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Fundamental Invalidity of all Michelson-Morley Type Experiments

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Abstract

The null result of Michelson-Morley experiment (MMX) laid the foundation of Relativity and rejected the Newtonian notions of absolute space and time. Logically the null result of any experiment cannot be used to reject the hypothesis under test because the null result could also be caused by invalidity of any of the associated assumptions. The basic design of MMX involves an implicit assumption that changes in the photon flight time in axial and transverse beams, induced by the absolute motion of the setup, can be directly correlated with the corresponding changes in the phase of two beams at the exit end of the beam splitter. We show in this paper that this assumed correlation is fundamentally wrong. It is true that the flight time of a photon between two fixed points on the experimental setup does change with absolute motion of the setup and this has been correctly modeled in the MMX design. The instantaneous phase difference in the light beam, between same two points, does not change with absolute motion of the setup. In the MMX design, phase difference between two fixed points on the setup has been calculated on the basis of time interval alone, without taking into account the shift in corresponding positions on the wave due to the absolute motion of the setup. All modern MMX type experiments with electromagnetic resonators are based on erroneous assumption that the resonant frequency ν is proportional to the relative light speed (c±v) rather than the absolute light speed c.

Keywords: MMX, ether, space, absolute, isotropic, relativity, phase shift

1. Introduction

Albert A. Michelson, the first American Nobel prize winner in 1907, was the pioneer of interferometry. He had been President of the American Physical Society, National Academy of Sciences and a Fellow of the Royal Astronomical Society and the Royal Society of London. His most widely known contribution to science is the Michelson-Morley experiment (MMX) of 1887. The null result of this experiment laid the foundation of Relativity; yet Michelson never believed relativity to be a tenable theory. Isaac Newton founded classical mechanics on the notions of absolute space and absolute time. The absolute space and time do not depend upon physical events, but are a backdrop within which physical phenomena occur. Newton defined the true motion of a body to be its motion through absolute space, with respect to an ether fixed reference frame and termed it absolute motion. It was argued that if earth is moving through absolute space then we should be able to detect this absolute motion. The famous experiment by Michelson and Morley (1887) attempted to detect this motion of earth. The null results of MMX were interpreted to rule out the existence of absolute space and ether.

1.1 Notion of Ether

When it was understood that light propagates as a transverse wave, it was logical to presume that the wave must have a medium in which to travel. Since no medium was apparent, it was presumed that this medium must be transparent and not readily observable; hence it was called 'ether'. This ether was assumed to be stationary and the ether fixed reference frame was called absolute reference frame. It was required to be an elastic solid to enable the transverse light wave propagation through it. At the same time it was supposed to be an extremely thin medium to enable resistance free motion of solid bodies through it. This was essentially due to the fact that matter and ether medium were regarded as two separate, independent entities. Now, there is a growing realization that matter and electromagnetic field, both appear to have a common origin in empty space or vacuum. There is also the phenomenon of creation, annihilation and transmutation of unstable elementary particles occurring in vacuum. More recently, the gravitational waves are believed to originate in four dimensional spacetime (Einstein, 1916) and propagate in space as strain waves which can be physically detected. This implies the physical space to be a deformable and elastic entity which can support strain waves

(Roychoudhuri & Ambroselli, 2013). Therefore, these notions of physical space, empty space, vacuum and ether, all mean the same entity which can support transverse electromagnetic waves as well as strain waves.

The existence of physical space does not depend in any way on the existence or non-existence of coordinate systems and coordinate spaces. Of course, for the study and analysis of physical space and the material particles and fields embedded in it, we do need the structure of coordinate systems and coordinate spaces as a quantification tool. Whereas the metric scaling property (g_{ij}) is only associated with coordinate spaces, the physical properties of permittivity (ε_0), permeability (μ_0) and intrinsic impedance (Z_0) are only associated with the physical space. Now we have two different notions of vacuum or physical space; one with physical properties of ε_0, μ_0, c and $Z_0$and the second with fundamental physical properties of elasticity and inertia to enable transverse wave propagation through it. Thus we assume that the parameter $1/\varepsilon_0$ (or $c.Z_0$) represents the elastic constant and μ_0 represents the inertial constant of the physical space continuum or vacuum. The plausibility of this assumption is confirmed by the fact that square root of (elastic constant / inertial constant) represents the speed of strain wave propagation in an elastic continuum and the square root of $((1/\varepsilon_0)/\mu_0)$ also represents the velocity of transverse electromagnetic wave propagation in vacuum.

Let us consider the next question as to how exactly particles of matter could move through an elastic space without any resistance. For this we need to view material particles as a sort of lumped up strain energy, or, a sort of localized strain wave packets. For the Elastic Space continuum, the equilibrium equations of elasticity can be shown (Sandhu, 2009) to be identical to the vector wave equation. Particular solutions of these equilibrium equations as functions of space and time coordinates, satisfying appropriate boundary and stability conditions within a bounded region, can be shown to represent various strain wave fields and strain wave packets. The electromagnetic field as well as all other forms of energy and matter can be shown to exist in the elastic space continuum as strain wave fields or strain wave packets. In this regard it is interesting to note that at subatomic scale the primary constituents of matter, namely the electrons and nuclear particles are known to occupy an extremely small volume fraction of the order of 10^{-12} percent of the physical volume of any material body.

1.2 Wave Propagation and Interference

Electromagnetic waves are synchronized oscillations of electric and magnetic fields that propagate at the speed of light through vacuum. The oscillations of the two fields are perpendicular to each other and perpendicular to the direction of wave propagation, forming a transverse wave. The transverse electromagnetic waves in free space, characterized by zero divergence are represented by the following standard wave equations in terms of electric and magnetic fields,

$$\nabla^2\mathbf{E} = (1/c^2)\,\partial^2\mathbf{E}/\,\partial t^2 \tag{1}$$

$$\nabla^2\mathbf{B} = (1/c^2)\,\partial^2\mathbf{B}/\,\partial t^2 \tag{2}$$

There is a simple set of complex traveling wave solutions to these equations. For electric field they are,

$$E(r,t) = E_0 e^{\iota(\mathbf{k}.\mathbf{r}-\omega t)} \tag{3}$$

Here the angular frequency $\omega = ck$ and $\mathbf{k}$ is wave vector of magnitude $2\pi/\lambda$. This solution is a wave traveling in the direction of $\mathbf{k}$ in the sense that a point of constant phase ($\mathbf{k}.\mathbf{r} - \omega t$), moves along this direction with a speed c which is ω/k. Equation (3) reduces to a simple form for plane waves propagating along X-axis as,

$$E(x,t) = E_0 \mathrm{Cos}(kx - \omega t) \tag{4}$$

This continuous wave train propagating along X-axis is characterized by maximum amplitude E_0, wave length λ and angular frequency ω. Equation (4) represents plane surfaces of constant phase ($kx-\omega t$) moving along X-axis at speed c. The term constant phase here implies constant value of the cosine term which gives constant amplitude. Hence whenever we refer to the phase of a wave at certain point x or at certain instant of time t, it signifies corresponding amplitude of the wave as obtained from equation (4). When we visualize this wave train at certain fixed instant, we find a sinusoidal wave of amplitude spread out along X-axis. This sinusoidal wave also represents the variation of phase along X-axis. In general it is convenient and useful to refer to the variations of phase, instead of amplitude, along the wave train. The phase parameter plays an important role during superposition interactions among different coherent waves.

Interference is a phenomenon in which two waves superpose to form a resultant wave of different amplitude. Interference usually refers to the interaction of waves that are coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. The principle of superposition of waves states that when two or more propagating waves of same type are incident on the same point, the total amplitude at that point is equal to the point wise sum of the amplitudes of the individual waves. If a crest of a wave meets a crest of another wave of the same frequency at the same point, then the magnitude of the amplitude is the sum of the individual magnitudes – this is constructive interference. If a crest of one wave meets a trough of another wave then the magnitude of the amplitudes is equal to the difference in the individual magnitudes – this is known as destructive interference.

Constructive interference occurs when the phase difference between the waves is a multiple of 2π, whereas destructive interference occurs when the phase difference is an odd multiple of π. If the difference between the phases is intermediate between these two extremes, then the magnitude of the amplitude of the summed waves lies between the minimum and maximum values. Such interference patterns during superposition of two or more coherent waves can be physically detected or displayed on the target screen.

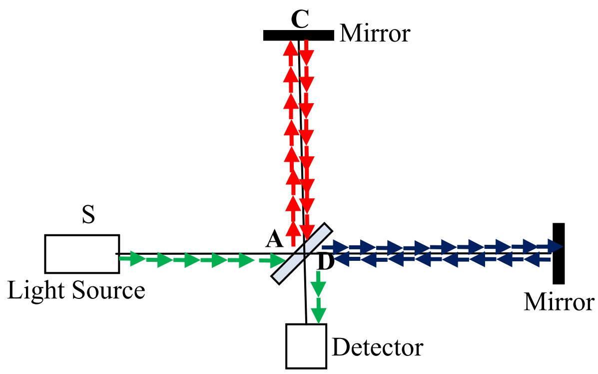

Figure 1. MMX setup – Static condition

2. Michelson-Morley Experiment (MMX)

The historic significance of MMX is due to the belief that it had proved the non-existence of ether whose rest frame would define Newton's absolute space. This test was planned to measure the speed of the Earth through the ether with Michelson interferometer. In the standard MMX setup a coherent beam of light from a single source is sent through a beam splitter that is used to split it into two beams. One of the beams continues to propagate in the original axial direction and the other propagates in the transverse direction. At the instant of split of the original beam at the beam splitter, both the axial and transverse components of the beam are in phase. After leaving the splitter at point A, the light beams propagate to the ends of long arms AC and AB, each of length L (say 11 m), where they are reflected back to the point D by small mirrors B and C (figure 1). The reflected beams then recombine on the far side of the splitter at D and then absorbed in a detector or an eyepiece E, producing a pattern of constructive and destructive interference fringes. Apparently, any slight change in the light path length of any of the beams in transit would then be observed as a shift in the positions of the interference fringes.

Let λ (say 550 nm) be the wavelength and f be the frequency of light waves propagating in the setup. When the MMX setup is stationary, the total light path length in each arm will be 2L and the number of wavelengths in each of the arms will be $N_0=2L/\lambda$. Total time taken by a photon or wave-front to travel this path length will be $T_0=2L/c$. Considering a photon to be represented by one wavelength of light, we can say that N_0 photons are lined up along light paths of the two beams, as illustrated in figure 1. Now consider the MMX setup to be moving with velocity **u** along the axial direction (figure 2). Because of the axial motion of the setup, during the time interval T_{ac} a photon in the transverse beam travels from the beam splitter A to the mirror C, the setup would have moved forward a distance uT_{ac}. Therefore, vertical component of light speed c will become $\surd(c^2\text{-}u^2)$ and the horizontal component u. Due to the symmetry of the outward and return paths, times of flight in the outward and return journeys will be equal. Hence the total flight time T_{acd} and the total light path length (L_{tr}) in the transverse arm for the outward A_1C_2 and return C_2D_3 paths will be,

$$T_{acd} = \frac{2L}{\sqrt{c^2-u^2}} = \frac{2L}{c}\frac{1}{\sqrt{1-\beta^2}} \tag{5}$$

$$\mathrm{L_{tr}} = \frac{2\mathrm{L}}{\sqrt{1-\mathrm{u}^2/_{\mathrm{c}^2}}} = \frac{2\mathrm{L}}{\sqrt{1-\beta^2}} \tag{6}$$

Here we have substituted β for u/c. Assuming that all photons in the transverse beam located within the MMX setup from front end A of the beam splitter to its rear end D, get aligned along the light path ($A_1C_2D_3$) length L_{tr}, the number of wavelengths (N_{tr}) will be given by,

$$\mathrm{N_{tr}} = \frac{2\mathrm{L}}{\lambda\sqrt{1-\beta^2}} = \frac{\mathrm{N_0}}{\sqrt{1-\beta^2}} \tag{7}$$

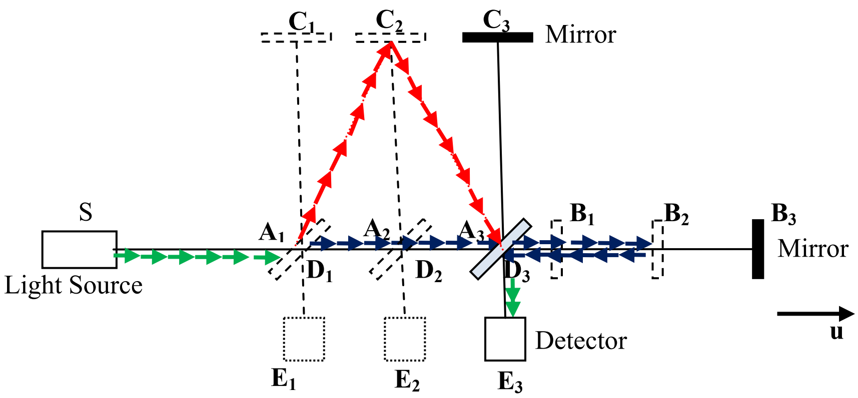

Figure 2. MMX setup in motion. Here photon traces $A_1C_2D_3$ and $A_1B_2D_3$ are assumed to represent transverse and axial light beams

Further, due to the axial motion of the setup, time taken by a photon in the axial beam to propagate from point A_1 in the beam splitter to mirror position B_2 will be L/(c-u). Similarly time taken by the reflected photon in the axial beam to propagate from mirror position B_2 to beam splitter position D_3 will be L/(c+u). The total time T_{abd} and total light path ($A_1B_2D_3$) length (L_{ax}) in the axial arm, both for the outward (A_1B_2) and return (B_2D_3) paths, will become,

$$\mathrm{T_{abd}} = \frac{\mathrm{L}}{\mathrm{c-u}} + \frac{\mathrm{L}}{\mathrm{c+u}} = \frac{2\mathrm{L}}{\mathrm{c}}\frac{1}{1-\beta^2} \tag{8}$$

$$\mathrm{L_{ax}} = \frac{\mathrm{L}}{1-\beta} + \frac{\mathrm{L}}{1+\beta} = \frac{2\mathrm{L}}{1-\beta^2} \tag{9}$$

Assuming that all photons in the axial beam located within the MMX setup from front end A of the beam splitter to its rear end D, get aligned along the light path ($A_1B_2D_3$) length L_{ax}, total number of wavelengths (N_{ax}) in the axial beam (figure 2) will be given by,

$$\mathrm{N_{ax}} = \frac{2\mathrm{L}}{\lambda(1-\beta^2)} = \frac{\mathrm{N_0}}{1-\beta^2} \tag{10}$$

Therefore, when the two beams finally recombine after leaving the splitter and after equal number of reflections from the mirrors, total change in time of propagation of a photon or wave-front (δT) in each beam in comparison with the propagation time T_0 in the static case, will be given by,

$$\delta T_{\mathrm{abd}} = \mathrm{T_{abd}} - \mathrm{T_0} = \mathrm{T_0}\left(\frac{1}{1-\beta^2} - 1\right) = \mathrm{T_0}\beta^2 \tag{11}$$

And

$$\delta T_{\mathrm{acd}} = \mathrm{T_{acd}} - \mathrm{T_0} = \mathrm{T_0}\left(\frac{1}{\sqrt{1-\beta^2}} - 1\right) = \frac{\mathrm{T_0}\beta^2}{2} \tag{12}$$

Net difference in photon propagation times along axial ($A_1B_2D_3$) and transverse ($A_1C_2D_3$) light paths will be,

$$\delta T_{\mathrm{net}} = \mathrm{T_{abd}} - \mathrm{T_{acd}} = \frac{\mathrm{L}}{\mathrm{c}}\beta^2 \tag{13}$$

This net difference in photon or light pulse propagation times along two mutually perpendicular paths works out to be of the order of femtoseconds. If this minute timing difference could be directly measured, it would have straight away provided a measure of absolute velocity u or β of the setup. Unfortunately this minute timing difference could not be directly measured. Under the circumstances, Michelson and Morley (1887) devised an ingenious method of detecting such minute timing differences by correlating it to the corresponding phase shifts in the two beams leading to observable fringe shifts on recombination of these beams. For establishing this correlation, light propagation times T_{abd} and T_{acd} are first converted to light path lengths L_{ax} and L_{tr} as in equations (9) and (6) above. From these path lengths, we can compute the number of wavelengths N_{ax} and N_{tr} accommodated on these light paths as in equations (10) and (7) above. Alternatively, the light propagation times T_{abd} and T_{acd} are directly converted to corresponding phase differences across the two beams as,

$$\Phi_{abd} = \omega T_{abd} = \frac{2\pi.cT_{abd}}{\lambda} = \frac{4\pi L}{\lambda}\frac{1}{1-\beta^2} \tag{14}$$

$$\Phi_{acd} = \omega T_{acd} = \frac{2\pi.cT_{acd}}{\lambda} = \frac{4\pi L}{\lambda}\frac{1}{\sqrt{1-\beta^2}} \tag{15}$$

Hence, the net phase difference between the two beams, on their recombination at the detector, will be given by,

$$\Phi_{abd} - \Phi_{acd} = 2\pi(N_{ax} - N_{tr}) = \frac{4\pi L}{\lambda}\left(\frac{1}{1-\beta^2} - \frac{1}{\sqrt{1-\beta^2}}\right) = \frac{2\pi L}{\lambda}\beta^2 \tag{16}$$

Taking estimated orbital speed of earth as 30km/s or $\beta=10^{-4}$, the expected phase difference of 0.4π between the two beams turns out to be quite small. After the device is rotated by 90 degrees, the axial and transverse beams would interchange. After rotating the setup one full circle and comparing the results from two maximum, minimum positions, double phase shift of 0.8π was expected which is equivalent to 0.4 fringe widths. When the experiment was actually performed there was no shift at all on rotation of the setup. Something had to be wrong either in the experiment, or the theory. Michelson and Morley were confident that there was no flaw in the experiment and hence lack of any fringe shift, known as 'null result', with rotation of the apparatus was quite perplexing.

3. Implication of the Null Result in Michelson-Morley Experiment

The null result of MMX implied that regardless of the relative velocity of MMX setup with respect to the ether fixed absolute reference frame, the axial and transverse beams actually always reach back in phase. It means that total number of wavelengths accommodated from entry point A to exit point D in each of the two beams either does not change with the motion of the setup or change by equal amounts. Apparently it implies that total time of flight of any photon from entry point A to exit point D in each of the two beams either does not change with the motion of the setup or changes by equal amount. This null result had so far been explained through ad hoc assumptions of length contraction in the direction of motion, time dilation and the postulates of Special Theory of Relativity.

The null result of Michelson-Morley experiment inadvertently turned out to be a pivotal turning point, the trigger for a paradigm shift in modern physics. This paradigm shift discarded the Newtonian notions of absolute space and time and pushed the fundamental physics into the realm of abstract mathematical models (Einstein, 1905, 1916). Following consequences of the null result of MMX have changed the course of modern physics.

a) Existence of luminiferous ether medium ruled out.

b) Isotropy of the speed of light in all inertial reference frames accepted as a postulate.

c) Relative distances and time in different inertial reference frames came under Lorentz Transformations.

d) Modern physics became completely frame invariant with the elimination of absolute reference frame.

e) Physical space changed to empty space and got characterized by metric properties.

f) Lorentz Invariance became the hallmark of all modern theories of physics.

g) Four dimensional spacetime, metric expansion of space and Big-Bang cosmology gained credibility.

Therefore, we need to re-examine the null result of Michelson-Morley experiment and seek an alternative interpretation for the same. Let us first examine efficacy of any Null experiment. For proper scientific evaluation of any hypothesis, an appropriate experiment is often designed to produce a measurable physical output in the event of a true or valid hypothesis. However, if such an experiment yields a null result, it is invariably interpreted as implying a false or invalid hypothesis. In the design of an appropriate experiment for evaluation of certain hypothesis, a number of assumptions are often required to be made. Some of these assumptions are implicit which are either not considered or their validity taken for granted as axiomatic. Positive outcome of the experiment is based on the strict condition that all of these assumptions must be valid in the physical environment under which the experiment is being conducted. If any one or more of the assumptions associated with the experiment are not true, the experiment will give a null result even if the main hypothesis under test is true. Hence, if an experiment designed to evaluate a particular hypothesis yields null result, we must discard the experiment as a failure but logically cannot confirm the invalidity of the hypothesis. Applying this logic to the null result of MMX, we need to examine whether any of the underlying implicit assumptions of the experiment are invalid or faulty.

4. Fundamental Error in the design of original MMX type Experiments

Basic design of the original MMX type experiments involves three essential steps.

- Splitting a coherent beam of light into axial and transverse beams at the entry point A of the beam splitter and after reflections from the end mirrors of each arm, their recombination at the exit point D of the beam splitter.
- Computing the time of flight of a photon or a wave-front from the entry point A to the exit point D of the beam splitter in each of the two beams. When the MMX setup is in absolute motion along one of the arms, the time of flight works out to be different for the two beams. The precise difference in the flight times in two beams depends on the absolute velocity of the setup.
- Since the difference in time of flight in two beams is too small for direct measurement, this difference in flight time is first correlated with the corresponding phase difference between two beams at the recombination point D. This phase difference leads to the measurable fringe shift at the detector end which could be used to estimate the absolute velocity of the setup.

The last step in the basic design of MMX involves an implicit assumption that changes in the photon flight time in axial and transverse beams, induced by the absolute motion of the setup, can be directly correlated with the corresponding changes in the phase of two beams at the exit end D of the beam splitter. The validity of this assumption has been taken for granted as a matter of fact and has never been questioned. We shall examine the basis of this assumption in detail and show its invalidity.

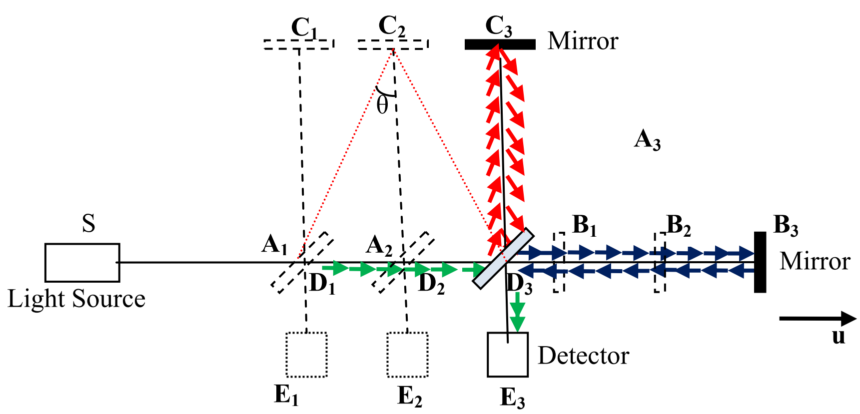

Figure 3. Photon traces $A_1C_2D_3$ and $A_1B_2D_3$ do not represent physical location of the light beams at any instant. Here each small arrow represents millions of wavelengths. Inclination angle θ is less than a milliradian which is exaggerated here for illustration

4.1 Photon Traces don't Coincide with Light Beams in Moving Setup

First of all let us examine the change in shape, length and relative orientation of the two light beams with the absolute motion of the setup. On comparing the beam traces in figures 1 and 2, we find that the transverse beam becomes inclined with respect to the transverse direction as represented by path $A_1C_2D_3$ in figure 2. Also the axial beam becomes of unequal length in its forward and return paths $A_1B_2D_3$. But on close scrutiny we find that the light paths $A_1C_2D_3$ and $A_1B_2D_3$ in figure 2 only represent the traces or paths of single photons in the two beams and do not represent the complete transverse and axial beams being located on these paths at any instant of time. Assuming there are a total of N photons contained in the outgoing transverse beam of light, then the path A_1C_2 is the trace of only one of the N photons which got reflected from the beam splitter at an instant t_1 when the splitter was located at A_1. At any later instant of time $t<t_2$ this photon will always be found on the intersection of A_1C_2 and the instantaneous transverse line joining beam splitter A to the mirror C, just because the axial component of light velocity **c** is equal to u. Traces of all other photons will be right shifted paths parallel to A_1C_2 but at any specific instant all N photons will be found located on the instantaneous transverse line joining beam splitter A to the mirror C. That is, at any instant of time whole of the transverse beam is physically located between points A and C along the transverse axis as shown in figure 3.

Similarly, the axial light path $A_1B_2D_3$ in figure 2 only represents the trace of a photon that crossed the beam splitter at instant t_1 (position A_1) and has just returned back to the beam splitter at point D_3. It does not represent the physical location of complete axial beam at any instant. At any instant of time whole of the axial beam is physically located between points A to B and B to D along the axial direction as shown in figure 3. Therefore, it is quite obvious that since the axial and transverse light beams are never physically located on the photon traces $A_1B_2D_3$ and $A_1C_2D_3$ (figure 2), the number of photons or wavelengths contained in these beams cannot be computed from the length of these photon traces. Even in the case of absolute motion of the MMX setup, both axial and transverse beams will be fully accommodated in between the beam splitter and the reflecting mirrors at all times (figure 3), just as in the static case. Hence the number of photons or wavelengths contained in these beams can be fully determined from the physical length of the two arms of the setup, irrespective of the state of motion of the setup.

4.2 Phase Differences Across a Propagating Wave Train

After ascertaining that both axial as well as transverse beams of light are completely accommodated in between the beam splitter and the reflecting mirrors at all instants of time, let us now examine the phase relationships at the two ends of these beams. Since both beams encounter equal number of reflections from mirrors, we need not consider phase changes after reflections in each of these beams while discussing their phase relationships at the two ends. As the source beam of light is a coherent beam, the axial and transverse beams must be in phase at the entry point A of the beam splitter. We need to determine their mutual phase difference $\Delta\Phi_d$ when they return back to point D for recombination. For this we must first ascertain the total phase change from entry point A to the exit point D of both the axial and transverse beams separately at any instant of time. Let this total phase change from A to D be Φ_{ax} for the axial beam and Φ_{tr} for the transverse beam at any given instant of time. Therefore, their mutual phase difference at point D will be given by,

$$\Delta\Phi_d = \Phi_{ax} - \Phi_{tr} \tag{17}$$

When the MMX setup is static in the absolute reference frame, with its axial and transverse arms of equal length L, total phase change from A to D in both arms will be equal.

$$\Phi_{ax} = \Phi_{tr} = 2\pi\left(\frac{2L}{\lambda}\right) \tag{18}$$

Hence the mutual phase difference $\Delta\Phi_d$ between the two beams at point D will be zero in the static case. Now we need to examine whether this mutual phase difference $\Delta\Phi_d$ will change with the absolute motion of the MMX setup or not. For this purpose we shall have to first examine the variation, if any, in the total phase change Φ_{ax} and Φ_{tr} in the two beams, with the absolute motion of the setup. Let us consider a monochromatic beam of light composed of a train of sinusoidal plane waves propagating along X-axis, as given by,

$$E(x,t) = E_0\mathrm{Cos}(kx - \omega t + \emptyset_0) = E_0\mathrm{Cos}\left(\frac{2\pi(x-ct)}{\lambda} + \emptyset_0\right) \tag{19}$$

Let this wave train pass through a hollow cylindrical pipe PQRS of length L as shown in figure 4. We may assume that the open ends PS and QR of this pipe are closed with thin transparent glass sheets. Let A be the entry point of the beam on face PS and B be the exit point from face QR. Therefore, length of the light beam enclosed within the pipe is L. As the light wave is propagating along X-axis, let x_1 be the location of point A and (x_1+L) be the location of point B be on the wave train at a given instant of time. Further at any instant t, let $\Phi_A(t)$ be the instantaneous phase of the light beam at point A and $\Phi_B(t)$ be the phase at point B of the pipe. Then the phase difference $\Phi_{BA}(t)$ between the two end points A and B at any instant t is given by $[\Phi_B(t)- \Phi_A(t)]$ as,

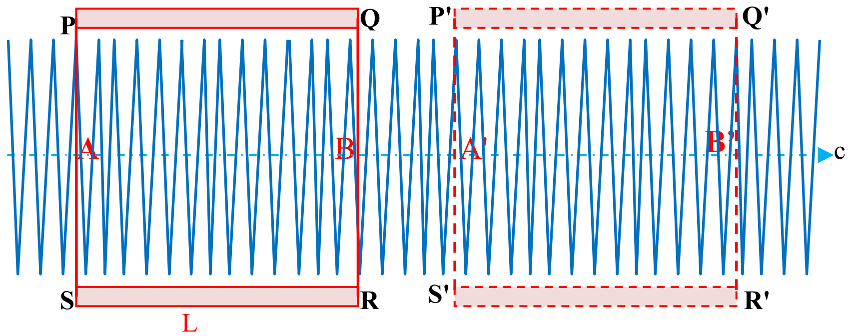

Figure 4. Illustration of phase difference Φ_{BA} on a wave train

$$\Phi_{BA}(t) = \left(\frac{2\pi(x_1+L-ct)}{\lambda} + \emptyset_0\right) - \left(\frac{2\pi(x_1-ct)}{\lambda} + \emptyset_0\right) = \frac{2\pi L}{\lambda} \tag{20}$$

It turns out that the phase difference between two ends of the pipe depends only on length L and wavelength λ and not on the instantaneous position of the pipe through which the beam of light is propagating.

This can also be visualized from figure 4 by noting that shifting the position of the pipe PQRS to any other position P'Q'R'S' along the wave train does not change the number of wavelengths accommodated within the pipe. This situation can be further generalized by letting the pipe change its position gradually along the wave train. That is, if we let the pipe move along X-axis at uniform speed u, the number of wavelengths accommodated within the pipe, at any instant of time, will remain unchanged as L/ λ. We can account for the effect of uniform speed u of the pipe along the wave train by substituting x_1+ut in place of x_1 in equation (20) above. This shows that the phase difference $\Phi_{BA}(t)$ between the two end points A and B at any instant t remains unchanged or invariant with absolute motion of the pipe PQRS. This is true for both positive and negative values of u. Even if we replace the pipe end B with a reflecting mirror (figure 5), the total phase difference across both ends of the pipe will still remain invariant with motion.

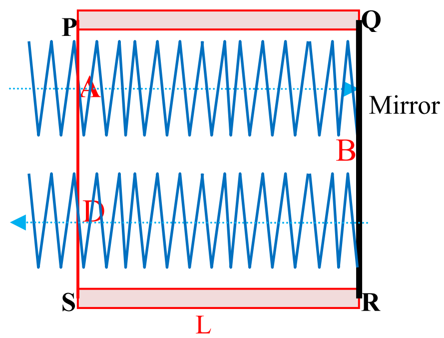

Figure 5. Illustration of total phase difference Φ_{DA} across a reflected wave train

4.3 Motion Induced Change in Photon Flight Time between Points A and B on the Setup

Now let us examine the time taken by a photon or a wave-front to travel from entry point A to the exit point B when the pipe PQRS is moving with uniform speed u along the X-axis. If we tag a particular photon or wave-front when it crosses point A on the pipe then during the time τ_1 it takes to reach the exit point B, whole pipe, including point B, would have moved forward by a distance $u\tau_1$. Hence time τ_1 will be given by,

$$\tau_1 = \frac{L}{c-u} \tag{21}$$

That means the photon or wave-front takes longer to travel from A to B when the pipe is moving with speed u in comparison with the static case. But if the pipe is moved in opposite direction with same speed, in a direction anti-parallel to the direction of propagation of the wave train, then the time taken by a photon to propagate from entry point A to exit point B of the pipe will be shorter and given by,

$$\tau_2 = \frac{L}{c+u} \tag{22}$$

If we replace the exit end B of the pipe with a reflecting mirror (figure 5) and assuming the reflected beam on its return path crosses the PS end at point D, total time taken by a photon to propagate from point A to B and back to D will be given by equation (8),

$$\tau_{abd} = \frac{L}{c-u} + \frac{L}{c+u} = \frac{2L}{c}.\frac{1}{1-\beta^2} \tag{23}$$

In fact if we could separately measure the two times τ_1 and τ_2 then from equations (21) and (22) we can directly compute the absolute speed u of the hardware setup as,

$$u = c.\frac{\tau_1-\tau_2}{\tau_1+\tau_2} \tag{24}$$

This confirms the variation in time of flight of a light pulse from A to B or A to D, with absolute motion of the hardware setup. A close scrutiny of the situation reveals that the absolute motion of the hardware setup, through which the wave train is propagating, does not affect the wave propagation in any way. Once we tag a particular photon crossing entry point A, it is the absolute motion of the target point B which leads to the variation in the time of flight and not any change in characteristics of the wave train. On the other hand the phase difference $\Phi_{BA}(t)$ between the two end points A and B remains unchanged or invariant with absolute motion of the pipe precisely because the phase of the wave at the end points A and B is determined at the same instant of time and the beam length L between the two end points remain unchanged. We may elaborate this point with reference to equation (19).

4.4 Phase Changes Across a Wave Train due to Time and Position Shifts

The phase parameter Φ in equation (19) depends on two variables, namely x and t. If we vary both x and t in such a way that x=ct then phase will remain constant and it will represent propagation of a constant phase wave-front along X-axis at speed c. If we fix $x=x_1$ and let only t vary then equation (19) will give us the pattern of phase variation at fixed location x_1 for different values of t. For example, at the fixed location x_1 we can determine the change in phase during a specific interval of time from t_1 to t_2 as,

$$\Phi_{12}(x_1) = \Phi(x_1, t_1) - \Phi(x_1, t_2) = \omega(t_2 - t_1) \tag{25}$$

It is important to note here that total change in phase during a time interval $(t_2\text{-}t_1)$ is always specified for some fixed location x_1, although this change does not explicitly depend on that location parameter x_1. This result (equation 25) will not be valid if during the time interval $(t_2\text{-}t_1)$ the location also changes from x_1 to say x_2. However, in MMX the time T_{abd} taken by a photon to propagate from point A to B and back to D (equation 8), has been erroneously used to compute the phase difference across the axial beam (equation 14) since absolute positions of the reference points do change during this time interval due to the absolute motion of the setup. Similarly the time T_{acd} taken by a photon to propagate from point A to C and back to D (equation 5), has been erroneously used to compute the phase difference across the transverse beam (equation 15) since absolute positions of the reference points do change during this time interval.

On the other hand, if we fix $t=t_1$ and let only x vary then equation (19) will give us the pattern of phase variation for different values of x at the given instant t_1. For example, at any instant of time t_1 we can determine the difference in phase over a specific segment of distance from x_1 to x_2 as,

$$\Phi_{21}(t_1) = \Phi(x_2, t_1) - \Phi(x_1, t_1) = \frac{2\pi(x_2-x_1)}{\lambda} \tag{26}$$

This relation is identical to equation (20) and gives the phase difference over a beam length $(x_2\text{-}x_1)$ at any specific instant of time t_1. It is important to note here that total phase difference over a distance segment $(x_2\text{-}x_1)$ is always specified for some instant of time t_1. This result (equation 26) will not be valid if along with distance the time also changes from t_1 to say t_2. That is, we cannot use equations (25) or (26) if we want to ascertain the phase difference between space-time points $P(x_1,t_1)$ and $Q(x_2,t_2)$ on the wave train. In such cases we need to use equation (19) for computing the phase difference. Thus the phase difference over a given beam length L is always ascertained at a given instant of time, even if this phase difference remains constant for all instants.

From the foregoing discussion we find that the most crucial step in the design of MMX that correlates the motion induced changes in the photon flight time in axial and transverse beams, to the corresponding changes in the phase of two beams is fundamentally wrong. This correlation has been found to be invalid primarily on following grounds.

a) Individual photon traces $A_1C_2D_3$ and $A_1B_2D_3$ on transverse and axial light paths (figure 2) do not represent the physical location of full transverse and axial beams of light consisting of billions of photons. Physical light beams actually remain located strictly on transverse direction ACD for the transverse beam and on axial direction ABD for the axial beam, as shown in figure 3, at all instants of time even during absolute motion of the setup.

b) Individual photons or light pulses after crossing point A of the beam splitter do experience a change in flight time for reaching up to point D on light paths $A_1C_2D_3$ and $A_1B_2D_3$ due to the absolute motion of the setup. This change is due to the fact that after crossing point A at an instant t_1, by the time a photon or light pulse reaches the target point D the target point itself shifts its position due to the absolute motion of the setup. This change in flight time is not attributed to any change in the wave characteristics of the propagating axial or transverse light beams.

c) Since the two beams are in phase at the instant of their separation at point A of the beam splitter, any difference in their phase on recombination at point D can only be due to some variation in the total phase difference Φ_{21} between two specific points x_1 and x_2 on the beam at any instant of time. But from equations (20) and (26) we have seen that between any two fixed points on the setup the total phase difference Φ_{21}, at any instant, does not vary with absolute motion of the setup. We may visualize this situation as a wave train (equation 19) propagating in the background absolute space, while points A and B on the hardware setup are just the position markers in the foreground local frame that correspond to points x_1 and x_2 on the background absolute frame. When the hardware setup moves, then both marker points just shift their position equally along the wave train without affecting total phase difference from x_1 to x_2 at any given instant. Therefore, for the axial and transverse beams of light AB,BD and AC,CD bound between fixed points of the MMX setup (figure 3),the total phase difference Φ_{DA} does not vary with absolute motion of the setup. Hence the change in flight times over two light paths cannot be correlated with any phase shifts on the axial and transverse light beams.

d) When the MMX setup is static, a photon flight time $T_0=2L/c$ can be used to compute the corresponding beam length and total phase difference across this beam length is given by ωT_0. However, when the MMX setup is in motion in the absolute reference frame, a photon flight time T_{abd} (equation 8) cannot be used to compute the beam length L_{abd} (figure 3) or total phase difference across this beam length. That is because during absolute motion of the setup both position (x) and time (t) parameters at the marker points A and D change for the wave train (Eqn. 19) and total phase change during an interval of time (T_{abd}) can be computed only when the position parameter x can be held constant (equation 25). Therefore, when photon flight time varies with absolute motion of the setup, it cannot be correlated with corresponding phase difference across the beam length defined by fixed points on the moving setup.

Therefore, we finally conclude that all MMX type of experiments that attempted to detect absolute motion through measurements of shifts in interference fringes on recombination of two mutually perpendicular beams of coherent light, were fundamentally flawed experiments. The fundamental error committed in the basic design of these experiments was the invalid correlation between motion induced variation in photon flight times and the corresponding variation in phase of the light beams across two fixed points on the setup. All modern MMX type experiments that rely on shift in interference fringes to measure photon flight time delays in two mutually perpendicular beams of coherent light are equally flawed and invalid. Hence all conclusions and fundamental viewpoints that were based on the null result of MMX type experiments need to be rejected or reviewed.

5. Explanation for Null Result in Advanced MMX Type Experiments

Kennedy and Thorndike (1932) conducted a modified form of the MMX experiment by making one arm of the classical MMX apparatus shorter than the other one. While the null result of the MMX could be relativistically explained by length contraction alone, the Kennedy–Thorndike experiment required time dilation in addition to length contraction to explain the null result. However, as discussed in previous section, the null results of both the MMX and Kennedy–Thorndike type experiments are actually attributed to the invalid correlation between absolute motion induced variation in photon flight times and the corresponding variation in phase of the light beams across two fixed points on the setup.

Modern MMX type experiments use electromagnetic resonators to probe for directional anisotropy of space. These are generally based on comparing the resonance frequencies of two similar orthogonal resonators while actively rotating the setup. The basic principle of a modern MMX type experiments is to search for absolute motion induced relative changes of the frequencies $\delta\nu/\nu_0$ in the employed resonators or microwave cavities. For example, Brillet and Hall (1979) mounted such a cavity on a rotating table. Any orientation dependent change in the speed of light would lead to a corresponding orientation dependence of the frequency of microwaves resonant with the cavity. The null result of the Brillet–Hall experiment, which looked for such dependence, was interpreted to imply isotropy of speed of light in all inertial reference frames in relative motion.

In a resonator cavity the light wave is repeatedly reflected from the end mirrors of the resonator. The electric field intensity of the wave at the mirrors is zero that constitutes a boundary condition for a node. At a given distance L, the mirrors can only form standing waves which have the field intensity of zero at both end nodes. Several waves can fit into the resonator if an integer multiple of half the wavelength (λ) is equal to L. Hence frequencies of electromagnetic waves resonant within a cavity of length L are $\nu=c/\lambda$, and $L=m\lambda/2$, where m is an integer that denotes the wave number of the resonant wave. Therefore the resonant frequency is,

$$\nu = \frac{c.m}{2L} \tag{27}$$

Here c is the speed of light in vacuum or ether or physical space which supports the propagation of light waves. That is, c is the speed of light with reference to the absolute reference frame. When the resonator hardware setup moves with speed v in the absolute frame, in a direction parallel or anti-parallel to the direction of propagation of light wave, then with respect to the resonator setup the relative speed of light wave propagation will be (c±v). In other words, from the perspective of an observer at rest in the resonator frame, the light wave will appear to be propagating at a relative speed of (c±v). However, the absolute motion of the hardware setup cannot influence or change the characteristics of the wave propagating in ether or absolute space until the wave starts interacting with the detector or gets absorbed in the detector. The main error in the design of all modern MMX type experiments using electromagnetic resonators is the implied assumption that the resonant frequency ν (equation 27) is proportional to the relative light speed (c±v) rather than the absolute light speed c. In reality the relative light speed is useful for computing the time of approach and modeling the matter-wave interaction at the time of light absorption in a detector but it cannot influence the propagation characteristics of the wave. The 'null result' obtained in all such experiments is directly attributed to this erroneous implicit assumption.

As discussed earlier, let us again consider a wave train (equation 19) passing through a hollow cylindrical pipe PQRS of length L as shown in figure 4. We found that the phase difference between two ends of the pipe depends only on length L and wavelength λ and not on the instantaneous position of the pipe through which the beam of light is propagating (equation 20). Even a shift in the position of the pipe PQRS to any other position along the wave train, does not change the number of wavelengths accommodated within the pipe. That is, if we move the pipe along the wave train at uniform speed v, the number of wavelengths accommodated within the pipe at any instant, will remain unchanged as L/λ. Thus, the main characteristics ν, λ and c of the wave train propagating in absolute space, cannot be influenced by any motion of the enclosing pipe PQRS.

Finally, let us assume that both ends of the hollow pipe PQRS are closed with perfectly reflecting mirrors, turning it into a resonator, so that the enclosed standing wave is represented by equation (27). When the resonator is moved axially towards either side, the end mirrors acting as boundary nodes of the standing wave will simultaneously move along by same amount. With this movement of the resonator, whole standing wave will get shifted without affecting its wave characteristics. When the resonator is set in motion in the physical space or ether, the space or ether medium within the resonator does not move along. The space or ether medium remains fixed in the absolute reference frame whereas the resonator does move in this frame. As such the wave characteristics of the standing wave are governed by the permittivity (ε_0) and permeability (μ_0) of the space which remains fixed in the absolute reference frame. Hence the speed of light c, characterizing the standing waves within the resonator, does not change with the absolute motion of the resonator. This explains the null result of all modern MMX type experiments using electromagnetic resonators which wrongly attempted to link the resonance frequency ν with the relative light speed (c±v) with respect to the moving resonator setup.

6. Alternative Test for Detection of Absolute Motion through Time Measurements

The original MMX was based on the motion induced change in photon flight time between two fixed points on the hardware setup. This change in photon flight time over two perpendicular arms of the setup was quantitatively related to the absolute velocity of the setup (equation 13). However, this time difference being of the order of a fraction of a femtosecond, could not be directly measured with available technology at that time. If Michelson and Morley could measure this minute time difference, they would have obtained a positive result and obviated the necessity of propounding the Relativity theory. By attempting to measure this minute time difference through erroneous correlation with phase changes across the two beams they gave way to the famous null result with serious repercussions. Unfortunately, all subsequent MMX type experiments continued to search for absolute motion induced shifts in phase or frequency of light waves with ever increasing sophistication but no one attempted to measure the absolute motion induced change in photon flight time.

With current technological advancements in atomic time measurements and pulsed lasers, modern MMX type experiments based on absolute motion induced change in light pulse propagation time across two perpendicular arms on the surface of earth, can be easily planned and conducted. One such experiment was proposed by Sandhu (2010) for detection of absolute motion simply by measuring pulse propagation times between two fixed points A and B on the surface of earth. Suppose an ultra short laser pulse takes T_{ab} time to propagate from point A to point B and another pulse takes T_{ba} time to propagate from point B to point A, then a component of absolute velocity U_{ab} along AB is given by (equation 24),

$$U_{ab} = c.\frac{T_{ab}-T_{ba}}{T_{ab}+T_{ba}} \tag{28}$$

To determine the complete absolute velocity vector U of earth, we need to determine one more component of this velocity in a direction perpendicular to AB. For this we can select another point C on the surface of earth such that line segment AC is perpendicular to AB. Again if an ultra short laser pulse takes T_{ac} time to propagate from point A to point C and another pulse takes T_{ca} time to propagate from point C to point A, then component of absolute velocity U_{ac} along AC is given by,

$$U_{ac} = c.\frac{T_{ac}-T_{ca}}{T_{ac}+T_{ca}} \tag{29}$$

Points AB and AC constitute two perpendicular arms of an L-shaped test setup, just as in Michelson interferometer. Each arm of this setup could be of 3 km to 30 km length depending on whether the atomic clock used in the test is of sub-nanosecond or nanosecond accuracy. The LIGO Livingston and Hanford Observatories support L-shaped ultra high vacuum systems, measuring 4 kilometers on each side. On the side lines of gravitational wave detection at these or similar observatories, the proposed tests for detection of absolute motion of earth can be easily conducted in a few days time. All components of the required test equipment are already in use in the 'Time Transfer through Laser Links' (T2L2) experiments (Guillemot et.al., 2009) which have been well established. Each set of the test equipment includes a solid state pulsed laser with picoseconds pulse width and single shot option, laser detector with focusing optics, Cesium atomic clock with picoseconds resolution, high precision event timer and data acquisition computer. Following the procedure detailed by Sandhu (2010), absolute velocity of earth can be easily determined. Determination of absolute velocity of earth has also been proposed by Sandhu, (2012) by physically measuring the absolute synchronization offsets between the master clocks at two distant Timing Labs with an appropriate portable clock.

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