2
	b	iii	$\dfrac{2.74}{4.5}$ ***OR*** $\dfrac{0.178}{2.94\times10^{8}}$ ✓ 0.608 ns ✓		2
	b	iv	it is measured in the frame of reference in which both events occur at the same position ***OR*** it is the shortest time interval possible ✓		1

Question			Answers	Notes	Total
6	a		$\Delta ct = 2.0$ km ***AND*** $\Delta x = 1.2$ km ✓ $v =$ «$\frac{\Delta x}{\Delta ct} = \frac{1.2}{2.0}$» $= 0.60c$ ✓	*Allow any correct read-off from graph.* *Accept answers from 0.57c to 0.63c.*	**2**
	b	i	1.6 km ✓ 	*Allow ±0.1 km.*	**1**

Question			Answers	Notes	Total
6	b	ii	8.8 μs ✓ 	*Allow ±0.5 μs.* *Allow ECF, the answer can be calculated from answers to (a) and (b)(i).*	1

Question			Answers	Notes	Total
6	c	i	events at same perpendicular distance from x' axis of rocket are simultaneous ***OR*** line joining X to Y is parallel to x' axis ✓ X and Y simultaneously then Z ✓ 	*MP1 may be present on spacetime diagram.*	**2**

Question			Answers	Notes	Total
6	c	ii	constructs light cones to intersect worldline of observer ✓ X first followed by Y and Z simultaneously ✓  	*Only Y and Z light cones need to be seen.*	2

Question			Answers	Notes	Total
7	a		region of space with extreme/very large curvature of spacetime ✓ such that light cannot escape the region ***OR*** escape speed within region is > *c* ✓	*Do not allow "large" or omission of degree of curvature.*	**2**
	b		time for 1 second spacecraft tick in observer frame $=1.07\text{ s}$ ✓ $1.07=\frac{1.00}{\sqrt{1-\frac{R_S}{2.3\times10^4}}}$ ***OR*** $R_S=2.96\times10^3\text{ m}$ ✓ $M=$ «$\frac{c^2\times2.96\times10^3}{2\times6.67\times10^{-11}}=$»$2.0\times10^{30}\text{ kg}$ ✓		**3**

Option B — Engineering physics					
Question			**Answers**	**Notes**	**Total**
8	**a**		because Mg and N act through the axis ***OR*** only F has a non-zero lever arm «about the axis» ✓		**1**
	b	**i**	***ALTERNATIVE 1*** use of Newton's law for linear motion: $Mg\sin\theta - F = Ma$ ✓ use of Newton's law for rotational motion: $FR = I\alpha$ ✓ combining $Mg\sin\theta = Ma + \frac{I\alpha}{R}$ ✓ substitution of $I = \frac{1}{2}MR^2$ and $\alpha = \frac{a}{R}$ ✓ to get result ***ALTERNATIVE 2*** $Mgh = \frac{1}{2}Mv^2 + \frac{1}{4}Mv^2$ «from $\frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{1}{2}MR^2\right)\frac{v^2}{R^2}$» ✓ $v^2 = \frac{4}{3}gh$ ✓ $v^2 = 2as = 2a\frac{h}{\sin\theta}$ ✓ manipulation to produce given answer ✓	*Accept correct use of torques about point of contact.*	**4**

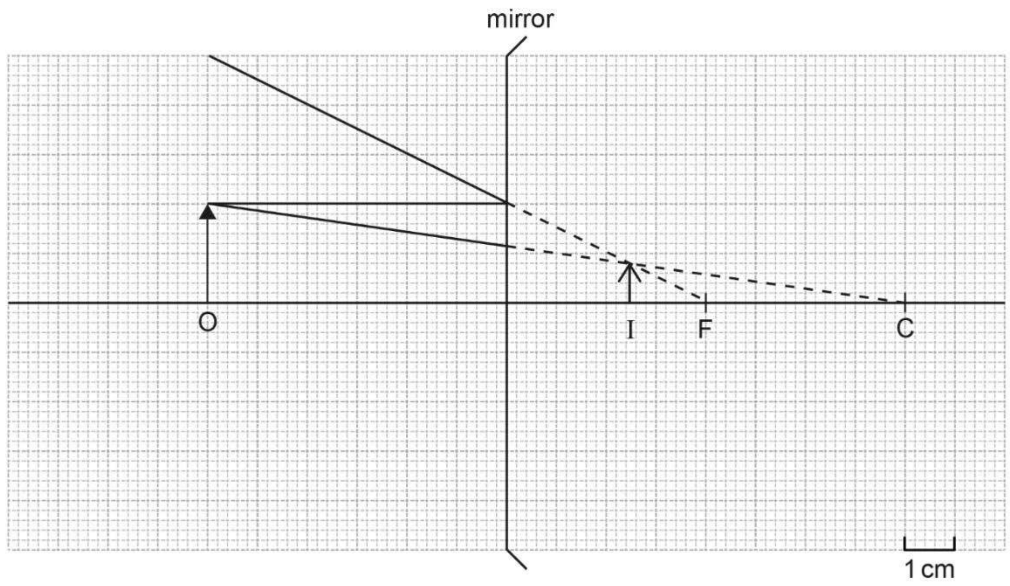
Question			Answers	Notes	Total
8	b	ii	rearranging $s = \frac{1}{2}at^2$ to get $t = \sqrt{\frac{2s}{a}}$ ✓ substitution to get $t =$ «$\sqrt{\frac{2 \times 1.5}{\frac{2}{3} \times 9.81 \times \frac{1}{2}}}$» $= 0.96$ s ✓		2
	c		<u>acceleration</u> of ice is $g\sin\theta$ whereas for the solid cylinder acceleration is two thirds of this «so speed of ice must always be greater at same point» ✓	*Allow answers in terms of energies, eg ice does not use energy to rotate and therefore will have a greater translational speed.*	1
	d		the hollow cylinder has a greater moment of inertia ✓ and hence a smaller acceleration ✓		2

Question			Answers	Notes	Total
9	a	i	1400 K ✓		**1**
	a	ii	$\frac{3}{2}P\Delta V = \frac{3}{2} \times 4 \times 10^{5} \times 3 \times 10^{-3}$ ✓ 1800 J ✓		**2**
	a	iii	$1800 + P\Delta V = 1800 + 4 \times 10^{5} \times 3 \times 10^{-3}$ ***OR*** use of $\Delta Q = \frac{5}{2}P\Delta V$ ✓ 3000 J ✓		**2**
	a	iv	curve starting at A ending on line CB ***AND*** between B and zero pressure ✓		**1**
	b	i	0 ✓		**1**
	b	ii	***ALTERNATIVE 1*** C has the same volume as B ***OR*** entropy is related to disorder ✓ higher temperature/pressure means greater disorder ✓ therefore entropy at C is greater «because entropy is related to disorder» ✓ ***ALTERNATIVE 2*** to change from B to C, $\Delta Q > 0$ ✓ so $\Delta S > 0$ ✓ ΔS related to disorder ✓		**3**

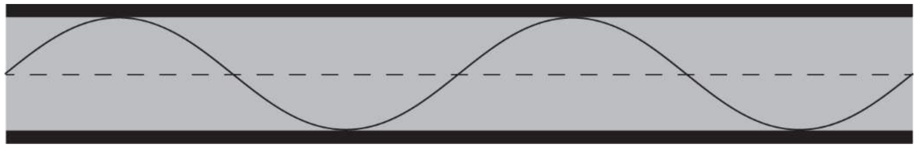
Question			Answers	Notes	Total
10	a		«118 + 105 kPa» = 2.23×10^{5} Pa ✓		1
	b		***ALTERNATIVE 1*** «from Bernoulli's Law» total pressure at Q = static pressure + dynamic pressure = constant «2.2×10^{5} Pa» ✓ dynamic pressure «$=\frac{1}{2}\rho v^2$» increases from zero, so static pressure decreases ✓ ***ALTERNATIVE 2*** water rushes out of tap at higher velocity, so pressure is lower ✓ due to Bernoulli's Principle ✓		2
	c	i	$R=\frac{1.27\times0.05\times1.00\times10^{3}}{1.8\times10^{-3}}$ ✓ $R=3.5\times10^{4}$ ✓	*Allow use of diameter to give $R=7.0\times10^{4}$.*	2
	c	ii	flow is turbulent ✓	*Answers in (c)(i) and (c)(ii) must be consistent.*	1

Question			Answers	Notes	Total
11	a		high Q means low damping ***OR*** system oscillates with low damping ✓ «exponential» decrease of amplitude/energy ***OR*** oscillates about 200 times before coming to rest ✓ loses about 3% of energy per cycle ***OR*** loses small amount of energy each cycle ✓		**2 max**
	b	i	large amplitude/resonance ✓		**1**
	b	ii	small amplitude ***AND*** A «almost» in phase with P ✓		**1**

Option C — Imaging

Question			Answers	Notes	Total
12	**a**		 one correct ray drawn ✓ another correct ray ✓ image located at intersection of rays, behind the mirror ✓	*Label I is required.*	**3**
	b		≈ 0.4 ✓		**1**
	c		image is in better focus/sharper ***OR*** parabolic do not suffer from spherical aberration ✓ parabolic mirrors reflect parallel rays through one point ✓ whereas spherical mirrors reflect parallel rays through different points ✓	*Award 3rd mark even if implied in the answer.*	**3**

Question			Answers	Notes	Total
13	a		$F_o + f_e = 84$ so $f_e = 84 - 82 = 2$ cm ✓ « $M = \frac{f_o}{f_e} = \frac{82}{2} =$ » 41 ✓		**2**
	b		a sign convention is a way to distinguish between real and virtual objects ***or*** images ***or*** converging and diverging lenses ✓		**1**
	c	i	image will be virtual $v = -25$ cm ✓ $\frac{1}{u} = \frac{1}{82} + \frac{1}{25}$ ✓ «=19 cm ***or*** 0.19 m»	*Award **[1 max]** if v = +25 cm used to give u = –36 cm.*	**2**
	c	ii	image will be real $v = 84 - 19 = 65$ «cm» ✓ « $\frac{1}{u} = \frac{1}{2} - \frac{1}{65}$ » so $u = 2.1$ cm ✓		**2**
	c	iii	$M_e =$ « $\frac{D}{f_e} + 1 = \frac{25}{82} + 1 =$ » 1.3 ***AND*** $m_o =$ « $\frac{v}{f_o} - 1 = \frac{65}{2} - 1 =$ » 31 ***or*** 32 ✓ so $M =$ « $M_e m_o = 1.3 \times 31 =$ » 40 ***or*** 41 ✓	*Far point adjustment gives M = 9.3 (accept answers from interval 9.3 to 9.6), award **[1 max]** for full working.*	**2**

Question			Answers	Notes	Total
14	**a**		curved, symmetrical path ✓ 	*Refraction on entry not required and ignored in diagram for simplicity.*	**1**
	b		waveguide dispersion means that rays not parallel to the central axis take longer to transmit ✓ in a graded-index fibre rays away from the central axis travel at a higher speed ***OR*** rays are «refracted» closer to the central axis ***OR*** effective diameter of the fibre is reduced ✓ because refractive index is greater in the centre ***OR*** refractive index is less at the edge ✓		**3**

15	**a**	**i**	$\mu = 2.7\times10^{-3}\left(\pm0.3\times10^{-3}\right)$ ✓ So $\frac{I}{I_o} =$ « $e^{-\mu x} = e^{-\left(2.7\times10^{-3}\times8\times10^{-2}\right)}$ » $= 0.9999 \approx 1.0$ ✓		**2**
	a	**ii**	« $\mu = 50$ to give» $\frac{I}{I_o} = 1.8\times10^{-2}$ ✓		**1**
	b		low energy radiation removed but not high energy radiation ✓ radiation has narrower range of energies ✓ only necessary radiation reaches the patient making it safer ✓		**2 max**

Question			Answers	Notes	Total
16	**a**		*Advantage*: no ionizing radiation ***OR*** high res images <u>of soft tissue</u> ***OR*** 3D images ✓ *Disadvantage*: «generally» more expensive ***OR*** takes much longer ***OR*** less detail of bony structures «than X-ray» ***OR*** noisy for patient ***OR*** claustrophobic for patient ***OR*** cannot be used for patients with metal implants ✓	*Do not accept advantages that are also true of X-rays, eg non-invasive.*	**2**
	b		a gradient field is added to a magnetic field that is originally uniform across patient ✓ the gradient field varies linearly across patient ✓ as the protons relax a «radio frequency» signal is emitted ✓ the emitted signal frequency is proportional to the total strength of the magnetic field ✓ the signal frequency depends on the emission position in the patient ✓		**3 max**

Option D — Astrophysics

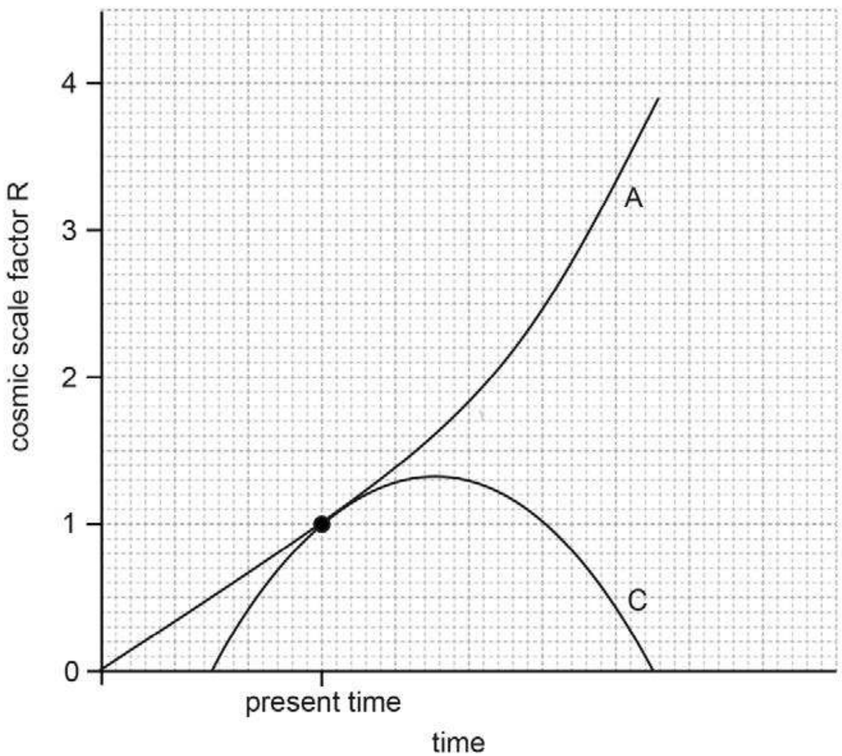
Question			Answers	Notes	Total
17	a		made of dust and/or gas ✓ formed from supernova ✓ can form new stars ✓ some radiate light from enclosed stars ✓ some absorb light from distant stars ✓		1 max
	b		$d = \frac{1}{8.32 \times 10^{-3}}$ ***OR*** 120 «pc» ✓ $120 \times 3.26 \times 9.46 \times 10^{15} = 3.70 \times 10^{18}$ m ✓	*Answer must be in metres, watch for POT.*	2
	c		distances are so big/large ***OR*** to avoid using large powers of 10 ***OR*** they are based on convenient definitions ✓		1

18	a		$T = \frac{2.9 \times 10^{-3}}{740 \times 10^{-9}}$ ✓ 3900 K ✓	*Answer must be to at least 2SF.*	2
	b		$L = 5.67 \times 10^{-8} \times 4\pi \times (3.1 \times 10^{10})^2 \times 4000^4$ ✓ $= 1.8 \times 10^{29}$ W ✓	*Accept use of 3900^4 to give 1.6×10^{29} W.*	2
	c		absorption lines in spectra ✓ are specific to particular elements ✓	*Accept "emission lines in spectra".*	2
	d		helium ✓		1

Question			Answers	Notes	Total
18	e		helium flash ✓ expansion of outer shell ***OR*** surface temperature increase ✓ planetary nebula phase ✓ only the core remains ✓ if below 1.4 M_S/Chandrasekhar limit then white dwarf ✓		**3 max**

19	a	i	$z=\frac{\Delta\lambda}{\lambda_o}$ where $\Delta\lambda$ is the redshift of a wavelength and λ_o is the wavelength measured at rest on Earth ***OR*** it is a measure of cosmological redshift ✓	*Do not allow just "redshift".*	**1**
	a	ii	«$z=\frac{R}{R_o}-1$, $\frac{R_o}{R}=\frac{1}{z+1}$» so $\frac{R_o}{R}=$ «$\frac{1}{1.16}$» $=0.86$ ✓	*Do not accept answer 1.16.*	**1**
	a	iii	$v=zc=0.16\times3\times10^{8}=4.8\times10^{4}$ «km s^{-1}» ✓ $d=\frac{v}{H_0}=\frac{4.8\times10^{4}}{68}=706\,\text{Mpc}$ ***OR*** $2.2\times10^{25}\,\text{m}$ ✓		**2**
	b		as the universe expanded it cooled/wavelength increased ✓ the temperature dropped to the present approximate 3 K ***OR*** wavelength stretched to the present approximate 1 mm ✓	*Value is required for MP2.*	**2**

Question			Answers	Notes	Total
20	**a**		a gas cloud will collapse to form a star ✓ if «the magnitude of» the gravitational potential energy of the particles is greater than the kinetic energy of the particles ***OR*** mass of the cloud is greater than the Jeans mass ✓		**2**
	b		Ia have consistent maxima in their light curves but II vary ✓ Ia has a strong ionized SiII line but II has hydrogen lines in their spectra ✓ Ia was a white dwarf but II are massive stars ✓ Ia form from binary systems but II are the result of core collapse of a star ✓ Ia can be used as standard candles but II are not ✓		**3 max**

Question			Answers	Notes	Total
21	a	i	curve beginning on $R = 0$ before present time and ending after present time on $R = 0$ ✓  		1
	a	ii	curve starting earlier than C with general shape shown above ✓ coincides with curve C at present time ✓	*Judge by eye.*	2

Question			Answers	Notes	Total
21	**b**		rotation speeds of galaxies is greater at the edges than expected ✓ so the density at the edges must be greater than that supplied by luminous matter alone ✓	*Accept any other valid piece of evidence, eg gravitational lensing, which provides a good measure of galactic cluster masses.*	**2**