Revisiting the Michelson and Morley experiment to reveal an Earth orbital velocity of 30 kilometers per second

Steven Bryant

Primitive Logic, Inc., 704 Sansome Street, San Francisco, California 94111

Steve.Bryant@RelativityChallenge.Com

The Michelson-Morley Interferometer experiment is commonly cited as experimental validation of Special Relativity. While Michelson and Morley concluded an Earth Orbital Velocity (EOV) of 5 to 7.5 km/s, their result is generally accepted as 0 km/s, with their observation attributed to experimental error. Here we find three specific problems in the Michelson-Morley analysis, principal of which is the recognition that their expected result equation does not mathematically compensate for interacting frequencies as governed by the superposition of waves principle. Once the expected result equation is corrected, their data is reevaluated to reveal an EOV of approximately 30 km/s, which was their expected result. This finding is confirmed by reanalyzing Miller's 1933 repeat Interferometer experiment, also revealing an EOV of 30 km/s. These experimental findings support the presumption of an electromagnetic wave medium and challenge the validity of Special Relativity.

Copyright © 2005-2006 Steven Bryant

Introduction

In 1887, Michelson and Morley published results of their Interferometer experiment.[1] The purpose of the Michelson-Morley experiment was to measure the timing difference in the arrival of light waves traveling through the electromagnetic wave medium (a.k.a. ether) along two perpendicular paths (or "arms"). They used a device called an Interferometer, which when rotated, would result in a change in the length of the two paths of yellow light. Their experimental objective was to use the length of the light paths to measure an Earth Orbital Velocity (EOV) of 30 km/s, supporting an ether based theory proposed by Fresnel.[2] They concluded that the actual results represented an EOV of 5 to 7.5 km/s, failing to provide support for Fresnel's theory.[3]

Special Relativity Theory (SRT) predicts a null result from the Michelson-Morley experiment.[4] This prediction of a null result has led to the generally accepted interpretation that the Michelson-Morley experiment produced a 0 km/s result, with their observed result of 5 to 7.5 km/s attributed to experimental error. [5] This interpretation, which serves as experimental validation of Special Relativity, is called into question since the author has identified mathematical problems with each of Einstein's derivations of the SRT transformation equations.[6,7] The necessary mathematical and theoretical corrections are established in the model of Complete and Incomplete Coordinate Systems (CICS),[8] which assumes an electromagnetic ether. The CICS model extends Einstein's postulates and introduces a new transformation model.[9] The CICS corrections, coupled

Copyright © 2005-2006 Steven Bryant

with an assumption of an underlying ether, suggest that the Michelson-Morley experiment should detect the EOV of 30 km/s.[10]

Michelson and Morley produced an equation to compute their expected result. This equation was developed from a perspective of length and time, where the number of cycles of yellow light represents a specific length. Recent reviews of the Michelson-Morley experiment continue with this assumption.[11,12,13] Differing from previous analysis, this paper treats the number of cycles as a measurement of frequency, governed by the rules and equations for combining interacting frequencies. A reexamination of the Michelson-Morley experiment from this perspective reveals three problems with their analysis.[14] First, their analysis does not mathematically account for the combination of frequencies as suggested by the superposition of waves principle. Second, their analysis does not account for their observation of the shift in the center of the fringe. Third, their comparison of actual to expected results is not performed for the same rotational angle of the Interferometer. Once these problems are corrected, the reanalysis results in an EOV of 32.2 km/s. Importantly, Miller's 1933 repeat Interferometer experiment[15] confirms this result when it is reanalyzed in the same manner, yielding 30 km/s.

The Michelson-Morley Experiment Expected Results

This analysis asserts that the Michelson-Morley experiment is a frequency-based experiment. To illustrate this assertion, consider a hypothetical Interferometer where the length of each arm is 299,792,458 meters. In any given second, the number of cycles, as

Copyright © 2005-2006 Steven Bryant

expressed as a frequency (e.g., Hertz), can be counted over this distance. The key point to remember is that frequency is expressed in cycles per second, as observed over a distance of 299,792,458 meters.* When the Interferometer is in motion, the change in frequency for the arm aligned in the direction of travel is found using the Doppler equations

$$f_{xa} = \frac{wf}{w - v}, \tag{1}$$

and

$$f_{xr} = \frac{wf}{w + v}, \tag{2}$$

for the approaching and receding directions.

Observe that when the two Doppler equations are summed such that $f_m = \left(f_{xa} + f_{xr}\right)$, the total number of cycles, f_m, occurs over a distance of 599,584,916 meters and requires 2 seconds to make the journey. This total number of cycles is not a measurement in Hertz since it occurs over two seconds. In order to convert f_m into a frequency that can be expressed in Hertz, this value must be divided by two. This finding is consistent with the

* This leads to a generalized definition of frequency as; a measurement of the number of cycles occurring in $\frac{m}{w}$ seconds as observable over a distance of m meters, where w is the propagation speed of the wave through the medium in one second. For light, w is 299,792,458 meters. Using this definition, Hertz, with respect to light, is defined as the specific case where m equals w; or simply as "the measurement of the number of cycles occurring in one second [as observable over a distance of 299,792,458 meters]." Notice that the part in brackets (above) is not explicitly stated when expressing a frequency in Hertz.

Copyright © 2005-2006 Steven Bryant

superposition of waves principle, which defines the combination of two frequencies as a new frequency[16], f_x, where

$$f_x = \frac{1}{2}\left(f_{xa} + f_{xr}\right). \tag{3}$$

Of course, building an Interferometer with an arm length of 299,792,458 meters would be an engineering challenge. Fortunately, the length of each arm can be shortened and the number of cycles occurring over this length found by multiplying by the scaling factor $\frac{m}{w}$, where m is the apparent length of the arm and w is 299,792,458 meters, resulting in

$$f_x = \frac{1}{2}\left(\frac{m}{w} f_{xa} + \frac{m}{w} f_{xr}\right). \tag{4}$$

After the device is rotated 90-degrees, the orientation of the arm is perpendicular to the direction of travel. The frequency equations for this orientation for the approaching and receding frequencies are given by[17]

$$f_{ya} = f_{yr} = \frac{f}{\sqrt{1-\frac{v^2}{w^2}}}. \tag{5}$$

Accounting for scaling, the combined frequency for the light traveling along the perpendicular arm, as defined by the superposition of waves principle, is

$$f_y = \frac{1}{2}\left(\frac{m}{w} f_{ya} + \frac{m}{w} f_{yr}\right). \tag{6}$$

Equations 4 and 6 are combined to produce the expected displacement, d, for one arm of the Interferometer during a 90-degree rotation of the Interferometer as $f_x - f_y$, or

$$d = \frac{m}{2w}\left[\left(f_{xa} + f_{xr}\right) - \left(f_{ya} + f_{yr}\right)\right]. \tag{7}$$

Copyright © 2005-2006 Steven Bryant

Since the Interferometer consists of two interacting arms, the total expected experimental displacement, d', is $2d$ or

$$d' = \frac{m}{w}\left[\left(f_{xa} + f_{xr}\right) - \left(f_{ya} + f_{yr}\right)\right], \qquad (8)$$

which simplifies as

$$d' = \frac{m}{w}\left(\frac{2f}{1-\frac{v^2}{w^2}} - \frac{2f}{\sqrt{1-\frac{v^2}{w^2}}}\right). \qquad (9)$$

In the Michelson-Morley experiment, m is 11 meters and f is approximately $5.45x10^{14}$ Hz. Figure 1 presents a graphical illustration of the frequency-based equations associated with the movement of the Interferometer.

Copyright © 2005-2006 Steven Bryant

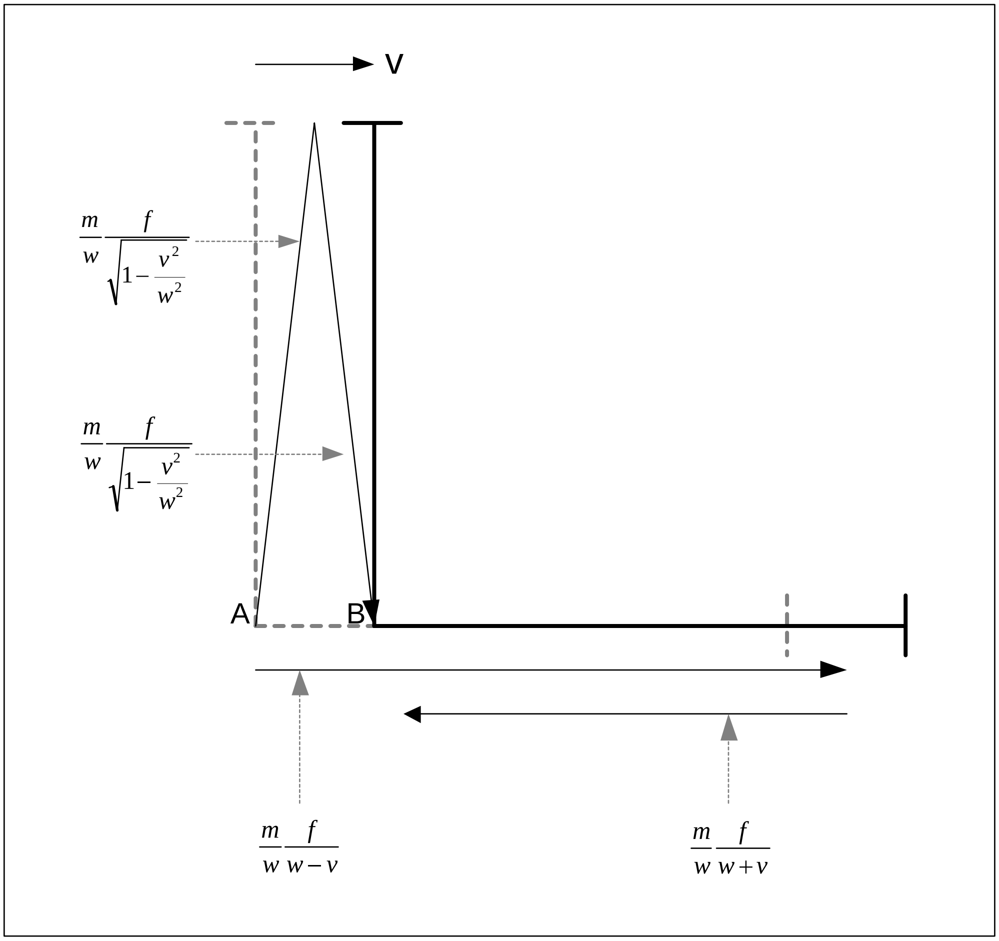

Figure 1. Illustration of the frequency-based equations when the Interferometer is moving through space at velocity v. Each equation is scaled by multiplying by $\frac{m}{w}$ to account for the apparent length of each arm of the Interferometer. Michelson and Morley implicitly define the number of cycles as $D = \frac{mf}{w}$ in their derivation.

This leads to the identification of the first Experimental Error (EE1), which is Michelson and Morley's combining frequencies without regard to the superposition of waves principle. It occurs because Michelson and Morley simply sum the values of the approaching and receding frequencies as

Copyright © 2005-2006 Steven Bryant

$$f_{mx} = \left(f_{xa} + f_{xr}\right) \text{ and } f_{my} = \left(f_{ya} + f_{yr}\right), \tag{10}$$

which, according to the superposition of waves principle, are too large by a factor of two. This finding is supported by realizing that Michelson and Morley's expected "frequencies", f_{mx} and f_{my}, for each arm of the Interferometer are in the ultraviolet region since each is approximately $2f$ Hz. Such frequencies are not within the visible spectrum and, therefore, could not be visually observed by the experimenter.

Michelson and Morley scale Equations 10 such that

$$f_{mx} = \left(\frac{m}{w} f_{xa} + \frac{m}{w} f_{xr}\right) \text{ and } f_{my} = \left(\frac{m}{w} f_{ya} + \frac{m}{w} f_{yr}\right), \tag{11}$$

and continue their derivation as outlined in this analysis to produce their final equation as

$$d'_m = \frac{2m}{w}\left[\left(f_{xa} + f_{xr}\right) - \left(f_{ya} + f_{yr}\right)\right] \tag{12}$$

or[†]

$$d'_m = \frac{2m}{w}\left(\frac{2f}{1 - \frac{v^2}{w^2}} - \frac{2f}{\sqrt{1 - \frac{v^2}{w^2}}}\right), \tag{13}$$

which, as previously discussed, is too large by a factor of two for each 90-degree rotation of the Interferometer. Michelson and Morley implicitly replace $\frac{mf}{w}$ with D in their

[†] This equation is mathematically equivalent to the equation given in the Michelson and Morley manuscript.

Copyright © 2005-2006 Steven Bryant

derivation. Their use of D instead of $\frac{mf}{w}$ hides the fact that the equations are frequency-based equations that must adhere to the superposition of waves principle.

Operating the Interferometer

The Interferometer operates by visually presenting the observer with a “fringe,” the optical representation of two interacting light waves. As the device is rotated, the fringe shifts to the left or right. The amount of the shift in the center of the fringe is measured and documented. Each measurement represents a certain number of cycles. In the Michelson and Morley experiment, each division of the micrometer screw represents approximately .02 cycles.[18] It is important to recognize that a fringe is actually the center of two interacting wave patterns, also governed by the superposition of waves principle. As conceptually illustrated in Fig. 2, a change of d' in the displacement between the two waves is measured as an observed shift of $\frac{1}{2}d'$ in the center of the fringe on the Interferometer.

Copyright © 2005-2006 Steven Bryant

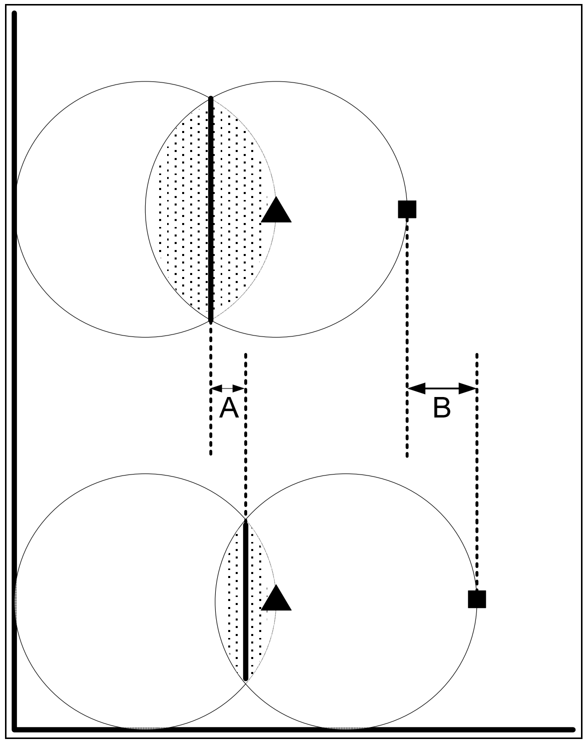

Figure 2. Conceptual illustration of the shift in the center of two interfering light waves. Mathematically, the distance of A (with a value of $\frac{1}{2}d'$) is the visible shift in the center of the interference pattern. The distance of B (with a value of d') is the change in displacement between the two interfering waves. The observable shift in the center of the fringe (represented by the vertical lines) is one-half of the change in displacement at the end of the waves (represented by the triangle and square).

This finding suggests that the observed fringe shift on the interferometer is one-half of Eq. 9, or

Copyright © 2005-2006 Steven Bryant

$$d'' = \frac{m}{w}\left(\frac{f}{1-\frac{v^2}{w^2}} - \frac{f}{\sqrt{1-\frac{v^2}{w^2}}}\right). \tag{14}$$

Thus, Eq. 14 is the expected result of the Interferometer experiment.

This leads to Michelson and Morley's second Experimental Error (EE2), which is that the Interferometer presents an optical representation of the shift in the center of the fringe, not an optical representation of the total expected displacement between the waves. The net result of the first two experimental errors is that the Michelson and Morley expected result equation produces values that are four times as large as can be detected by the Interferometer.

Comparing Expected and Actual Results

Equation 14 produces the expected result for the observed fringe shift during one 90-degree rotation of the Interferometer. However, during the experiment, measurements are gathered during each 22.5-degree rotation of the device. The third Experimental Error (EE3), as illustrated in Fig. 3, involves the comparison of actual results for 22.5-degree rotations against expected results for 90-degree rotations of the Interferometer.

Copyright © 2005-2006 Steven Bryant

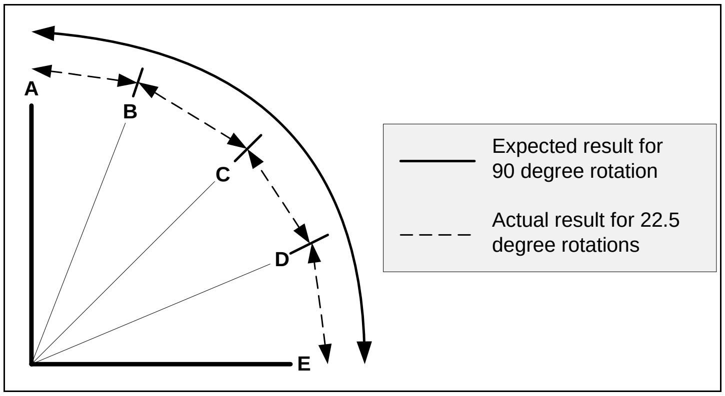

Figure 3. Illustration of the expected and actual results. The expected result is computed for a 90-degree rotation of the Interferometer (e.g., A to E). The actual results are measured at smaller increments (e.g., A to B, B to C, etc.), where each measurement represents a 22.5-degree rotation of the Interferometer.

The actual results, presented in the following Tables, are derived from the data tables presented in Michelson and Morley's 1887 paper. There are several methods that can be used to determine the actual results for a 90-degree rotation of the Interferometer. First, each column is labeled consecutively, C_0 through C_{16}. **Method 1** takes the absolute value of the value in column C_0 subtracted from the value in column C_4 to find the actual result for the first 90-degree rotation. This process is repeated to find the average values for the remaining three 90-degree rotations of the device. **Method 2** takes the absolute value of the value in column C_0 subtracted from the value in column C_{16}, which is then divided by 4 to find the result for a 90-degree rotation. **Method 3** sums the absolute value of each segment to compute the total number of micrometer adjustments made during the course of the experiment. This value is then divided by four to find the result for a 90-degree rotation. Mathematically, this is represented by the equation

Copyright © 2005-2006 Steven Bryant

$$\frac{\sum_{n=0}^{15} \left| C_n - C_{n+1} \right|}{4} . \tag{15}$$

The analysis presented in this paper uses Method 3, which accounts for every measurement during the operation of the Interferometer.

Analysis

The equation that Michelson and Morley used in their analysis is mathematically equivalent to Eq. 13, the latter of which is used in this paper to produce their actual results. Accordingly, the Michelson and Morley analysis does not correct for the experimental errors, EE1 and EE2, as discussed in this paper. Furthermore, their analysis does not correct for EE3, and instead compares the actual results for 22.5-degree rotations of the Interferometer against the expected result for 90-degree rotations of the device. As presented in Table I, without correcting for EE1, EE3, and EE3, the Michelson and Morley experiment produces a result of 8.1 km/s.[‡] This finding is consistent with Michelson and Morley's analysis of their data.

[‡] This computation is performed using Method 3 where each turn of the interferometer is used, with 16 used in the denominator of the Eq. 15, instead of 4, to account for 22.5-degree rotations. If Method 1 is used instead, the result of the analysis is 7.5 km/s.

Copyright © 2005-2006 Steven Bryant

Table I. Actual results of the Michelson and Morley experiment without correcting for experimental errors EE1, EE2, and EE3.

Measurement	Actual Results			
	Average micrometer divisions per 360 degree rotation of the Interferometer	**Number of micrometer divisions per 22.5 degree rotation of the Interferometer**	**Displacement per 22.5 degree rotation of the Interferometer (Hertz)**	**Computed Earth Velocity (approx. - meters per second)**
Morning Results				
Jul 08	31.00	1.9375	0.0388	9340
Jul 09	22.60	1.4125	0.0283	7975
Jul 11	22.20	1.3875	0.0278	7905
Morning Average	25.27	1.5792	0.0316	8425
Evening Results				
Jul 08	21.10	1.3188	0.0264	7990
Jul 09	19.40	1.2125	0.0243	7390
Jul 12	22.20	1.3875	0.0278	7905
Evening Average	20.90	1.3063	0.0261	7661
Overall Average	23.08	1.4427	0.0289	8060
Standard Deviation				655

Correcting EE1 and EE2 by using Eq. 14, and counting each measurement of the Interferometer using Method 3 to correct EE3, produces the actual results found in Table II. This analysis of the Michelson and Morley data reveals an EOV of 32.2 km/s, which is statistically equivalent to their expected result of 30 km/s.

Copyright © 2005-2006 Steven Bryant

Table II. Actual results of the Michelson and Morley experiment after correcting for experimental errors EE1, EE2, and EE3.

Measurement	Actual Results			
	Average micrometer divisions per 360 degree rotation of the Interferometer	Number of micrometer divisions per 90 degree rotation of the Interferometer	Displacement per 90 degree rotation of the Interferometer (Hertz)	Computed Earth Velocity (approx. - meters per second)
Morning Results				
Jul 08	31.00	7.7500	0.1550	37325
Jul 09	22.60	5.6500	0.1130	31870
Jul 11	22.20	5.5500	0.1110	31590
Morning Average	25.27	6.3167	0.1263	33700
Evening Results				
Jul 08	21.10	5.2750	0.1055	30800
Jul 09	19.40	4.8500	0.0970	29530
Jul 12	22.20	5.5500	0.1110	31590
Evening Average	20.90	5.2250	0.1045	30500
Overall Average	23.08	5.7708	0.1154	32210
Standard Deviation				2689

Discussion

Table III is a comparison of the results of the original Michelson and Morley analysis with the results of the revised analysis presented in this paper.

Copyright © 2005-2006 Steven Bryant

Table III. Comparison of the analyses of the Michelson-Morley experiment. (Accuracy is defined as Average Actual Result minus Expected Result. Since SRT expects 0 km/s, this value is used as the expected result for the original Michelson-Morley analysis. The known EOV of 29.78 km/s is used as the expected result of the revised analysis.)

(1)	(2)	(3)	(4)	(5)	(6)
				Accuracy	
	Observed	Computed Velocity Results		Velocity	
Measurement Time	Avg. Number of Divisions	Revised Analysis	Original Analysis	Revised Analysis	Original Analysis
Morning Results					
Jul 08	31.00	37325	9340	7545	9340
Jul 09	22.60	31870	7975	2090	7975
Jul 11	22.20	31590	7905	1810	7905
Morning Average	25.27	33700	8425	3920	8425
Evening Results					
Jul 08	21.10	30800	7990	1020	7990
Jul 09	19.40	29530	7390	-250	7390
Jul 12	22.20	31590	7905	1810	7905
Evening Average	20.90	30500	7661	720	7661
Overall Average	23.08	32210	8060	2430	8060
Standard Deviation	4.05	2689	655	--	--

When evaluated using the superposition of waves model, the Michelson-Morley experiment returned actual results consistent with their expected result. Furthermore, the actual result of 32.2 km/s is consistent with the mathematical and theoretical predictions of the CICS model. The standard deviation, σ, of the velocity measurement is 2.689 km/s. The difference between the actual result and the expected result is -0.90σ. The expected result of 29.7 km/s falls well within the 99.9% confidence interval of $32.20 \pm 3.39\sigma$ km/s. Based on this analysis, the amount of experimental error, is less than 4 divisions of the micrometer screw per 360-degree rotation of the Interferometer.

Copyright © 2005-2006 Steven Bryant

Conversely, Michelson and Morley's original results, which do not compensate for EE1, EE2, and EE3, found a velocity of 8.1 km/s. The standard deviation, σ, of the expected result is 0.655 km/s. Therefore, the difference between the actual result and the SRT expected result[§] of 0 km/s is 12.31σ. Since the SRT expected result of 0 km/s is well outside of the 99.9% confidence interval of $8.1 \pm 3.39\sigma$ km/s, a null interpretation of the result is not statistically supported. Importantly, a null interpretation of the Michelson-Morley result would require that the measurement of 23.08 divisions of the micrometer screw per 360-degree rotation of the Interferometer be explained as experimental error.

Miller's Experimental Confirmation

In 1933, Miller published results of his repeat experiment, with the goal of demonstrating the detection of the electromagnetic ether using a more robust and accurate Interferometer.[19] He increased the apparent length of each arm to 32.03 meters and used light at a frequency of approximately $5.20x10^{14}$ Hz.[20] Each measurement increment of the fringe on the Interferometer is 0.1 cycles.[21] In his paper, Miller provided one data set as a representative example of his findings.[22] Although this observation represents one measurement, it is comprised of twenty, 360-degree readings of the Interferometer.[23] When Miller's data set is analyzed using Eq. 14 and Method 3, we find that he detected an EOV of 29.97 km/s.

[§] Michelson and Morley expected to detect 30 km/s. However, since the Michelson and Morley experiment is cited as experimental confirmation of Special Relativity, 0 km/s is used as the SRT expected result for the experiment.

Copyright © 2005-2006 Steven Bryant

Conclusion

This paper presents an analysis of the interferometer experiment using a frequency-based superposition of waves principle, rather than the time-based phase shift principle as originally performed by Michelson and Morley. As a result, the Michelson-Morley expected result for a 90-degree rotation of the Interferometer is four times larger than could be detected through the visual observation of the fringes on the Interferometer. Additionally, the Michelson-Morley actual results are four times too small, representing measurements for each 22.5-degree rotation of the Interferometer instead of each 90-degree rotation. The original Michelson-Morley data, when reanalyzed after correcting these problems, reveals the observation of an Earth Orbital Velocity of 30 km/s, a finding supported by the reanalysis of Miller's 1933 Interferometer experiment. Importantly, the accuracy of the frequency-based analysis with the expected result of 30 km/s is less than 4 divisions of the micrometer screw, while the accuracy of the original analysis with the SRT expected result of 0 km/s is more than 23 division of the micrometer screw.

The positive result corresponds to the experimenter's expected result of 30 km/s. While this positive result contradicts the theoretical predictions of Special Relativity (which requires the experiment to produce a null result) it supports the interpretation and predictions of the author's model of Complete and Incomplete Coordinate Systems. This finding suggests the existence of an electromagnetic ether and supports the assertion that the CICS model corrects specific theoretical and mathematical problems identified with

Copyright © 2005-2006 Steven Bryant

SRT. Because this finding presumes the position that light waves are quantized, the CICS model may also align with Quantum Mechanics.

Acknowledgement

I want to thank Irene Cole, Manoj Thulasidas, Jim Cole, and Robert Canup II for their critical review and feedback of this paper. I also thank readers on the Internet for their feedback on earlier iterations of the paper and analysis.

---

[1] A. Michelson and E. Morley, American Journal of Sciences **34**, 333 (1887).

[2] Ibid.

[3] Ibid.

[4] R. Serway and J. Jewett, *Physics for Scientists and Engineers with Modern Physics*, **6**th edition (Brooks/Cole – Thomson Learning, Belmont, California, 2004)

[5] Ibid.

[6] S. Bryant, *Reexamining Special Relativity: Revealing and correcting SR's mathematical inconsistency*, (2005), Available at http://www.RelativityChallenge.Com/papers.htm

[7] S. Bryant, *Communicating Special Relativity Theory's Mathematical Inconsistencies*, Accepted by Galilean Electrodynamics (September 2005), A pre-publication version is available at http://www.RelativityChallenge.Com/papers.htm

[8] S. Bryant, 2005, op. cit. (see reference 6)

[9] Ibid.

Copyright © 2005-2006 Steven Bryant

---

[10] Ibid.

[11] C-C Su, Europhysics Letters **56** (2), 170-174 (2001)

[12] R. Cahill and K Kitto, *Michelson-Morley Experiments Revisited and the Cosmic Background Radiation Preferred Frame*, available at arXiv:physics/0205065

[13] H. Munéra, Apeiron **5**, 37 (1998)

[14] A. Michelson and E. Morley, 1887, op. cit. (see reference 1)

[15] D. Miller, Reviews of Modern Physics **5**, 203 (1933)

[16] R. Serway and J. Jewett, 2004, op. cit. (see reference 4)

[17] S. Bryant, 2005, op. cit. (see reference 6)

[18] A. Michelson and E. Morley, 1887, op. cit. (see reference 1)

[19] D. Miller, 1933, op. cit. (see reference 15)

[20] Ibid.

[21] Ibid.

[22] Ibid.

[23] Ibid.

Copyright © 2005-2006 Steven Bryant