A-Level Physics

Length Contraction

Mark Scheme

Time available: 45 minutes
Marks available: 26 marks

1. (a) (i) speed of light (in free space) independent of motion of source **(1)**
and of motion of observer **(1)**
[*alternative (i)*
speed of light is same in all frames of reference **(1)**]

(ii) laws of physics have same form in all inertial frames **(1)**
inertial frame is one in which Newton's 1 st law of motion obeyed **(1)**
laws of physics unchanged in coordinate transformation
from one inertial frame of reference to any other inertial frame **(1)**

(max 4)

(b) (i) $m\left(= m_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}\right) = 1.88 \times 10^{-28}\,(1-(0.996)^2)^{-\frac{1}{2}}$ **(1)**

$= 2.10 \times 10^{-27}$ kg **(1)**

(ii) $t_0 = 2.2 \times 10^{-6}$ s **(1)**

$t\left(= t_0\left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}}\right) = 2.2 \times 10^{-6}\,(1-(0.996)^2)^{-\frac{1}{2}}$ (s) **(1)**

$= 2.46 \times 10^{-5}$ (s) **(1)**

$s(= vt = 3.00 \times 10^8 \times 0.996 \times 2.46 \times 10^{-5}) = 7360$ m **(1)**

[*alternative (ii)*
$l\,(= vt = 0.996 \times 3.0 \times 10^8 \times 2.2 \times 10^6) = 657$ (m) **(1)**

correct substitution of l in $l = l_0\sqrt{1-\frac{v^2}{c^2}}$ **(1)**

$l_0\left(= \frac{l}{\sqrt{1-\frac{v^2}{c^2}}}\right) = \frac{657}{\sqrt{1-0.996^2}}$ **(1)**

$l_0 = 7360$ m **(1)**

(6)

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2. (a) (i) $l = (vt = 1.00 \times 10^8 \times 15 \times 10^{-9}) = 1.50\text{m}$ **(1)**

(ii) $\left(l = l_0 \sqrt{1 - \frac{v^2}{c^2}} \right)$

$1.50 = l_0 \sqrt{1 - \frac{(1.00 \times 10^8)^2}{(3.00 \times 10^8)^2}}$ **(1)**

$l_0 \left(= \frac{1.50}{0.943} \right) = 1.59\text{ m}$ **(1)**

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(b) (i) $m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$ **(1)** $\left[\text{or } \frac{m_0}{\sqrt{1 - \frac{(1.00 \times 10^8)^2}{(3.00 \times 10^8)^2}}} \right]$

$m \left(\text{or } \frac{m_0}{\sqrt{1 - \frac{(1.00 \times 10^8)^2}{(3.00 \times 10^8)^2}}} \right) = 1.06 m_0$

[or = $1.06 \times 1.67 \times 10^{-27}$ or 1.77×10^{-27} kg] **(1)**

kinetic energy = $(m - m_0)c^2$ **(1)**

[or = $0.06 m_0 c^2$ or $0.06 \times 1.67 \times 10^{-27} \times (3 \times 10^8)^2$]

= 9.1×10^{-12} (J) **(1)**

(ii) total k.e. = $(10^7 \times 9.1 \times 10^{-12}) = 9.1 \times 10^{-5}$ (J) **(1)**

k.e. per second $\left(= \frac{9.1 \times 10^{-5}}{1.5 \times 10^{-9}} \right) = 6080\text{W}$

max 5

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3. (a) (i) (use of $v = \frac{d}{t}$ gives) $v = \frac{240}{0.84 \times 10^{-6}}$ = 2.8(6) × 10^8 m s^{-1} **(1)**

(ii) actual length = 240 m **(1)**

(use of $l = l_0\left(1 - \frac{v^2}{c^2}\right)^{1/2}$ gives)

length in particle frame, $l = 240\left(1 - \frac{2.86^2}{3^2}\right)^{1/2}$ **(1)**

(allow C.E. for value of v)

l = (240 × 0.30) = 72(.5) m **(1)**

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(b) time between two events depends on speed of observer

[or $t = t_0\left(1 - \frac{v^2}{c^2}\right)^{1/2}$ or rocket time depends on speed of traveller] **(1)**

traveller's journey time is the proper time between start and stop

[or t_0 is the proper time or t is the time on Earth] **(1)**

journey time measured on Earth > journey time measured by traveller

[or $t > t_0$ or rocket time slower / less than Earth time] **(1)**

traveller younger than twin on return to Earth **(1)**

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