MICHELSON-MORLEY EXPERIMENT AND ITS OUTCOME

Background (The ether hypothesis) : Previous experience regarding the necessity of a medium for the propagation of mechanical wave forced the nineteenth century physicists to think that the existence of a medium that fills all space and penetrates all matter is essential for the propagation of light and other electromagnetic wave in free space. Therefore, they assumed that the entire space of the universe including vacuum is filled by a hypothetical light transmitting medium, called **ether** which is rigid, invisible, massless, perfectly transparent, perfectly non-resistive, continuous and stationary solid like steel having a very high elasticity and negligible density. All bodies (light or heavy) including earth move freely through hypothetical medium (ether) without disturbing it. Thus, ether provides a fixed frame of reference which was called **ether frame** or **rest frame or absolute frame of reference.**

Upto the end of the nineteenth century the ether hypothesis, was considered as the most promising and even necessary hypothesis, as it was very successful in the explanation of the phenomena of interference and diffraction. At that time, no one seemed to object the existence of a medium.

On the necessity of the medium scientists were of the view that if the ether hypothesis is correct then it should be possible to determine the absolute velocity of the earth with respect to stationary ether frame. Many experiments with sophisticated instruments were performed in this direction. The most famous among them was performed by **Michelson and Morley using Michelson Interferometer which is as follows :**

Experiment : The main objective of conducting the Michelson-Morely experiment was to confirm the existence of a stationary ether (frame). Michelson and Morley in 1887 performed an extremely sensitive experiment, for measuring the absolute velocity of the earth with respect to stationary ether. This experiment has long been regarded as one of the greatest experiment in physics and one of the main experimental pillars of special theory of relativity. The essential features of this apparatus, universally known as **Michelson interferometer, is shown in Fig. 3.** The two plane mirrors M_1 and M_2 used in the apparatus are highly silvered on their front surfaces to avoid multiple internal reflections. A beam of light from an

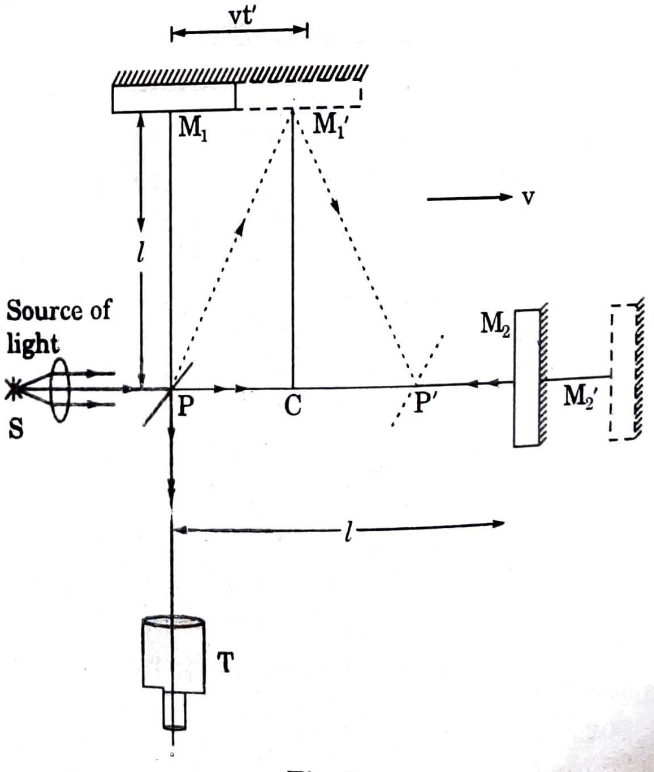

Fig. 3

extended source S is incident on a semi-silvered glass plate, P inclined at an angle 45° to the beam. This plate splits the light into two pats. One part of the beam travels through the plate P and falls normally on the mirror M_2 which reflects it back to the point P. The other part of the beam after reflection from the plate P falls normally on the mirror M_1 which also reflects it back to P. The two parts of the beam returned to P are directed towards the telescope. During their journey toward the telescope the two beams interfere and form interferance fringes that can be observed by the telescope T.

Let the two mirrors M_1 and M_2 be at the equal distance l from the plate P. If the apparatus is at rest in ether then the two rays (reflected and transmitted) would take equal time to return to P. But, in fact the earth, and hence, the whole apparatus is moving with earth through the ether with a velocity, say, v. Suppose the direction of motion of the earth is along the direction of incident light, that is from P to M_2. If the incident beam strikes the glass plate P in the position shown in Fig. 3, then the paths of the two rays and the positions of their reflections from the mirrors M_1 and M_2 will be shown by the dotted lines in the figure. Due to the motion of apparatus with earth, the time taken by two rays in their journey would not be the same. This time difference may be measured as follows :

Let c be the velocity of light through ether. According to Galilean transformations, the velocity of light with respect to the apparatus along the path PM_2 is $(c - v)$ in the forward trip and is $(c + v)$ in the backward trip. If t_1 be the time taken by this ray to travel from P to M_2 and back, that is PM_2P, then

$$t_1 = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2l_c}{c^2 - v^2} = \frac{2\,l}{c}\left(\frac{1}{1 - v^2/c^2}\right) \qquad ...(1)$$

The part of the beam moving towards the mirror M_1 with respect to the apparatus retains its velocity c. If t' be the time taken by the beam in going from the point P to M_1, then the distance travelled by it is ct'. In the same time t', the mirror M_1 shifted to M_1' after covering a horizontal distance vt'. Therefore, in the right angled triangle PM_1M_1'

$$(PM_1')^2 = (PM_1)^2 + (M_1M_1')^2$$

Here $PM_1 = l,\ M_1M_1' = vt'$ and $PM_1' = ct'$

$$\therefore \quad (ct')^2 = l^2 + (vt')^2$$

or
$$t' = \frac{l}{(c^2 - v^2)^{1/2}} = \frac{1}{c\sqrt{1 - (v/c)^2}}$$

Therefore, the total time taken by the beam in travelling from P to M_1' and then from M_1' to P' would be

$$t_2 = 2t' = \frac{2l}{c}\,\frac{1}{\sqrt{1 - (v/c)^2}} \qquad ...(2)$$

Hence, the time difference, Δt between the times of travel of the two beams is, given by

$$\Delta t = t_1 - t_2 = \frac{2l}{c(1 - v^2/c^2)} - \frac{2l}{c\sqrt{1 - v^2/c^2}}$$

$$= \frac{2l}{c}[(1 - v^2/c^2)^{-1} - (1 - v^2/c^2)^{-1/2}]$$

Using binomial expansion $[(1 + x)^n = 1 + nx + ...]$ and neglecting higher terms, we get

$$\Delta t = \frac{2l}{c}\left[\left(1 + \frac{v^2}{c^2} + ...\right) - \left(1 + \frac{1}{2}\frac{v^2}{c^2} + ...\right)\right]$$

$$= \frac{2l}{c}\left[\frac{1}{2}\frac{v^2}{c^2}\right] = \frac{l v^2}{c^3} \qquad ...(3)$$

$\therefore$ The corresponding path difference, $\Delta = c.\,\Delta t = c\,\frac{lv^2}{c^3}$

or $$\Delta = \frac{l v^2}{c^2} \qquad ...(4)$$

We know that if the path difference between the two interfering rays changes by λ, the shifting of one fringe in the field of view of the telescope is observed. Therefore, if n be the number of fringes that shift when interferometer is suddenly brought to rest (that is, v is made zero), then, from eqn. (4), we have

$$n = \frac{\Delta}{\lambda} = \frac{l v^2}{c^2 \lambda}$$

In the actual experiment, the whole apparatus which was placed on a block of stone floated on mercury, was turned through 90° so that the path PM_1 became longer than the path PM_2 by an amount (lv^2/c^2). Thus, the rotation of apparatus through 90° introduces a path difference of the same amount in opposite direction so that the total path difference between the two rays became $2\,lv^2/c^2$. Hence, a shift of $\frac{2\,lv^2}{c^2\lambda}$ was expected.

To get accurate results, the distance l was effectively increased to a value upto 11 meters by Michelson and Morley by the method of multiple reflections by using a system of mirrors .Taking earth's velocity through ether equal to its orbital velocity, that is, $v = 3 \times 10^4$ m/sec, the expected fringe shift for visible light ($\lambda = 5.5 \times 10^{-7}$ m) is

$$\Delta n = \frac{2\,lv^2}{c^2} \cdot \frac{1}{\lambda} = \frac{2 \times 11 \times (3 \times 10^4)^2}{(3 \times 10^8)^2} \times \frac{1}{5.5 \times 10^{-7}} = 0.4$$

or a shift of four-tenths a fringe. A shift of this magnitude can be easily measured with the help of Michelson-Morley set up.

Michelson and Morley were extremely surprised to see that no shift in the fringe was observed when the interferometer was rotated 90°. Michelson and

Morley repeated the experiment at different places, different times of the year, and at different heights, but they always found no shift. That is , they could not detect the relative velocity of the earth with respect to stationary ether. Trouton and Noble, in the year 1902, performed an electromagnetic experiment for the same purpose but failed to achieve positive result. It means that the relative velocity between the earth and the ether is zero. Thus, the motion of the earth through the ether could not be detected experimentally. Hence, **the hypothesis of the existence of stationary medium was disapproved.**

EXPLANATION AND INTERPRETATION OF THE NEGATIVE RESULT

A number of explanation were offered to interpret the negative results of Michelson-Morely experiment and to preserve the concept of stationary ether. Nevertheless all of them failed. Here, we are giving a summary of three main explanations.

1. Ether-Drag Hypothesis : This hypothesis assumed that there is an ether medium which is centered on the earth and moves with the earth in its motion through space. Therefore, there should be no relative motion between the earth and ether and hence, the question of shift does not arise. But this explanation was discarded due to following two arguments : (*i*) Ether-drag hypothesis goes against the observed aberration of light from stars, that is, it is against the phenomenon of stellar aberration. (*ii*) Fizeau's experimental conclusion revealed that a moving body could drag the light waves only partially .This partial dragging of light waves was explained on the basis of electromagnetic theory, without using the ether-drag hypothesis.

2. Fitzgerald-Lorentz Contraction Hypothesis : Fitzgerald proposed a hypothesis to explain the negative results of Michelson-Morley's experiment and to retain the concept of preferred ether frame. According to this hypothesis all material bodies are contracted in the direction of motion relative to stationary ether by a factor $\sqrt{(1 - v^2/c^2)}$. It can be easily observed that such a contraction in the interferometer arm would equalize the two times t_1 and t_2 taken by the ray in travelling towards the mirrors M_1 and M_2, and thus no fringe-shift would be expected. This explanation also could not gain acceptance because contraction hypothesis was purely mathematical without any logic behind it and without any experimental confirmation. Further, Rayleigh worked out that such a contraction is expected to produce double refraction which was however, never observed.

3. Constancy of Speed of Light Hypothesis : It was proposed that light travels with a constant velocity not with respect to the stationary ether but with respect to the source. Thus, the light from a moving source has a velocity which is the vector sum of its natural velocity and the velocity of source. This explains the negative results, but it was in conflict with the wave theory of light and there is an astronomical evidence concerning double stars which goes against this hypothesis. Hence, this explanation was also rejected.

EINSTEIN NOVEL AND REVOLUTIONARY IDEA

True explanation of negative results or failure of Michelson-Morley and other like experiments was offered by Einstein. He proposed, in the year 1905, a radically new profound idea that represented a vast revolution in physical thought. **Einstein put forward that the motion through stationary ether is a meaningless concept; only motion relative to material bodies has physical significance.** The frame of reference may be a road, the earth, the sun, the centre of our galaxy, but in every case we must specifiy it, If we were isolated in the universe there would be no way in which we could determine whether we are in motion or not. That is why it is impossible to perform any experiment for detecting earth's motion through ether. This idea was ultimately developed in the form of special theory of relativity by Einstein. He announced to the world his fascinating special theory of relativity.

SIGNIFICANCE OF NEGATIVE RESULTS

Following important conclusions can be drawn from the negative results of Michelson-Morley experiment.

1. The velocity of light is constant in all directions.
2. The affects of presence of ether in the entire space of the universe are undetectable. Therefore, all efforts to make ether a universal frame of reference are meaningless.
3. A new theory with different concepts of space, time and mass is needed. Thus, we must think of different set of transformations in contrast to Galilean transformation which failed to give correct results.