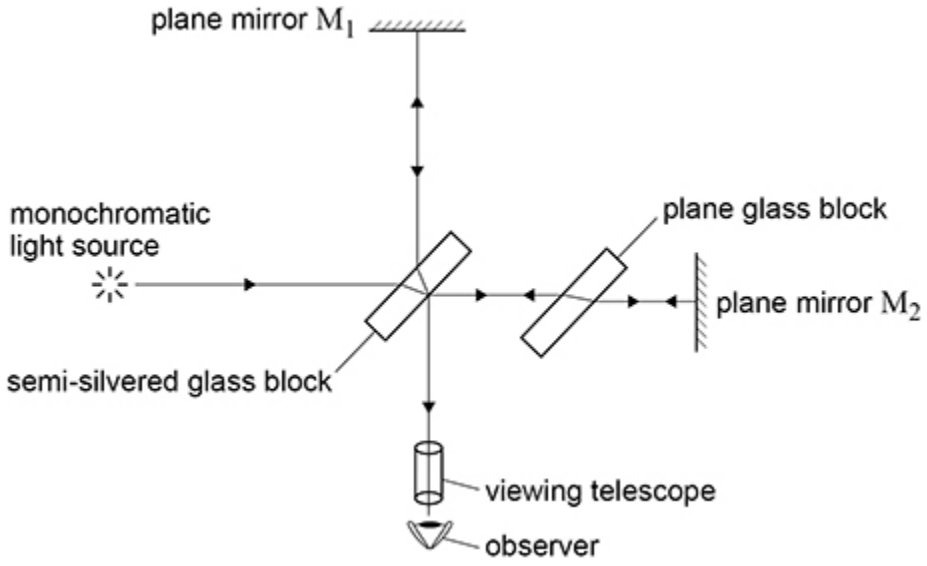
1. The figure below shows the features of a Michelson-Morley interferometer.



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. Cosmic rays detected on a spacecraft are protons with a total energy of 3.7×10^9 eV.

Calculate the velocity of the protons as a fraction of the speed of light.

proton velocity = _____ c

(Total 3 marks)

3. (a) A muon travels at a speed of $0.95c$ relative to an observer.

The muon travels a distance of 2.5×10^3 m between two points in the frame of reference of the observer.

Calculate the distance between these two points in the frame of reference of the muon.

distance = _____ m

(2)

(b) Measurements of muons created by cosmic rays can be used to demonstrate relativistic time dilation.

State the measurements made and the observation that provides evidence for relativistic time dilation.

(2)

(c) As the muons travel through the atmosphere, their speeds are reduced by interaction with the particles in the air.

Discuss, with reference to relativity, the effect that this reduction of speed has on the rate of detection of the muons on the surface of the Earth.

(3)

(Total 7 marks)

4. (a) A student models a spacecraft journey that takes one year. The spacecraft travels directly away from an observer at a speed of 1.2×10^7 m s^{-1}. The student predicts that a clock stationary relative to the observer will record a time several days **longer** than an identical clock on the spacecraft.

Comment on the student's prediction. Support your answer with a time dilation calculation.

(4)

(b) In practice, the gravitational field of the Sun affects the motion of the spacecraft and it does not travel directly away from the Earth throughout the journey.

Explain why this means that the theory of special relativity cannot be applied to the journey.

(2)

(Total 6 marks)

5. (a) State what is meant by an inertial frame of reference.

(1)

(b) A pair of detectors is set up to measure the intensity of a parallel beam of unstable particles.
In the reference frame of the laboratory, the detectors are separated by a distance of 45 m.
The speed of the particles in the beam is $0.97c$.

The intensity of the beam at the second detector is 12.5% of the intensity at the first detector.

Calculate the half-life of the particles in the reference frame in which they are at rest.

half-life = _____ s

(4)

(c) In calculations involving time dilation, it is important to identify proper time.

Identify the proper time in the calculation in part (b).

_____

_____

_____

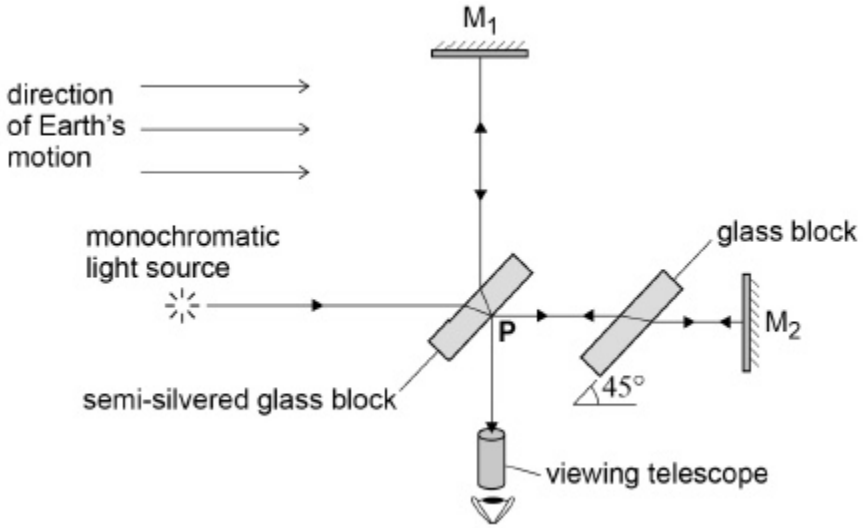
(1)

(Total 6 marks)

6. **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.

_____

_____

_____

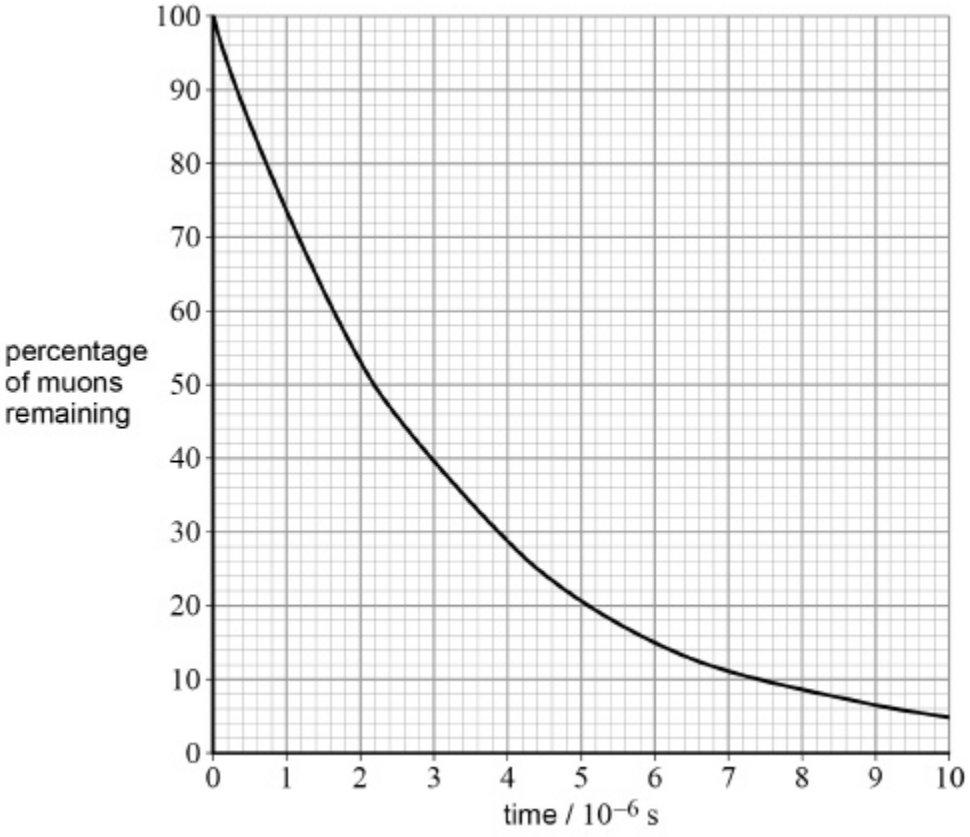
(1)

(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)