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Michelson – Morley experiment and Aether theory

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Abstract: This article is about the famous experiment which disproved the existence of aether.

Towards the end of the nineteenth century, the physics was based on the validity of Newtonian mechanics, Maxwell's field equation and the Galilean transformation. Those principles seemed completely valid and passed a good number of experiments. The Galilean relativity or Galilean invariance says, Newton's laws remain invariant or same under any inertial transformation. Maxwell's equations are very symmetric in general. They remain invariant under translation and rotation of coordinates. The problem arises while writing Maxwell's wave equations under Galilean transformation. The wave equation completely changes its mathematical form under Galilean transformation.

Maxwell's wave equation:

$$\frac{d^2E}{dx^2} - \frac{1}{c^2}\frac{d^2E}{dt^2} = 0.$$

Maxwell's wave equation after Galilean transformation:

$$\left(1 - \frac{v^2}{c^2}\right)\frac{d^2E}{dx'^2} - \frac{1}{c^2}\frac{d^2E}{dt'^2} + 2\frac{v}{c}\frac{d^2E}{x'dt'} = 0.$$

Let the solution of the new equation is:

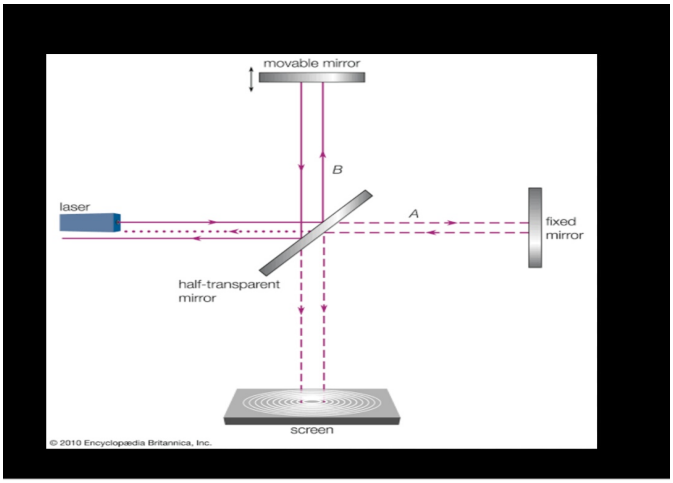
y=Af(x+c't)+Bf(x-c't)

Substituting it in that new equation, we get c'=c+v or c'=c-v

This means, if the Maxwell's equations is to remain invariant, the velocity of light should change. But what is this v in the equation. Physicists hypothesized, the whole space is filled with a massless but elastic medium named Aether. The original Maxwell's wave equation is only valid in aether frame, that is, the absolute rest frame. In Aether's frame, the velocity of light is 3×108m/s. And the v is the aether wind faced by the moving frame. It is same as a person feels wind blowing when moving with speed through air, here the medium is aether instead of air.

The experiment:

Michelson-Morley designed an experiment to demonstrate the existence of aether and therefore to prove the hypothesis. The apparatus or the instrument was called Interferometer. It is used to perform interference between two light rays by inducing a path difference between them.



Pic1: Michaelson-Morly Interferometer

The aim of the experiment was to compare the time

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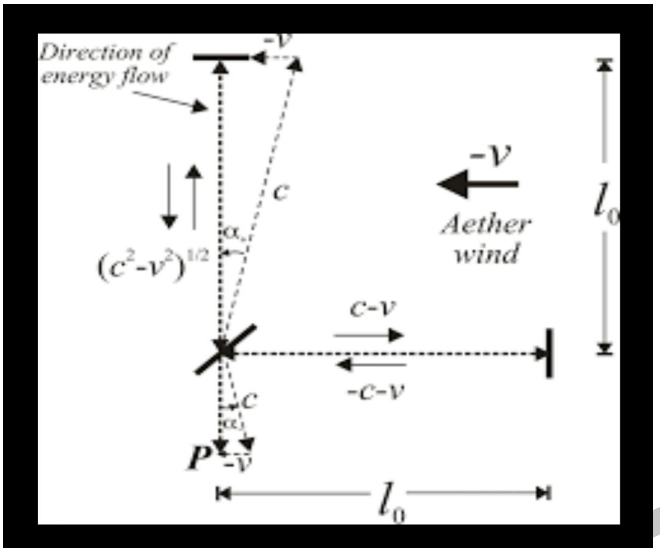
taken by the light rays to travel back and fourth, perpendicular and parallel to the aether.

Theoretical basis: Earth is an inertial frame, moving with respected to aether frame with a velocity v. The Interferometer is in the earth's frame. There will be interference between light ray in the perpendicular and parallel arm.



Pic2: illustration of the change in travel time

Time difference that will arise due to back and forth travel time of parallel and perpendicular components is dv^2/c^3. Now the whole set up is rotated by 90° in the same horizontal plane, so that, the role of the two rays become opposite. This leads to the time difference of $(-dv^2/c^3)$. Difference between the two time-differences before and after rotation by 90° is $2(dv^2/c^3)$. As there is time difference between before after rotation, a shift in the interference fringe is expected. That number is expected to be 0.4 and instrument is sensitive enough to detect change in even 1/10th of the expected amount. But absolutely no fringe shift was detected. The experiment was conducted with many different positions, in different seasons but no fringe shift was noticed. That means there is no aether wind.

Conclusion:

Many scientists tried to save the aether hypothesis by proposing other more hypothesis like aether drag, emissions and contraction theory, but they faded away. But in the process, interferometers became even more sensitive and sophisticated and this helped a lot in the field of optics.

Reference:

1] Modern physics, AB Gupta

Image reference:

2] Picture1: Britannica
3] Picture2: physics.gen-ph