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MICHELSON-MORLEY EXPERIMENT WITHIN THE QUANTUM MECHANICS FRAMEWORK

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Abstract

It is revisited the Michelson-Morley experiment within the quantum mechanics framework. One can define the wave function of photon in the whole space at a given moment of time. The phase difference between the source and receiver is a distance between the source and receiver at the time of reception hence it does not depend on the velocity of the frame. Then one can explain the null result of the Michelson-Morley experiment within the quantum mechanics framework.

The Maxwell-Lorentz equations describe electromagnetic field as a wave propagating with the velocity c. It is reasonable to think that electromagnetic wave propagates with the velocity c with respect to a privilege frame. If some frame moves with the velocity v with respect to a privilege frame then one can expect that electromagnetic wave propagates with the velocity $\vec{c} - \vec{v}$ with respect to the moving frame. The Michelson-Morley experiment was suggested to determine the velocity of electromagnetic wave with respect to a moving frame with the earth being taken as a moving frame. However the Michelson-Morley experiment [1] yielded the null result. The special relativity [1] explains the null result of the Michelson-Morley experiment with the Lorentz transformation for coordinates of space and time. Electromagnetic field is a quantum object. Below we shall revisit the Michelson-Morley experiment within the quantum mechanics framework.

Consider electromagnetic field within the Newtonian framework. Consider electromagnetic field as a wave with the vector potential $\vec{A}$ in the Euclidean space and time of a privilege frame. We shall take the cosmic microwave background radiation (CMB) [2] as a privilege frame. The Maxwell-Lorentz equations for the electromagnetic wave are given by [3]

$$\triangle\vec{A} - \frac{1}{c^2}\frac{\partial^2\vec{A}}{\partial t^2} = 0 \qquad (1)$$

where c is the velocity of light. One can represent the solution of eq. (1) as a plane monochromatic wave

$$\vec{A} = \vec{A}_0 e^{-i\phi} \qquad (2)$$

with the phase

$$\phi = \omega t - kr \qquad (3)$$

where ω is the frequency, k is the wave vector.

In the quantum mechanics [4], one can consider electromagnetic field as a bunch of photons with the momentum and energy given by respectively

$$p = \hbar k \qquad \mathcal{E} = \hbar\omega \qquad (4)$$

where $\hbar$ is the Planck constant. One can conceive the photon as a particle exhibiting wave behaviour. In the quantum mechanics the wave given by eq. (2) is thought of as a wave function of photon associated with a single photon. For photons the Heisenberg uncertainty principle holds true

$$\Delta p \Delta r \geq \frac{\hbar}{2} \qquad \Delta \mathcal{E} \Delta t \geq \frac{\hbar}{2}. \tag{5}$$

In view of eq. (4), the Heisenberg uncertainty principle restricts the wave function of photon in the space and time.

Consider the photon as a particle with the momentum p at the time t. Introduce the wave function of photon with the wave vector $k = p/\hbar$. In the stationary state the momentum of photon is fixed. Then the uncertainty in momentum is $\Delta p = 0$, the uncertainty in the wave vector is $\Delta k = \Delta p/\hbar = 0$. ¿From eq. (5) it follows the uncertainty in space coordinate $\Delta r = \infty$. This means one cannot specify the space coordinate hence one can consider the wave function of photon with the wave vector $k = p/\hbar$ in the whole space at the time t. One can describe the wave function of photon by eq. (2) like the classical wave. However one cannot treat electromagnetic field as a classical wave and conceive it as a fluid consisting of a number of photons. One can treat electromagnetic field as a wave function accompanying to a single photon.

Consider propagation of a photon between the source and receiver. We shall regard the case when the region of propagation of photon is much more than the wave length of photon $\Delta r \gg \lambda = 1/k$. Then one can think of the photon as a point-like quasi-classical particle propagating with the velocity c with respect to the CMB frame. In view of the above reasoning one can define the wave function of photon in the whole space at the time of reception. Then the phase difference between the source and receiver is a distance between the source and receiver at the time of reception

$$\Delta\phi = \phi_r(t_r) - \phi_s(t_r) = k[r_r(t_r) - r_s(t_r)]. \tag{6}$$

We come to the definition of phase within the quantum mechanics framework. In the classical physics the phase is defined through the space coordinate of the source at the time of emission $r_s(t_e)$. In the quantum mechanics the phase is defined through the space coordinate of the source at the time of reception $r_s(t_r)$. The quantum mechanics definition of phase proceeds from the fact that the wave function of photon is associated with a single photon hence is defined in the whole space at the time of reception.

Consider the Michelson-Morley experiment in a frame moving with the velocity v with respect to the CMB frame. Suppose that electromagnetic field (photon) moves with the velocity c with respect to the CMB frame independently of the source (receiver). Then the travel time is a function of the velocity of the frame with the maximum difference of travel time between two legs for two-way travel being $\Delta t = (l/c)(v^2/c^2)$ where l is the length of the leg. According to the quantum mechanics [4] a single photon interferes with itself. The wave function of photon is a superposition of the waves specified along two different legs with the photon as a particle moving along one of the legs. In view of eq. (6), the phase difference between the source and receiver is a distance between the source and receiver at the time of reception. If the lengths of the legs are not the same there is a phase shift between two waves specified along two different legs $\Delta\phi = k(l_2 - l_1)$. When determining the distance between the source and receiver at one and the same moment of time it does not depend on the velocity of the frame. Hence the phase difference between the source and receiver does not depend on the velocity of the frame. Hence there is no phase shift due to the velocity of the frame between two waves specified along two different legs. Thus one can explain the null result of the Michelson-Morley experiment within the quantum mechanics framework without invoking the Lorentz transformation.

According to the special relativity [1] coordinates of space and time follow the Lorentz transformation (LT), $r' = r\mathrm{LT}$, $t' = t\mathrm{LT}$ while the wave vector and frequency of electromagnetic wave follow the inverse Lorentz transformation $k' = k\mathrm{LT}^{-1}$, $\omega' = \omega\mathrm{LT}^{-1}$. Here the non-primed values are the proper ones while the primed values are the apparent ones. The phase of electromagnetic wave is Lorentz invariant $\phi' = \omega' t' - k' r' = \omega t - kr = \phi$ that explains the null result of the Michelson-Morley experiment.

Explanation of the null result of the Michelson-Morley experiment within the quantum mechanics framework allows Galilean invariance of the electromagnetic wave. One may treat the phase given by eq. (6) as Galilean invariant. That is both observers in a privilege and in a moving frames determine the same space coordinate difference and the same wave vector. The wave vector of the electromagnetic wave emitted in a moving frame is Lorentz shifted in a privilege frame (Doppler effect). Assume that electromagnetic wave behaves in a different way under propagation of the electromagnetic wave and under interaction with the source. Under propagation electromagnetic wave is Galilean invariant while under interaction with the source is Lorentz invariant. Then we may apply the conventional special relativity under interaction of the electromagnetic wave with the source. After emission the wave vector of the electromagnetic wave is the same for both observers in a privilege and in a moving frames. That is Galilean invariance of the phase under propagation of the electromagnetic wave means $\phi = k'r =$ Gal inv.

So putting the quantum mechanics definition of the wave function of photon one can explain the null result of the Michelson-Morley experiment without invoking the Lorentz transformation. It is reasonable to assume that under propagation electromagnetic wave is Galilean invariant. Explanation of the Doppler effect needs the Lorentz transformation. It is reasonable to assume that under interaction with the source electromagnetic wave is Lorentz invariant.

References

[1] W. Pauli, *Theory of Relativity* (Pergamon, New York, 1958).

[2] C.H. Lineweaver et al., Astrophys. J. **470** (1996) 38.

[3] L.D. Landau and E.M. Lifshitz, *The classical theory of fields*, 4th Ed. (Pergamon, Oxford, 1976).

[4] P.A.M. Dirac, *The Principles of Quantum Mechanics* (Oxford University Press, London, 1958).

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The author presents a reinterpretation of the famous Michelson-Morley experiment within quantum-mechanics, which has been so important in the developement of physics and in particular of special relativity. The main conclusion of the work of Dr. Khokhlov, which if correct is a purely wave-mechanical interpretation of the experiment, is that the null result of the experiment is easy to explain from the lack of velocity dependence in the distance between the source and the receiver when considering the quantum nature of the photon. While the idea is interesting, I am suspicious on the results. The main point of this comment is related to the "quantum-mechanical interpretation" claimed. First, the results show no dependence upon $\hbar$ or other important physical scale, so any semiclassical limit (photon considered as a classical particle) which would allow to see the emergence of the expected dependence of the relative velocity between the source and observer, is not obvious. Moreover, it is not clear to me that the results incorporate true quantum-mechanical features, e.g. the bosonic or fermionic nature of the particles. The fact that the author uses Heisenberg inequalities, in my opinion, does not makes the result quantum-mechanical but only wave-mechanical, as such inequalities also appear there.

I would like to conclude my comment stating that, while I am not an expert of this field, the fact that no relevant physical scale appears in the results, thinking on a semiclassical limit, makes me quite suspicious on the results and their interpretation by the author. As referee I would ask the author to consider the semiclassical limit and show that the "expected" classical result appears. Taking into account the actual scope of this journal, I am in favour of the publication of this paper, looking forward to read the opinion and reaction of experts on this paper.

Comment

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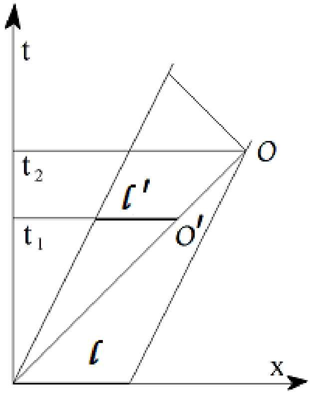
Galilean analysis of the Michelson–Morley experiment yields a difference in the light phases. But the experiment itself gives a null result. Invoking the Lorentz transformations removes the paradox — it is a generally accepted explanation.

The author instead purports that he has found another explanation, but unfortunately he is wrong. He claims that the difference of phases at a given moment is equal (proportional) to the distance, and he is right, but further reasoning is incorrect as follows from the figure.



One leg of length l is parallel to the axis x, whereas the second one, invisible in the figure, is parallel to the axis y which is orthogonal to the plane of the figure. At the moment t_1 the ray traveling along the invisible leg in the plane orthogonal to the plane of the figure (this plane crosses the plain of the figure along the green line which is the world-line of the laboratory) reaches the end of the leg. Consequently, the difference of the phases equals l. But at the moment $t_1(\neq t_2)$ the second ray reaches only the point O' (not the point O) and this difference of phases is $l'(\neq l)$. Therefore the distances and the phases are different.

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The points raised in this article are such as, to my mind, deserve an airing in front of the entire scientific community so that they may be examined by a wide varietry of scientists. However, I do feel that two issues should be noted and considered:

(i) it is assumed here that the Michelson-Morley experiment yielded null results. There are many articles concerned with this point which actually raise questions about the validity of the claim, but I would refer, for example, to the work of Reg Cahill which appears in Progress in Physics. (see vol.3, October 2005, p 25 and references cited there. The electronic form of this journal is available at http://www.geocities.com/ptep_online).

(ii) it seems that the usual Maxwell electromagnetic equations are being used here but they were derived for a medium at rest. If you derive the equations from first principles for a moving medium, different equations result, equations which are invariant under Galilean transformation. (see, for example, "Maxwell's electromagnetic equations revisited", Hadronic Journal 25 (2002) 251-260 and "A re-examination of Maxwell's electromagnetic equations" Progress in Physics 3 (2005) 48-50 http://uk.arXiv.org physics/0406056).

Considering the lingering doubts about the results of the Michelson-Morley experiment - did it produce null results or not? - and concerns about the range of validity of the normally accepted form of Maxwell's electromagnetic equations, it seems that extra care should be exercised when commenting in this field. It also seems that these two points, which have serious implications for Physics in general, need to be addressed and the issues involved need to be cleared up openly within the scientific community as soon as possible. Lingering doubts concerning these is doing Physics no good at all but scientific fact, rather than perceived conventional wisdom, is what must determine the final outcome.