ib Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2025

Physics

Higher level

Paper 2

ib International Baccalaureate
Baccalauréat International
Bachillerato Internacional

Subject Details: Physics HL Paper 2 Markscheme

Mark Allocation

Candidates are required to answer ALL questions. Maximum total = [90 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. For numerical answers, a correct answer with no working is awarded full marks UNLESS stated otherwise in the "Notes". For correct numerical answers with working the working must be checked. If the working contains minor omissions or errors full marks are awarded. If the working contains wrong Physics or wrong method the correct answer obtained will be the result of numerical coincidence. In that case the answer is penalized.
6. An alternative wording is indicated in the "Answers" column by a slash (/). Either wording can be accepted.
7. An alternative answer is indicated in the "Answers" column by "OR" between the alternatives. Either answer can be accepted.
8. Words in angled brackets « » in the "Answers" column are not necessary to gain 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.
10. 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.
11. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.
12. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in a marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then error carried forward (ECF) marks should be awarded. When marking, indicate this by adding ECF on the script. When ECF is not to be applied "Do not allow ECF" will be displayed in the "Notes" column.
13. Do not penalize candidates for errors in units or significant figures, unless it is specifically referred to in the "Notes" column.
14. Allow alternative formats such as c for rad or use of E for scientific notation.

Question			Answers	Notes	Total
1	**a**	**i**	Work <<done on the car by *F*>> **OR** Kinetic energy <<of the car>> ✓		**1**
	a	**ii**	Area $=2.4\times10^5$ J ✓ $«2.4\times10^5 = \frac{1}{2}\times1.6\times10^3\times v^2 \Rightarrow» v = 17$ m s^{-1} ✓	*Ignore units, they are not required for the answer. They have been included for clarity.* *Allow ECF from incorrect area.*	**2**
	b		$cv^2 = \frac{P}{v}$ **OR** $c = \frac{P}{v^3}$ ✓ $c = 1.5$ ✓ kg m^{-1} ✓	*Do not award ECF from part a) as this is about a different car.*	**3**

Question			Answers	Notes	Total
2	a		The use of Kepler's 3rd law, e.g. $\left(\dfrac{r_{\text{V}}}{r_{\text{E}}}\right)^3 = \left(\dfrac{225}{365}\right)^2$ ✓ $\dfrac{r_{\text{V}}}{r_{\text{E}}} = 0.724$ ✓		2
	b		Any 2 from: Identifies gravitational force «of the Sun» as causing circular/orbital motion ✓ Identifies orbital radius and orbital period of a planet about the Sun as observable/known quantities ✓ The mass of the Sun/central body is a constant in the equation that relates r and T **OR** Suggests an equation that combines r, T and M, e.g. $\dfrac{4\pi^2 rm}{T^2} = \dfrac{GMm}{r^2}$ or $\dfrac{r^3}{T^2} = \dfrac{GM}{4\pi^2}$ ✓	*Do not allow a bald statement of Newton's Law of Gravitation.* *Do not allow mention of gravitational force unless it is linked to orbital motion.*	Max 2
	c		The use of $g = \text{«–»}\dfrac{\Delta V}{\Delta r}$, e.g. $\dfrac{3.0\times10^7}{5.0\times10^9}$ ✓ 6.0×10^{-3} m s^{-2} ✓	*Ignore units as they are not required for the answer.*	2

Question			Answers	Notes	Total
3	**a**	**i**	<<at closest approach alpha is within the range of the>> strong nuclear interaction/force «of the gold nucleus» ✓		**1**
	a	**ii**	Recognizes that nuclear radius is «approximately» the distance of closest approach ✓ Explains calculation of r from energy conservation, e.g. $E_0 = k\dfrac{Qq}{r}$ with symbols explained or description of initial KE of alpha particle being converted to electrical potential energy.✓	MP1 can be implied if the answer discusses the distance of closest approach. Use of r in an algebraic expression isn't sufficient for MP1.	**2**
	b	**i**	«$\dfrac{\ln 2}{2.69 \times 24 \times 3600} =$»$2.98 \times 10^{-6}$ s^{-1} ✓	*Unit is not required.*	**1**
	b	**ii**	Undecayed mass $= 5.0 \times e^{-2.98 \times 10^{-6} \times 7 \times 24 \times 3600}$«$= 0.82$ mg» **OR** $5.0 \times \left(\dfrac{1}{2}\right)^{\frac{7.0}{2.69}}$ «0.82 mg» ✓ Mass of Hg-198 $=$«$5.0 - 0.82 =$»4.2 mg ✓	*Unit is not required.* *Check the steps in the calculation.* *If the unit is missing in the answer, check the calculation to see whether the candidate is working in mg or kg and ensure that the power of ten is correct. If any other unit is given, the power of ten and the prefix must match e.g. 4.2 x 10³ μg.*	**2**

	c		« $E = hf$ hence» observed gamma photons have fixed / discrete energies **OR** *Use of $E = hf$ to calculate at least one photon energy* ✓ Gamma energy equals the difference between nuclear energy levels **OR** Gamma photons are emitted when the nucleus undergoes transitions between its energy levels ✓	*Energies are* *6.63 x 10^{-14} J OR 0.41 MeV* *1.08 x 10^{-13} J OR 0.68 MeV* *1.74 x 10^{-13} J OR 1.1 MeV* *Do not award MP2 if transitions of electrons are discussed.*	**2**

Question			Answers	Notes	Total
4	a		B <<has more microstates>> ✓		2
			Because there are many ways to swap the particles/exchange energy of the particles in B		
			OR		
			Because any energy exchange starting in A results in a different configuration «so A has only one microstate» ✓		
	b		A valid reference to the 2nd law, e.g. that the entropy of an isolated system never decreases ✓	*Allow 'degree of disorder' for entropy.*	3
			The entropy is greater in configuration B «because entropy is proportional to $\ln\Omega$» ✓	*Accept reverse statement for configuration A.*	
			Process 1 leads to an increase in entropy ✓	*Accept reverse statement for process 2.*	

Question			Answers	Notes	Total
5	**a**	**i**	Away from loudspeaker ✓		**1**
	a	**ii**	$1600 = 1700 \times \dfrac{340 - v}{340}$ ✓ $v = 20 \text{ m s}^{-1}$ ✓	*Unit is not required.* *Check the steps in the calculation.* *Allow use of $\frac{\Delta f}{f} \approx \frac{v}{c}$ which also gives 20.* *Award [0] for use of moving source equation which gives 21.3.* *Award [1] for use of incorrect sign (leads to –20) if no further comment is made, but award [2] if they state '20 away from the speaker'.*	**2**
	b	**i**	$«\dfrac{340}{1700} =» 0.20 \text{ m}$ ✓	*Unit is not required.*	**1**
	b	**ii**	Path difference $= «2 \times 0.50 - 0.70 =» 0.30 \text{ m}$ ✓ This is 1.5λ **or** $phase\ difference = 3\pi$ «hence destructive interference» ✓	*Allow statement that* $\Delta l = \left(n + \frac{1}{2}\right)\lambda\ AND\ n = 1$ *Accept π phase difference.* *Only award ECF from incorrect **wavelength** or **path difference** if it correctly leads to destructive interference.*	**2**

c		Angle of incidence at $P = \sin^{-1}\left(\frac{0.35}{0.50}\right) = 44^o$ ✓	MP2 and 3 can only be awarded from one Alternative	
		ALTERNATIVE 1	Award ECF from an incorrect angle of incidence	
	3	Critical angle $= \sin^{-1}\left(\frac{340}{1500}\right) = 13°$ ✓		**3**
		$\theta > \theta_{crit}$ hence the sound can't enter water at P ✓		
		ALTERNATIVE 2		
		$\frac{\sin\theta_2}{\sin 44} = \frac{1500}{340}$ **or** $\sin\theta_2 = 3.1$ ✓		
		$\sin\theta_2 > 1$ **or** θ_2 *is undefined* hence the sound can't enter water at P ✓		

Question			Answers	Notes	Total
6	a		Use of $\Delta E_{\mathrm{K}} = e \times V$, e.g. $\frac{1}{2} \times 9.11 \times 10^{-31} \times \left(9.4 \times 10^{6}\right)^{2} = 1.60 \times 10^{-19} V$ **OR** Use of $Fd = qV$, $F = ma$ and $v^2 = u^2 + 2as$ ✔ $V = 250$ V ✔	*Ignore units as they are not required for the answer.*	2
	b	i	Upwards «on the diagram»/ towards the positive plate ✔		1
	b	ii	Correct symbolic or substituted expression for the force, e.g. $\dfrac{qV}{d}$, $\dfrac{1.60 \times 10^{-19} \times 30}{0.04}$, 1.2×10^{-16} N ✔ $a = \dfrac{1.2 \times 10^{-16}}{9.11 \times 10^{-31}}$ **or** 1.3×10^{14} m s^{-2} ✔	*Unit is not required.* *Ignore any negative sign in the answer.* *Check the steps in the calculation.* *Allow ECF from MP1 if 4 cm used. Leads to 1.3 x 10^{12}.* *Allow ECF from MP1 if 0.02 m or 2 cm is used.* *Do not allow ECF from MP1 if* *250 V used for V.*	2

c	The use of an appropriate kinematics equation for time, e.g. $0.02 = \frac{1}{2} \times 1.32 \times 10^{14} \times t^2$, $t = 1.7 \times 10^{-8}$ s ✓ Recognizes constant horizontal velocity, e.g. $x = 9.4 \times 10^6 t$ ✓ 0.16 m ✓	*Ignore units as they are not required for the answer.* *Accept any valid rounding of acceleration, e.g. $a = 1.0 \times 10^{14}$ m s^{-2} leads to $t = 2 \times 10^{-8}$ s and $x = 0.19$ m.* *Allow ECF from MP1.* *Watch for ECF from bii). Candidates may obtain an answer for acceleration which is incorrect but rounds to 10^{14}.*	**3**
d	**ALTERNATIVE 1** $evB = e\frac{V}{d} \Rightarrow B = \frac{V}{vd}$ ✓ $«\frac{30}{9.4 \times 10^6 \times 0.04} =» 8.0 \times 10^{-5}$ T ✓ **ALTERNATIVE 2** evB = Force from bii) MP1✓ $B = « \frac{1.2 \times 10^{-16}}{1.6 \times 10^{-19} \times 9.4 \times 10^6} =» 8.0 \times 10^{-5}$ T✓	*Marks can only be awarded from one Alternative* *Ignore units as they are not required for the answer.* *Allow ECF from bii).* *Accept use of F = ma for electric force with the acceleration calculated in bii). This leads to 6.1 x 10^{-5} <<T>>if rounded value used.*	**2**

Question			Answers	Notes	Total
7	**a**	**i**	Correct readoffs $\Delta x = 3$ m, $c\Delta t = 1$ m ✓ $(\Delta s)^2 = «1^2 - 3^2 =» -8$ m² ✓	*Ignore units as they are not required for the answer.* *Do not award MP2 if the answer is positive*	**2**
	a	**ii**	Does not depend on/is independent of the reference frame **OR** Is the same according to every «inertial» reference frame ✓	*Do not allow vague answers that describe quantities that don't change.*	**1**
	b	**i**	x' correct ✓ ct' consistent with their x' ✓ 	*Lines must start at origin.* *Allow a tolerance of ± 1 small grid square at the end of each line.*	**2**
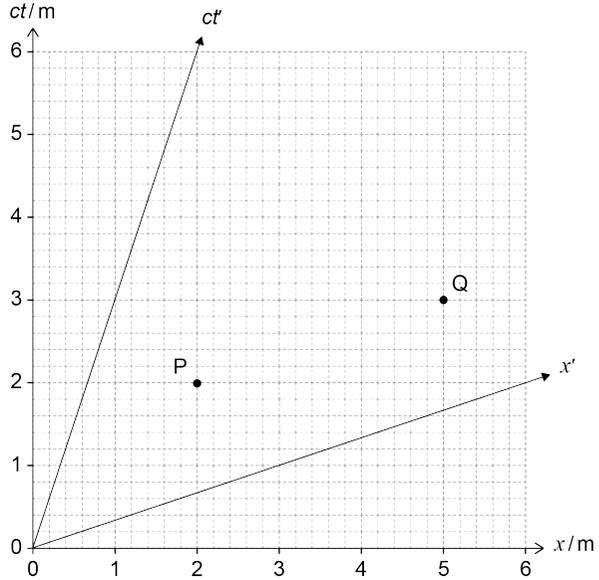
b	**ii**	«$\dfrac{v}{c} = \dfrac{1}{3}$ so» $v = 0.33c$ **or** 1.0×10^8 m s^{-1} ✓	*Watch for ECF from bi.* *Allow fraction as the answer, i.e.* $\dfrac{c}{3}$	**1**

Question			Answers	Notes	Total
8	a		The intensity <<of solar radiation>> received by the Earth ✓	*Accept 'power per unit area' for intensity.*	1
	b	i	<<Absorption by GHG molecules of>> radiation whose energy matches the energy difference between molecular levels **OR** <<Absorption of radiation that causes>> resonance of the GHG molecule ✓ Followed by emission «from GHG molecules» in random/all directions ✓	*For MP2 do not accept towards the surface as that is in the stem of the question.*	2
	b	ii	Average incoming intensity $=\dfrac{S}{4}$«$=340\ \text{W m}^{-2}$» ✓ Absorbed intensity $=(1-0.30)\times340$ *or* $238\ \text{W m}^{-2}$ ✓	*The steps in the calculation must be shown.*	2

	b	iii	Emitted intensity $=$«$5.67\times10^{-8}\times0.90\times288^{4}=$»351 W m^{-2} ✔ Intensity leaving Earth $=$238 W m^{-2} ✔ Re-radiated intensity $=$«$351-238=$»113 W m^{-2} ✔	*Ignore units as they are not required for the answer.* *The steps in the calculation must be checked.* *Accept outgoing intensity = 240 W m^{-2} for MP2.*	**3**
	c		Recognition that $r = 1.5 \times 10^{11} m$ **AND** $S = 1.36 \times 10^{3} W\, m^{-2}$ ✔ $4\pi\left(1.5\times10^{11}\right)^{2}\times1.36\times10^{3}$ or 3.8×10^{26} W ✔	*Unit is not required.* *The values of r and S must be seen to award MP1.* *Allow ECF from use of* $S = 1.4 \times 10^{3} W\, m^{-2}$	**2**

continued…

Question 8 continued.

d	**i**	**ALTERNATIVE 1** $\Delta m = 4 \times 1.007276 + 2 \times 0.000549 - 4.001506 \text{«}= 0.028696 \text{ u»}$ ✓ $\text{«}0.028696 \times 931.5 =\text{»}26.7 \text{ MeV}$ ✓ **ALTERNATIVE 2** $\Delta m = 4 \times 938 + 2 \times 0.511 - 4.001506 \times 931.5 \ll= 25.6\ MeV\ c^{-2} \gg$ ✓ 25.6 MeV ✓	*Marks can only be awarded from one Alternative* *Unit is not required.* *Particle masses in u and MeV c^{-2} lead to differently rounded answers, working must be checked.* *Award [1] max if electrons are omitted. This leads to ALT 1 25.7 <<MeV>>, ALT 2 24.6 <<MeV>>* *Award ECF if incorrect number of particles used e.g. 1 electron rather than 2.*	**2**
d	**ii**	<<Photons emitted>> in fusion give rise to outward/ thermal/radiation pressure ✓ Which prevents the Sun from collapsing due to <<inward>> gravitational forces ✓	*For MP1, outward/thermal/ radiation pressure must be linked to fusion reactions*	**2**
d	**iii**	Any mention of absorption or emission spectrum «of the Sun» ✓ Observed lines/wavelengths/frequencies match those of helium **OR** Helium lines/wavelengths/frequencies are present «in the spectrum» ✓	*Allow solar spectrum*	**2**
e	**i**	«red» supergiant ✓	*Do not allow 'red giant'.*	**1**

	e	ii	The Sun only fuses hydrogen <<to helium>> **OR** Antares allows heavier elements «than hydrogen» to be fused **OR** Antares has fusion up to iron ✓ Fusion in Antares occurs at a greater rate «because of greater mass/later evolutionary stage» **OR** Fusion in Antares requires a higher «core» temperature/density «because of greater mass/later evolutionary stage» ✓ Antares has regions/shells where different elements are fused «due to its late evolutionary stage» ✓	*MP1 is about what is fusing to what* *Do not allow ECF from white dwarf for MP1* *MP2 is about fusion rate/conditions for fusion* *MP3 is about where fusion occurs*	**3**

Question			Answers	Notes	Total
9	**a**		Evidence of equating weight and the spring force, e.g. $7.4x = 0.12 \times 9.8$ **or** $x = \dfrac{0.12 \times 9.8}{7.4}$ **OR** $x = 0.159...$ m ✓ $\dfrac{1}{2} \times 7.4 \times (0.159...)^2 = 9.3 \times 10^{-2}$ J ✓	*Ignore units, they are not required for the answer. They have been included for clarity.*	**2**
	b	**i**	Up/upwards ✓ Elastic PE decreases hence the extension of the spring decreases ✓	*Do not allow 'towards equilibrium position' alone.*	**2**
	b	**ii**	Kinetic energy AND elastic potential energy are converted✓ to gravitational potential energy ✓		**2**

continue…

Question 9 continued.

c	**i**	**ALTERNATIVE 1** Correct equation for the minimum **OR** the maximum extension of the spring, e.g. $\frac{1}{2} \times 7.4 \times x_{min}^2 = 1.0 \times 10^{-2}$, $\frac{1}{2} \times 7.4 \times x_{max}^2 = 26 \times 10^{-2}$ ✓ Correct calculation, e.g. $x_{min} = 0.052\,m$, $x_{max} = 0.265\,m$ ✓ Subtraction involving their answer in (a)(i), e.g. $x_o = 0.159 - 0.052 = 0.107\,m$ **OR** $x_o = 0.265 - 0.159 = 0.106\,m$ ✓ **ALTERNATIVE 2** Elastic PE difference between min and max $= 25 \times 10^{-2}$ J ✓ Equates the result to the gravitational PE difference, $0.12 \times 9.8 \times \Delta x = 25 \times 10^{-2}$ ✓ $x_o = \frac{\Delta x}{2} = 0.106\,m$ ✓	*Marks can only be awarded from one Alternative* *Ignore units, they are not required for the answer. They have been included for clarity.* *Allow working to the effect of* $\frac{1}{2}(x_{max} - x_{min})$ *for MP3 in ALT 1.* *Allow ± 1 x 10⁻² J* *Allow g = 9.8, 9.81, 10* *ECF can be awarded from incorrect energy in MP1.*	**3**

c	**ii**	***Alternative 1*** $$\omega = \frac{2\pi}{0.80} \ \textit{ or } \ \sqrt{\frac{7.4}{0.12}} \ \text{«} = 7.85 \text{ rad s}^{-1} \text{»} \ \checkmark$$ $$\text{«} v_{max} = \omega x_0 = \text{»} \ 0.83 \text{ m s}^{-1} \ \checkmark$$ ***Alternative 2*** $$\ll E_{K\,max} = E_{Total} - GPE - E_p \gg E_{K\,max} = 4.1 \times 10^{-2} J \checkmark$$ $$\ll v_{max} = \sqrt{\frac{2 \times 4.1 \times 10^{-2}}{0.12}} =\gg 0.83 \ ms^{-1} \checkmark$$	*Ignore units as they are not required for the answer.* *Allow rounding differences caused by rounding of g* *To allow ECF from incorrect max KE it must be clear that the candidate thinks they have the max KE. Eg. KE max = ...* *Just seeing an energy is insufficient and no ECF can be awarded.*	**2**

c	iii	ALTERNATIVE 1 $v = 0.83 \times \sin(7.85 \times 0.15) \ll= 0.767\ m\ s^{-1} \gg$ OR $v = 0.83 \times \cos\left(7.85 \times 0.15 \pm \frac{\pi}{2}\right) \ll= 0.767\ m\ s^{-1} \gg$ ✔ $\ll E_K = \frac{1}{2} \times 0.12 \times v^2 =\gg 3.5 \times 10^{-2} J$ ✔ ALTERNATIVE 2 $E_P = 14 \times 10^{-2} J \rightarrow x = 0.195\ m$ ✔ $\ll E_K = \frac{1}{2} \times 0.12 \times \left(\frac{2\pi}{0.8}\right)^2 (0.106^2 - (0.195 - 0.159)^2) =\gg 3.7 \times 10^{-2} J$ ✔ ALTERNATIVE 3 $E_P = 14 \times 10^{-2} J \rightarrow x = 0.195\ m$ ✔ $\ll 14 \times 10^{-2} + E_K + mgh = 26 \times 10^{-2},\ h = (0.159 + 0.106 - 0.195) \gg$ $\ll E_K =\gg 3.5 \times 10^{-2} J$ ✔	*Marks can only be awarded from one Alternative* *Ignore units as they are not required for the answer.* *Watch for ECF from cii)* *Accept answers in the range 3.4 - 3.8.*	**2**
2				

Question 9 continued.

d	**i**	Lists any **two** of the following: amplitude of oscillation, period/frequency of oscillation, magnetic field strength of the magnet, number of turns of the coil, area of the coil, average distance between the coil and the magnet ✓ States that the induced emf depends on the rate of change of flux linkage through the coil / quotes Faraday's law ✓ Correctly relates each of the factors listed for MP1 to the rate of change flux linkage. This must include how the change in flux is affected, how the time is changed or how the rate of change of flux linkage is changed (one ✓ for each factor) ✓✓ *E.g. increased amplitude leads to a greater change ΔΦ <<in the same time>>; reduced period means that the <<same>> change of flux occurs over a shorter time Δt, increasing the number of coils increases the rate of change of flux linkage <<so increasing the emf>>*	*Accept mass and spring constant as factors affecting period or frequency.* *Award [2 max] for answers that list and discuss one factor only.* *Do not award MP3 and 4 for answers which simply relate the factor to the emf. E.g. increasing the number of coils increases the emf.* *Allow 'rate of cutting flux' or 'cutting field lines' in MP3 and 4 but not in MP2.*	**4**
d	**ii**	A current is induced in the coil ✓ **ALTERNATIVE 1** This <<current>> gives rise to a magnetic field ✓ The field <<due to the induced current>> opposes the motion of the magnet / produces a resistive magnetic force on the magnet <<due to Lenz's Law>>✓ **ALTERNATIVE 2** This current leads to a dissipation of electrical energy as heat in the resistor ✓ The source of this energy is the mechanical energy of the magnet «which therefore decreases» ✓	*Allow the induced emf causes a current in the coil* *MP2 and 3 can only be awarded from one Alternative*	**3**