

MOMENTUM

IB Physics HL

Relativity - Set 1 - Markscheme

A.5 | First assessment 2025 | Higher Level

Independent examination-style practice material

10 original problems

Task 01 - Light emitted inside a moving train

Paper 2 style | IB code A.5 | Total [7]

Part	Marking guidance	Marks
(a)	Both observers measure c .	2
(b)	$\gamma = 1.25$, so $L = L_0/\gamma = 240$ m.	2
(c)	Initial distance is 120 m and closing speed is $c-0.600c$; $t = 1.00$ microsecond.	3

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Task 02 - Lightning strikes a moving train

Paper 2 style | IB code A.5 | Total [6]

Part	Marking guidance	Marks
(a)	Length contraction gives $\Delta x = 480 \text{ m}$.	2
(b)	$\Delta t' = \gamma(\Delta t - v \Delta x/c^2) = -1.20 \text{ microseconds}$.	3
(c)	The strike at the front occurs first in the train frame.	1

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Task 03 - A moving light clock

Paper 2 style | IB code A.5 | Total [6]

Part	Marking guidance	Marks
(a)	$T_0 = 2L/c = 8.00 \text{ ns}$.	2
(b)	$\gamma = 5/3$, so $T = 13.3 \text{ ns}$.	2
(c)	One leg has duration $T/2$, so distance $cT/2 = 2.00 \text{ m}$.	2

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Task 04 - Cosmic-ray muons

Paper 2 style | IB code A.5 | Total [8]

Part	Marking guidance	Marks
(a)	$\gamma = 5.025$; mean distance $v \gamma \tau_0 = 3.25$ km.	3
(b)	Surviving fraction = $\exp(-10.0/3.25) = 0.0461$.	3
(c)	The atmosphere is length-contracted, so the ground is closer in the muon frame.	2

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Task 05 - A spacecraft and a tunnel

Paper 2 style | IB code A.5 | Total [6]

Part	Marking guidance	Marks
(a)	$\gamma = 5/3$; contracted length is 72.0 m.	2
(b)	Yes, it fits within the 100 m tunnel at one tunnel-frame instant.	1
(c)	Door closures simultaneous in the tunnel frame are not simultaneous in the spacecraft frame; the tunnel is also length-contracted there.	3

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Task 06 - A relativistic journey to a star

Paper 2 style | IB code A.5 | Total [5]

Part	Marking guidance	Marks
(a)	$t = 8.00/0.800 = 10.0$ years.	1
(b)	$\Delta\tau = t/\gamma = 6.00$ years.	2
(c)	$L = L_0/\gamma = 4.80$ light-years.	2

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Task 07 - Energy and momentum of a proton

Paper 2 style | IB code A.5 | Total [6]

Part	Marking guidance	Marks
(a)	$\gamma = E/(mc^2) = 2.132$ and $\beta = \sqrt{1-1/\gamma^2} = 0.883$.	3
(b)	Uses $E^2 = (pc)^2 + (mc^2)^2$ to obtain $p = 1.77 \text{ GeV}/c$.	2
(c)	$K = E - mc^2 = 1.06 \text{ GeV}$.	1

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Task 08 - Electron-positron annihilation

Paper 2 style | IB code A.5 | Total [5]

Part	Marking guidance	Marks
(a)	Initial momentum is zero; two photons moving in opposite directions can have zero resultant momentum, whereas one photon cannot.	2
(b)	Each photon has 0.511 MeV; $\lambda = hc/E = 2.43 \text{ pm}$.	3

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Task 09 - Threshold for pair production

Paper 2 style | IB code A.5 | Total [4]

Part	Marking guidance	Marks
(a)	Minimum energy is $2m_e c^2 = 1.022 \text{ MeV}$.	1
(b)	Energy and momentum cannot both be conserved for a single photon producing only the pair in vacuum.	2
(c)	The nucleus takes recoil momentum.	1

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Task 10 - Events on a spacetime diagram

Paper 2 style | IB code A.5 | Total [6]

Part	Marking guidance	Marks
(a)	$c \Delta t = 600 \text{ m} < \Delta x$, so the interval is spacelike.	2
(b)	No signal at or below c can connect them.	1
(c)	Set $\Delta t' = \gamma(\Delta t - v \Delta x/c^2) = 0$, giving $v = c^2 \Delta t / \Delta x = 0.667c$.	3

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