

# Markscheme

**May 2023**

**Physics**

**Higher level**

**Paper 2**

17 pages

© International Baccalaureate Organization 2023

All rights reserved. No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without the prior written permission from the IB. Additionally, the license tied with this product prohibits use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, whether fee-covered or not, is prohibited and is a criminal offense.

More information on how to request written permission in the form of a license can be obtained from <https://ibo.org/become-an-ib-school/ib-publishing/licensing/applying-for-a-license/>.

© Organisation du Baccalauréat International 2023

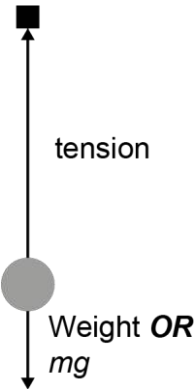
Tous droits réservés. Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite préalable de l'IB. De plus, la licence associée à ce produit interdit toute utilisation de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, moyennant paiement ou non, est interdite et constitue une infraction pénale.

Pour plus d'informations sur la procédure à suivre pour obtenir une autorisation écrite sous la forme d'une licence, rendez-vous à l'adresse <https://ibo.org/become-an-ib-school/ib-publishing/licensing/applying-for-a-license/>.

© Organización del Bachillerato Internacional, 2023

Todos los derechos reservados. No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin la previa autorización por escrito del IB. Además, la licencia vinculada a este producto prohíbe el uso de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales—, ya sea incluido en tasas o no, está prohibido y constituye un delito.

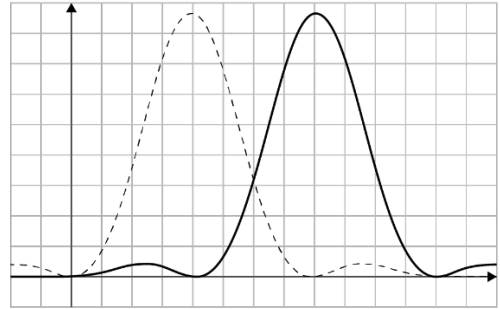
En este enlace encontrará más información sobre cómo solicitar una autorización por escrito en forma de licencia: <https://ibo.org/become-an-ib-school/ib-publishing/licensing/applying-for-a-license/>.

Question			Answers	Notes	Total
1.	a	i	Tension upwards, weight downwards ✓ Tension is clearly longer than weight ✓	Look for: 	2
1	a	ii	$v = \sqrt{2 \times 9.81 \times 0.95}$ OR $= 4.32 \text{ «ms}^{-1}\text{»}$ ✓	Must see either full substitution or answer to at least 3 s.f.	1
1	a	iii	$T - mg = F_{\text{net}}$ OR $T - mg = \frac{mv^2}{r}$ ✓ $T \llcorner = 0.800 \times 9.81 + \frac{0.800 \times 4.317^2}{0.95} \llcorner = 23.5 \text{ «N»}$ ✓		2
1	b	i	Use of conservation of momentum. ✓ Rebound speed = $2.16 \text{ « m s}^{-1}\text{»}$ ✓ Calculation of initial KE = $\llcorner \frac{1}{2} \times 0.800 \times 4.317^2 \llcorner = 7.46 \text{ « J »}$ ✓ Calculation of final KE = $\llcorner \frac{1}{2} \times 0.800 \times 2.16^2 + \frac{1}{2} \times 2.40 \times 2.16^2 \llcorner = 7.46 \text{ «J»}$ ✓ «hence elastic»		4

Question			Answers	Notes	Total
1	b	ii	<p><b>ALTERNATIVE 1</b> Rebound speed is halved so energy less by a factor of 4 ✓ Hence height is <math>\frac{95}{4} = 23.8</math> «cm» ✓</p> <p><b>ALTERNATIVE 2</b> Use of conservation of energy / <math>\frac{1}{2} \times 0.800 \times 2.16^2 = 0.800 \times 9.8 \times h</math></p> <p><b>OR</b> Use of proper kinematics equation (e.g. <math>0 = 2.16^2 - 2 \times 9.8 \times h</math>) ✓ <math>h = 23.8</math> «cm» ✓</p>	Allow <b>ECF</b> from <b>b(i)</b>	2
1	c		<p><b>ALTERNATIVE 1</b> Frictional force is <math>f = 0.400 \times 2.40 \times 9.81 = 9.42</math> «N» ✓ <math>9.42 \times d = \frac{1}{2} \times 2.40 \times 2.16^2</math> <b>OR</b> <math>d = \frac{5.5987}{9.42}</math> ✓ <math>d = 0.594</math> «m» ✓</p> <p><b>ALTERNATIVE 2</b> <math>a = \frac{f}{m} = \mu g = 0.4 \times 9.81 = 3.924</math> «m s<sup>-2</sup>» ✓ Proper use of kinematics equation(s) to determine ✓ <math>d = 0.594</math> «m» ✓</p>		3

Question		Answers	Notes	Total
2.	a	<p>Reads change in temperature to be 45 – 31 <b>OR</b> 14 °C ✓</p> $Q = 0.082 \times 1.6 \times 10^3 \times 14 = 1.84 \times 10^3 \text{ «J» } \checkmark$ $P = \frac{1.84 \times 10^3}{2.0 \times 60} = 15.3 \approx 15 \text{ «W» } \checkmark$	<p><i>Must see either full substitution <b>OR</b> answer to at least 3 s.f. in <b>MP3</b></i></p>	3
2	b	$Q = 15.3 \times 4.0 \times 60 = 3.67 \times 10^3 \text{ «J» } \checkmark$ $L = \frac{3.67 \times 10^3}{0.082} = 4.5 \times 10^4 \text{ «J kg}^{-1}\text{» } \checkmark$		2
2	c	<p>Internal energy is greater at <math>t = 6</math> min <b>OR</b> internal energy is lower at <math>t = 2</math> min <b>OR</b> internal energy increases «as energy is added to the system» ✓</p> <p>Because kinetic energy «of the molecules» is the same <b>AND</b> potential energy «of the molecules» has increased / <b>OWTTE</b> ✓</p>		2

Question			Answers	Notes	Total
3.	a	i	«A wave where the» displacement of particles/oscillations of particles/movement of particles/vibrations of particles is perpendicular/normal to the direction of energy transfer/wave travel/wave velocity/wave movement/wave propagation ✓	<i>Allow medium, material, water, molecules, or atoms for particles.</i>	1
3	a	ii	$v = \ll 0.50 \times 16 \Rightarrow 8.0 \ll \text{ms}^{-1} \gg$ ✓		1
3	a	iii	P at (8,1.2) ✓		1
3	a	iv	<p><b>ALTERNATIVE 1</b></p> <p>Phase difference is <math>\frac{2\pi}{\lambda} \times \frac{\lambda}{2}</math> ✓</p> <p>«= <math>\pi</math> »</p> <p><b>ALTERNATIVE 2</b></p> <p>One wavelength/period represents «phase difference» of <math>2\pi</math> and «corks» are <math>\frac{1}{2}</math> wavelength/period apart so phase difference is <math>\pi</math>/<b>OWTTE</b> ✓</p>		1
3	b		<p>light acts as a wave «and not a particle in this situation» ✓</p> <p>light at slits will diffract / create a diffraction pattern ✓</p> <p>light passing through slits will interfere / create an interference pattern «creating bright and dark spots» ✓</p>		2 max

Question			Answers	Notes	Total
3	c	i	The amplitude «at $x = 0$ » will be doubled ✓ intensity is proportional to amplitude squared / $I \propto A^2$ ✓		2
3	c	ii	Use of $s = \frac{\lambda D}{d} \Rightarrow \lambda = \frac{sd}{D}$ <b>OR</b> $s = \frac{n\lambda D}{d} \Rightarrow \lambda = \frac{sd}{nD}$ ✓ $\lambda = \left\langle \frac{0.567 \times 10^{-2} \times 0.18 \times 10^{-3}}{2.2} \right\rangle \Rightarrow 4.6 \times 10^{-7}$ «m» ✓		2
3	c	iii	Stays the same: Position/location of maxima/distance/separation between maxima «will be the same» / <b>OWTTE</b> ✓ Changes: Intensity/brightness/width/sharpness «of maxima will change»/ <b>OWTTE</b> ✓	Allow other phrasing for maxima (fringes, spots, etc).	2
3	d	i	Maximum coinciding with first minimum <b>AND</b> minimum coinciding with maximum ✓	<p>intensity</p>  <p>Allow a graph drawn to the left of the original graph with these same characteristics.</p>	1

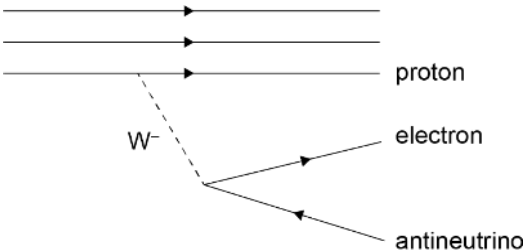
Question			Answers	Notes	Total
3	d	ii	<p><b>ALTERNATIVE 1</b></p> $\frac{d}{D} = 1.22 \times \frac{\lambda}{b} \text{ therefore } d = \frac{1.22 \times \lambda \times D}{b} \checkmark$ $\llcorner d \approx 1.22 \times \frac{3.2 \times 10^{-2} \times 1.1 \times 10^{23}}{300} \llcorner = 1.4 \times 10^{19} \llcorner \text{«m»} \checkmark$ <p><b>ALTERNATIVE 2</b></p> $\theta = \llcorner 1.22 \frac{\lambda}{b} = 1.22 \times \frac{3.2 \times 10^{-2}}{300} \llcorner \Rightarrow 1.3 \times 10^{-4} \llcorner \text{«radians»} \checkmark$ $d = \llcorner (1.1 \times 10^{23})(1.3 \times 10^{-4}) \llcorner \Rightarrow 1.4 \times 10^{19} \llcorner \text{«m»} \checkmark$		2

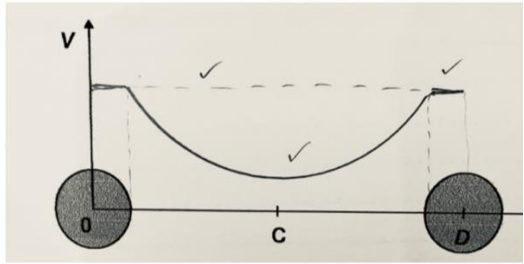


Question			Answers	Notes	Total
4.	a	i	Voltage across P is 1.4 «V» ✓ Voltage across Q is 4.6 «V» ✓ And $6 - 1.4 = 4.6$ «V» ✓	Need to see a calculation involving the two voltages and the total voltage in the circuit for <b>MP3</b> (e.g. $1.4 + 4.6 = 6$ ).	3
4	a	ii	Current in R is « $(0.45 - 0.4) =$ » 0.05 A ✓ So resistance is « $\frac{1.4}{0.05}$ » = 28 «Ω» ✓	Allow <b>ECF</b> from a(i) Allow <b>ECF</b> from <b>MP1</b>	2
4	a	iii	« $0.45 \times 6.0$ » = 2.7 «W» ✓		1
4	b		Q will have a smaller resistance ✓ «Because total resistance in the circuit is now larger so» the current «through the circuit/Q» is smaller / <b>OWTTE</b> ✓	Allow similar argument for <b>MP2</b> based on voltage across Q becoming smaller.	2

Question			Answers	Notes	Total
5.	a		Weak nuclear: 2 ticks ✓ Strong nuclear: quarks only ✓		2
5	b	i	$\llcorner\mu\llcorner = 2.0141 + 3.0160 - (4.0026 + 1.008665) \llcorner = 0.0188 \text{ u}\llcorner$ <b>OR</b> <i>In MeV:</i> $1876.13415 + 2809.404 - (3728.4219 + 939.5714475) \llcorner$ $= 0.0188 \times 931.5 \text{ OR } = 17.512 \llcorner \text{MeV}\llcorner \llcorner$	<i>Must see either clear substitutions or answer to at least 3 s.f. for MP2.</i>	2

Question			Answers	Notes	Total
5	b	ii	<p><b>ALTERNATIVE 1</b></p> <p>0.40 kg of deuterium is <math>\llcorner \frac{400}{2} \times 6.02 \times 10^{23} \gg = 1.2 \times 10^{26}</math> nuclei                      «0.60 kg of tritium is the same number» ✓</p> <p>So specific energy <math>\llcorner \frac{1.2 \times 10^{26} \times 17.51 \times 10^6 \times 1.6 \times 10^{-19}}{0.4 + 0.6} \gg = 3.4 \times 10^{14}</math> «J kg<sup>-1</sup>» ✓</p> <p><b>ALTERNATIVE 2</b></p> <p>«<math>17.51 \times 10^6 \times 1.6 \times 10^{-19} \Rightarrow 2.8 \times 10^{-12}</math> «J»</p> <p><b>AND</b></p> <p>«<math>(2.0141 + 3.0160) \times 1.66 \times 10^{-27} \Rightarrow 8.35 \times 10^{-27}</math> ✓</p> <p>«<math>\frac{2.8 \times 10^{-12}}{8.35 \times 10^{-37}} = 3.4 \times 10^{14}</math> «Jkg<sup>-1</sup>» ✓</p>	<p>Allow <math>\sim 2.1 \times 10^{27}</math> MeV kg<sup>-1</sup> for <b>MP2</b>.</p> <p>Allow <b>ECF</b> from <b>MP1</b> for both <b>ALTs</b>.</p>	2
5	c	i	<p>Requires high temp/pressure ✓</p> <p>Must overcome Coulomb/intermolecular repulsion ✓</p> <p>Difficult to contain / control «at high temp/pressure» ✓</p> <p>Difficult to produce excess energy/often energy input greater than output / <b>OWTTE</b> ✓</p> <p>Difficult to capture energy from fusion reactions ✓</p> <p>Difficult to maintain/sustain a constant reaction rate ✓</p>		2 max
5	c	ii	<p>Plentiful fuel supplies <b>OR</b> larger specific energy <b>OR</b> larger energy density <b>OR</b> little or no «major radioactive» waste products ✓</p>	<p>Allow descriptions such as “more energy per unit mass” or “more energy per unit volume”</p>	1

5	d	i	3 ✓	<i>Do not accept <math>{}^3_2\text{He}</math> by itself.</i>	1
5	d	ii	Proton shown ✓ W- shown ✓ Produces electron/e <sup>-</sup> / β <sup>-</sup> and antineutrino / $\bar{\nu}$ with proper arrow directions. ✓	 <p><i>Allow solid, dashed, or wavy line for W-particle.</i>  <i>Must see bar on antineutrino if symbol used.</i></p>	3
5	d	iii	$\lambda = \left\langle \frac{\ln 2}{12.3} \right\rangle 0.056 \langle y^{-1} \rangle$ <b>OR</b> $0.5^{\frac{1}{12.3}}$ <b>OR</b> $e^{-1 \times \frac{\ln 2}{12.3}}$ ✓ 0.945 <b>OR</b> 94.5% ✓	<i>Allow ECF from MP1</i>	2

Question			Answers	Notes	Total
6.	a	i	Constant, non-zero within spheres ✓ A clear, non-zero positive minimum at C ✓ Symmetric bowl shaped up curved shape in between ✓	 <p>Do <b>not</b> allow a bowl shaped down curve for <b>MP3</b>.</p>	3
6	a	ii	$V_{\ll} = 2 \times \frac{8.99 \times 10^9 \times 2.0 \times 10^{-3}}{0.60} \gg = 6.0 \times 10^7 \ll V \gg \checkmark$ $W = \ll qV = 6.0 \times 10^7 \times 4.0 \times 10^{-9} \gg = 0.24 \ll J \gg \checkmark$	Allow <b>ECF</b> from <b>MP1</b>	2
6	b	i	The restoring force/acceleration is opposite to the displacement/towards equilibrium / <b>OWTTE</b> ✓ and proportional to displacement from equilibrium / <b>OWTTE</b> ✓	Allow discussions based on the diagram (such as towards C for towards equilibrium). Accept $F \propto x$ <b>OR</b> $a \propto x$ for <b>MP2</b>	2
6	b	ii	$\omega = \sqrt{\frac{32kQq}{mD^3}} \quad \text{OR use of } F = m\omega^2 r \quad \text{OR } F = 1.33x \quad \text{OR } a = 53.3x \checkmark$ $\ll = \sqrt{\frac{32 \times 8.99 \times 10^9 \times 2.0 \times 10^{-3} \times 4.0 \times 10^{-9}}{0.025 \times 1.2^3}} \gg = 7.299 \ll s^{-1} \gg \checkmark$		2

Question		Answers	Notes	Total
6	c	the net force will no longer be a restoring force/directed towards equilibrium  <i>OR</i>  the gravitational force is attractive/neutral mass would be pulled towards larger masses/ <i>OWTTE</i> ✓  «and so» no, motion will not be the same/no longer be SHM / <i>OWTTE</i> ✓		2

Question			Answers	Notes	Total
7.	a		<p>The induced emf is equal/proportional/related to the «rate of» change of «magnetic» flux/flux linkage ✓</p> <p>Flux is changing because the area pierced/enclosed by magnetic field lines changes «decreases»</p> <p><b>OR</b></p> <p>Flux is changing because the loop is leaving/moving out of the «magnetic» field. ✓</p>	<p>Need to see a connection between the EMF and change in flux for <b>MP1</b>.</p> <p>Need to see a connection between the area changing or leaving the field and the change in flux for <b>MP2</b></p>	2
7	b		<p><math>mg = BIL</math> <b>OR</b> <math>I = 0.33</math> «A» ✓</p> <p><math>BvL = IR</math> <b>OR</b> <math>\mathcal{E} = 8.25 \times 10^{-3}</math> «V» <b>OR</b> <math>\mathcal{E} = 0.12v</math> ✓</p> <p>Combining results to get <math>v = \frac{mgR}{B^2L^2}</math> ✓</p> <p><math>v = \frac{0.0040 \times 9.81 \times 0.025}{0.80^2 \times 0.15^2} \Rightarrow 0.068</math> «ms<sup>-1</sup>» ✓</p>	<p>Allow <b>ECF</b> between steps if clear work is shown.</p>	4
7	c	i	<p>The 2 in parallel give a total of 6.0 «μF» ✓</p> <p>The total is <math>\left(\frac{1}{3} + \frac{1}{6}\right)^{-1} = 2.0</math> «μF» ✓</p>	<p>Allow <b>ECF</b> from <b>MP1</b></p> <p>Accept other powers of 10 for capacitances with proper unit included.</p>	2
7	c	ii	<p><math>E = \frac{1}{2} CV^2 = \frac{1}{2} \times 2.0 \times 10^{-6} \times 12^2 = 1.44 \times 10^{-4}</math> «J» ✓</p>	<p>Allow <b>ECF</b> from <b>c(i)</b> (=72 x <b>c(i)</b>)</p>	1

7	c	iii	<p><b>ALTERNATE 1</b></p> <p>Voltage across <math>C_2</math> is half that across <math>C_1</math> ✓</p> <p>So voltage across <math>C_2</math> is 4.0 V ✓</p> <p>Charge is «<math>C_2 V_2 = 2.0 \times 10^{-6} \times 4.0</math>» <math>8.0 \times 10^{-6}</math> «C» ✓</p> <p><b>ALTERNATE 2</b></p> <p>Charge on <math>C_1</math> is «<math>C_1 V_1 = 2.0 \times 10^{-6} \times 12</math>» <math>24</math> «<math>\mu\text{C}</math>» ✓</p> <p>So voltage across <math>C_1</math> is «<math>\frac{24}{3.0}</math>» <math>8.0</math> «V» ✓</p> <p>Charge on <math>C_2</math> is «<math>C_2 V_2 = 2.0 \times 10^{-6} \times 4.0</math>» <math>8.0 \times 10^{-6}</math> «C» ✓</p> <p><b>ALTERNATE 3</b></p> <p>«<math>C_3 = 2C_2</math> leading to » <math>q_3 = 2q_2</math> ✓</p> <p>Total charge in parallel = «<math>q_2 + q_3 = q_2 + 2q_2 =</math>» <math>3q_2</math> ✓</p> <p><math>3q_2 = 24</math> leading to <math>q_2 = 8 \times 10^{-6}</math> «C» ✓</p>	<p><i>ECF for MP3 allowed in ALT 1 and ALT 2</i></p>	3
---	---	-----	--	--	---



Question			Answers	Notes	Total
8.	a	i	Use of $E_{\max} = \frac{hc}{\lambda} - \phi \Rightarrow \phi = \frac{hc}{\lambda} - E_{\max} \checkmark$ $\phi = \left\langle \frac{hc}{\lambda} - E_{\max} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(468 \times 10^{-9})(1.6 \times 10^{-19})} - 1.8 \right\rangle = 0.85625 \approx 0.86 \text{ «eV»} \checkmark$		2
8	a	ii	Use of $\frac{hc}{\lambda} = \phi \Rightarrow \lambda = \frac{hc}{\phi} \checkmark$ $\lambda = \left\langle \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{(468 \times 10^{-9})(1.6 \times 10^{-19})} \right\rangle = 1.45 \times 10^{-6} \text{ «m»} \checkmark$	Allow <b>ECF</b> from a(i)	2
8	b	i	2e <b>AND</b> 82e seen <b>OR</b> 3.2x10 <sup>-19</sup> «C» <b>AND</b> 1.312x10 <sup>-17</sup> «C» seen $\checkmark$ $d = \frac{8.99 \times 10^9 \times (2e)(82e)}{5.9 \times 10^6 \times e} = 3.998 \times 10^{-14} \approx 4 \times 10^{-14} \text{ «m»} \checkmark$	Must see either clear substitutions or answer to at least 4 s.f. for <b>MP2</b> .	2
8	b	ii	The closest approach is «significantly» larger than the radius of the nucleus / far away from the nucleus/ <b>OWTTE</b> . $\checkmark$ «Therefore» the strong nuclear force will not act on the alpha particle. $\checkmark$		2