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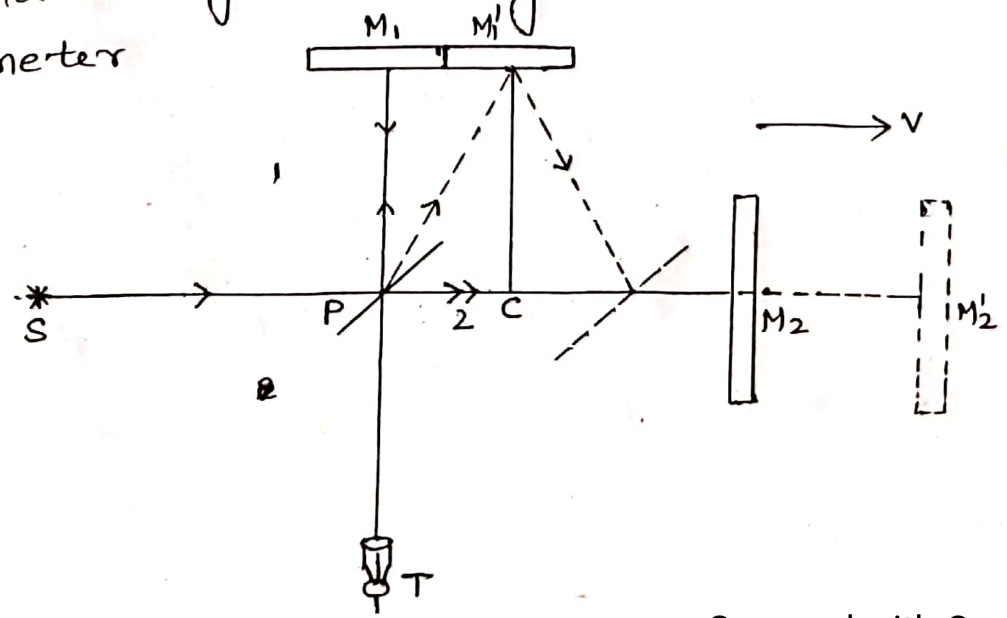
Michelson - Morley Experiment

According to the wave theory of light, a light source set up a disturbance travelling in all directions through a hypothetical medium, called 'ether' which fills all space and penetrates all matter. Bradley's observation of the aberration of light from stars had indicated that the ether must be stationary in space. It means that if a material body, say earth, moves in space, there is a relative motion between the body and the ~~earth~~ ether. A number of experiments were performed to detect a relative motion between the earth and the ether. The most famous among them is the one performed by Michelson and Morley in 1887 using the Michelson interferometer



A Simplified plant of the experiment is Shown figure. A beam of light from from a Source S falls upon a half-silvered glass plate P placed at 45° to the beam and is divided into two beam 1 and 2. The beam 1 and 2 travelling at right angles to each other, fall normally on mirrors M_1 and M_2 which reflect them back to P. The Two beams returned to P are directed towards a telescope T in which interference fringes are observed.

Let the mirror M_1 and M_2 be at the Same distance l from the plate P. Then if the apparatus were at rest in ether, the two beams would take the Same time to return to P. But actually the earth, and hence the apparatus, is moving in space through the ether with a velocity v. Suppose this motion is in the direction of the initial beam of light. Then, if the initial beam strikes the plate P in the position in figure. the paths of the two beams ~~Strikes the plate~~ P and the positions of there reflection from the mirrors will be the dotted lines. The time taken by the two beams on their Journeys are not equal.

Let c be the Velocity of light through the ether. The beam 2 moving towards M_2 has a velocity (c-v) relative to the appartus on the outgoing trip, and (c+v) on the return trip. If t_2 be the total time taken by this beam to go from p to M_2 and back, then

$$t_2 = \frac{l}{c-v} + \frac{l}{c+v}$$

$$= \frac{l(c+v)+l(c-v)}{(c-v)(c+v)}$$

$$= \frac{lc+lv+lc-lv}{c^2-v^2}$$

$$= \frac{2lc}{c^2-v^2}$$

$$\therefore t_2 = \frac{2lc}{c^2(1-v^2/c^2)}$$

$$= \frac{2l}{c}\left(1-\frac{v^2}{c^2}\right)^{-1}$$

$$\therefore t_2 = \frac{2l}{c}\left(1+\frac{v^2}{c^2}\right) \quad \text{——— (1)}$$

neglecting terms smaller than $\frac{v^2}{c^2}$

The beam 1 is moving transversely with respect to the apparatus retains its velocity c throughout. Let it take a time t' to go from p to strike M_1, travelling a distance ct'. In the same time, the mirror M_1 advances a distance vt'. Thus in the right-angle triangle pM_1M_1'.

$$PM_1 = l, \quad M_1M_1' = vt' \text{ and } PM_1' = ct'$$

Hence

$$(ct')^2 = l^2 + (vt')^2$$

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

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

$$t' = \frac{l}{c}\left(1+\frac{v^2}{2c}\right)$$

If t_1 be the total time taken by the beam to travel the whole path $PM_1'P'$ then

$$t_1 = 2t'$$

$$= \frac{2l}{c}\left(1+\frac{v^2}{2c^2}\right) \quad \text{——— (2)}$$

Hence the difference between the times of interval of the two beams is from equation (1) and (2)

$$t_2 - t_1 = \frac{2l}{c}\left(1+\frac{v^2}{c^2}\right) - \frac{2l}{c}\left(1+\frac{v^2}{2c^2}\right)$$

$$= \frac{2l}{c}\left(1+\frac{v^2}{c^2}-1-\frac{v^2}{2c^2}\right)$$

$$= \frac{2l}{c}\left(\frac{v^2}{c^2}\right)$$

$$\therefore t_2 - t_1 = \frac{lv^2}{c^3}$$

The effective path difference, in terms of wavelength of light used is

$$\delta = \frac{c(t_2-t_1)}{\lambda}$$

$$\delta = \frac{lv^2}{c^2\lambda} \text{ wavelengths}$$

if the interferometer were suddenly brought to rest, $\delta = 0$. the fringes pattern must be shifted through $\frac{lv^2}{c^2\lambda}$ fringes. In the actual experiment, the whole appartus, which was placed on a block of stone floated on mercury. was rotated through $90°$. This introduced a path difference of the same amount in the opposite direction. Hence a shift of $\frac{2lv^2}{c^2\lambda}$ was expected.

To have an observable shift, Michelson and Morley increased the effective value of l upto 11 meters by reflecting the light back and forth several times. Then using values. $l = 1100$ cm, $v = 3\times10^6$ cm/s., $c = 3\times10^{10}$ cm/s and $\lambda = 6\times10^{-5}$ cm, the expected shift is

$$\frac{2lv^2}{c^2\lambda} = \frac{2\times1100\times(3\times10^6)^2}{(3\times10^{10})^2(6\times10^{-5})} = 0.37 \text{ of}$$

fring-width