Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

November 2024

Physics

Higher

Paper 3

26 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.

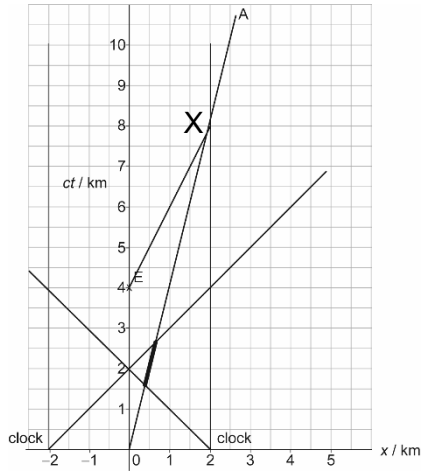
14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

Question			Answers	Notes	Total
1	a	i	Straight line within all error bars ✓		1
	a	ii	Correct reading of two points at least 35ºC apart ✓ 0.019 to 0.024 ✓	*Allow ECF from a) i) if mark not scored.*	2
	a	iii	Read their R_0 from the y-intersection ✓ gradient $= \alpha R_0$ **OR** substitute into equation coordinates of a point on the line ✓ Correct calculation of their alpha ✓ K^{-1} or $°C^{-1}$ ✓	*If line not drawn or extended to y-axis, accept R_0 from 5.6 to 6.1* *Allow ECF for MP3.*	4

Question			Answers	Notes	Total
2	a		Read at least two points correctly and consistently ✓ Use $\frac{1}{2} \cdot g \cdot t^2$ with a length interval from two non-consecutive points OR for two (or more) length intervals, using consistent time intervals ✓ Correct calculation of g ✓	*Award [2] max if they use one single length interval of consecutive points.* *Award [1] max if they miss to subtract the initial point in their length interval or if they use inconsistent time intervals.* *Do not penalize significant figures in the final answer.*	**3**

	b		Use 10% for delta t^2 ✓ Estimate an uncertainty for s using an absolute of 0.5 OR 1 mm AND propagate it to 1/their length interval OR 2/their length interval respectively ✓ Add both relative or percentage uncertainties AND calculate the absolute uncertainty ✓	*Allow ECF for MP3.* *Do not penalize significant figures in the final answer.*	**3**
	c		Flash must be so short that blurring is within the absolute uncertainty / error of determination of *s* ✓ (Final) speed is around 2 m s^{-1} and error is about 1 mm so (maximum) duration around $\frac{1}{2000}$ *s* ✓	*Award [1] max if they argue that images might merge and state a maximum of 0.025 s (or less).* *Award [1] max if they use the uncertainty of time and state a time of (2 x) 0.05 x 0.05 s = 0.005 s (or less).* *Award MP2 if they state an interval of 0.001 s or less.*	**2**

Question			Answers	Notes	Total
3	a		1.7*c* ✓		1
	b		$\left[\frac{c+0.70c}{1+\frac{(c\cdot 0.70c)}{c^2}}\right]$ *or* $\left[\frac{c-(-0.70c)}{1-\frac{c(-\cdot 0.70c)}{c^2}}\right]$ *seen* ✓ c ✓	*Award MP2 if no calculation seen.*	2
	c		(Discovery implied that) speed of light (in vacuum) is constant / invariant / does not depend on speed of source / same in all inertial frames ✓		1

Question			Answers	Notes	Total
4	a	i	**Alternate 1** Place light source midway between clocks / at origin O ✓ set clocks at 2000/c and start them with flash of light from O ✓ **Alternate 2** Initially together (at origin) and synchronised ✓ then moved apart (infinitely) slowly✓		**2**
		ii	$\tan\theta = \frac{1}{4}$ ✓ $v = 0.25c$ ✓	*Accept BCA*	**2**
		iii	Correct construction of light cones seen✓ Line identified on diagram✓		**2**
	b	i	Line at correct angle intersecting A at worldline of right-hand clock.		**1**
		ii	$\frac{8000}{c} = 2.7\text{x}10^{-5}$ **«s»** ✓	*Allow ECF fron b) i)*	**1**

	c	**i**	two construction lines✓ difference in time identified correctly ✓		**2**
		ii	A has changed from one inertial reference frame to another (when it changed velocity) ✓	*Accept* "Due to acceleration at turnaround"	**1**

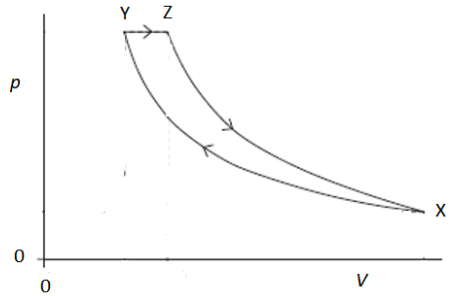
Question			Answers	Notes	Total
5	**a**		$\gamma = 4.5$ ✓ time interval in Earth frame = $= 9.9$ **«**μs**»**✓		**2**
	b		**ALTERNATIVE 1** For Earth time of flight = 8.5μs ✓ 8.5μs **>>** 2.2μs so muons should have decayed ✓ but 9.9μs (time dilation) > 8.5μs so many muons survive OWTTE ✓ **ALTERNATIVE 2** Without time dilation the distance travelled in Earth frame = $0.975 \times c \times 2.2 \times 10^{-6} = 0.64$ ≪km≫ ✓ With time dilation the distance travelled in Earth frame = $0.975 \times c \times 9.9 \times 10^{-6} = 2.9$ ≪km≫ ✓ Without time dilation, most of the muons would have decayed before reaching the surface ✓		**3**

Question			Answers	Notes	Total
6	**a**		Accurate readoff E_k for particular γ or use of $m_0c^2 = \frac{E_k}{\gamma - 1}$ ✓ 106 **«**MeV**»** ✓	*Accept a reading within* ±5MeV of their γ value. *Award MP2 for a correct final answer arising from their reading.*	**2**
	b	**i**	Calculate γ (γ = 3.6) ✓ 270 **«**MV**»** ✓	*Allow ECF from a).*	**2**

Question			Answers	Notes	Total
7	a		Spacecraft observer sees ray propagating in straight line OR distant observer sees ray moving in curved path ✓ both must observe the same physical outcome✓ According to the distant observer the spacecraft is accelerating so light must bend OR Spacetime for the distant observer is curved by mass of black hole✓ spacecraft observer's frame is (locally) equivalent to an inertial/nonaccelerating frame✓		**3 max**
	b	**i**	Use of $t_{\text{distant}} = \frac{7.5}{\sqrt{1-\frac{300}{400}}}$ ✓ 15 «μs» ✓		**2**
		ii	Use of $M = \frac{R_s c^2}{2G}$ 2.0×10^{32} «kg» ✓		**1**

Question			Answers	Notes	Total
8	a	i	correct use of rotational kinetic energy formula for one angular speed ✓ $\frac{1}{2}\times\frac{0.072\times(8400^2-3600^2)}{9.6}$ OR 216 «kW» ✓	*Award [1 max] if $(8400 – 3600)^2$ seen*	**2**
	a	ii	**ALTERNATIVE 1** $\Gamma=\frac{\text{power}}{\text{average rotational speed}}=\frac{2.16\times10^5}{\left(\frac{8400+3600}{2}\right)}$ ✓ 36 «N m» ✓ **ALTERNATIVE 2** Angular acceleration = $(-)\frac{(8400-3600)}{9.6}=500$ <<rad s^{-2} >> ✓ $\Gamma=(I\alpha=500\times0.072=)36$ <<N m>> ✓	*Allow ECF from a) i).*	**2**
	a	iii	$\Gamma\theta=\Delta E$ *or* Use of $\theta=\omega_{ave}\times t$ ✓ *or* $\theta=\omega t-\frac{1}{2}\alpha t^2$ Correct conversion into revolutions «r$\frac{57600}{2\pi}$ = 9170 rev» ✓	*Allow ECF from a i) and ii)* *Award MP2 for any correct conversion of an angle in radians to number of revolutions.*	**2**

	b		increase moment of inertia/density/mass of cylinder ✓ increase radius/depth of cylinder/mass distribution further from centre ✓ use greater angular velocity / torque applied ✓		**Max 2**

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>9</td><td>a</td><td></td><td>Z located horizontally to the right of Y ✓
 

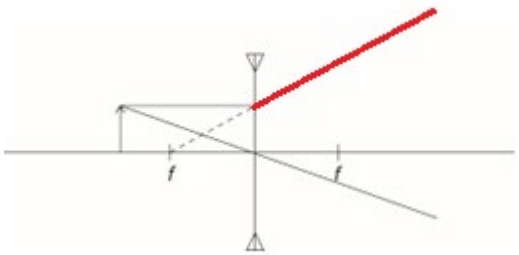
Correct overall shape ✓</td><td>Arrows not required.</td><td>2</td></tr>
<tr><td></td><td>b</td><td></td><td>$\frac{0.1\times1.2\times10^{-3}}{0.48}$ ✓</td><td>Accept BCA if given to 3sf</td><td>1</td></tr>
<tr><td></td><td>c</td><td>i</td><td><table>
<tr><td>process</td><td>Q / J</td><td>ΔU / J</td><td>W / J</td></tr>
<tr><td>X⇨Y</td><td>-188</td><td>0</td><td>-188</td></tr>
<tr><td>Y⇨Z</td><td>+262</td><td>+157</td><td>+105</td></tr>
<tr><td>Z⇨X</td><td>0</td><td>-157</td><td>+157</td></tr>
<tr><td>whole cycle</td><td>+74</td><td>0</td><td>+74</td></tr>
</table>
Line 1 correct ✓
Line 3 correct ✓
Lines 2 and 4 correct ✓</td><td></td><td>3</td></tr>
<tr><td></td><td>c</td><td>ii</td><td>$W = 105 = p(V_Z - V_Y)$ ✓
$= 0.48\times10^{6}\times(V_Z - 0.25)\times10^{-3}$
so V_Z = 0.47 x 10^{-3} «m^3 » ✓</td><td>Award [2] for a BCA

Award [2] for correct use of the adiabatic equation</td><td>2</td></tr>
</table>

		iii	Uses 4th row of *Q* and 2nd row of *Q* for working values ✓ $\eta = \frac{74}{262} = 0.28 \text{ or } 28\%$ ✓	*Allow ECF from incorrect values in table.* *Award 0 if $\eta \geq 1$ OR 100%* *Award [2] for a BCA*	**2**
	d		Isothermal process needs engine to run very (infinitely) slowly ✓ Adiabatic process needs engine to run very (infinitely) quickly OR requires insulation ✓	*Treat reference to frictional and other dissipative losses as neutral.*	**2**

Question			Answers	Notes	Total
10	a		$R = \frac{vr\rho}{\eta} = \frac{6.6\times10^{-2}\times0.13\times1000}{1.1\times10^{-3}}$ ≈ 7800 so R > 1000 and turbulent ✓	*Accept use of diameter for R = 15600.*	**1**
	b		Flow speed at hole = $\frac{\pi\times0.13^2\times6.6\times10^{-2}}{\pi\times0.019^2}$ **«** = 3.1 ms^{-1}**»** ✓ **Alternative 1** Water head, $h = \frac{1}{2g}\times v^2$ = $\frac{1}{2\times9.81}\times3.1^2$ **«** = 0.49 m**»** ✓ Water depth = 0.49 + 0.80 = 1.3 m ✓ **Alternative 2** $\rho gd + p_0 = \frac{\rho v^2}{2} + p_0 + \rho g\times0.80$ ✓ $d = \frac{v^2}{2g} + 0.80 = \frac{3.1^2}{2g} + 0.80 = 1.3$ m ✓	*Allow ECF for MP2 and MP3*	**3**
	c		(Buoyancy force emerges) due to the pressure difference (between top and base) ✓ links pressure to force (x area) (so there is a net upwards force on the block) ✓		**2**

Question			Answers	Notes	Total
11	a		Bumps are met at $\left(\frac{1.2}{3.0}\right) = 0.4$ s intervals ***OR*** time period of oscillation = $\left(\frac{1}{2.6} =\right) 0.38$ s ` ***OR*** Bump frequency = 2.5 **«**Hz**»** ✓ There is «an oscillation close to**»** resonance OR amplitude of oscillation is large OR bumping frequency and natural frequency are very close OR bumping period and period of oscillation are very close ✓		**2**
	b		less/reduced amplitude of vibration ✓ resonant frequency lower ✓ resonance occurs at lower speed ✓ oscillations die out (faster) ✓		**Max 2**

Question			Answers	Notes	Total
12.	**a**		Applies correctly the magnification to the situation given: $-\frac{v}{u} = -4 \quad OR \quad \frac{v}{u} = 4$ ✓ Replaces into lens law equation, e.g. $\frac{4}{v}+\frac{1}{v}=\frac{1}{f}$ ✓ $f = \left[\frac{v}{5}=\frac{40}{5}=\right] 8.0$ <<cm>> ✓	*Award [1] max if they use v/u = -4 leading to f = -(1/7.5) cm or -0.13 cm*	**3**
	b		 2 rays correct ✓ virtual **OR** upright ***OR*** diminished/smaller ✓	*Do not award MP2 if one feature given is incorrect.* *Allow ECF for MP2*	**2**

Question			Answers	Notes	Total
13.	**a**	**i**	concave / converging / parabolic [primary] mirror ✓ plane [secondary] mirror ✓	*treat mention of eyepiece as neutral*	**2**
	a	**ii**	Longer focal length «for a particular tube length» ✓ higher magnification «for a particular eyepiece» ✓ brighter image / less loss of intensity ✓		**1 max**
	b	**i**	$2.5 \times 10^{-3} \times 8 = 2.0 \times 10^{-2}$ **«m»** ✓	*Do not accept 2.5 x 8 = 20 if no unit stated.* *Do not penalize use of sin or tan.*	**1**
	b	**ii**	rays reflect from primary and converge towards a point on secondary ✓ rays reflect off secondary and converge at X ✓	Do not award MP2 if rays parallel to principal axis	**2**
	b	**iii**	*8 – 4.5 or 3.5, or 4.5 - 8 or –3.5* seen or used ✓ *u* = -3.5 m and *v* = 4.5 **«m»** so ♦*f* = $\frac{1}{\left(-\frac{1}{3.5}+\frac{1}{4.5}\right)} = -15.8$ **«m»** ✓	*Award [2] for a BCA*	**2**

Question			Answers	Notes	Total
14	**a**		$n_{\text{core}} \times \sin c = n_{\text{cladding}} \times \sin 90$ OR $1.59 \sin c = 1.48 \sin 90$ ✓ 69 / 68.6°✓	*Accept Snell's law expressed without sin90 for MP1*	**2**
	b	**i**	Angle of refraction in core = 90 – 68.6 = 21.4° ✓ $<< 1 \times \sin I = 1.59 \times \sin 21.4 >>$ 35.5°✓	*Allow ECF from a) and from MP1*	**2**
	b	**ii**	these rays enter the cladding✓		**1**
	c		$\log_{10}\left(10^6\right) = 6$ so range is 60 dB ✓ $<< \frac{60}{5.5} =>> 10.9 / 11$ **«km»** ✓		**2**

Question			Answers	Notes	Total
15.	**a**		Units is m^{-1} for linear ✓ Unit is m^2 kg^{-1} for mass ✓ mass a.c = linear a.c ÷ density OR mass attenuation coefficient is the linear attenuation coefficient per unit density ✓ mass attenuation coefficient refers to the absorption per unit mass ✓ linear attenuation coefficient refers to the absorption per unit length ✓ mass attenuation is the same for a particular substance [whatever its phase] ✓ linear attenuation coefficient depends on density of material ✓	*Accept other units of distance or mass used.*	**2 max**
	b		maximum contrast will be obtained when $\frac{\mu_b}{\mu_m}$ is greatest ✓ ln(E) = -4.7 ✓ Correct conversion of any ln(E) to E ✓ 6700 - 12000 **«**eV**»** ✓	*MP2 implies MP1* *Accept between –5 and –4.4 for MP2.* *Allow ECF for MP3 and 4.* *Accept final answer, if unit stated, in keV or MeV.* *Do not allow ECF if they read the y-coordinate.*	**4**

Question			Answers	Notes	Total
16.	**a**		To align the **«**spin of**»** protons OR to make the protons precess OR to allow detection of **«**Larmor**»** frequency ✓		**1**
	b		frequency depends on / is directly proportional to **«**magnetic**»** field «strength» ✓ **«r**esultant**»** field **«**of gradient field and uniform field**»** depends on position ✓ **«**a radio frequency is emitted so that**»** protons precess at different frequencies ✓ Protons deexcite / emit a radio signal ✓ Frequency / intensity / phase **«**of this radio signal**»** is related to the position **«**and distances inside patient can be determined**»** ✓	*Allow vibrate / rotate OWTTE for precess*	**3 max**

Question			Answers	Notes	Total
17.	**a**		Compares by number of stars (globular ~ 10^4 – 10^6 / more stars OR open ~ 10^2 , fewer) ✓ Compares by gravitational interactions (globular bound / open loosely bound, disrupted by gas clouds, evaporation etc) ✓ Compares by age of stars (Globular clusters older) ✓ Globular spherical open more irregular ✓ Presence of gas and dust in open✓		**2 max**
	b		cepheid stars pulsate / vary their size / vary their luminosity ✓ connects period and luminosity ✓ **«**distance can be determined with**»** observations of apparent brightness **«**from Earth**»** OR mentions use of $L = 4\pi bd^2$ ✓		**3**
	c		the distance estimate will be too large / an overestimate ✓ as apparent brightness is lower/underestimated ✓		**2**

Question			Answers	Notes	Total
18.	**a**		use of $A = 4\pi R^2$ ✓ use of $L = \sigma A T^4$ e.g. $\frac{A_L}{A_\odot} = \frac{L_L T_\odot^4}{L_\odot T_L^4}$ ✓ $\frac{R_l}{R_\odot} \ll= \sqrt{\frac{100000}{6.3^4}} \gg= 8.0$ ✓	*Award [3] for a BCA*	**3**
	b		Use of $L \propto M^{3.5}$ e.g. $\left(1.0\times10^5\right)^{\frac{1}{3.5}}$ ✓ 27 ✓		**2**
	c		«Max initial mass around 30$M_\odot$ so» likely fate is black hole / neutron star ✓ Reference to Oppenheimer-Volkoff limit / remaining mass/core about 3 $M_\odot$ ✓		**2**

Question			Answers	Notes	Total
19.	**a**		*v = 0.025c* ✓ *v= Hd = zc* ✓ correct conversion of *v* to km s^{-1} ***AND*** *d* to Mpc so that $H\left(=\frac{v}{d}\right)$ = 69.9 **«**km s^{-1} Mpc^{-1} **»**✓	*Accept other correct values close to 70 (e.g. 70.1) due to rounding.*	**3**
	b	**i**	Correct conversion of *H* units to m s^{-1} and m✓ $T=\frac{1}{H}=$ 4.4 x 10^{17} **«s»** ✓	*Allow ECF from a)*	**2**
		ii	rate of expansion is constant **«**at its present value**»**	*Accept constant speed of recession*	**1**

Question			Answers	Notes	Total
20.	**a**		When cloud mass > Jeans mass **OR** it is the minimum mass of the cloud ✓ For the cloud to collapse / form a protostar / OWTTE✓		**2**
	b		Jeans mass = 1.3 x10^{31}kg ✓ mass of cloud = $\frac{4}{3}\pi\rho R^3$ ✓ = 7.2x10^{29}kg ✓ Mass of cloud < Jeans mass so cloud stable/will not collapse **«**to form star**»** ✓	*MP4 for a consistent conclusion from the calculation done.*	**4**

Question			Answers	Notes	Total
21.	**a**		Mention of homogeneous **OR** isotropic ✓ A view *out* at boundary would be different from the view *in* from the boundary, this contravenes isotropy ***OR*** The density will change at the boundary, this contravenes homogeneity ✓	*Accept a correct explanation of either concept for MP1*	**2**
	b		enabled the formation of stars / galaxies ✓ **«**as small variations in temperature**»** occurred very early in universe ***OR*** **«**as small variations in temperature**»** led to variations in density ✓	*Accept reference to uneven distribution of matter for MP2*	**2**