Topic: Concept of ether and Principle of Relativity(Einstein and Galilean), B.Sc. Physics (Hons.) Part -1, Paper 1

By Dr. Supriya Rani, Guest Faculty, Department of Physics, Magadh Mahila College, PU

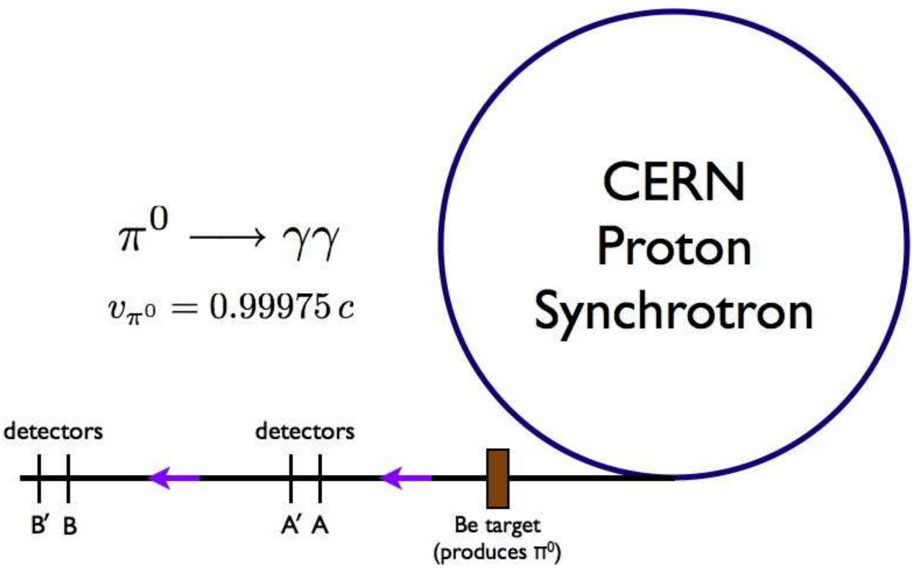

Figure : Experimental setup of Alvager *et al.* (1964), who used the decay of high energy neutral pions to test the source velocity dependence of the speed of light.

The Michelson-Morley experiment, was a landmark result. It had been proposed that the ether could be dragged, either entirely or partially, by moving bodies. If the earth dragged the ether along with it, then there would be no ground-level 'ether wind' for the MM experiment to detect. Other experiments, however, such as stellar aberration, in which the apparent position of a distant star varies due to the earth's orbital velocity, rendered the "ether drag" theory untenable – the notional 'ether bubble' dragged by the earth could not reasonably be expected to extend to the distant stars.

A recent test of the effect of a moving source on the speed of light was performed by T. Alva ˚ (1964), who measured the velocity of γ-rays (photons) emitted from the decay of highly energetic neutral pions (π^0). The pion energies were in excess of 6 GeV, which translates to a velocity of $v = 0.99975\ c$, according to special relativity. Thus, photons emitted in the direction of the pions should be traveling at close to $2c$, if the source and photon velocities were to add. Instead, the velocity of the photons was found to be $c = 2.9977 \pm 0.0004 \times 10^{10}$ cm/s, which is within experimental error of the best accepted value.

Einsteinian and Galilean relativity

The *Principle of Relativity* states that the laws of nature are the same when expressed in any inertial frame. This principle can further be refined into two classes, depending on whether one takes the velocity of the propagation of interactions to be finite or infinite.

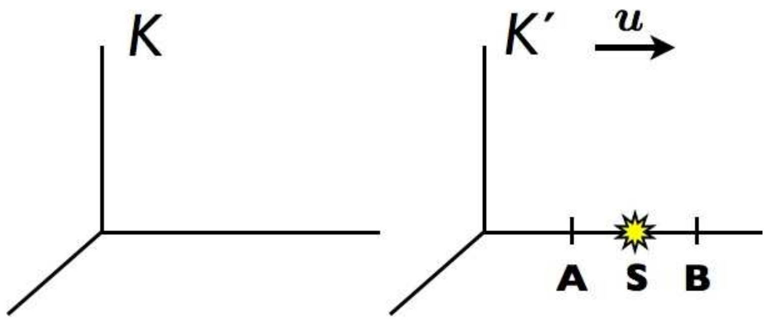

Figure : Two reference frames.

The interaction of matter in classical mechanics is described by a potential function $U(\boldsymbol{r}_1, \ldots, \boldsymbol{r}_N)$. Typically, one has two-body interactions in which case one writes $U = \sum_{i<j} U(\boldsymbol{r}_i, \boldsymbol{r}_j)$. These interactions are thus assumed to be instantaneous. The interaction of particles is mediated by the exchange of gauge bosons, such as the photon (for electro-magnetic interactions), gluons (for the strong interaction, at least on scales much smaller than the 'confinement length'), or the graviton (for gravity). Their velocity of propagation, according to the principle of relativity, is the same in all reference frames, and is given by
the speed of light, $c = 2.998 \times 10^8$ m/s.

Since c is so large in comparison with terrestrial velocities, and since d/c is much shorter than all other relevant time scales for typical interparticle separations d, the assumption of an instantaneous interaction is usually quite accurate. The combination of the principle of relativity with finiteness of c is known as Einsteinian relativity. When $c = \infty$, the combination comprises Galilean relativity:

$$\begin{aligned} c < \infty \quad &: \quad \text{Einsteinian relativity} \\ c = \infty \quad &: \quad \text{Galilean relativity} \ . \end{aligned}$$

Let a train moving at speed u. In the rest frame of the train track, the speed of the light beam emanating from the train's headlight is $c + u$. This would contradict the principle of relativity. This leads to some very peculiar consequences, foremost among them being the fact that events which are simultaneous in one inertial frame will not in general be simultaneous in another. In Newtonian mechanics, on the other hand, time is absolute, and is independent of the frame of reference. If two events are simultaneous in one frame then they are simultaneous in all frames. This is not the case in Einsteinian relativity.

Let us consider the case in fig. in which frame K' moves with velocity $u\,\hat{\boldsymbol{x}}$ with respect to frame K. Let a source at S emit a signal (a light pulse) at $t = 0$. In the frame K' the signal's arrival at equidistant locations A and B is simultaneous. In frame K,, A moves toward left-propagating emitted wavefront, and B moves away from the right-propagating wavefront. For classical sound, the speed of the left-moving and right-moving wavefronts is $c \mp u$, taking into account the motion of the source, and thus the relative velocities of the signal and the detectors remain at c. But according to the principle of relativity, the speed of light is c in all frames, and is so in frame K for both the left-propagating and right-propagating signals. Therefore, the relative velocity of A and the left-moving signal is $c + u$ and the relative velocity of B and the right-moving signal is $c - u$. Therefore, A 'closes in' on the signal and receives it before B, which is moving away from the signal. We might expect the arrival times to be ${t^*}_{\mathrm{A}} = d/(c+u)$ and ${t^*}_{\mathrm{B}} = d/(c-u)$, where d is the distance between the source S and either detector A or B in the K' frame. We get the result as

$$t^*_{\mathrm{A}} = \sqrt{\frac{c-u}{c+u}} \cdot \frac{d}{c} \qquad , \qquad t^*_{\mathrm{B}} = \sqrt{\frac{c+u}{c-u}} \cdot \frac{d}{c} \ . \tag{1}$$