Access Tuition

A-Level Physics

Einstein's Theory of Special Relativity

Mark Scheme

Time available: 30 minutes
Marks available: 24 marks

Mark schemes

1. (a) One which moves at constant velocity

Allow: a reference frame in which Newton's laws / Newton's first law holds.

1

(b) In frame of particle beam

Distance between detectors = $45\sqrt{1 - \frac{(0.97c)^2}{c^2}}$ = 10.9 m ✓

Time = 10.9 / 0.97c = 3.8×10^{-8} s ✓

Half-life = time/3 ✓ = 1.3×10^{-8} s ✓

MP1 is for determination of distance between detectors in ref frame of particles

MP2 is for determining the time between detectors in the ref frame of particles

MP3 is for use of reduction to 12.5% is equivalent to 3 half-lives

MP4 is for correct final answer

Allow alternative route from ref frame of detectors

4

(c) The time taken for particle beam to travel between detectors 'measured' in the reference frame of particle beam✓

Accept: shortest observable time for a particle passing between detectors.

Accept 3.8×10^{-8} s

1

[6]

2. (a) c is the same, regardless of the speed of the light source or the observer **(1)**

1

(b) distance between detectors in rest frame of particles
$(= 25 \times (1 - 0.98^2)^{1/2}) = 5.0$ m **(1)**

time taken in rest frame of particles $\left(= \frac{distance}{speed} = \frac{5.0}{0.98c}\right) = 1.7 \times 10^{-8}$ s **(1)**

time taken to decrease by ¼ = 2 half lives **(1)**

half life $(= 1.7 \times 10^{-8}/2) = 8.5 \times 10^{-9}$ s **(1)**

[**alternatively**

time taken in rest frame of detectors $\left(= \frac{distance}{speed} = \frac{25.0}{0.98c}\right) = 8.5 \times 10^{-8}$ s

time taken in rest frame of particles
$(= 8.5 \times 10^{-8} \times (1 - 0.98^2)^{1/2}) = 1.7 \times 10^{-8}$ s)]

4

[5]

3. (a) $10m_0 = m_0\left(1 - \frac{v_2}{c^2}\right)^{-\frac{1}{2}}$ **(1)**

gives $\frac{v^2}{c^2} = 1 - 0.01 = 0.99$ **(1)**

v $(= 0.995c) = 2.98(5) \times 10^8$ m s^{-1} **(1)**

3

(b) $m = m_0\left(1 - \frac{v_2}{c^2}\right)^{-\frac{1}{2}}$ **(1)**

$m \rightarrow$ infinity as $v \rightarrow c$ **(1)**

[or m increases as v increases]

$E_k (= mc^2 - m_0c^2) \rightarrow$ infinity as $v \rightarrow c$ **(1)**

$v = c$ would require infinite E_k (or mass) which is (physically)

impossible **(1)**

Max 3

[6]

4. (a) Lo = 2500 m

Length = 2500 x (1 -0.95^2)^{½} ✓

length = 781 (780) m ✓

2

(b) Number of muons passing through detector per second measured at top of mountain/in upper atmosphere AND

Allow "intensity of muons"

Number of muons passing through detector per second measured on ground. ✓

Allow number decayed/difference in numbers at upper atmosphere and ground

Measurements show far fewer muons decay than expected in time taken (in observer's frame of reference) for muons to travel from upper atmosphere to ground (as the clock in muons frame of ref runs slower than observer so half-life appears longer). ✓

Allow more muons reach the ground than expected

2

(c) Lower velocity means

Take longer to travel to ground (in either frame of reference) ✓

And time dilation effect less (in Earth frame of reference)/length contraction effect less (in muon frame of reference) (as not so close to c) ✓

More muons decay before reaching ground so rate of detection reduced ✓

If there is no reference to frame of reference or relativistic effects award Max 1.

Answer needs to be consistent with the implicit frame of reference being discussed

3

[7]