Mark schemes

1. **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2-mark (L1), 3 or 4-mark (L2) and 5 or 6-mark (L3) answer.**

Mark	Criteria
6	6 All three areas covered with at least two aspects covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all three areas. If there are several errors or missing parts then 5 marks should be awarded.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	None of the three areas covered without significant error.
0	No relevant analysis.

The following statements are likely to be present.

A – outline of experimental procedure

Semi-silvered glass block splits the beam of monochromatic light into two beams

(The plane block ensures that both beams pass through the same thickness of glass and air)

(Beams travel at right angles, to M1 and M2 , and return to) combine at telescope with a path difference

Observer sees interference pattern from two beams

Apparatus rotated 90 degrees and pattern observed

B – expected result

Pattern would shift

As path length/speed of light different depending on (orientation relative to) motion of apparatus

So ether exists/absolute motion of Earth detected

C – actual result and significance

No shift in pattern

No evidence of ether

Speed of light is invariant/all motion is relative/no absolute motion

[6]

2. Conversion of 3.7×10^9 eV to 5.9×10^{-10} J ✓

Accept substitution of $3.7 \times 10^9 \times 1.6 \times 10^{-19}$

Correct use of

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \dfrac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

including correct substitution ✓

0.97(c) ✓

[3]

3. (a) Lo = 2500 m

Length = 2500 x (1 -0.95²)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

(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]

4. (a)   (for Proper time, t_0 = 31,536,000 s / 365 days)
Dilated time, t = 31,561,259 s ✓

Time dilation is 25,259 s / 421 minutes / 7.0 hours / 0.29 days ✓

The recorded time will be longer (as predicted) ✓
The recorded time will be less than several days longer (as predicted) ✓

> *Accept answers in other units (e.g. 365.3 days)*
>
> *Accept an answer of 31582876 seconds / 365.5 days where a proper time of 365.25 days has been used.*

4

(b)   Theory of Special Relativity requires no acceleration ✓

(The spacecraft/frame of reference is) accelerating ✓

Alternative answer:

Theory of Special Relativity requires inertial reference frame ✓

(The spacecraft/frame of reference is) not an inertial reference frame ✓

> *Accept change in direction / speed / velocity as alternatives for accelerating.*

2

[6]

5. (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]

6. (a) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer.**

Level	Criteria	QoWC
6 marks	<u>A thorough and well communicated</u> discussion using most of the statements in bullets 1 2 and 3	The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.
5 marks	<u>A explanation that includes</u> discussion using most of the statements in bullets 1 , 2 and 3 but may contain minor errors or omissions	
4	<u>The response includes</u> a well presented discussion of two from bullets 1 and two from bullet 3 and one from bullet 2	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.
3	<u>The response includes</u> a discussion of one comment from each bullet	
2	<u>The response</u> makes comments about two bullet points (This is likely to be from bullets 2 and 3)	The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.
1	Makes relevant comment from the list	
0	No relevant coverage of the likely statements.	The student's presentation, SP&G seriously obstruct understanding.

The following statements are likely to be present:

Bullet point 1 in question

(Explanation of how shift expected)

1. PM_2 lies in the direction of the Earth's velocity

2. Speed of light different in the two directions

3. The time taken for light to travel from P to M_2 and back to P would be greater than the time taken from P to M_1 and back to P

4. If the speed of light depends on the Earth's velocity through the ether

5. Rotating the apparatus through 90° would cause the time difference to reverse/change

6. When rotated there would be a change in the phase difference between the waves (at each point in the fringe pattern)

Bullet point 2 in the question

(Results compared with prediction)

7. The apparatus was capable of detecting shifts of 0.05 fringe

8. No shift was detected then or in later experiments when apparatus rotated

Bullet point 3 in the question (Conclusions)

9. The experiment showed that there is no absolute motion

10. Ether did not exist so light travels without the need for a material medium

11. The Earth was dragging the ether with it

Many responses fail to demonstrate an understanding that the shift pattern is there in the first place and the shift occurs due to rotation of the apparatus

They often imply that the shift is due to differences in the distance travelled

6

(b)   Correct postulate

Invariance of the speed of light <u>in free space/vacuum</u>

Speed of light the same in free space

1

(c)   Laws of physics have the same form in all inertial frames

Laws of physics unchanged from one inertial frame to another

> *The <u>same</u> laws of physics are obeyed/apply/hold in (all) inertial frames of reference/non accelerating frames of reference/frames moving at a constant velocity*
>
> *Not Allowed*
>
> *All laws of physics*
>
> *Laws of physics are the same*
>
> *Laws of physics are constant...*
>
> *Mention of Newton's laws being obeyed*
>
> *Allow 1 here if both (b) and (c) are correct but reversed*

1

(d)   Time of flight is found to be 4.41×10^{-6} s ✓

$t_o = t\sqrt{1 - \frac{v^2}{c^2}}$ **OR** $t_0 = 4.41 \times 10^{-6}\sqrt{1 - 0.99^2}$ ✓

(Proper time t_0 is) 6.22×10^{-7} s ✓

Percentage remaining is (found from the graph) 82 +/– 1

OR

In muon reference frame

$L = 1310\sqrt{1 - 0.99^2}$ ✓

185 m✓

$t = \frac{185}{0.99 \times 3 \times 10^8} = 6.23 \times 10^{-7}$ s✓ allow ecf for incorrect length calculation

82 +/– 1%✓

> *May do*
>
> *Number of half lives = $6.22 \times 10^{-7}/2.2 \times 10^{-6}$*
>
> *fraction remaining = $0.5^{0.283} = 0.82$*
>
> *185 m seen scores 2*
>
> <u>*Must see this stage with speed = $0.99 \times 3 \times 10^8$*</u>
>
> *Final answer in range can be awarded even if 0.99 omitted in MP3*
>
> *Allow <u>minor</u> differences in time (3rd sf) due to rounding in processing*

4

[12]