InkPhysics

ANSWER BOOK

The Michelson–Morley experiment

Turning points · Year 13

AQA 3.12.3.1, 3.12.3.2

17 questions · 49 marks

NAVY EDITION

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SECTION A · Warm-up

A1 A half-silvered mirror splits one light beam along two equal arms at right angles to mirrors that return them (1); the recombined beams interfere, and the fringe pattern registers any difference in the two round-trip times (1). [2]

A2 One: physical laws have the same form in all inertial frames (1). Two: the speed of light in free space is invariant, the same for every inertial observer (1). [2]

A3 A frame of reference moving at constant velocity, without acceleration or rotation (1), in which Newton's first law holds: objects with no resultant force stay at rest or move uniformly (1). [2]

A4 Every known wave travelled through a medium: sound through air, ripples through water (1). Light, established as a wave, was therefore assumed to need a medium of its own filling all space, which was named the ether (1). [2]

A5 The Earth's absolute motion through the ether, appearing as an ether wind blowing across the apparatus (1). [1]

SECTION B · Standard

B1 Across: cross-stream speed $\sqrt{(4.0^2 - 2.4^2)} = 3.2$ m s^{-1} (1) [4]
$t = 96/3.2 = 30$ s (1)
Along: $48/1.6 + 48/6.4 = 37.5$ s (1)
A medium's motion separates the two round trips, which is exactly what the interferometer's two arms were built to detect for light in the ether (1)

B2 $v/c = 10^{-4}$, so $\Delta t \approx (11/(3.0 \times 10^8)) \times 10^{-8}$ (1) [3]
$\Delta t = 3.7 \times 10^{-16}$ s (1)
Path difference $c\Delta t = 1.1 \times 10^{-7}$ m, about a fifth of a wavelength of visible light, well within the instrument's sensitivity (1)

B3 Rotation swaps which arm lies along the supposed ether wind (1), reversing the predicted time difference between the arms (1). The fringes should therefore shift visibly as the apparatus turns, without needing the two arms to be perfectly equal in length (1). [3]

B4 Six months apart, the Earth moves in opposite directions around the Sun (1), so its velocity through any ether must differ by twice the orbital speed (1). A null result at every season rules out the lucky case of the laboratory happening to be momentarily at rest in the ether (1). [3]

B5 So the whole apparatus could be rotated smoothly and continuously while the fringes were watched (1); vibration or distortion of the arms during rotation would itself shift the fringes and mask the effect being looked for (1). [2]

B6 (a) Inertial: constant velocity, so Newton's first law holds on board (1). (b) Not inertial: the direction of motion is changing, so the car is accelerating even though its speed is constant (1). (c) Not inertial: its velocity is changing, an accelerating frame (1). [3]

SECTION C · Stretch

C1 Absolute motion cannot be detected (1): no measurement revealed the Earth's motion through any ether, so there is no privileged frame at rest (1). And the speed of light is invariant (1): the two beams' round trips tied exactly whatever the apparatus's motion or orientation, so the measured speed of light does not depend on the motion of source or observer (1). [4]

C2 It arrives at exactly c, not 1.40c (1). The invariance of c means the speed of light is independent of the source's motion (1); the everyday addition of velocities is only a low-speed approximation and cannot be applied to light (1). [3]

C3 It was sensitive enough to see the predicted effect and cleanly saw nothing, so the absence is itself a measurement (1): it retired the ether, established the invariance of c, and supplied the experimental foundation on which special relativity was built (1). [2]

C4 $\Delta t \approx (1.2/(3.0 \times 10^{8})) \times 10^{-8} = 4.0 \times 10^{-17}$ s (1). Path difference $c\Delta t = 1.2 \times 10^{-8}$ m (1), which is $1.2 \times 10^{-8}/(5.5 \times 10^{-7}) \approx 0.02$ of a wavelength (1). This is below the 0.05-wavelength detection limit, so the 1881 instrument could not reliably have seen the effect (1). The expected shift scales with arm length: at 11 m it becomes about 0.2 of a wavelength, comfortably detectable, hence the repeated reflections (1). [5]

C5 It is self-propagating: the oscillating electric field generates an oscillating magnetic field, which in turn regenerates the electric field (1). Nothing material has to oscillate, so no medium is required (1). [2]

C6 A half-silvered mirror splits a single beam along two equal arms at right angles; mirrors return the beams, which recombine and interfere, so the fringe pattern records any difference in the two round-trip times (1). If an ether wind blew through the laboratory, the arm lying along it should have the longer round-trip time (1). Rotating the whole apparatus through 90° swaps the arms' roles and reverses the difference, so the fringes should shift as it turns (1). No fringe shift was seen, at any orientation or time of year, despite sensitivity well beyond the predicted effect (1). Conclusions: absolute motion, through any ether, cannot be detected (1); and the speed of light is invariant, the same whatever the motion of the apparatus, the experimental foundation of special relativity (1). [6]