A Reconsideration of the Michelson-Morley Experiment

by Jim Spinosa

Is there a flaw in the mathematical theory that underpins the Michelson-Morley experiment? Could such a conceptual flaw be serious enough to nullify either the results of the experiment or its conclusions?

The Michelson-Morley experiment, which was first performed in 1887, used a complex apparatus to probe the nature of the luminiferous ether. The luminiferous ether is often referred to as the ether wind or simply the ether. The term "ether wind" is misleading because the prevailing opinion among scientists in the late 19^{th} century was that the luminiferous ether was stationary under most conditions. The ether wind effect is caused by the motion of the earth through the ether. It is similar to the experience produced by riding a bicycle on a windless day. The bicycle rider feels as though a wind is blowing on his face. The wind increases in its apparent speed as the speed of the bicyclist increases.

The experiment was also designed so that the absolute velocity of the earth could be determined. To accomplish this a precise time measurement needed to be made. It required a measurement of the difference in the time between the duration of a light beam's round trip journey along one arm of the apparatus as compared to the duration of the light beam's round trip journey along the other arm of the apparatus.

The centerpiece of the Michelson-Morley experiment is a device is called an interferometer; it is a device that divides a light ray into two beams and then brings them together again to cause interference. The recombination of these two beams of light produces interference fringes (bands of more intense color). When these fringes are counted, they give information about the light.

The main part of the apparatus consists of two identical arms that are fitted together to form a right angle. When one arm is aligned with the motion of the earth, the other arm will be perpendicular to it. Each arm is of equal length. At the arms' vertex a single ray of light is split into two beams by a half-silvered mirror. One beam travels up one arm, and the other beam travels up the other arm. A fully-silvered mirror is located at the far end of each arm. Each half of the split light ray travels back down its respective arm, and the two beams rejoin producing interference fringes.

If the earth was moving through a stationary ether, it was mathematically determined that one light beam would take longer than the other to complete its round trip journey. This conclusion was decisively drawn, even though the arms were of equal length. The round trip journey of the light beam traveling in the arm aligned with the motion of the earth would take longer to complete than the round trip journey of the light beam traveling in the arm that was perpendicular to the motion of the earth. If the ether surrounding the earth was partially dragged along by the motion of the earth, the overall outcome would still be the same. The only change would be in the magnitude of the difference that resulted from comparing the round trip duration for each arm. The interferometer could detect and distinguish each of these possible outcomes as a distinct set of slight changes in the interference fringes of the recombining light beams.

The entire apparatus was mounted on a granite slab. Floating in a basin filled with mercury, the granite slab could be rotated. It was hypothesized that the rotation of the apparatus would produce slight changes in the interference fringes. They would occur as the arm of the interferometer perpendicular to the motion of the earth was rotated until it exchanged position with the arm of the interferometer aligned with the motion of the earth.

The formula for the time, t_1, it takes the light beam to make a round trip journey in the arm of the apparatus that is aligned with the motion of the earth is introduced quite early in chapter 2 of L. R. Lieber's book, The Einstein Theory of Relativity. L. R. Lieber writes, "Therefore the time required to travel from A to B would be $a/(c - v)$, where a represents the distance AB, and the time required for the trip from B to A would be $a/(c + v)$. Consequently, the time for the round trip would be $t_1 = a/(c - v) + a/(c + v)$ or $t_1 = 2ac/(c^2 - v^2)$."[1]

The formula for the time, t_2, it takes the light beam to make a round trip journey in the arm of the apparatus that is perpendicular to the motion of the earth is introduced 2 pages later. L. R. Lieber writes, "Hence the time for the round trip from A to C and back to A, would be

$t_2 = 2a/(c^2 - v^2)^{1/2}$."[2]

a = the length of the light path, which is the same in both arms of the apparatus.

c = the speed of light.

v = the velocity of the apparent ether wind.

When the formulas t_1 and t_2 are analyzed mathematically, it is revealed that t_1 is greater than t_2. Therefore, it takes more time for the light beam in the arm

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[1]Lillian R. Lieber, The Einstein Theory of Relativity: A Trip to the Fourth Dimension (New York: Rinehart & Company, Inc., 1936, 1945), p. 9

[2]Ibid., p. 11

of the apparatus aligned with the motion of the earth to make its round trip journey than it does for the light beam in the arm of the apparatus that is perpendicular to the motion of the earth. There are two crucial requirements in making this analysis. The first requirement is that a represents the same length in both equations. The second requirement, which must be met, is that both equations contain the term $(c^2 - v^2)$.

These requirements cause difficulties when analyzing the behavior of the light beam in the arm of the apparatus perpendicular to the motion of the earth. In this arm, the apparent ether wind should sweep the light beam downwind. That would make its light path longer than light path a. This is analogous to a swimmer who tries to swim across a river. To make his journey as short as possible, the swimmer will try to adhere to a line that runs perpendicularly to the shoreline and intersects his starting point. But, inevitably, the current will sweep the swimmer downstream, which increases the distance of his journey.

He actually ends up swimming along the hypotenuse of a right triangle, instead of one of its legs.

This difficulty is overcome in the formula t_2 by using the term $(c^2 - v^2)^{1/2}$. This insures that the light path in formula t_2 equals the light path in the formula t_1. But, it introduces its own difficulties. A further examination of the analogy between the light beam and a swimmer will provide the explanation. The light path a is represented by a perpendicular line running across the river that begins at the swimmers starting point. If the swimmer knows three facts, he can calculate the precise angle by which he must deviate from the perpendicular in an upstream direction to counteract the effects of the current. These three facts are: the velocity of the current, the speed at which he swims and the trigonometric equations known as the Law of Sines. The swimmer must also know that the current flows perpendicularly to a line measuring the width of the river. The swimmer swims upstream at an angle expressly chosen so that, when the current sweeps him downstream, his path forms a line that is perpendicular to the flow of the river and intersects his starting point.

Here is an example of the calculation a swimmer can make, and it should be noted that the velocity of the current is crucial to the calculation. Let's say there is a river that flows east to west. The swimmer is on the south bank and wants to swim to the north bank along a perpendicular line. The width of the river is 20 miles. The width of the river is side a of a right triangle. The current flows at a rate of 3 mph. The swimmer swims at a speed of 5 mph. The length of side b of the triangle is unknown. The length of the hypotenuse c of the triangle is unknown. It is known that the ratio b/c = 3 mph/5 mph. The ratio b/c equals this ratio: the speed of the current/the speed of the swimmer. This is true because of the principle of similar triangles. Solving the ratio for b gives: b = c(3/5) = c(.6).

The Law of Sines is: a/Sine A = b/Sine B = c/Sine C. The angles A, B, and C represent the angles directly opposite the respective sides a, b, and c. We know angle

C is 90° because the current flows perpendicularly to a line measuring the width of the river. The sine of 90° equals 1. If we substitute c(.6) for b and 20 miles for a and 1 for sine C we have: 20miles/sine A = c(.6)/sine B = c/1. Solving the equation for sine B we have sine B = .6. Therefore, angle B equals approximately 36.87°. The swimmer must swim at an upstream angle of approximately 36.87° from the perpendicular in order for the current to carry him back to the perpendicular.

A swimmer can swim at an angle that deviates from the perpendicular in a precise manner. Swimming at this angle allows the current to carry him back to the perpendicular. A light beam can also deviate from the perpendicular light path a in a precise manner. This deviation will allow the apparent ether wind to carry the light beam back to the perpendicular light path a. The term $(c^2 - v^2)^{1/2}$ is the proper term to use when the light beam is being carried back to the perpendicular by the apparent ether wind. Once the light beam is carried back, it is mathematically changed from the hypotenuse of a right triangle into the leg of a right triangle. The Pythagorean theorem determines that the length of the leg a of a right triangle is: $a = (c^2 - b^2)^{1/2}$.

The difficulty arises in determining the precise angle the light beam should deviate from the perpendicular. This angle must allow the apparent ether wind to carry it back to the perpendicular. To calculate that angle, the velocity of the apparent ether wind must already be known. The velocity of the apparent ether wind is unknown. The formula t_2 cannot be employed unless the precise angle of deviation is already known. But, we don't know the angle that the light beam (in the arm of the interferometer perpendicular to the motion of the earth) must deviate from the perpendicular in order for the apparent ether wind to blow it back to the perpendicular. Therefore, the equation $t_2 = 2a/(c^2 - v^2)^{1/2}$ is invalid.

Instead, the equation $t_{2'} = 2b/(c^2 + v^2)^{1/2}$ must be used to describe the path of the light beam when it travels perpendicularly to the apparent ether wind. It's use does not require a known angle of deviation.

b = the distance the light beam travels when swept downwind by the apparent ether wind–it is a longer distance than that of light path a.

c = the speed of light.

v = the velocity of the apparent ether wind.

An argument can be made that to correctly employ the formula $t_2 = 2a/(c^2 - v^2)^{1/2}$ it is not required that the precise angle of deviation must be known. The argument is that since the interferometer rotates, it will pass through the precise angle of deviation necessary for formula t_2 to be correctly employed. It is true that the interferometer will pass through the precise angle of deviation. It is analogous to a swimmer swimming across a river many times and each time at a different angle as measured from the perpendicular. By trial and error he will discover the precise angle that allows the current to carry him back to the perpendicular.

But, when arm A of the rotating interferometer comes to the precise angle of deviation that allows the apparent ether wind to blow the beam of light (traveling along its arm) so that it is perpendicular to the apparent ether wind, the other arm, arm B, of the interferometer will not be perpendicular to that beam of light. The apparent ether wind blows the beam of light in arm A so that it advances to its "correct" position.[3] The apparent ether wind does not blow the beam of light in arm B so that it advances to its "correct" position.[4] Therefore, the beam of light in arm B lags behind from its "correct" position.

Arm B of the interferometer is not perpendicular to the beam of light in arm A because the beam of light in arm A has been blown by the apparent ether wind. It has been

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[3] The "correct" position for the light beam in arm A is perpendicular to the apparent ether wind.

[4] The "correct" position for the light beam in arm B is aligned with the apparent ether wind.

blown until it is perpendicular to the apparent ether wind while the beam of light in arm B of the interferometer has lagged behind and so will not be aligned with the motion of the apparent ether wind. Therefore, the formula for the beam of light in arm B, $t_1 = 2ac/(c^2 - v^2)$ cannot be correctly employed. Arm B of the interferometer is not perpendicular to the beam of light that has been blown by the apparent ether wind. Arm B of the interferometer is still perpendicular to arm A because the arms themselves are not effected by the apparent ether wind, only the light beams traveling along the arms are effected by the apparent ether wind.

The light beam traveling along arm A of the interferometer has been blown by the apparent ether wind. Therefore, it is no longer parallel to arm A. Since it is no longer parallel to arm A, it cannot be perpendicular to arm B because the arms are at right angles to one another. Since the light beam traveling along arm A is not perpendicular to arm B, it isn't perpendicular to the light beam traveling along arm B.

The effect that the apparent ether wind has on the light beam traveling along arm B is very slight, but it actually increases the amount by which the beam of light in arm B lags behind from its “correct” position. One might suspect that these effects could be demonstrated with an electric fan and strips of cardboard fixed at right angles. But, you would need a more complex apparatus. You would need wooden boards fix at right angles and then the strips of cardboard would need to be attached at the vertex of the wooden boards to a device that allowed them to both freely rotate and rotate independently of each other.

Even though the rotating interferometer passes through the precise angle of deviation required for formula t_2 to be correctly employed, it does so in a manner that makes it incorrect to employ formula t_1. There is one remaining problem with the argument. The mirror at the far end of arm A of the interferometer would need to be tilted at a precise angle in order to meet two requirements: (1)

that the incoming light beam's path changes from the hypothenuse of a right triangle into the leg of a right triangle and (2) so that the returning light beam will be traveling at the proper angle for it to be blown back to the perpendicular by the apparent ether wind. These two requirements may be incompatible with each other. And, the precise angle the mirror must be tilted to fulfill either requirement is unknown. Therefore, for all the reasons listed above $t_{2'}$ is the correct equation to employ.

The equation $t_{2'} = 2b/(c^2 + v^2)^{½}$, as with the other equations already mentioned, is an expression of the general equation time = distance/speed. The distance is 2b because the light beam makes a round trip journey, and each leg has a length which equals b. The speed of the light beam is $(c^2 + v^2)^{½}$. The speed is determined by the addition of vectors.

A vector is a mathematical expression denoting a combination of both magnitude and direction. The vectors used in these equations express the speed and the direction of either a light beam or the apparent ether wind or a light beam under the influence of the apparent ether wind. The vector for the velocity of the apparent ether wind will have the same speed as the vector for the absolute velocity of the earth. However, the direction for the vector of the absolute velocity of the earth is the reverse of the direction of the apparent ether wind's vector. When the vectors for the apparent ether wind and the velocity of light are added together, they form a third vector. It results from the combination of the speeds and directions of these two vectors.

Here is an example of vector addition. Let's say there is a river that flows east to west at a rate of 3 mph. There is also a swimmer positioned on the river's south bank who is ready to swim to the north bank, at a speed of 4 mph. The river's current can be represented by an arrow 3 units long, pointing towards the west, and beginning at the swimmer's starting point. The swimmer can be represented by an arrow 4 units long, pointing towards the north. This arrow also begins at the swimmer's starting point. These two vectors form two sides of a parallelogram. The other two sides of the parallelogram can be constructed because they mirror the two sides already formed by these two vectors. Once we construct the parallelogram, we can draw the third vector. It represents the addition of the current vector and the swimmer's vector. We begin the third vector at the swimmer's starting point. We end the third vector at the diagonally opposite corner of the parallelogram. The length of the third vector represents the speed of the swimmer under the influence of the river's current. The position of the third vector represents the direction of the swimmer under the influence of the river's current.

In this example, the third vector is the hypotenuse of a right triangle. One leg of the triangle is 3 units, and the other leg is 4 units. Using the Pythagorean theorem we find the length of the hypotenuse/vector is $(3^2 + 4^2)^{1/2}$ or 5 units. The length of the vector equals the speed of the swimmer under the influence of the river's current. It is 5 mph.

The same reasoning is used to determine the speed of the light beam under the influence of the apparent ether wind. The speed of the light beam is $(c^2 + v^2)^{1/2}$ when the light beam begins its journey perpendicular to the apparent ether wind. Likewise, the speed of the light beam under the influence of the apparent ether wind is $(c^2 - v^2)^{1/2}$ when the light beam begins its journey at one specific upwind angle from a line drawn perpendicularly to the apparent ether wind.

Since it is impossible to determine the one specific upwind angle that would cause the beam of light to follow the perpendicular light path a, it is invalid to use the term $(c^2 - v^2)^{1/2}$. We are compelled to use the term $(c^2 + v^2)^{1/2}$. When that term is used, it is impossible to mathematically determine which of the two possible round trip journeys will have the greatest duration. We cannot mathematically determine which will take longer: the journey of the light beam in the arm of the interferometer perpendicular to the motion of the apparent ether wind or the journey of the light beam in the arm of the interferometer aligned with the motion of the apparent ether wind.

It cannot be mathematically determined whether $t_1 = 2ac/(c^2 - v^2)^{1/2}$ is greater than, less than, or equal to $t_{2'} = 2b/(c^2 + v^2)^{1/2}$. Since this is the case, the experimental result that the light beams in each arm of the interferometer take the same amount of time to complete their round trip journeys is not in conflict with this new mathematical analysis. The original mathematical analysis of equations t_1 and t_2 was in conflict with the empirical results of the experiment. Part of the original mathematical analysis was based on the legitimate assumption that the apparent ether wind had to have a velocity greater than zero. The most palatable way to resolve the conflict using the original equations was to assume that the velocity of the apparent ether wind was zero.

If the velocity of the apparent ether wind is zero, it must mean that the earth totally drags along the surrounding ether with it as it moves. And, what is true of the earth would be true for all matter. In this scenario, the ether surrounding the earth is the same as the air inside your car with the windows shut. It doesn't matter how fast your car is traveling; the air inside your car has a velocity of zero when measured from within your car. An anemometer inside your car will measure the air speed as zero. A weather vane inside your car will not detect a wind blowing from any direction.

The conclusion that the earth totally dragged along the surrounding ether was in direct conflict with the results of many other experiments. They all showed that the earth only partially dragged along the surrounding ether. The conclusions of the Michelson-Morley experiment were in direct conflict with the results of many other experiments. However, the conclusions of the Michelson-Morley experiment were drawn from an invalid mathematical analysis.

To avoid any further invalid analyses, two statements made earlier, must be re-examined. One involves the absolute velocity of the earth. The other involves the time, $t_{2'}$.

It has been stated: if the vector that represents the apparent ether wind is transformed so that its direction is reversed, then this newly formed vector will represent the absolute velocity of the earth. This notion needs to be refined. A weather vane discloses the direction of the wind. An anemometer measures the speed of the wind. What happens if you position a powerful fan directly above or below a weather vane? When the fan is turned on, will the weather vane disclose the direction of this powerful, yet localized wind? No, a weather vane can only rotate around its vertical axis. It can only disclose the direction of winds that blow horizontally relative to the weather vane's vertical axis. The wind must blow horizontally relative to the weather vane's vertical axis or, at least, have a horizontal component. Only under these circumstances can the weather vane disclose either the wind's direction or the horizontal component of its direction. Like a weather vane the anemometer can only rotate around its vertical axis. It cannot measure the speed of a wind blowing from directly above it or from directly below it.

The interferometer, as well, can only rotate around its vertical axis. By noting the different effect of the apparent ether wind on a light beam in the arm of the interferometer aligned with the apparent ether wind as compared to a light beam in the arm perpendicular to the apparent ether wind, a measurement can be made of the apparent ether wind's velocity. If the apparent ether wind were to blow from directly above or directly below the interferometer, the speed and the direction of the apparent ether wind wouldn't be registered by the interferometer. The interferometer only measures the component of the apparent ether wind's velocity that is moving horizontally relative to the interferometer's vertical axis. It is entirely possible that the interferometer only detects a component of the earth's absolute velocity when it measures the velocity of the apparent ether wind.

The notion that the formula $t_{2'} = 2b/(c^2 + v^2)^{1/2}$ is completely accurate also needs to be refined. When the light beam begins its journey traveling perpendicularly to the apparent ether wind, it is blown downwind by the apparent ether wind. When the light beam strikes the mirror located at the end of the interferometer's arm, it is no longer perpendicular to the mirror. When the light beam strikes the mirror, its angle of incidence will be equal to its angle of reflection. When the light beam begins its return journey, it is not traveling perpendicularly to the apparent ether wind; it is already traveling at a downwind angle before it is effected by the apparent ether wind. The effect of the apparent ether wind is to blow the light beam even farther downwind. The light beam's return journey does not measure length b because it travels a distance whose measurement is longer than length b. We can refer to this measurement as length f. The time it takes the light beam to travel length f is given by the formula:

$$t_f = f/(c^2 + v^2 - 2cv \cos F)^{1/2}$$

c = the velocity of light.

v = the velocity of the apparent ether wind.

cosF = the cosine of the angle directly opposite vector f.

Vector f is the longest leg of an oblique triangle. The second longest leg is d, and it is equal in length to b. It represents the path the returning light beam would have taken if it wasn't effected by the apparent ether wind during its return journey. It represents the reflection of light path b according to the rule that the angle of incidence equals the angle of reflection. The shortest leg of this oblique triangle is e. It represents a measurement of the total distance the light path f is blown in a downwind direction by the apparent ether wind.

In the equation for t_f, listed above, the Law of Cosines is used to add the vectors c and v. The Pythagorean theorem isn't used because the vectors no longer form a right angle. The light beam is no longer perpendicular to the apparent ether wind when it begins its return journey. This is so because the angle of reflection equals the angle of incidence, and the angle of incidence wasn't a right angle.

There is a further difficulty. The light beam's return journey down the arm of the interferometer will not bring it back to the exact point from which it began to travel up the arm of the interferometer. It will return to a point downwind from its starting point. How does the light beam return from this downwind position? The light beam must travel back from its downwind position in order to recombine and interfere with the light beam returning from the other arm of the interferometer.

Even if a river had only a modest current, a swimmer would face the same type of situation swimming across the river and back. Once the swimmer returned to the side from which he started, he would need to swim upstream to reach his starting point. Swimming upstream would be slow going for the swimmer because he would have to contend with the full force of the current. The swimmer can consciously make the decision to swim upstream; however, that is not possible for a beam of light.

Once the light beam has somehow traveled the upwind distance necessary to reach its starting point, it must make a 90° turn so that it can recombine and interfere with the returning beam of light from the other arm.

We can refer to the upwind distance the light beam must travel to reach its starting point as g. The time it takes the light beam to travel length g is given by the formula:

$$t_g = g/(c - v)$$

c = the velocity of light.

v = the velocity of the apparent ether wind.

The light path that the beam of light traveling perpendicular to the apparent ether wind must travel is triangular in shape. The triangle it forms is like the outline of an asymmetrical icicle. The narrow base of the icicle represents the upwind journey of the light beam.

The total time for the round trip journey of a beam of light traveling perpendicular to the apparent ether wind is given by the formula:

$$t_{2''} = t_b + t_f + t_g$$

or

$$t_{2''} = b/(c^2 + v^2)^{1/2} + f/(c^2 + v^2 - 2cv \cdot \cos F)^{1/2} + g/(c - v)$$

c = the velocity of light.

v = the velocity of the apparent ether wind.

cosF = the cosine of the angle directly opposite length f.

b, f, and g = light paths of various lengths that can be expressed in terms of the known length a.

The results of the Michelson-Morley experiment require that $t_1 = t_{2''}$. Solving this equation for v is difficult. Compared to the original equation for t_2 the new equation $t_{2''}$ is cumbersome. It would simplify matters if we could determine the precise upwind angle to direct a beam of light so that the apparent ether wind would blow it back to the perpendicular in the arm of the interferometer perpendicular to the apparent ether wind. Even if we were to somehow determine such an angle, there would still be difficulties. The mirror in the arm of the interferometer perpendicular to the apparent ether wind would need to be precisely tilted. It could then impart the proper upwind angle to the reflected light beam. This would allow it to be blown back to the perpendicular on its return journey. Both arms of the interferometer must be identical because they are interchangeable. This requirement would cause a problem. It would mean that the arm of the interferometer aligned with the motion of the earth would now also have a tilted mirror. Under these circumstances, in the arm of the interferometer that was aligned with the motion of the earth, the light beam traveling up the arm would be aligned with the motion of the earth, but the reflected light beam making its return journey would not be, because it would have been reflected from a tilted mirror, not a perpendicular one.

The conclusion of this reconsideration of the Michelson-Morley experiment is that the experiment is invalid. The formula for the time it takes a beam of light to make a round trip journey in an arm of the interferometer that is perpendicular to the apparent ether wind is incorrect. The correct formula for the time it takes a beam of light to make a round trip journey under the same conditions is cumbersome. It is difficult to solve the equation for the variable v, the velocity of the apparent ether wind. Since the conclusions of the Michelson-Morley experiment are invalid, there is no empirical evidence that the luminiferous ether is totally dragged along by the earth. There is no empirical evidence to contradict the evidence, garnered from many ingenious experiments, that the luminiferous ether is only partially dragged along by the earth. There is no longer any contradictory empirical evidence about the nature of the luminiferous ether. There is no need to introduce the Lorentz and Fitzgerald contraction of matter to explain away a contradiction that no longer exists.

The Lorentz and Fitzgerald contraction of matter explained the empirical result that t_1 equals t_2. It did so without making it necessary that the earth totally drags along the surrounding ether as it moves. If matter contracts along the axis that represents the direction of motion, it would explain why t_1 equals t_2. Even though according to the mathematical analysis they should not be equal. The mathematical analysis definitively claimed this: the time, t_1, of a round trip journey of a beam of light traveling first against the apparent ether wind and then returning with the apparent ether wind would be longer than the time, t_2, of a round trip journey of a beam of light traveling perpendicularly to the apparent ether wind.

The contradiction between the mathematical analysis and the empirical evidence could be explained by assuming a contraction of matter along the t_1 axis. That is along the axis that represents the direction of motion of the apparent ether wind. The light beam making the round trip journey that includes first traveling against the apparent ether wind and then returning with the apparent ether wind should take a longer time to make its round trip journey than the light beam making around trip journey perpendicular to the apparent ether wind. And, it would, except for this supposition: the distances the light beams travel are no longer equal because of the Lorentz and Fitzgerald contraction of matter along the axis of motion. The supposition of Lorentz and Fitzgerald is that the length of the arm of the interferometer aligned with the motion of the earth contracts just enough to make the round trip times equal in each arm of the interferometer.

Once the original mathematical analysis is shown to be invalid, there is no need to introduce the Lorentz and Fitzgerald contraction of matter along the axis of motion to reconcile the empirical results with the mathematical analysis.

If equation t_1 is set equal to equation $t_{2''}$ (or appropriately modified versions of each of these equations that take into account the exact design parameters and operational conditions of the Michelson-Morley experiment), there may emerge new problems from a mathematical analysis. Problems that cannot be solved by setting the apparent ether wind equal to zero.

It is almost certain there will be two versions of formula t_1 that can be set equal to one another. A second version of formula t1 can be generated by rotating the interferometer 90o from a starting position that has one arm of the interferometer perpendicular to the apparent ether wind. It is likely that the only way to allow the formulas to be equal will be to disregard the versions of tg in each formula. This would imply that the interferometer is not sensitive enough to distinguish durations as short as those on the order of one or another of the versions of tg.

There is another possibility in which the light beam would not have to travel upwind to its exact starting place in order to interfere with the beam of light from the other arm. The beam of light from the other arm could continue its return journey past its starting point. Once the beam of light from the other arm made its way past the partially silvered mirror, it could continue traveling in its downwind direction until it intersected the beam of light blown downwind by the apparent ether wind. The extra distance downwind the beam of light from the other arm would have to travel would be equal to length g. But, the speed of the light beam would be (c + v) instead of (c - v). This would require that an alteration of the formulas t_1 and $t_{2''}$: t_g must be added to formula t_1 and t_g must be deleted from $t_{2''}$. This alternative possibility is not included in the calculations below.

In 1984 Stanley Goldberg's book, Understanding Relativity: Origin and Impact of a Scientific Revolution, was published. Appendix 5 of his book, "Ether Drift

Experiments: The Search for the Absolute Frame of Reference," contains a six page long description of the Michelson-Morley experiment. There are several curious features in his description. The observer observing the light beams is at rest with respect to absolute space. The light beams do not recombine. There is no ether wind present in the experiment. These curious features can be seen as an effort to overcome the shortcomings of the experiment that have enumerated in the preceding pages.

S. Goldberg's description and his accompanying schematic diagram are not without contradictions.

> The Michelson-Morley experiment depends on observing the behavior of fringes when light beams are combined and allowed to interfere. While all such instruments are known as "interferometers," that term more and more is reserved for the particular interferometers of the Michelson-Morley experiment.
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> The apparatus is depicted, schematically, in Figure 11.