



A-Level Physics
The Michelson-Morley
Experiment
Mark Scheme

Time available: 49 minutes
Marks available: 33 marks

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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.

(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

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(b) Correct postulate

Invariance of the speed of light in free space/vacuum

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 same 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 ✓

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

(Proper time t_0 is) 6.22×10^{-7} s ✓

Percentage remaining is (found from the graph) 82 ± 1

OR

In muon reference frame

$$L = 1310 \sqrt{1 - 0.99^2} \quad \checkmark$$

185 m ✓

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

$82 \pm 1\%$ ✓

May do

$$\text{Number of half lives} = 6.22 \times 10^{-7} / 2.2 \times 10^{-6}$$

$$\text{fraction remaining} = 0.5^{0.283} = 0.82$$

185 m seen scores 2

Must see this stage with speed = $0.99 \times 3 \times 10^8$

Final answer in range can be awarded even if 0.99 omitted in MP3

Allow minor differences in time (3rd sf) due to rounding in processing

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3.

- (a) They expected the time taken for the light to travel in one direction to be different from the other ✓

or

Expected light to travel at different speeds in the two directions

However expressed e.g. in terms of the different times taken parallel and at right angles to the Earth's motion (through the Aether)

There would be a phase shift / change in the phase relationship

Not

longer / different paths

or

path difference

2

- (b) (i) Speed through aether

$$= \frac{\text{circumference of Earth orbit around the Sun}}{\text{time for one orbit (1 year)}}$$

Need to be clear about the distance and time

or $v = (GM / r)^{1/2}$ with M and r defined

Watch out for confusion between Earth's orbit around the Sun and Earth's rotation on its axis

1

- (ii) 11 m

1

- (c) Experiment showed speed of light from moving object is same as that from stationary object or

Speed of light in direction of motion is same as in perpendicular direction or

Speed of light does not depend on speed of source or observer

Speed of light being invariant

or

Aether theory incorrect / no aether / no absolute motion

Allow is always $3 \times 10^8 \text{ m s}^{-1}$ in air or vacuum instead of invariant

It was a postulate / assumption of the theory of special relativity

Or this supports the theory ✓

Second mark is for explicitly linking the observation to Einstein's theory

2

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4.

- (a) no change in the fringe pattern on rotation (1)

the speed of light is the same in the two directions (1)

the speed of light from a light source on Earth is

unaffected by the motion of the Earth (1)

[or the speed of light is invariant

or independent of the motion of the source or observer] **(1)**

the laws of dynamics cannot be applied to light **(1)**

no ether **(1)**

(max 3)

(b) (i) $\text{time} \left(= \frac{\text{distance}}{\text{speed}} = \frac{16cT_{\text{one year}}}{0.8c} \right) = 20 \text{ yr} \text{ (1)}$

(ii) $L_0 = 16c$ [or 16 light years] **(1)**

$$L \left(= L_0 \left(1 - \frac{v^2}{c^2} \right)^{\frac{1}{2}} \right) = 16(1 - 0.8^2)^{\frac{1}{2}} (= 0.6 \times 16c) = 9.6c \text{ (1)}$$

(iii) $\Delta t = 20 \text{ years} \text{ (1)}$

$$\Delta t_0 = \Delta t \left(1 - \frac{v^2}{c^2} \right)^{\frac{1}{2}} = 20(1 - 0.8^2)^{\frac{1}{2}} \text{ (1)}$$

$$= 0.6 \times 20 = 12 \text{ yr} \therefore \text{age} = 21 + 12 = 33 \text{ yr} \text{ (1)}$$

(6)

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