<u>Michelson-Morley Revisited with Occam's Razor</u>

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<u>Abstract</u>. *The results of the Michelson-Morley Experiment (MMX), allegedly showing that an aether medium for the propagation of light did not exist, were interpreted by Einstein under the constraint of a constant light speed. This led him to invent Special Relativity, not necessarily the simplest or most logical explanation, as would have been recommended by Occam's Razor. MMX is revisualized here, relaxing these constraints to show what might have been the better conclusion, or at least dismissal of the MMX as a basis for inventing Special Relativity.*

<u>Key Words</u>: Michelson-Morley, Dayton Miller, Light, Aether, Lasers, Interferometer, Relativity, Occam's Razor

1. INTRODUCTION

The Michelson Morley Experiment (MMX) was a key to Einstein proposing his theory of Special Relativity, based on the alleged "null" result indicating no aether existed. Given his constraint of a constant light speed (c), he felt compelled to assume relativistic effects (length contraction/time dilation via Lorentz transforms) to explain why there was no difference in the behavior of light over the two perpendicular directions. In actuality, MMX did observe some difference (later confirmed even more strongly by Dayton Miller), albeit viewed as sufficiently less than expected for the then known only motion of the Earth through an assumed "stationary" aether at 30 km/s. [1]

The following examines the two extremes from MMX (difference in light behavior observed [but dismissed] by MMX vs. no difference concluded by MMX), without invoking relativity, by treating light first as a "ballistic" phenomenon (e.g., photon "particle") and then as a wave phenomenon (generated by an aether medium). In the spirit of Occam's Razor ("in light of multiply possible explanations, the simplest is usually best"), we show that inventing Special Relativity did not satisfy Occam's Razor since simpler, logical explanations were possible, both without and with and aether. [2] Finally, the case for "partially entrained (dragged)" aether is presented (and a parallel for the "no-aether" case), corresponding to what might actually have been the true results from MMX and Dayton Miller.

2. CASE 1: NO AETHER, LIGHT SPEED CONSTANT AT C

Lasers did not exist at the time of MMX, so performing the experiment with monochromatic, unidirectional light was not an option. Calkins has championed the use of lasers in light experiments [3], and it is with this in mind the following revisualization of MMX is presented. Figure 1 shows a revisualization of just the portion of the MMX interferometer from the junction of the two arms where the original beam was split to the two reflecting mirrors. Now, place red and blue lasers at this junction and allow them to activate simultaneously, sending monochromatic, unidirectional red and blue beams along arms. Assume the red beam reaches the mirror/laser at end of its arm in time τ; the blue beam reaches the mirror/laser at end of its arm at time t. To avoid any complication of possible "absorption effect" at each mirror, we can visualize two lasers exactly the same as the originals that activate upon impingement of respective beams, corresponding to "perfect" reflection (i.e., no delay or loss of energy) of the beams by the mirrors. Let the red beam returns to original launch point in time θ; the blue beam returns to original launch point in same time t as before due to symmetry in the perpendicular direction. Assume the entire interferometer is in orbit above the Earth and moving to the right at maximum constant speed v = 0.003c, derived as follows.

The orbital speed of an object about the equator ≈ 8 km/s. [4] Earth's rotational speed at the equator ≈ 0.5 km/s. [5] Earth's speed of revolution about the sun ≈ 30 km/s. [6] The sun's speed of revolution about the galaxy ≈ 230 km/s. [7] The Milky Way Galaxy's speed through "space" ≈ 580 km/s. [8] Combining these yields a total maximum orbital speed through "space" ≈ 850 km/s, rounded to 900 km/s, or 0.3% light speed c (3.00 x 10^5 km/s). Note that this approximation would hold even for the fastest man-made object ever launched.

> *The record holder is ... the New Horizons mission to Pluto and the Kuiper belt. Launched by NASA in 2006, it shot directly to a solar system escape velocity. This consisted of an Earth-relative launch of 16.26 kilometers a second (that's about 36,000 miles per hour), plus a velocity component from Earth's orbital motion (which is 30 km/s tangential to the orbital path). Altogether this set New Horizons barreling off into the solar system with an impressive heliocentric speed of almost 45 km/s or 100,000 miles per hour."* [9]

Let us view light motion from the "preferred" reference frame of "space" (i.e., that frame in which the galaxy is moving at 580 km/s,) such that the interferometer, when all vectors align as optimally as possible, moves at 900 km/s. Note that, unlike Calkins, the laser beam is assumed to acquire the motion of its source, essential for the blue beam being able to complete its round trip.

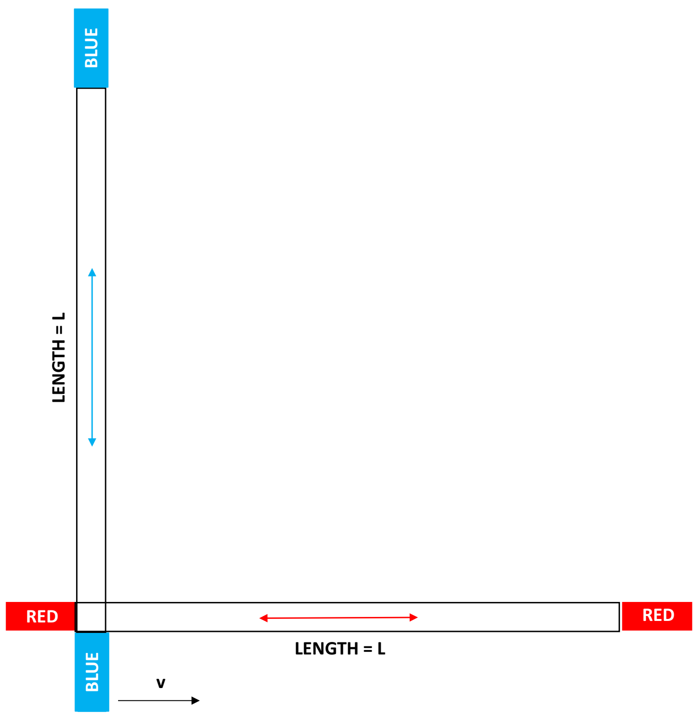


Figure 1. Interferometer with Laser Light Sources

The blue beam travels a distance = $\sqrt{L^2 + v^2t^2}$ in time t at speed c from the launch point to its mirror/laser (the interferometer has traveled a distance vt to the right), where $t = \sqrt{L^2 + v^2t^2}/c \rightarrow c^2t^2 = L^2 + v^2t^2 \rightarrow t = L/\sqrt{c^2 - v^2}$. Meanwhile, the red beam travels a distance $= L + v\tau$ in time τ at speed c from the launch point to its mirror/laser (the interferometer has traveled a distance $v\tau$ to the right), where $\tau = (L + v\tau)/c \rightarrow c\tau = L + v\tau \rightarrow \tau = L/(c - v)$. Since $t/\tau = (c - v)/\sqrt{c^2 - v^2} = (c - v)/\sqrt{(c + v)(c - v)} = \sqrt{(c - v)/(c + v)} < 1$, the blue beam travel time is shorter. For the return trips, the blue beam again travels the same distance at the same speed (the interferometer has traveled an additional distance vt to the right), so $t = L/\sqrt{c^2 - v^2}$ as before. Now the red beam travels a distance $= L - v\theta$ in time θ at speed c from the mirror/laser back to the original launch point (the interferometer has traveled an additional distance $v\theta$ to the right), where $\theta = (L - v\theta)/c \rightarrow c\theta = L - v\theta \rightarrow \theta = L/(c+v)$. Since $t/\theta = (c+v)/\sqrt{c^2 - v^2} = (c+v)/\sqrt{(c+v)(c - v)} = \sqrt{(c+v)/(c-v)} > 1$, the red beam travel time is now shorter. In total, the blue beam travel time is $2t = 2\,L/\sqrt{c^2 - v^2}$; the red beam travel time is $\tau + \theta = L/(c - v) + L/(c+v) = 2Lc/(c^2 - v^2)$. Since $2t/(\tau + \theta) = (c^2 - v^2)/c\sqrt{(c^2 - v^2)} = \sqrt{(c^2 - v^2)}/c = \sqrt{1 - v^2/c^2} < 1$, the total round trip for the blue light is shorter. Therefore, one should see the blue light flash slightly before the red light upon their return to the interferometer junction. Of course, given v = 0.003c at most, this time difference will be only 4.5 x 10^{-4}%. If we could even construct, say, an interferometer in earth orbit with arm lengths = 100 m (roughly a football field), the time difference would amount only to $\frac{2(100m)(4.5x10^{-6})}{3.00\ x\ 10^8 m/s} = 3x10^{-12}\ s$, i.e., 3 ps, or the time for light to travel about 1 mm – the wavelength of the shortest microwaves. [10]

3. CASE 2: NO AETHER, VARIABLE LIGHT SPEED (LIGHT ACQUIRES VELOCITY OF SOURCE)

As in Case 1, the blue beam travels a distance = $\sqrt{L^2 + v^2t^2}$ in time t at speed $\sqrt{(c^2 + v^2)}$ from the launch point to the mirror/laser (the interferometer has traveled a distance vt to the right), where $t = \sqrt{L^2 + v^2t^2}/\sqrt{(c^2 + v^2)} \rightarrow c^2t^2 + v^2t^2 = L^2 + v^2t^2 \rightarrow t = L/c$. Meanwhile, the red beam travels a distance $= L + v\tau$ in time τ, but now at speed $c + v$ from the launch point to its mirror/laser (the interferometer has traveled distance $v\tau$ to the right), where $\tau = (L + v\tau)/(c+v) \rightarrow c\tau + v\tau = L + v\tau \rightarrow \tau = L/c = t$, i.e., both beams have the exact same travel times. For the return trips, the blue beam again travels the same distance at the same speed (the interferometer has traveled an additional distance vt to the right), so $t = L/c$, as before. Now the red beam travels a distance $= L - v\theta$ in time θ at speed $c - v$ from its mirror/laser to the original launch point (the interferometer has traveled additional distance $v\theta$ to the right), where $\theta = (L - v\theta)/(c - v) \rightarrow c\theta - v\theta = L - v\theta \rightarrow \theta = L/c$, the same as τ and t, i.e., both beams again have the exact same travel times. Since $t = \tau = \theta$, both beams have the exact same travel times for their round trips and should flash simultaneously upon their return to the interferometer junction.

MMX alleged to observe no fringe shifts, which would be analogous to both beams completing their round trips simultaneously. However, fringe shifts were observed, but less than expected for the Earth's then known 30.5 km/s velocity, so a "null result" was declared. Dayton Miller later observed fringe shifts as well, suggesting possibly a "partially entrained (dragged)" aether (or some variation on variable light speed, with or without an aether).

4. CASE 3. "STATIONARY" AETHER (WITH RESPECT TO "PREFERRED" REFERENCE FRAME OF "SPACE") WITH CONSTANT LIGHT SPEED

As before, the interferometer moves to the right at constant speed v = 0.003c, but now through a "stationary" aether. Rather than using lasers to create our beams, we now use a flash, one red, one blue, that activate simultaneously at the same location (interferometer junction). Each will spread as a spherical wave front (or a circular one, in the illustrated two dimensions), as shown in Figure 2. At the end of each arm, we now have an equivalent flash (rather than an equivalent laser) along with a mirror to activate and return the pulse instantaneously upon impingement (for the same reason as before). The results through the four time steps indicate that the results exactly match those for Case 1 (no aether, light speed constant at c), as follows.

4.1. Step I

The blue pulse reaches its mirror/flash after traveling at speed c for time t over a distance $\sqrt{(L^2 + v^2t^2)}$, such that $t = \sqrt{(L^2 + v^2t^2)}/c \rightarrow c^2t^2 = L^2 + v^2t^2 \rightarrow t = L/\sqrt{(c^2 - v^2)}$. The red pulse (not shown) is in exact same position as blue pulse, i.e., it has not yet reached its mirror/flash.

4.2. Step II

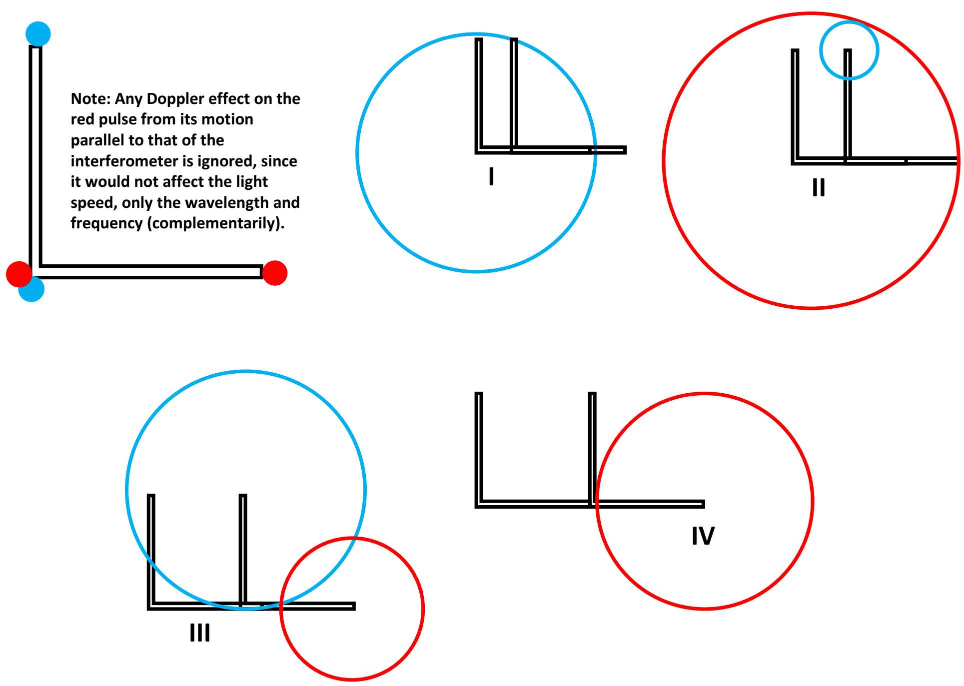
The red pulse reaches its mirror/flash after traveling at speed c for time τ over a distance $L + v\tau$, such that $\tau = (L + v\tau)/c \rightarrow c\tau = L + v\tau \rightarrow \tau = L/(c - v)$. Meanwhile, the blue pulse from its mirror/flash has begun its journey back over additional time interval $\tau - t$.

4.3. Step III

The blue pulse completes its round trip back to the interferometer junction after traveling at speed c for time t over a distance $\sqrt{(L^2 + v^2t^2)}$, such that $t = \sqrt{(L^2 + v^2t^2)}/c \rightarrow c^2t^2 = L^2 + v^2t^2 \rightarrow t = L/\sqrt{(c^2 - v^2)}$, as before. Meanwhile, the red pulse from its mirror/flash has begun its journey back over additional time interval $2\mathrm{t} - \tau$.

4.4. Step IV

The red pulse completes its round trip back to the interferometer junction after traveling at speed c for additional time θ over a distance $L - v\theta$, such that $\theta = (L - v\theta)/c \rightarrow c\theta = L - v\theta \rightarrow \theta = L/(c + v)$. Note that all the results for t, τ and θ are exactly the same as in Case 1 for no aether and a constant light speed c. Thus, the blue pulse should flash back at the interferometer junction 3 ps before the red pulse.



<u>Figure 2</u>. Interferometer with Flash Light Sources in "Stationary" Aether (Four Time Steps Shown)

5. CASE 4. "FULLY ENTRAINED (DRAGGED)" AETHER (WITH RESPECT TO "PREFERRED" REFERENCE FRAME OF "SPACE") WITH CONSTANT LIGHT SPEED C

As before, the interferometer moves to the right at constant speed v = 0.003c, but now through a "fully entrained (dragged)" aether moving at the same velocity v with the interferometer itself. Rather than using lasers to create our beams, we again use flashes, one red and one blue, that activate simultaneously at the same location (interferometer junction). Each will spread as a spherical wave front (shown as a circular one, in the illustrated two dimensions). The results through the two time steps indicate that the results exactly match those for Case 2 (no aether, variable light speed), as follows (Figure 3).

5.1. Step I

Both the blue and red pulses reach their respective mirrors/flashes simultaneously (and, therefore, shown as violet) after traveling at speed c for time t over a distance L, since their point of origin (interferometer junction), and the entire aether medium itself, has moved along with the interferometer itself a distance vt to the right, i.e., $t = ([L + vt] - vt)/c = L/c$.

5.2. Step II

Both pulses complete their round trips back to interferometer junction after traveling for additional time t over a distance L, since their point of origin (interferometer junction), and the entire aether medium itself, has moved along with the interferometer itself another distance vt to the right, i.e., $t = (\llbracket\{[L + vt] - vt\} + vt\rrbracket - vt)/c = L/c$. Both pulses reach the interferometer junction simultaneously (so they should flash as violet). Note that the results for t are exactly the same as in Case 2 for no aether and a variable light speed.

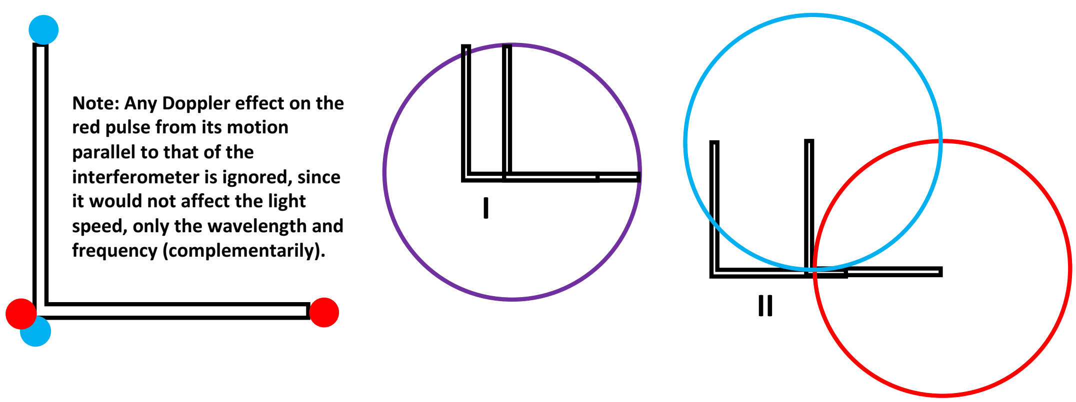


Figure 3. Interferometer with Flash Light Sources in "Fully Entrained (Dragged)" Aether (Two Time Steps Shown)

6. CASE 5. "PARTIALLY ENTRAINED (DRAGGED)" AETHER (WITH RESPECT TO "PREFERRED" REFERENCE FRAME OF "SPACE") WITH CONSTANT LIGHT SPEED C

This case (see again Figure 2) lies intermediate between Cases 3 and 4, with the only difference being that the aether is partially "dragged along" with the moving interferometer at a speed u, where $0 < u < v\ (= 0.003c)$.

6.1. Steps I and II

With reference to these two cases, when the interferometer has moved a distance vt to the right, i.e., a total distance of $L + vt$, where t = time for blue pulse to reach its mirror/flash, the blue pulse will have traveled a distance $\sqrt{(L^2 + [v - u]^2t^2)}$ at speed c relative to the aether, such that $t = \sqrt{(L^2 + [v - u]^2t^2)}/c \rightarrow c^2t^2 = L^2 + [v - u]^2t^2 \rightarrow t = L/\sqrt{(c^2 - [v - u]^2)}$. Note that this reduces to $t = L/\sqrt{(c^2 - v^2)}$ as in Case 3 for a "stationary" aether (u = 0), and $t = L/c$ as in Case 4 for a "fully entrained (dragged)" aether (u = v). Analogously, when the interferometer has moved a distance $v\tau$ to the right, i.e., a total distance of $L + v\tau$, where τ = time for red pulse to reach its mirror/flash, the red pulse will have traveled a distance $L + (v - u)\tau$ at speed c relative to the aether, such that $\tau = (L + [v - u]\tau)/c \rightarrow c\tau = L + (v - u)\tau \rightarrow \tau = L/(c - [v - u])$. Note that this reduces to $\tau = L/(c - v)$ as in Case 3 for a "stationary" aether (u = 0), and $\tau = L/c = t$ as in Case 4 for a "fully entrained (dragged)" aether (u = v).

6.2. Steps III and IV

Similarly, the analyses for Steps III and IV corresponding in Cases 3 and 4 are as follows. When the blue pulse, reflected/reflashed from its mirror/flash at time t, completes its round trip to the interferometer junction after an additional time t, it will have again traveled a distance $\sqrt{(L^2 + [v - u]^2t^2)}$ at speed c relative to the aether, such that $t = L/\sqrt{(c^2 - [v - u]^2)}$, as before. Again, note that this reduces to $t = L/\sqrt{(c^2 - v^2)}$ as in Case 3 for a "stationary" aether (u = 0), and $t = L/c$ as in Case 4 for a "fully entrained (dragged)" aether (u = v). The red pulse, reflected/reflashed from its mirror/flash at time τ, completes its round trip to the interferometer junction after an additional time θ over distance $L - (v - u)\theta$ at speed c relative to the aether, such that $\theta = (L - [v - u]\theta)/c \rightarrow c\theta = L - (v - u)\theta \rightarrow \theta = L/(c + [v - u])$. Note that this reduces to $\theta = L/(c - v)$ as in Case 3 for a "stationary" aether (u = 0), and $\theta = L/c = \tau = t$ as in Case 4 for a "fully entrained (dragged)" aether (u = v). We've already examined the two extremes (u = 0 and u = v) in Cases 3 and 4, the first yielding the blue flash completing its round trip 3 ps faster than the red, while the second yields simultaneous completions (violet flash).

With a "partially entrained (dragged)" aether, the result is intermediate. Since now $2t/(\tau + \theta) = (c^2 - [v - u]^2)/c\sqrt{(c^2 - [v - u]^2)} = \sqrt{(c^2 - [v - u]^2)}/c = \sqrt{1 - [v - u]^2/c^2} < 1$, the total round trip for the blue light is still shorter and one should again see the blue light flash slightly before the red light upon their return to the interferometer junction. For example, if $u = \frac{1}{3}v = \frac{1}{3}(0.003c) = 0.001c, v - u = 0.002c$ and this time difference will be only 2.0 x 10^{-4}%. For an interferometer in earth orbit with arm lengths = 100 m (roughly a football field), the time delay between the blue and red flashes reduces to $\frac{2(100m)(2.0x10^{-6})}{3.00\ x\ 10^8 m/s} \approx 1x10^{-12}$ s, i.e., 1 ps. If $u = \frac{2}{3}v = \frac{2}{3}(0.003c) = 0.002c, v - u = 0.001c$ and this time difference will be only 5.0 x 10^{-7}%. The time delay between the blue and red flashes reduces even more to $\frac{2(100m)(5.0x10^{-7})}{3.00\ x\ 10^8 m/s} \approx 3x10^{-13}$ s, i.e., 0.3 ps.

At this point, it should be evident that one cannot distinguish between Cases 1 and 3 or between Cases 2 and 4 based solely on the MMX results. And the actual MMX (and Dayton Miller) results suggest Case 5.

7. CASE 6. NO AETHER, VARIABLE LIGHT SPEED (LIGHT ACQUIRES ONLY PARTIAL VELOCITY OF SOURCE) [PRESENTED FOR THE SAKE OF COMPLETENESS AS A PARALLEL TO CASE 5]

As a no-aether parallel to Case 5 (see Figure 2), assume the laser beam (now refer back to Figure 1) acquires only part of the source motion, i.e., a speed u < v. Note that, unlike Calkins [3], the laser beam is now assumed to acquire only part of the motion of its source, still essential for the blue beam being able to complete its round trip.

7.1. Steps I and II

Time t for the first part of the blue beam's travel to its mirror/laser will be $t = \sqrt{(L^2 + v^2t^2)}/\sqrt{(c^2 + u^2)} \rightarrow c^2t^2 + u^2t^2 = L^2 + v^2t^2 \rightarrow t = L/\sqrt{(c^2 - [v - u]^2)}$. This exactly matches the equation for t in Case 5. Note that this reduces to $t = L/\sqrt{(c^2 - v^2)}$ as in Case 1 for no aether and constant light speed c (u = 0) , and $t = L/c$ as in Case 2 for no aether but variable light speed with acquisition of source velocity (u = v). Time τ for the first part of the red beam's travel to its mirror/laser will be $\tau = (L + v\tau)/(c + u) \rightarrow c\tau + u\tau = L + v\tau \rightarrow \tau = L/(c - [v - u])$. This exactly matches the equation for τ in Case 5. Note that this reduces to $\tau = L/(c - v)$ as in Case 1 for no aether (u = 0) and constant light speed c, and $\tau = L/c = t$ as in Case 2 for no aether but variable light speed with acquisition of source velocity (u = v).

7.2. Steps III and IV

The symmetry between the blue beam's initial travel to its mirror/laser and its return to the interferometer junction yields the same result for t, i.e., $t = L/\sqrt{(c^2 - [v - u]^2)}$. Again, this exactly matches the equation for t in Case 5 and reduces to $t = L/\sqrt{(c^2 - v^2)}$ as in Case 1 for no aether and constant light speed c (u = 0), and $t = L/c$ as in Case 2 for no aether but variable light speed with acquisition of source velocity (u = v). For the red beam's return from its mirror/laser to the interferometer junction, time $\theta = (L - v\theta)/(c - u) \rightarrow c\theta - u\theta = L - v\theta \rightarrow \theta = L/(c + [v - u])$. This exactly matches the equation for θ in Case 5. Note that this reduces to $\theta = L/(c + v)$ as in Case 1 for no aether (u = 0) and constant light speed c, and $\theta = L/c = t$ as in Case 2 for no aether but variable light speed with acquisition of source velocity (u = v). Since these results all exactly match those for Case 5, similar calculations for the time delay between arrival of the blue beam then the red beam apply, i.e., $u = \frac{1}{3}v \rightarrow \sim 1\ ps$ delay, and $u = \frac{2}{3}v \rightarrow \sim 0.3\ ps$ delay.

The prime reason for presenting this case was to show the similarity among Cases 1, 2 and 6 for no aether and among Cases 3, 4 and 5, respectively, for an aether (i.e., $1 \leftrightarrow 3,\ 2 \leftrightarrow 4,\ 6 \leftrightarrow 5$). It is relatively easy to conceive of a "partially entrained (dragged)" aether as in Case 5 to form the intermediate between Cases 3 and 4. It seems a bit of a stretch to conceive of light acquiring only part of its source velocity here in Case 6 to form the intermediate between Cases 1 and 2. Nonetheless, for completeness, and to eliminate nothing *a priori*, this case is presented and, not surprisingly, upholds the symmetry with the aether cases.

8. CONCLUSION

Because MMX allegedly yielded a "null" result, and Einstein constrained himself to light traveling at a constant speed c without an aether, he was stuck between Cases 1 and 2 (albeit without the benefit of a laser). The "null" result aligned with Case 2, but the restriction of constant light speed corresponded to Case 1. Since the fringe shift, analogous to the time delay between blue and red beams, was allegedly not observed, to align Case 1 with Case 2, Einstein invented his Special Relativity, relying on "relativistic" effects (length contraction/time dilation via the Lorentz transforms) to explain how the results from Case 2 could be possible given the constraints of Case 1. He rejected the applicability of Case 2 (or Case 4) as responsible for the alleged "null" result. In actuality, fringe shifts were observed, and later confirmed by Dayton Miller, suggesting that Case 5 may have been the "Occam's Razor" explanation (or Case 6, although how light would acquire only part of its source velocity in the absence of an aether is difficult to conceive). In hindsight, MMX appears to have been inconclusive regarding the nature of light's motion or the presence of an aether, certainly not a firm basis upon which to build Special Relativity.

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