Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

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Physics

Higher level

Paper 3

25 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	i	(2.2 × 0.09 =) 0.2«ms» ✓	*Do not apply POT for 0.2 s*	1
1.	a	ii	line drawn at correct point from 2.0 to 2.4 ✓	*Allow ECF from (a)(i).*	1
1.	b		line of best fit drawn ✓	*Straight line, points at L=30 and 70 are above the line AND points at L=40 and 60 below the line.*	1
1.	c		attempt to use gradient over more than half the line of best fit, delta L at least 40 cm ***OR*** attempt to use one point from the line of best fit, L at least 40 cm ✓ speed of sound = **«**2 / gradient =**»** 340 ✓ m s^{-1} ✓	*For MP1, accept inverse gradient.* *For MP2, accept value from interval 330 to 350.* *For awarding both, MP2 and MP3, unit must be consistent with the value, for example accept 35 cm/ms.*	3

1.	**d**		time measurements **«**of B**»** all increase/change/affect by the same amount ***OR*** graph shifted upwards/left ✓ gradient stays the same so speed of sound is unchanged ✓	*Ignore parts of discussion proposing value L+10cm on the horizontal axis OR shifting of graph to the right".*	**2**

2.	**a**	**i**	**«**16000/(0.25 × 14) =**»** 4600 **«**Jkg^{-1}K^{-1}**»** ✓	*Accept unrounded answer.*	**1**
2.	**a**	**ii**	ALTERNATIVE 1 evidence of one fractional uncertainty found **«**0.002/0.25 or 0.5/14 or 300/16000**»** ✓ the three correct fractional uncertainties correctly summed **«**= 0.002/0.25 + 0.5/14 + 300/16000 = 0.0625**»** ✓ absolute uncertainty **«**0.0625 x 4571**»**=286 **«**J kg^{-1}K^{-1}**»** ✓ ALTERNATIVE 2	*Allow % uncertainty.* *Allow ECF from (a)(i).* *Allow ECF from MP2 to MP3.*	**3**

			evidence of max/min approach ✓ maximal value = 16300 / (13.5 x 0.248) = 4868 **«**J $kg^{-1}K^{-1}$**»** ***OR*** minimal value = 4571 **«**J $kg^{-1}K^{-1}$**»** ✓ 4868-4571=298 **«**J $kg^{-1}K^{-1}$**»** ✓		
2.	**a**	**iii**	4600± 300 **«**J $kg^{-1}K^{-1}$**»** ✓	*Allow ECF from (a)(i).* *This mark requires 1 significant figure for uncertainty AND appropriate rounding of the heat capacity.*	**1**

(continued…)

(Question 2 continued)

Question			Answers	Notes	Total
2.	**b**		water evaporated / decreasing mass ***OR*** energy transferred from the water to the surroundings ***OR*** energy transferred to the beaker / not all input energy is transferred to water ✓ overestimates value/ the calculated/measured value is higher than the real value ✓	*For MP1, answer like the process is not 100% efficient is not enough, we require a specific source of systematic error. We can award MP2 for such answers.* *If only systematic error in the any value given is correctly discussed, award MP2 only.*	**2**

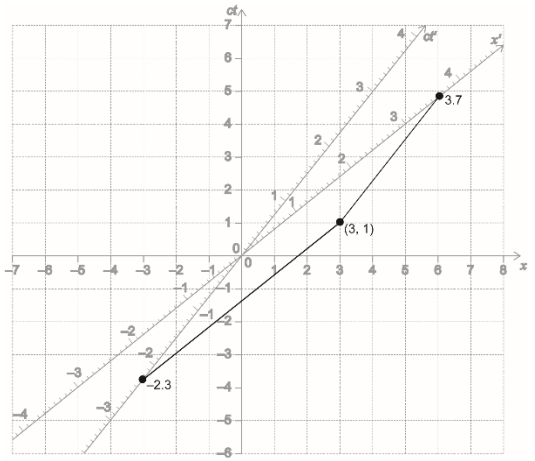
Section B

Option A — Relativity

Question			Answers	Notes	Total
3.	**a**		100«m» ✓		**1**
3.	**b**	**i**	the length measured by an observer at rest « with respect to the object being measured » ✓	*Accept the length of an object in the object's **rest** frame.* *Allow "the maximal measurable length/ longest measurable distance of object.*	**1**
3.	**b**	**ii**	$\gamma =$« $\left\{ \frac{1}{\sqrt{1-\frac{0.6^2}{1^2}}} \right\}$ » = 1.25 ✓ «100/1.25 =»80«m» ✓		**2**
3.	**c**		Newton assumed that «time and» space are absolute / *OWTTE* ***OR*** relativity assumes that « time and » space are not absolute/constant ✓ different length measurements contradict *Newton's* assumption / *OWTTE* ✓		**2**

4.	**a**		$\frac{-0.75-0.6}{1+0.75\times0.6}c$ ✓ $-0.93c$ ✓		**2**
4.	**b**		$\Delta t' = \gamma\left(0-\frac{v\Delta x}{c^2}\right)$ OR mention of gamma factor for Y with respect to ground ✓ Conclude $\Delta t' \neq 0$, meaning that the particles were not emitted at the same time ✓		**2**

Question			Answers	Notes	Total
5.	**a**		evidence of attempt to find gradient or tan θ ***OR*** $x/ct = 4/5$ ✓ $0.8c$ ✓		**2**
5.	**b**	**i**	point drawn at (3, 1) in *x*-*ct* coordinates ✓	*Point must be labelled as E*	**1**
5.	**b**	**ii**	lines drawn from (3, 1) roughly parallel to *x′* to intersect with *ct′* axis ✓ according to B, event is taking place at *t′* < 0/before origin **«**so before**»** ✓	*Watch for ECF from bi).* *Allow working on diagram OR correct arguments in the answer box.* *Accept use of Lorentz transformation to show ct' = –2.3.*	**2**
5.	**b**	**iii**	***ALTERNATIVE 1*** using diagram: line drawn in (b)(ii) intersecting *ct′* between -2 and -2.75 ✓ line drawn parallel to *ct′* intersecting with *x′* from (3, 1) ✓ *x′* between 3 and 4 ✓ ***ALTERNATIVE 2*** using Lorentz transformation: $\gamma = 1.66$ ✓ $ct' \text{ «} = \gamma\left(ct - \frac{vx}{c}\right) = 1.66(1 - 0.8 \times 3) \text{»} = -2.3$ ✓ $x' \text{ «} = \gamma(x - vt) = 1.66(3 - 0.8 \times 1) \text{»} = 3.7$ ✓ **ALTERNATIVE 3**	*Allow ECF from (a).* *Without explicit answer, award [2max], even if working on diagram seems to be correct.* *Penalise for incorrect signs.*	**3**

			line drawn in (b)(ii) intersecting *ct′* between −2 and −2.75 ✓ use of invariant formula as in b(iv) with values ✓ to get x'=3.7 ✓		
5.	**b**	**iv**	$(ct)^2-(x)^2=1^2-3^2=-8$ ✓ $(ct')^2-(x')^2=2.3^2-3.7^2\approx-8$ ✓	*Allow ECF from (b)(iii).*	**2**

Question			Answers	Notes	Total
6.	**a**		$V = \frac{1}{e}(\gamma - 1)m_e c^2$ ✓ $V = 0.51$ **«**MV**»** ✓	*For answer 0.51 V apply POT (do not award MP2), otherwise ignore unit.*	**2**
6.	**b**		according to the lab, $E^2 - p^2c^2 = 1100^2 - 450^2 = 1000^2$ ✓ realization that $E^2 - p^2c^2 =$ constant ✓ $p = \sqrt{1700^2 - 1000^2} = 1374$ **«**MeVc^{-1}**»** ✓	*Allow a negative answer for p.*	**3**
7.	**a**		presence of mass warps/curve spacetime ✓ photon follows the shortest/straight-line path in spacetime ✓ the path is curved/bent **«** in space **»** ✓		**3**
7.	**b**		$f = \frac{E}{h} = \frac{14000 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 3.4 \times 10^{18}$ **«**Hz**»** ✓ $\Delta f = \text{«}\frac{fg\Delta h}{c^2} = \frac{3.4 \times 10^{18} \times 9.8 \times 10}{(3 \times 10^8)^2} =\text{»} 3700$ **«**Hz**»** ✓	*Allow minus sign.*	**2**

Option B — Engineering physics

Question			Answers	Notes	Total
8.	a	i	$\theta = \frac{L}{R}$ ✓	*Accept: L and θ are directly proportional.*	**1**
8.	a	ii	ALTERNATIVE 1 use of rotational kinematics equation to get $\alpha = \frac{2\theta}{t^2}$ ✓ $\theta = «\frac{1.5}{0.555} =» 27.3 «\text{rad}»$ ✓ $\alpha = «\frac{2 \times 27.3}{0.96^2} =» 59 «\text{rad } s^{-2}»$ ✓ ALTERNATIVE 2 final speed v=2x1.5/0.96 = 3.12 ms^{-1} ✓ final angular speed ω=v/R ✓ α = ω/0.96 = 59 «rad s^{-2} » ✓ ALTERNATIVE 3 acceleration = $2L/t^2$ ✓ acceleration = 3.26 m s^{-2} ✓ angular acceleration = acceleration/R = 59 «rad s^{-2} » ✓	*Award [3] for bald correct answer from interval 58.0 to 59.3.*	**3**
8.	b		ring has a larger moment of inertia/ mass further from the axis of rotation ✓ ring will have smaller angular acceleration ***OR*** higher portion of/more energy is stored in rotational KE for ring ✓	*Reverse argument allowed in terms of the disk.*	**3**

			ring arrives last ✓	*Award MP3 only if MP1 or MP2 are awarded.* *Award [0] for work based on idea that ring has lower moment of inertia.*	

9.	**a**		the distance between the **«**centre of**»** planet and **«**the centre of the**»** star ✓	*Accept radius/radius of the planet around star.*	**1**
9.	**b**		$L = \text{«}mr^2\frac{v}{r}\text{=»}\ mvr$ ✓ Correctly shown that since $r_A < r_B$, $v_A > v_B$ ✓		**2**

(continued…)

(Question 9 continued)

Question			Answers	Notes	Total
9.	**c**		**«** gravity is **»** an external force on the planet **«**so linear momentum is not conserved**»** ***OR*** linear speed is different at A and B ✓ gravity acts towards the center and therefore does not create a net torque **«**so angular momentum is conserved**»** ✓		**2**

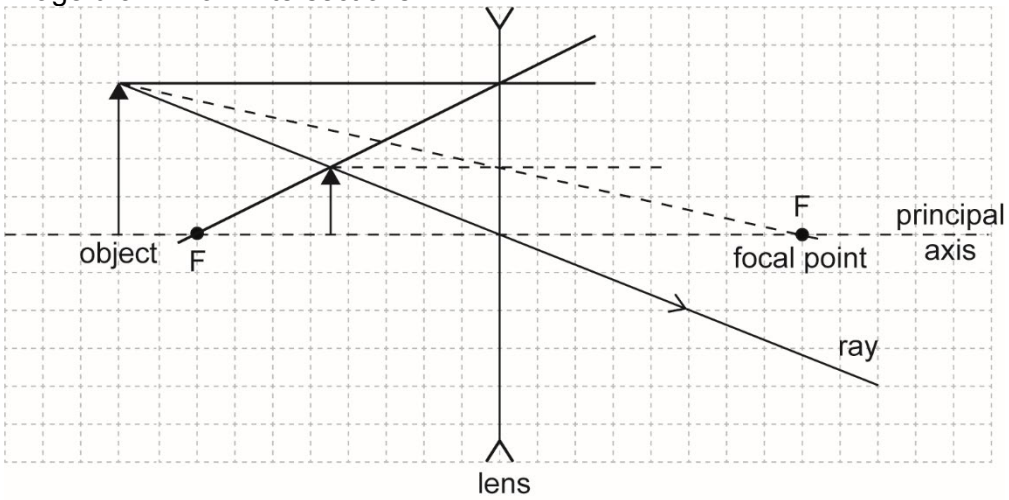
10.	**a**		**«** for Carnot cycle, A to B is **»** isothermal process / no change in T / $\Delta U = 0$ ✓ expansion so $W > 0$ ✓ $Q = W > 0$ ✓	*MP3 can only be awarded if MP1 and MP2 are achieved.* *Allow working with W as negative for "work done on system".*	**3**
10.	**b**	**i**	Any use of adiabatic formula✓ $V_D =$ **«** $4.3(2.2\ 10^{-3})^{5/3} = 1.7(V_D)^{5/3}$ **»** $= 3.8\ 10^{-3}$ **«**m^3**»** ✓	*Answer to 2 or more SF OR clear working/substitution is required for MP2.*	**2**
10.	**b**	**ii**	$\text{efficiency} = 1 - \frac{T_D}{T_A}$ ✓ $\frac{T_D}{T_A} = \frac{P_D V_D}{P_A V_A}$ ✓ $=$ **«** $1 - \frac{1.7 \times 3.8}{4.3 \times 2.2}$ **=»** 0.32 or 32% ✓	*Allow use hot/cold instead A, D.* *Award [3] for bald correct answer for interval [0.28, 0.34]*	**3**

Question			Answers	Notes	Total
11.	**a**		the flow rate at A is the same as at B ***OR*** same volume/mass per unit time passing through A and B ✓ as the diameter/area at B is smaller, a larger *v* is needed for constant flow rate ✓	*Award MP1 if expressed by the equation of continuity* $A_A \times v_A = A_B \times v_B$	**2**
11.	**b**		correct use of density / rate at A = density × Area × v_B ✓ $v_B = \text{«}\frac{\text{rate at A}}{\text{density} \times \pi r^2} = \text{»} \frac{2.3}{900 \times \pi \times 0.012^2}$ ✓ $v_B = 5.6 \text{«ms}^{-1}\text{»}$ ✓		**3**

12.	**a**		energy after one oscillation $= E_0\left(1 - \frac{2\pi}{Q}\right)$ ✓ energy stored $= \frac{1}{2} k \Delta x^2$ ***OR*** energy stored $\propto x^2$ ✓ $\frac{x_1}{x_0} = \sqrt{1 - \frac{2\pi}{200}} = 0.984$ ✓	*For MP3, at least 3 significant figures or clear evidence of correct substitution must be seen.* *For MP1 and MP2, allow use of* $Q = 2\pi \frac{x_0^2}{x_0^2 - x^2}$	**3**
12.	**b**	**i**	curve drawn **«** of similar shape **»** with a larger amplitude at resonant frequency ✓	*Allow peak at slightly higher frequency.*	**1**
12.	**b**	**ii**	larger Q factor implies less damping / OWTTE ✓ **«**therefore maximum amplitude will be larger **»**	Allow correct use of formula, lower Q implies higher x	**1**

				$Q = 2\pi \frac{x_0^2}{x_0^2 - x^2}$	

Option C — Imaging

Question			Answers	Notes	Total
13.	a		the two sides of the lens are «almost» parallel/no curvature ✓ « first » incident and « second » refracted/deflected ray are «almost» equal/OWTTE ✓		2
13.	b		ray parallel to principal axis and emerging from the focal point (either solid lines or dashed lines on diagram below) ✓ image drawn from intersections ✓  	*For MP2, arrow is required.* *Award [0] for rays of converging lens.*	2
13.	c		ALTERNATIVE 1 u = 10 squares and v = – 4.5 squares ***OR*** ho = 4 squares and hi = 1.8 squares ✓ M = 0.45 ✓ ALTERNATIVE 2	*Allow ECF from 13(b), for any image drawn.*	2

			« $\frac{1}{-8}=\frac{1}{10}+\frac{1}{v}$ used to get » v = - 40/9 ✓ M = 4/9 ***OR*** 0.44 ✓	*Do not allow ECF from MP1 to MP2.* *Award [2] for bald correct answer from interval 0.4 to 0.5.* *If mistake in the sign, award [1max].*	
13.	**d**		« parallel » rays that pass through the lens « at different places » do not focus at the same point/OWTTE ✓ can be reduced by adjusting the shape of the lens ***OR*** can be reduced by only letting light rays strike close to the centre of the lens ***OR*** can be reduced by double lens ✓	*For MP1, focus of the rays must be mentioned.*	**2**

Question			Answers	Notes	Total
14.	**a**		«$\frac{1}{v_0}=\frac{1}{f_0}-\frac{1}{u_0}$» $v_0 = 8.3$ «cm» ✓ angular magnification: $M = m_0 \times m_e$ ✓ $M = «\frac{v_0}{u_0}\left(\frac{D}{f_e}+1\right) = » -\frac{8.3}{0.91}\times\left(\frac{25}{2.9}+1\right) = -87.7$ ✓	*For MP3 look for evidence of correct working or answer to at least 2 significant figures.* *For MP3, allow positive sign.*	**3**
14.	**b**		virtual AND inverted ✓		**1**

15.	**a**		to ensure total internal reflection takes place ✓ with very large critical angle ✓ so only nearly paraxial rays are transmitted ***OR*** to reduce « waveguide/modal » dispersion ✓		**2 max**
15.	**b**		graded-index fibre has the highest refractive index at the centre and then gradually decreases ✓ slows down rays travelling parallel to the fibre / at centre of fibre ***OR*** rays taking longer paths travel relatively faster ✓ so rays arrive almost at the same time / reduces time delay between rays ✓	*Do not award marks for just repeating information from the question.*	**3**
15.	**c**		I/Io = 0.04 ✓ −1.1 X = 10log(0.04) ✓ X = 13 «km» ✓	*Award [3] for bald correct answer.*	**3**

Question			Answers	Notes	Total
16.	**a**		$I_A = I_0 e^{-0.13 \times 20}$ ✓ $I_B = I_0 e^{-0.13 \times 11} e^{-0.59 \times 9}$ ✓ $\frac{I_A}{I_B} = \text{«} \frac{e^{-0.13 \times 20}}{e^{-0.13 \times 11} e^{-0.59 \times 9}} = e^{-0.13 \times 9 + 0.59 \times 9} = \text{»}$ 62.8 ✓	*Award [3] for bald correct answer.* *If soft tissue around the bone omitted, giving answer 15, award [2] .*	**3**
16.	**b**		how much resistance/opposition an ultrasound beam encounters as it passes through ***OR*** density x speed of sound ✓	*Terms in equation must be defined for mark to be awarded.* *Do not allow absorption.*	**1**
16.	**c**		$Z_1 = 1760000$ **OR** $Z_2 = 7995000$ ✓ correct substitution to get 0.41 ✓	*Award 2 for bald correct answer.*	**2**
16.	**d**		*Advantage*: higher penetration ✓ gives better images of bones and internal organs/higher resolution ✓ *Disadvantage*: more difficult to transport X-ray machine ✓ ionizing radiation /more harmful ✓ X-rays cannot be used on pregnant women without a risk ✓	*Award **[1] max** for advantage and **[1] max** for disadvantage.* *For advantage, look for more detailed answer than just better for bones.* *For disadvantage, do not award mark for answers like cause damage to body, without details.*	**2 max**
16.	**e**		**«** the signal strength **»** depends on **«** the number/density **»** of protons relaxing ✓ number of protons depends on water/hydrogen density ***OR***		**2**

			bone takes less time to relax ✓		

Option D — Astrophysics

Question			Answers	Notes	Total
17.	**a**	**i**	parallax angle $= \frac{0.18}{2}$ ✓ distance $= \text{«} \frac{1}{0.09} = \text{»}$ 11 «pc» ✓	*Allow ECF for MP2.* *For MP2, working or answer to at least 2 significant figures must be seen.*	**2**
17.	**a**	**ii**	$11 \times 3.26 \times 9.46 \times 10^{15} = 3.4 \times 10^{17}$ «m» ✓ $\frac{3.4 \times 10^{17}}{1.50 \times 10^{11}}$ ***OR*** 2.3×10^{6} ✓	*Award [2] for BCA from interval* 2.0 x10^6 *to* 2.4 x10^6	**2**
17.	**b**		group of stars that appear to be close to one another/form a shape/pattern ✓ but are not gravitationally bound ***OR*** are not necessarily close in space ✓		**2**
17.	**c**	**i**	identify peak wavelength ✓ use peak wavelength « in Wien's law $\lambda_{\max} T = 2.9 \times 10^{-3}$ » to get T ✓		**2**
17.	**c**	**ii**	use of mass-luminosity relationship to get $M = 2.5 M_{SUN}$ ✓ white dwarf ✓	*Do not allow use of temperature or wavelength, without considering the mass.*	**2**

				Do not allow ECF from MP1.	
17.	**d**		surface area/radius/size/temperature of the star increases and decreases ***OR*** the star expands and contracts periodically ✓ as it expands, it cools/brightness decreases ***OR*** as it contracts, the temperature raises/brightness increases ✓		**2**

Question			Answers	Notes	Total
18.	**a**		**«** isotropic: **»** the radiation must have been emitted from a single point in all directions ✓ **«** *T*: **»** as the universe expanded, the *T* decreased/redshifted suggesting a hot initial universe ✓		**2**
18.	**b**	**i**	$d = \frac{zc}{H_0}$ ✓ $d = \frac{0.01 \times 3 \times 10^5}{70}$ ✓ $d = 43 \ll \text{Mpc} \gg$ ✓	*If not unit given in answer assume Mpc.* *Award **[2] max** for POT mistake.* *Award [3] for bald correct answer.*	**3**
18.	**b**	**ii**	Attempt to use t = $1/(70 \times 10^{-3})$ = **«** $\frac{1 \times 10^6 \times 3.26 \times 9.46 \times 10^{15}}{70 \times 10^3}$ **»** ✓ $= 4.4 \times 10^{17}$ **«s»** ✓	*Award [2] for bald correct answer.* *In MP1, accept 70 in denominator.*	**2**
18.	**c**		Brightness/redshift/increased wavelength of **«**distant**»** type I a supernovae show they are further away **«** than expected **»** /OWTTE ✓	*Allow answer like "redshift keep increasing".*	**1**

19.	**a**		a red super giant has higher temperature in its core ✓ fusion reactions take place at a larger rate ✓ outward/fusion pressure is higher ✓	*Greater mass/pressure is not enough for MP1.*	**2**
19.	**b**		the r process is **«** the rapid **»** absorption of neutrons ✓ absorption happens faster than beta decay occurs ✓ for this to happen high temperature ✓ and high neutron density is required ✓		**3 max**

Question			Answers	Notes	Total
20.	**a**		quotes the orbital formula and assigns mass of galaxy to M ***OR*** $F = G\frac{Mm}{d^2} = \frac{mV_{\text{rot}}^{\ 2}}{d}$ ✓ substitute $M = p\frac{4}{3}\pi d^3$ to get $V_{\text{rot}} = \sqrt{\frac{4\pi Gp}{3}}d$ ✓		**2**
20.	**b**	**i**	roughly horizontal line drawn for large d ✓		**1**
20.	**b**	**ii**	**«**because V_{rot} is constant**»** it is proposed there must be more mass than observed at the edge of galaxies/around galaxies ✓ hence dark matter was proposed ✓		**2**