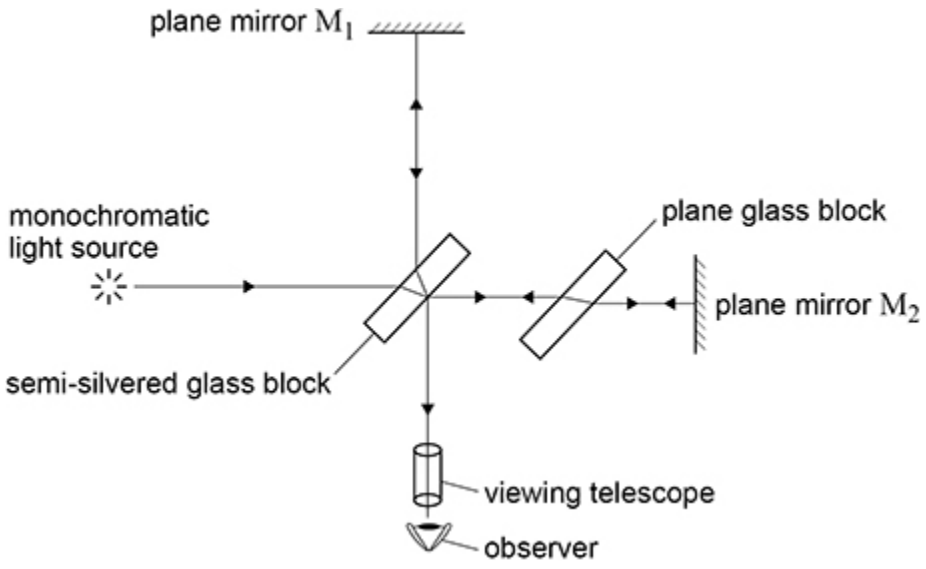
A-Level Physics

The Michelson-Morley Experiment

Question Paper

Time available: 49 minutes
Marks available: 33 marks

1. The figure below shows the features of a Michelson-Morley interferometer.



Explain how, using this arrangement, Michelson and Morley attempted to detect the absolute motion of the Earth.

In your answer you should:

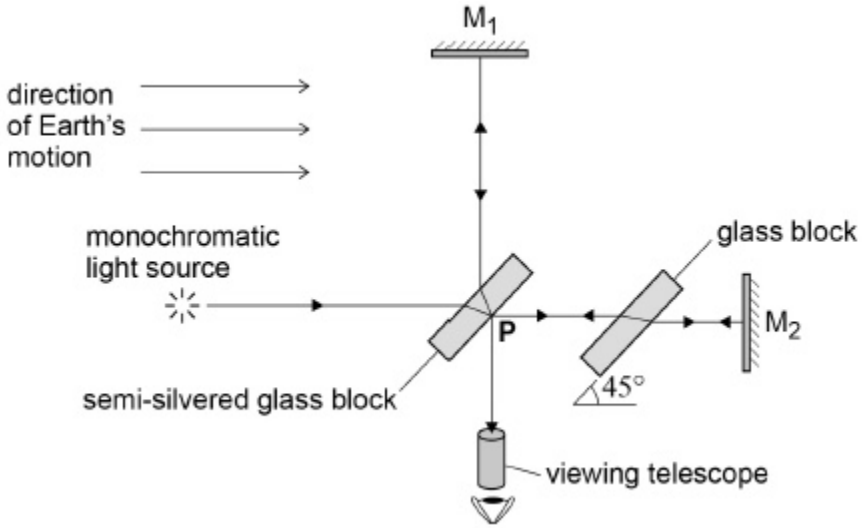
- outline the experimental procedure
- explain the expected result of the experiment
- describe the actual result and explain the significance of this result.

(Total 6 marks)

2. **Figure 1** shows a diagram of the Michelson-Morley interferometer that was used to try to detect the absolute motion of the Earth through the ether (æther).

Light from the monochromatic source passes through the semi-silvered glass block and takes two different paths to the viewing telescope. The two paths, PM_1 and PM_2, are the same length. Interference fringes are observed through the viewing telescope.

Figure 1



It was predicted that when the interferometer was rotated through 90° the fringe pattern would shift by 0.4 of the fringe spacing.

(a) Explain how the experiment provided a means of testing the idea that the Earth had an absolute motion relative to the ether.

Your answer should include:

- an explanation of why a shift of the fringe pattern was predicted
- a comparison of the results of the experiment to the prediction
- the conclusion about the Earth's absolute motion through the ether.

(6)

(b) The Michelson-Morley experiment provides evidence for one of the postulates of Einstein's theory of special relativity.

State this postulate.

(1)

(c) State the other postulate of Einstein's theory of special relativity.

_____

_____

_____

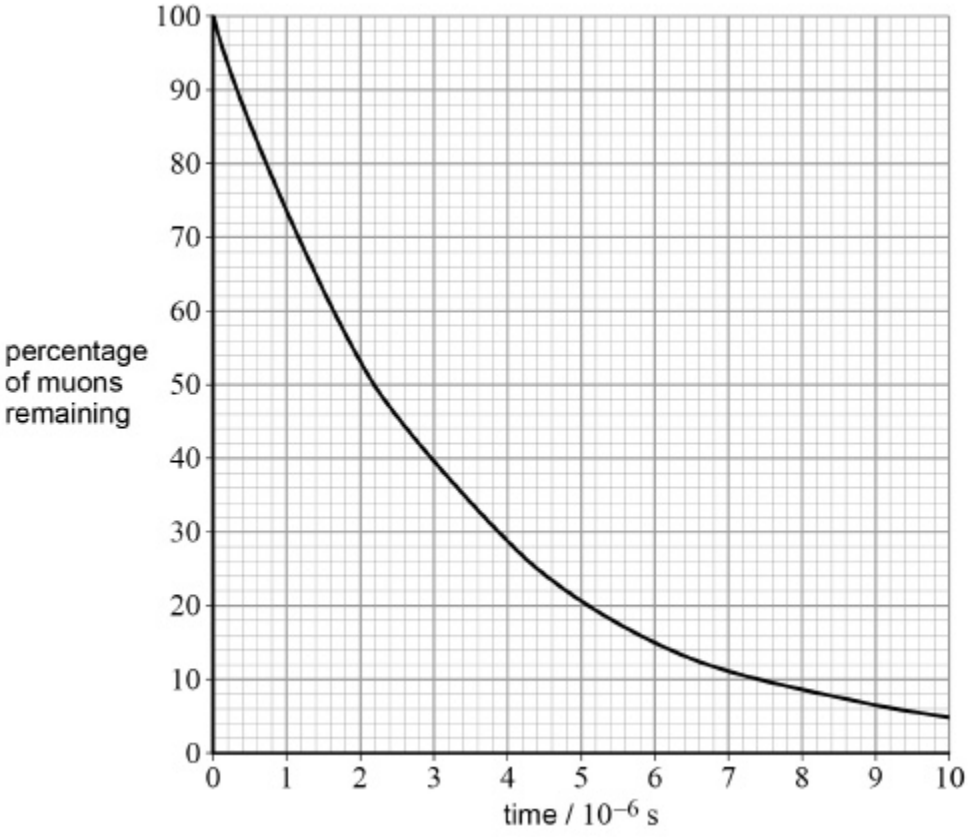
(1)

(d) One consequence of the special theory of relativity is length contraction.

Experimental evidence for length contraction is provided by the decay of muons produced in the atmosphere by cosmic rays.

Figure 2 shows how the percentage of the number of muons remaining in a sample changes with time as measured by an observer in a frame of reference that is stationary relative to the muons.

Figure 2



In a particular experiment, muons moving with a velocity 0.990c travel a distance of 1310 m through the atmosphere to a detector.

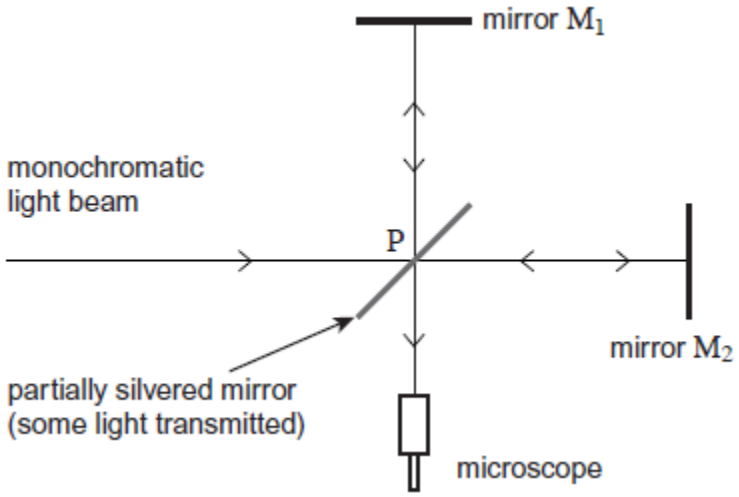
Determine the percentage of muons that reach the detector.

percentage = _____ %

(4)

(Total 12 marks)

3. The diagram shows the paths of light rays through a simplified version of the apparatus used by Michelson and Morley.



In the apparatus, light waves reflected by the mirrors M_1 and M_2, meet at P so that they superpose and produce interference fringes. These are observed using the microscope.

Michelson and Morley predicted that the fringes would shift when the apparatus was rotated through 90°. They thought that this shift would enable them to measure the speed of the Earth through a substance, called the aether, that was thought to fill space.

(a) Explain why Michelson and Morley expected that the fringe positions would shift when the apparatus was rotated through 90°.

(2)

(b) In their apparatus they made the distances PM_1 and PM_2 the same and equal to d. They used light of wavelength (λ) about 550 nm and knew that the speed of light c was 3.0×10^8 m s^{-1}. Using known astronomical data, they calculated the speed v at which they thought the Earth moved through the aether. They were then able to predict that when the apparatus was rotated through 90° the fringes should shift by a distance $0.4f$, where f was the fringe spacing.

(i) To determine v, Michelson and Morley assumed that the Sun was stationary with respect to the aether as the Earth moved through it.

Suggest, using this assumption, how the speed v of the Earth through the aether could be determined. You do not need to do the calculation.

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(1)

(ii) Michelson and Morley calculated v to be 3.0×10^4 m s^{-1}.

They worked out Δf, the magnitude of the expected shift of the fringes, using the formula $\Delta f = \frac{2v^2 d}{c^2 \lambda} f$.

Calculate the distance d they used in their experiment.

d = _____ m

(1)

(c) Although a shift of 0.4 f was easily detectable, no shift was observed. Explain what this null result demonstrated and its significance for Einstein in his special theory of relativity.

(2)

(Total 6 marks)

4. (a) Michelson and Morley attempted to detect absolute motion by investigating whether or not the speed of light in a direction parallel to the Earth's motion differs from the speed of light perpendicular to the Earth's motion.

Discuss what resulted from this experiment and what was concluded.

(3)

(b) In a science fiction story, a space rocket left the Earth in 2066 and travelled out of the Solar System at a speed of 0.80c, where c is the speed of light in vacuo, to a star 16 light years from the Earth.

(i) How many years, in the frame of reference of the Earth, did the spacecraft take to reach the star?

(ii) What was the distance, in the frame of reference of the spacecraft, between the Earth and the star?

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_____

_____

(iii) A member of the crew was 21 years old on leaving the Earth. How old was this person on arrival at the star?

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(6)

(Total 9 marks)