

Experimental and Theoretical Test of Cahill's Detection of Absolute Velocity in Gas-mode Interferometer Experiments

Jay R. Seaver

Energy Matters Foundation, PO BOX 2588, Longmont, CO 80502, USA
E-mail: jay@energy-matters.org

Several papers by Cahill, et al. assert that Michelson-Morley type experiments performed in gas have small but non-null results which, when properly analyzed, show that the absolute speed of the earth was detected. Here we show that Cahill made a fundamental error in his assumptions and that the mathematical analysis upon which he based his conclusions is invalid. We also include a report on an experiment that verifies these mathematical conclusions. The experiment uses water instead of air as the wave medium. The much larger index of refraction of water (1.33 vs. 1.00029) greatly amplifies the effect Cahill predicts and makes the null result of the new experiment dramatically apparent. This confirms both theoretically and experimentally that absolute velocity was not and cannot be detected in Michelson-Morley type experiments regardless of the refractive medium in which they are performed.

1 Introduction

I was intrigued by several papers by Cahill [1–4] that purport to re-evaluate the original Michelson-Morley (MM) and other “gas-mode” interferometer experiments and prove that they actually measured the absolute speed of the earth through space. Cahill shows in these papers that the index of refraction of air caused results that although small were not completely null. He asserts that the absolute velocity of the earth was measured and that absolute space was detected — but was it?

I set out to test Cahill's assertions by designing an experiment capable of getting a larger non-null result. This experiment uses water as the medium through which the light propagates so that the “incomplete cancellation of the geometrical effects” (according to Cahill) would be greatly amplified by the much larger index of refraction. This allows easy detection of the interference-fringe shifts in a low-cost Michelson-type interferometer.

The experiment had a resolution that was more than 10^3 times greater than the effect Cahill's equations predicted. The results of the experiment were unequivocally null. Based on the null results, I set out to reexamine Cahill's assumptions and mathematical derivations. It was through this reexamination that I derived the correct equations and proved that the so-called “cancellation of the geometrical effects” is complete and the results of any MM type experiment must be null whether done in vacuum or in a refractive medium. We show that both the herein derived equations and the results of the present experiment are in complete agreement that absolute space cannot be detected with these types of experiments.

Our derivations (and Cahill's) are based on classical physics. By “classical physics” we mean merely that the equations of the special theory of relativity (SRT) will not be used to transform values between inertial reference frames. All

measurements in the derivations are made in the rest frame (or what Cahill calls the “quantum foam” frame) where light-speed is constant and isotropic. But in SRT, light-speed is constant and isotropic in *all* frames. Therefore our derivations will be in complete compliance with the formalism of SRT, while at the same time satisfying Cahill and his followers that they are also valid in Cahill's absolute frame.

The value measured in the experiment is the shift, measured in wavelengths, of the interference pattern of two light beams. Because this measurement is a scalar value, independent of the actual length of the wavelength, it is invariant in all reference frames. This is what allows us to do the entire analysis from the rest frame but make the actual measurement in the laboratory frame — they must agree.

2 Correcting Cahill's derivations

We will use Cahill's equations as derived in [1] for this analysis.

Cahill begins his analysis by making the following (incorrect) assumption regarding the speed of light in the refractive medium of air: “If the gas is moving with respect to the quantum foam, as in an interferometer attached to the earth, then the speed of light relative to the quantum foam is still $V = c/n$ up to corrections due to the Fresnel drag. *But this dragging is a very small effect and is not required in the present analysis*”. [emphasis added]) He is correct that Fresnel drag is a very small effect, but as will soon be evident, it is not small compared to the effect he is trying to measure and it cannot be ignored.

The laboratory frame is assumed to have an arbitrary velocity v with respect to the rest frame. We also make the following two assumptions which Cahill made in his analysis and which are entirely consistent with SRT: 1) clocks slow down with velocity and 2) lengths contract with velocity. The

factor by which they slow down is defined as

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}. \tag{1}$$

For convenience, we also make the following definition:

$$\beta = \frac{v}{c} \Rightarrow \gamma = \frac{1}{\sqrt{1 - \beta^2}}. \tag{2}$$

If both arms of the interferometer are of rest-length L and one is aligned parallel to the velocity of the laboratory and the other is aligned at right angles to this velocity, then the length of the orthogonal arm in the rest frame is still L , but the length of the parallel arm experiences a contraction if measured in the rest frame,

$$L_{\parallel} = L \sqrt{1 - \beta^2} = \frac{L}{\gamma}. \tag{3}$$

Cahill defines n to be the index of refraction of the gas and uses the same value n in both frames. This seems perfectly reasonable, since n is a scalar and therefore invariant. But just because it has the same value in both frames does not mean that it affects the path of the waves in both frames the same way. This will be demonstrated by observing *from within the rest frame* how observers *within the moving frame* measure and define n . It then becomes apparent that in the rest frame the velocity of light in a moving refractive medium is not simply c/n plus the traditional drag term.

Before observing how n is measured, we must first understand how clocks are synchronized using Einstein's method. We will do this by observing from the rest frame as clocks are synchronized in the laboratory frame. Let there be clocks at each end of the arm aligned parallel to the velocity which we designate as clock A and clock B . According to Eq. (3) this distance between the two clocks is L/γ in the rest frame. The procedure for synchronizing the two clocks in the moving frame is as follows:

1. A light wave leaves clock A at time 0 on clock A in the moving frame and also at time 0 in the rest frame.
2. The light beam propagates towards clock B at velocity c in both frames. In the rest frame clock B is moving at velocity v in the same direction as the light beam.
3. The light arrives at B at time t_1 in the rest frame.
4. The total distance the light travels in the rest frame on the outbound path is $c t_1$. This can be separated into two distances: 1) the length of the contracted arm L/γ and the distance clock B moved during the time t_1 which is $v t_1$. Solving for t_1 , we get

$$t_1 = \frac{L}{\gamma(c - v)}. \tag{4}$$

5. The light reflects from a mirror at B and returns to A at time t_2 in the rest frame. Since the clock at A was moving towards the light during this leg, the distance that

the light traveled before reaching A was $L/\gamma - v(t_2 - t_1)$. Using the same logic as above, the time $t_2 - t_1$ to make the return trip as measured in the rest frame is

$$t_2 - t_1 = \frac{L}{\gamma(c + v)}. \tag{5}$$

6. Solving for t_2 , the total time to make the round trip as measured in the rest frame is

$$t_2 = \frac{L/\gamma}{c + v} + \frac{L/\gamma}{c - v} = \frac{2L/\gamma}{c(1 - v^2/c^2)} = \frac{2L}{c} \gamma. \tag{6}$$

7. The clocks in the moving frame run slower by a factor of γ than the clocks in the rest frame. Therefore, the time on clock A when the light returns is

$$t_A = \frac{t_2}{\gamma} = \frac{2L}{c}. \tag{7}$$

8. Using Einstein's method of synchronization, clock B is defined to be synchronized to clock A if at the moment of reflection the time on clock B is set to $t_A/2$.

$$t_B = \frac{L}{c}. \tag{8}$$

As expected, the observers in the laboratory frame measure the speed of light to be c in both directions. But notice that at the moment of reflection of the light from clock B , the time is t_1 in the rest frame and t_B on clock B in the moving frame. But what is the time on clock A at that moment? Since clock A was defined to be 0 at time 0 in the rest frame, and since clock A runs slower by a factor of γ than clocks in the rest frame, the time on clock A must be t_1/γ . But that means that to an observer in the rest frame, there is a bias between clocks A and B ,

$$t_{bias} = t_B - \frac{t_1}{\gamma} = \frac{L}{c} - \frac{L}{\gamma^2(c - v)} = -\frac{vL}{c^2}. \tag{9}$$

Please note that this is in complete agreement with SRT. Position-dependent clock biases are the source of relative simultaneity in SRT. Events are defined to be simultaneous in the moving frame when the clocks at the sites of the two events read the same value. But because of the permanent bias between the clocks (when observed from the rest frame), those same two events are never simultaneous within the rest frame. From this exercise we see that there is nothing mysterious or magical about relative simultaneity — it is simply a byproduct of defining the one-way time of flight of a light wave to be 1/2 of the two-way time of flight.

The bias in Eq. (9) is the same position-dependent bias that occurs in the transformation of time between frames using the Lorentz transformation of SRT. But we have determined its value not by performing this transformation but by simply observing from the rest frame as clocks were synchronized in the moving frame. We have used nothing more than

this definition and classical physics to derive the same bias between the clocks as defined in SRT.

Now that we understand how clocks in the moving frame appear to observers in the rest frame, we are ready to see how the index of refraction, when measured in the laboratory, appears to observers in the rest frame. To measure the index of refraction in the laboratory, a light beam is sent from clock *A* at time 0 through a refractive material and arrives at clock *B* at time t_{Bn} , where the n in the subscript indicates time through the refractive material. This is the time of flight of the light beam as measured in the laboratory. The index of refraction is then defined as

$$n = \frac{c t_{Bn}}{L}. \tag{10}$$

This corresponds to a velocity of light in the refractive medium of c/n as measured in the laboratory. Let us now look at that same velocity as measured in the rest frame. Because of the bias on clock *B*, although the time on clock *A* is 0 when the light is emitted, the observer in the rest frame sees the light wave leave clock *A* when clock *B* reads $-vL/c^2$. The elapsed time on clock *B* for the time of flight is therefore

$$\Delta t_{Bn} = t_{Bn} + \frac{vL}{c^2}. \tag{11}$$

Using Eq. (10) to substitute for t_{Bn} , and remembering that clocks in the moving frame run slower by a factor of γ , the elapsed time in the rest frame for the time of flight is

$$\Delta t_0 = \frac{L(c n + v) \gamma}{c^2}. \tag{12}$$

We defined the direction from *A* to *B* to be the same direction as the velocity of the moving frame. Since lengths contract with velocity, the total distance the light propagated during this time, as measured in the rest frame, is

$$\Delta d_0 = \frac{L}{\gamma} + v \Delta t_0 = \frac{L}{\gamma} + \frac{vL(c n + v) \gamma}{c^2}. \tag{13}$$

The velocity of the light beam in the refractive material as measured in the rest frame is this distance divided by the propagation time, which simplifies to

$$c_{n0+} = \frac{\Delta d_0}{\Delta t_0} = \frac{c(c + n v)}{c n + v}. \tag{14}$$

Notice that this can be put in the following form:

$$c_{n0+} = \frac{c/n + v}{1 + \frac{(c/n) v}{c^2}}. \tag{15}$$

In this form it is very obvious that we have derived the velocity addition formula of SRT where the two velocities are c/n and v . This shows that there is nothing mysterious about the velocity addition formula of SRT. It is easily derived using classical physics if one acknowledges that clocks

and lengths change with velocity. The only mystery is what causes velocity-dependent lengths and clock-rates in the first place. But that is a topic for a separate paper.

We can also write this equation in a different form,

$$c_{n0+} = \frac{c}{n} + \left(\frac{n^2 - 1}{n^2} \right) \left(\frac{n}{n + \beta} \right) v. \tag{16}$$

In this form, we can clearly see that the Fresnel drag coefficient is simply a consequence of the velocity addition formula. They are not separate phenomena. Prior to Lorentz and Einstein, it was thought that the Fresnel drag term consisted only of the $\frac{n^2 - 1}{n^2} v$ term. The $\frac{n}{n + \beta}$ term is so close to 1 that except for extremely high velocities it was unobservable.

What we have shown in this derivation is that the Fresnel drag term is automatically included in our derivation once we acknowledge that lengths and times change with velocity. In fact, Fresnel drag is proof that lengths and times really do change with velocity.

When the light is sent in the opposite direction through the refractive medium, the sign of the laboratory's velocity v in equation (14) is inverted resulting in a reverse speed of

$$c_{n0-} = \frac{c(c - n v)}{c n - v}. \tag{17}$$

Summing the times of propagation for these out and back velocities, we can calculate the total time for a round trip on the parallel arm in the rest frame if the light is passing through a moving refractive medium with an index of refraction n :

$$\Delta t_{||0} = \frac{L}{\gamma(c_{n0+} - v)} + \frac{L}{\gamma(c_{n0-} + v)} = 2 \frac{L}{c/n} \gamma. \tag{18}$$

Not surprisingly, this is the same value we would have calculated if we had simply used the Lorentz transforms of SRT to transform the time on clock *A* into the rest frame for a round trip of length $2L$ at velocity c/n . Be we have derived it using nothing but classical physics and the two assumptions regarding length contraction and the slowing of clocks with velocity.

We will now look at the time for the round trip on the orthogonal arm. In the laboratory frame, n has the same value in all directions.* Therefore, as measured in the laboratory frame, the round-trip time in the orthogonal direction is

$$\Delta t_{\perp} = \frac{2L}{c/n} = \frac{2Ln}{c}. \tag{19}$$

With the arm oriented orthogonal to the velocity, the light-propagation times for the outbound and return trips are equal in the rest frame so there is no bias between clocks *A* and *B*. Since clocks in the moving frame run slower when observed

*This is proven in Section 4.2 where the velocity of light in a moving refractive medium is derived for any arbitrary direction.

from the stationary frame, this same time in the stationary frame is simply the elapsed time in the rest frame multiplied by γ ,

$$\Delta t_{\perp 0} = 2 \frac{L}{c/n} \gamma. \tag{20}$$

We see that this is exactly the same as the time for the parallel path given in equation (18) so the MM experiment is doomed to give null results regardless of the index of refraction of the medium.

3 Comparing to Cahill’s results

We now compare these results to Cahill’s results (we use subscript C for Cahill’s times), which come from his equations (7) and (10) in [1]:

$$\left. \begin{aligned} \Delta t_{\parallel C} &= \frac{2L}{\gamma \frac{c}{n} \left(1 - \frac{v^2}{c^2} n^2\right)} = \frac{2L\gamma}{c/n} \left(\frac{1}{\gamma^2 (1 - n^2 \beta^2)}\right) \\ \Delta t_{\perp C} &= \frac{2L}{\sqrt{\frac{c^2}{n^2} - v^2}} = \frac{2L\gamma}{(c/n)} \left(\frac{1}{\gamma \sqrt{1 - n^2 \beta^2}}\right) \end{aligned} \right\}. \tag{21}$$

The right-most terms in parenthesis are the error factors Cahill introduced by ignoring the “drag” effect. Without these terms, the times are identical. Notice that both of these error terms are very close to 1. In fact for a velocity of 360 km/sec and $n = 1.00029$ (which are the approximate values Cahill used in his paper), the two terms in parenthesis are $(1 + 8 \times 10^{-10})$ and $(1 + 4 \times 10^{-10})$, respectively. It is easy to see why Cahill thought they could be ignored and simply set to 1.

The difference between equations (21) is Cahill’s measured time difference between the parallel and orthogonal orientations. It can be shown that for $v/c = \beta \ll 1$ this difference can be approximated by

$$\Delta t_{\parallel C} - \Delta t_{\perp C} = \frac{Ln}{\gamma c} \left(\frac{(n^2 - 1)\beta^2}{1 - n^2\beta^2}\right). \tag{22}$$

In the original MM experiment, $L = 11$ and $n \approx 1.00029$. The absolute velocity that Cahill calculated was on the order of 360 km/sec, which results in $\beta \approx 0.0012$. Substituting these into equation (22) results in a measured time difference of

$$\Delta t_{\parallel C} - \Delta t_{\perp C} \approx 3.1 \times 10^{-17}. \tag{23}$$

This confirms Cahill’s estimate of a difference on the order of 10^{-17} sec. The wavelength of light used in the original experiment was approximately 600 nm which for a velocity of c has a temporal period of about 2.0×10^{-15} sec. Since there is one spatial period (wavelength) for each temporal period, the fringe shift in wavelengths is the total time delay of Eq. (23) divided by the temporal period of the light wave:

$$\Delta \lambda = \frac{3.1 \times 10^{-17}}{2.0 \times 10^{-15}} \lambda \approx 0.016 \lambda. \tag{24}$$

This represents a predicted fringe shift of about 1.6% of a wavelength in the original experiment. It is this value that Cahill used to predict the non-null results.

We conclude that Cahill made a fatal mistake when he assumed he could ignore the Fresnel drag effects. It is precisely the ignoring of Fresnel drag that creates the 1.6% difference in phase. Quoting Cahill, “Of course experimental evidence is the final arbiter in this conflict of theories.” In that spirit, we will present the design and results of an experiment that proves that an index of refraction greater than 1 does not give non-null results in Michelson-interferometer experiments as Cahill asserts.

Cahill’s analysis of the raw data from the original MM experiment shows a non-null result which is sidereal in nature and which agrees, according to Cahill, with his above calculations. It is beyond the scope of this paper to address the source of the non-null, sidereal effect found in the raw data. But one paper that has addressed this issue shows that the very large drift in the experiment combined with an improper statistical analysis is entirely responsible for the apparent non-null result [5].

4 Design of the new experiment

The analysis of the experiment to test Cahill’s results is again done as if we are an observer in a rest frame where light speed is isotropic. Since we are constrained to make all of the actual measurements in the moving frame of our laboratory, we define the results of the experiment in terms of an invariant scalar value that will have the same value in all frames. This is done by measuring the shift of an interference pattern in units of wavelengths. This is a scalar value that must be the same in all frames and allows us to make measurements in the moving frame that are in full agreement with those same measurements made in the hypothetical rest frame.

As mentioned above, the non-null result that Cahill predicted is less than 2% of a wavelength. This is much too small to be measured in an inexpensive, home-built interferometer. To increase the sensitivity of the experiment, the index of refraction was increased from 1.00029 of air to 1.33 of water. Of course, the experiment cannot be done completely submerged in water, so a refractive block containing water was introduced into one of the paths.

Figure 1 shows the physical layout of the experiment. A laser emits a beam that is split into two separate beams. One beam travels exclusively through air on its path to the detector. The other beam travels the same distance, but part of this path passes through a block of refractive material of length L that slows the wave down. When it exits the refractive block (RB), it then continues at the normal speed of light until it is recombined with its sister beam at the detector. Distilled water with an index of refraction of 1.33 is used for the refractive block. Unfortunately, using a refractive block is not the same as performing the entire experiment while im-

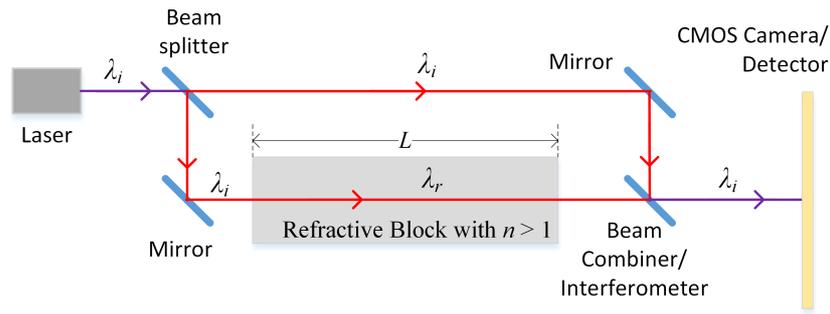


Fig. 1: Layout of experiment.

mersed in a high-refractive medium. Specifically, it complicates the mathematics by introducing refraction in the beam as it passes through the boundary between the air and the water. But the complication is worth it because it allows a large enough fringe shift (according to Cahill’s equations) that even our inexpensive interferometer is sensitive enough to measure it.

The wavelength that is emitted from the laser after taking into account the velocity-dependent slowing of the clocks and the Doppler shift, is designated as the incident wavelength λ_i . At the first beam splitter, one wave goes straight along an unrefracted path. The other beam gets reflected downward (in the figure) before reflecting off a second mirror that puts it on a trajectory that is parallel to the first beam but which passes through the refractive block. The two beams recombine at the beam combiner and propagate together to the camera detector. The phase and frequency shifts due to the reflection of the mirrors and beam splitters are exactly the same for the two paths and exactly cancel one another so they can be ignored. The wavelength leaving the laser and arriving at the phase detector is also the same for both paths.

It is the phase relationship between the two beams at the detector that we are interested in. Since the entire path is identical for both beams except for the length L of the RB, we only need to calculate the phase shift that occurs through the RB and compare it to the phase change that occurs over this same distance in the other path to account for the entire phase shift at the detector. All other effects will be identical on both paths and cannot alter the phase difference caused by the delay through the RB. By rotating the experiment 90 degrees we can measure the phase shift in each direction. Any difference between the two directions is a measure of absolute velocity through space — which Cahill predicts will be non-zero.

4.1 Velocity and the path of the beam

In this analysis, we are only going to look at the two cases where the velocity of the laboratory is orthogonal to the beam and parallel to the beam, respectively. We will be discussing multiple angles in this analysis. To keep these angles straight, the following definitions will be used:

1. The symbol φ will be used for the angle between the velocity vector of the refractive medium (laboratory) and the light wave path within the medium. It will have no subscript in the moving frame and a 0 subscript in the rest frame.
2. The symbol θ_i will be used for the incident angle of the wave path at the surface of the refractive block. It is defined as the angle between the light wave path and the normal to the refractive surface, which is the standard definition from geometric optics. It will have a subscript 0 when measured in the rest frame and no additional subscript in the moving frame.
3. The symbol θ_r will be used for the refracted angle of the wave path within the refractive block. It is defined as the angle between the light wave path in the RB and the line that is normal to the refractive surface, which is again the standard definition from geometric optics. It will have a subscript 0 when measured in the rest frame and no additional subscript in the moving frame.
4. In the case where the velocity is parallel to the line that is normal to the refractive surface, the θ angles will have an additional \parallel symbol in the subscript. If the velocity is orthogonal to the normal a \perp symbol will be used. Since the φ angles are by definition between the light path and the velocity, no subscript is necessary to indicate velocity direction.

Figure 2 shows a laser diode with a highly divergent beam that is collimated using an aperture. In actual lasers, a collimating lens is used instead of an aperture because a lens can capture most of the light. Obviously the aperture loses all of the light that doesn’t pass through it. But for our purposes the math and visualization is easier with the aperture and the principle is the same. The view in Figure 2 is for a laser that is stationary with respect to the observer.

Figure 3 shows what happens to the path of the beam if the laser is moving up (orthogonal to beam) in this figure at velocity v . The laser and aperture position are shown at time t for an emission that occurred at time 0. Notice that during the time that a wave front in the beam travels a distance ct (in vacuum), the aperture and laser move a distance vt . This

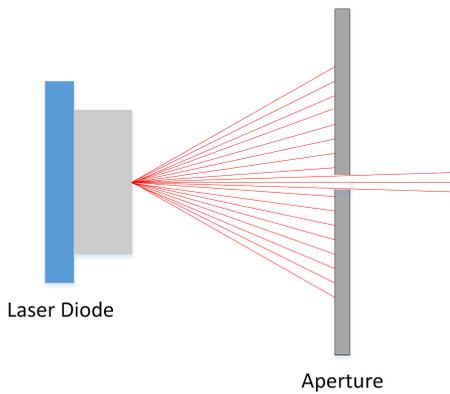


Fig. 2: Laser collimation using an aperture.

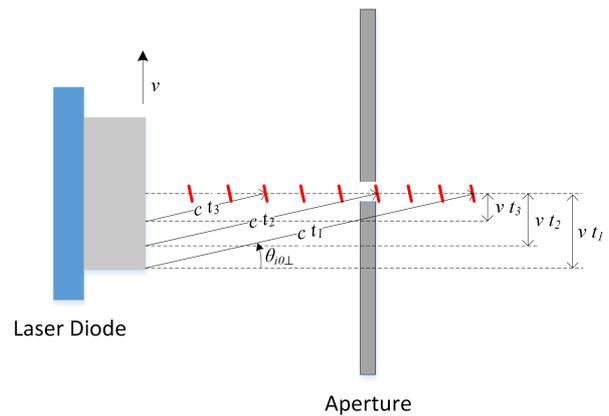


Fig. 4: Snapshot of laser beam for orthogonal direction.

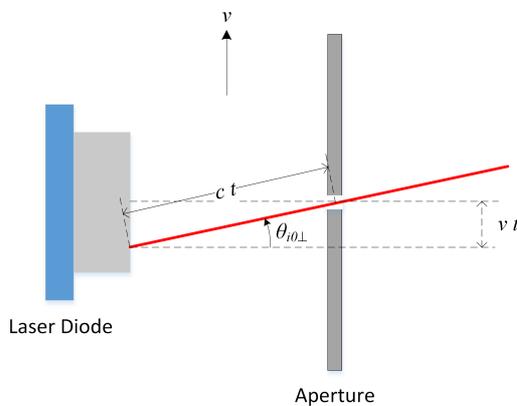


Fig. 3: Path of a single wavelet/photon for orthogonal direction.

means that only waves that left the laser at an angle of $\theta_{i0\perp}$ (in the rest frame) make it through the aperture — hence we have only shown one path in the figure. This angle assures that the orthogonal component of the velocity of the wave is exactly v and the parallel velocity of the wave is $\sqrt{c^2 - v^2}$.

Since every wave leaving the laser that makes it through the aperture follows a similar path, the resulting beam, which is made up of all of these individual wavelets, appears to remain perfectly aligned with the laser and with the aperture. The solid red line in Figure 3 shows the path of an individual wavelet from its emission at the laser surface to its exit from the aperture. Although the wavelet moves at an angle $\theta_{i0\perp}$, the beam one would see at any instant in time is the collection of all of the wavelets that have left the laser. A “snapshot” of the positions of several of these wavelets, each on its own unique path, is shown in Figure 4. Notice that the three wavelets that have been propagating for times t_1 , t_2 and t_3 each remain perfectly aligned with each other and with the center of the laser because the aperture assures that their velocity component in the orthogonal direction is exactly v . Any wavelets with different orthogonal velocities are blocked by the aperture.

We see that Mother Nature has conspired with light so that an observer in any frame sees a straight, horizontal beam going from the center of the laser through the center of the aperture and arriving at a distant target still centered — just as it appears when the system is stationary. This assures that the path of the composite beam relative to the laboratory is independent of the velocity of the laboratory even though the individual wavelets are moving at a velocity-dependent angle.

Since the index of refraction of air is so close to 1 and since the effect of the index of refraction of the refractive block is so much larger, we are going to simplify the math by treating the air as if the index of refraction were exactly 1. From Figure 3, we can see that the sine and cosine of $\theta_{i0\perp}$ are given by

$$\left. \begin{aligned} \sin \theta_{i0\perp} &= \frac{v}{c} = \beta \\ \cos \theta_{i0\perp} &= \sqrt{1 - \sin^2 \theta_{i0\perp}} = \sqrt{1 - \beta^2} = \frac{1}{\gamma} \end{aligned} \right\} \quad (25)$$

4.2 Velocity of light in a moving medium at arbitrary angle

In the orthogonal direction, we can see that the wavelets enter the refractive block at an angle. This means that the wavelet angle will be refracted upon passing through the surface of the RB. The angle of refraction of a moving block cannot be determined by Snell’s law alone – it is much more complicated.

Before calculating exactly how a beam refracts in a moving medium, we will first derive the general term for the velocity of light in a moving medium where the angle between the wavelet path and the velocity of the medium is an arbitrary angle between 0 and π .

In the rest frame of the medium, the geometry is as shown in Figure 5. The path AB is that of a laser beam propagating a distance L in a medium with an index of refraction of n . The source A and destination B are on opposite ends of an arm

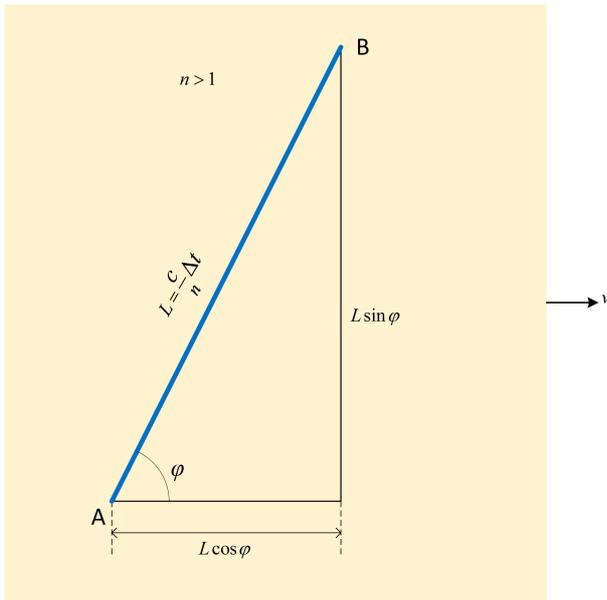


Fig. 5: Beam path at arbitrary angle in rest frame of medium.

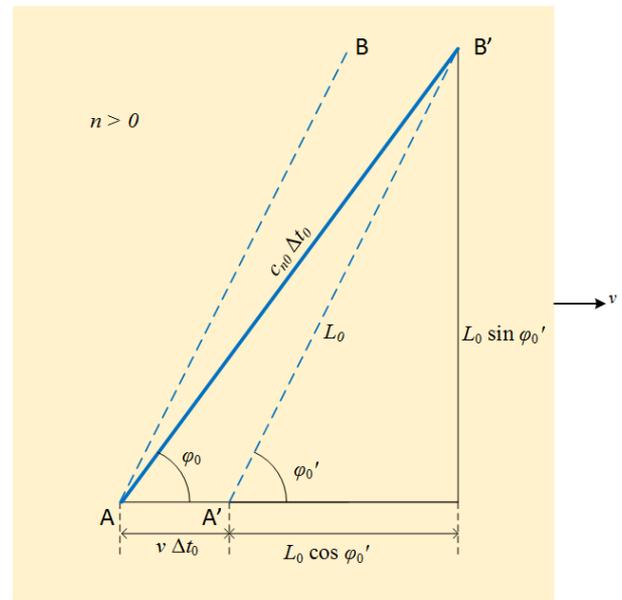


Fig. 6: Wavelet path at arbitrary angle in absolute frame.

of the experiment. The arm and the medium are both moving in the direction shown at velocity v with respect to the rest frame. The values given in the figure are for measurements made by an observer within the moving frame. In this frame, the time for a wavelet in the beam to travel from the source to the destination is by definition of the index of refraction n ,

$$\Delta t = \frac{Ln}{c}. \tag{26}$$

Figure 6 shows the path of the same wavelet if the beam is observed from the rest frame. The dotted lines show the instantaneous positions of the ensemble of wavelets that make up the beam at two different times. And the angle φ'_0 is the angle that the visible composite beam makes with the velocity. The bold solid line shows the path that an individual wavelet takes.

In the moving frame, the clocks at A and B are assumed to have been synchronized using Einstein's method. As we derived earlier, synchronizing the clocks in the moving frame will create a bias between the clocks when observed from the rest frame:

$$t_{0bias} = \frac{vL \cos \varphi}{c^2}. \tag{27}$$

Taking this into account and also accounting for the fact that clocks run slower in the moving frame, the time for a wavelet to propagate from A to B' in the rest frame is

$$\Delta t_0 = (\Delta t - t_{0bias}) \gamma = \left(\frac{Ln}{c} + \frac{vL \cos \varphi}{c^2} \right) \gamma. \tag{28}$$

Length contraction in the direction of the velocity causes the angle φ in the moving frame to increase to φ'_0 in the rest

frame (beam and wavelet path are the same within the moving frame). The length of the arm L will decrease in the rest frame to L_0 :

$$L_0 = L \sqrt{\frac{\cos^2 \varphi}{\gamma^2} + \sin^2 \varphi}. \tag{29}$$

Since lengths do not contract in directions orthogonal to the velocity,

$$L \sin \varphi = L_0 \sin \varphi'_0. \tag{30}$$

From the right triangle with hypotenuse AB' in Figure 6, we get the following relationship for angle φ_0 :

$$\sin \varphi_0 = \frac{L \sin \varphi}{c_{n0} \Delta t_0}. \tag{31}$$

Pythagorean's Theorem requires that

$$(c_{n0} \Delta t_0)^2 = (v \Delta t_0 + L_0 \sin \varphi'_0)^2 + (L_0 \sin \varphi'_0)^2. \tag{32}$$

Using equations (30), (31) and (32) we can solve for c_{n0} and $\sin \varphi_0$:

$$c_{n0} = \sqrt{\frac{L_0^2}{\Delta t_0^2} + v^2} \pm \frac{2\sqrt{(L_0^2 - L^2 \sin^2 \varphi)} v^2}{\Delta t_0}, \tag{33}$$

$$\sin \varphi_0 = \frac{L \sin \varphi}{\sqrt{\frac{L_0^2}{\Delta t_0^2} + v^2} \pm \frac{2\sqrt{(L_0^2 - L^2 \sin^2 \varphi)} v^2}{\Delta t_0}}. \tag{34}$$

Substituting equations (28) and (29) into these equations, results in solutions involving only the angle φ in the rest frame of the medium:

$$c_{n0} = c \sqrt{1 - \frac{n^2 - 1}{\gamma^2 (n + \beta \cos \varphi)^2}}, \tag{35}$$

$$\sin \varphi_0 = \frac{\sin \varphi}{\sqrt{\gamma^2 (n + \beta \cos \varphi)^2 - n^2 + 1}}. \tag{36}$$

From which we can also calculate the cosine:

$$\cos \varphi_0 = \sqrt{1 - \frac{\sin^2 \varphi}{\gamma^2 (n + \beta \cos \varphi)^2 - n^2 + 1}}. \tag{37}$$

Equation (35) is the speed of an individual wavelet as measured in the rest frame when the medium (i.e. laboratory) is moving at velocity $v = c\beta$. It demonstrates that there is not a unique index of refraction $n_0 = c/c_{n0}$ for a moving medium. The speed of light through the medium is a function of both the velocity of the medium and the angle which the beam makes with that velocity. Cahill ignored the “drag” component and assumed the velocity in the moving medium was the same c/n as in the stationary medium. This is what introduced his error.

The angle φ is the angle as measured in the moving frame between the velocity of the frame and the direction of the light waves. Equations (36) and (37) describe the angle φ_0 at which the light waves are moving in the rest frame in terms of φ in the moving frame.

The velocity of the light wavelets can be separated into two components, one parallel to the laboratory velocity and one orthogonal to the laboratory velocity. In Figure 6, these two components are

$$\left. \begin{aligned} c_{n0\perp} &= c_{n0} \sin \varphi_0, \\ c_{n0\parallel} &= c_{n0} \cos \varphi_0 \end{aligned} \right\}. \tag{38}$$

Substituting equations (35), (36) and (37) into these equations gives us the expressions for the parallel and orthogonal components of wavelet velocity in the rest frame:

$$\left. \begin{aligned} c_{n0\perp} &= \frac{c}{n} \left(\frac{\sin \varphi}{\gamma \left(1 + \frac{\beta}{n} \cos \varphi \right)} \right) \\ c_{n0\parallel} &= \frac{c}{n} \left(\frac{\cos \varphi + \beta n}{1 + \frac{\beta}{n} \cos \varphi} \right) \end{aligned} \right\}. \tag{39}$$

With the parallel and orthogonal components of the velocity, we know everything about the velocity and direction of the wavelets within the moving medium. We are now ready to investigate how this affects the refraction of a beam that is entering a moving medium as observed from the rest frame.

4.3 Refraction of light entering a moving refractive medium

For our analysis of refraction, we will refer to Figure 7 where we have added the incident and refracted angles. This figure again shows a moving refractive medium with index of refraction n as measured in the moving frame. A laser source is attached to and moving along with the refractive medium. Both the medium and the laser are moving at velocity v in the rest frame in the direction shown, which is orthogonal to the line which is normal to the refractive surface. The line normal to the refractive surface will be referred to as the normal line. The medium is shown at two different positions separated in time. The laser source is shown at three different times.

The dotted lines leaving the laser again show the location of the ensemble of wavelets that make up the composite visible laser beam at these times. This is the apparent path of the laser beam. The bold line shows the path that is actually taken by an individual wavelet or photon within the beam in propagating from the source to A and then through the medium to B’.

It is readily apparent that the relationship between the angles is

$$\theta_{r0\perp} = \frac{\pi}{2} - \varphi_0. \tag{40}$$

This can be expressed as

$$\left. \begin{aligned} \sin \varphi_0 &= \cos \theta_{r0\perp} \\ \cos \varphi_0 &= \sin \theta_{r0\perp} \end{aligned} \right\}. \tag{41}$$

These angles as measured in the moving frame will have a similar relationship:

$$\left. \begin{aligned} \sin \varphi &= \cos \theta_{r\perp} \\ \cos \varphi &= \sin \theta_{r\perp} \end{aligned} \right\}. \tag{42}$$

From Snell’s law, the incident and refracted angles in the moving frame (i.e. in the rest frame of the RB) are related by

$$\sin \theta_{i\perp} = n \sin \theta_{r\perp}. \tag{43}$$

Substituting this into equations (42) results in

$$\left. \begin{aligned} \sin \varphi &= \sqrt{1 - \frac{\sin^2 \theta_{i\perp}}{n^2}} \\ \cos \varphi &= \frac{\sin \theta_{i\perp}}{n} \end{aligned} \right\}. \tag{44}$$

Substituting these into equations (39) gives us the parallel and orthogonal components of the wave velocity in the rest frame as a function of the incident angle in the moving frame:

$$c_{n0\parallel} = \frac{c}{n} \left(\frac{\sin \theta_{i\perp} + \beta n^2}{n + \frac{\beta}{n} \sin \theta_{i\perp}} \right) \tag{45}$$

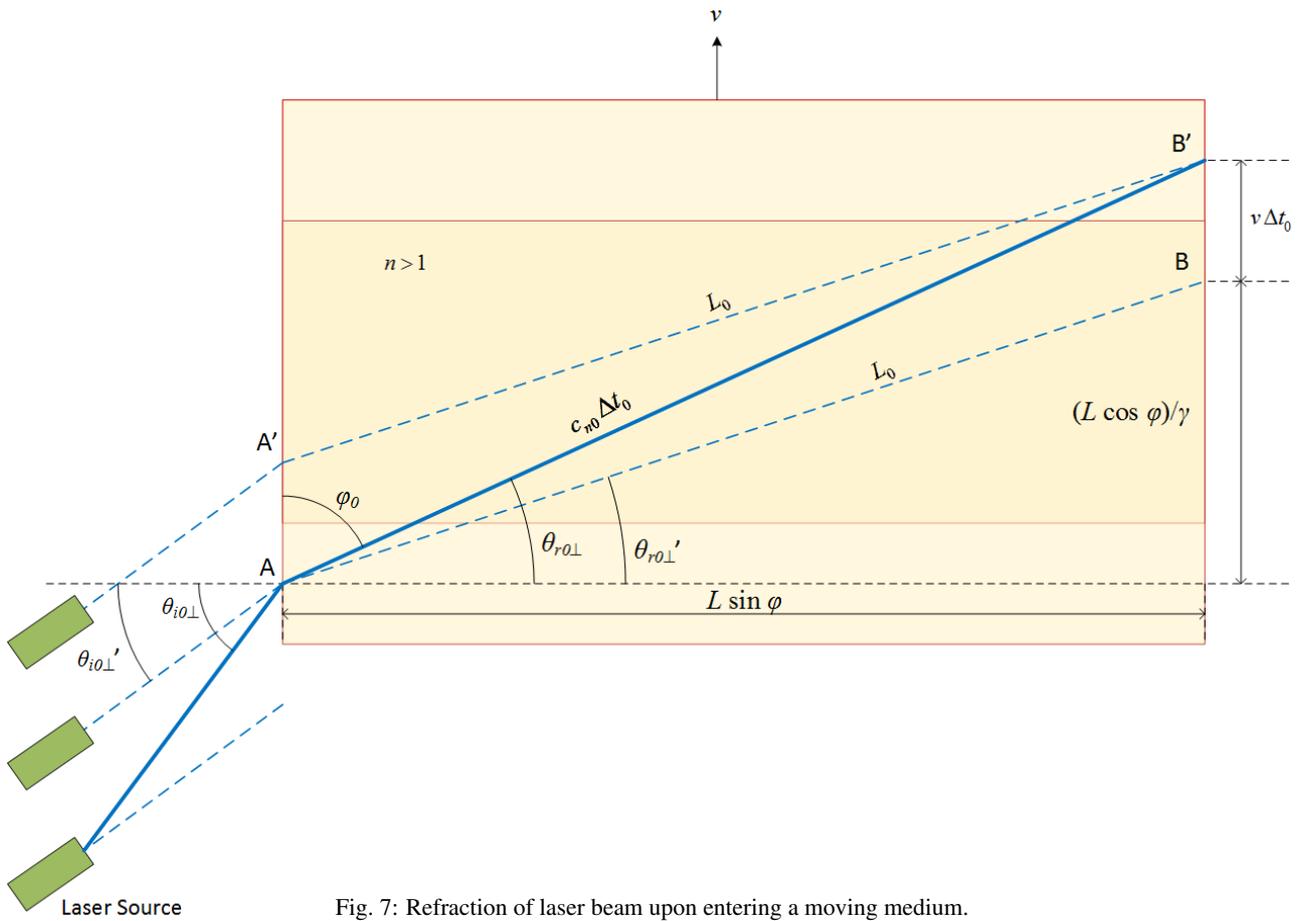


Fig. 7: Refraction of laser beam upon entering a moving medium.

$$c_{n0\perp} = \frac{c}{n} \left[\frac{n \sqrt{1 - \frac{\sin^2 \theta_{i\perp}}{n^2}}}{\gamma \left(n + \frac{\beta}{n} \sin \theta_{i\perp} \right)} \right]. \quad (46)$$

$$c_{n0\perp} = \left(\frac{c}{n} \right) \frac{\sin \theta_{i\parallel}}{\gamma \left(n + \beta \sqrt{1 - \frac{\sin^2 \theta_{i\parallel}}{n^2}} \right)}. \quad (49)$$

A similar set of equations can be obtained when the velocity is parallel to the normal line. Although the parallel case is not shown in the figure, it is easy to see that in this case the refracted angle is equal to φ_0 so that

$$\left. \begin{aligned} \sin \varphi &= \sin \theta_{r\parallel} = \frac{\sin \theta_{i\parallel}}{n} \\ \cos \varphi &= \cos \theta_{r\parallel} = \sqrt{1 - \frac{\sin^2 \theta_{i\parallel}}{n^2}} \end{aligned} \right\}. \quad (47)$$

Substituting these into equation (39) gives the orthogonal and parallel components of the wave velocity for the parallel orientation:

$$c_{n0\parallel} = \left(\frac{c}{n} \right) \frac{\left(n\beta + \sqrt{1 - \frac{\sin^2 \theta_{i\parallel}}{n^2}} \right)}{1 + \frac{\beta}{n} \sqrt{1 - \frac{\sin^2 \theta_{i\parallel}}{n^2}}}, \quad (48)$$

We now have a complete description of how an incident wave is refracted when it enters a moving refractive medium. Equations (45) and (46) govern the refraction if the medium is moving orthogonal to the normal line. Equations (48) and (49) govern when the medium is moving parallel to the normal line.

4.4 Refraction with $\theta_i = 0$ and velocity orthogonal to beam

With the general equations derived, we are now ready to analyze the specific situation of this experiment. The incident angle, as measured in the moving frame (i.e. rest frame of the medium) is zero whether the direction is orthogonal or parallel:

$$\theta_{i\parallel} = \theta_{i\perp} = 0. \quad (50)$$

Substituting these into the expressions for the wave velocity components when the velocity is orthogonal to the normal

line (Equations (45) and (46)), we get

$$c_{n0\parallel} = \frac{c}{n} \left(\frac{\beta n^2}{n} \right) = v, \tag{51}$$

$$c_{n0\perp} = \frac{c}{n} \left[\frac{n\sqrt{1-\beta^2}}{\gamma(n)} \right] = \frac{c}{n\gamma}. \tag{52}$$

And for the case when the velocity is parallel to the normal line (Equations (48) and (49)), we have

$$c_{n0\parallel} = \left(\frac{c}{n} \right) \frac{(n\beta + 1)}{1 + \frac{\beta}{n}} = \frac{c + cn\beta}{n + \beta} = \frac{c(c + nv)}{cn + v}, \tag{53}$$

$$c_{n0\perp} = 0. \tag{54}$$

We already derived this expression for the parallel case in equation (14). We repeat it here to show that equations (48) and (49) are consistent with the earlier derivation.

The angle of propagation in the parallel case is 0, but in the orthogonal case it is defined by

$$\sin \varphi_0 = \frac{c_{n0\parallel}}{\sqrt{c_{n0\parallel}^2 + c_{n0\perp}^2}} = \frac{v}{\sqrt{v^2 + \frac{c^2}{n\gamma^2}}}. \tag{55}$$

Equations (51) and (52) are quite remarkable. Equation (51) shows that the velocity component of the wave velocity that is parallel to the medium velocity v is always exactly equal to v . It is completely independent of the index of refraction n . This is what guarantees that the path that a wave takes through the medium will not change relative to the medium no matter how fast the source and medium are moving or no matter what the index of refraction is. This is why observers in the medium cannot detect any change in the trajectory of the waves when their velocity changes.

Equation (52) gives the component of wave speed that is orthogonal to the velocity of the medium. This is the term that guarantees that the time measured for the wave to pass through the medium is always measured to be c/n in the moving frame (the rest frame of the medium). For example, if the laboratory is at rest the velocity of a wave is c/n , and the time to pass through a block that is of length L is Ln/c . If the laboratory is then accelerated to a velocity of v in the orthogonal direction, the clocks in that frame slow so that the time Ln/c becomes $Ln\gamma/c$. But from equation (52) we see that the orthogonal component of the wave speed slows down by the same factor of γ so that the time measured in the laboratory to traverse length L remains at Ln/c .

5 Calculating time delays and phase shifts

Knowing the incident wavelengths, velocities and directions, we can calculate the change in phase shift that occurs with velocity. The only place that the phase can be different between the two paths is when the beam is passing through

the refractive block. The distance that the unrefracted beam races ahead of the refracted wave while the refracted wave is slowed down by the RB is proportional to the phase difference between the two paths.

We will begin by analyzing the parallel direction where the velocity of the medium and velocity of the light beam are aligned.

5.1 Time delay and phase shift with light beam parallel to velocity

In this case, the laboratory is moving at velocity v with the light beam parallel to the velocity. The length of the RB will contract to

$$L_{0\parallel} = \frac{L}{\gamma}. \tag{56}$$

The velocity of the light within the refractive material, with respect to the rest frame, is given by equations (53) and (54):

$$\left. \begin{aligned} c_{n0\parallel} &= \frac{c}{n} \left(\frac{1 + \beta n}{1 + \frac{\beta}{n}} \right) = \frac{c(c + nv)}{cn + v} \\ c_{n0\perp} &= 0 \end{aligned} \right\}. \tag{57}$$

The refractive block itself is moving at velocity v , so the effective velocity of the light with respect to the RB is

$$c_{n0\parallel e} = c_{n0\parallel} - v = \frac{c(c + nv)}{cn + v} - v = \frac{c}{\gamma^2} \left(\frac{1}{n + \beta} \right). \tag{58}$$

At this relative velocity, the total time it takes a wave to propagate through the RB is

$$\Delta t_{0\parallel} = \frac{L_{0\parallel}}{c_{n0\parallel e}} = \frac{L}{\gamma \frac{c}{\gamma^2} \left(\frac{1}{n + \beta} \right)} = \frac{L(n + \beta)\gamma}{c}. \tag{59}$$

The total distance a wavelet propagates in the parallel direction while inside the RB is measured in the rest frame to be

$$\Delta x_{0\parallel} = \frac{L}{\gamma} + v \Delta t_{0\parallel} = \frac{L}{\gamma} + L\beta(n + \beta)\gamma = L\gamma(1 + n\beta). \tag{60}$$

The total distance the unrefracted beam propagates in this same time is

$$\Delta x_{0u\parallel} = c \Delta t_{0\parallel} = L(n + \beta)\gamma. \tag{61}$$

The difference between these two distances for the refracted and unrefracted paths is the spatial phase shift that occurred between the two waves as a result of the path through the RB:

$$\Delta x_{\parallel} = \Delta x_{0\parallel} - \Delta x_{0u\parallel} = L\gamma(n - 1)(1 - \beta). \tag{62}$$

Dividing this difference by the wavelength of the incident wave gives the phase shift in wavelengths in the parallel orientation:

$$k_{\parallel} = \frac{L}{\lambda_{i0\parallel}} \gamma (n - 1) (1 - \beta). \quad (63)$$

This is a scalar value. Like the number of marbles in a bowl, it is the same for all observers in all frames. It represents the phase difference between the refracted path and the unrefracted path in the parallel direction as measured in wavelengths.

Since it is an invariant, we should be able to verify that it is the same value as measured in the moving frame. The phase shift in that frame that would be expected is

$$k_{\parallel} = \left(c - \frac{c}{n}\right) \frac{\Delta t}{\lambda_i} = \left(c - \frac{c}{n}\right) \left(\frac{Ln}{\lambda_i c}\right) = \frac{L}{\lambda_i} (n - 1). \quad (64)$$

To show that equations (63) and (64) are, in fact, the same scalar value, we note that the frequency of the laser source will be reduced in the rest frame and there will also be a Doppler shift of the wavelength in that frame. Thus, the wavelength of the incident wave in the rest frame is

$$\lambda_{i0\parallel} = \lambda_i \gamma (1 - \beta) = \lambda_i \sqrt{\frac{(1 - \beta)^2}{(1 + \beta)(1 - \beta)}} = \lambda_i \sqrt{\frac{1 - \beta}{1 + \beta}}. \quad (65)$$

Substituting this into equation (63) gives the total phase shift in wavelengths between the two paths in the parallel orientation:

$$k_{\parallel} = \frac{L}{\lambda_i} \sqrt{\frac{1 + \beta}{1 - \beta}} \gamma (n - 1) (1 - \beta) = \frac{L}{\lambda_i} (n - 1). \quad (66)$$

This is, of course, the same scalar value measured in the moving frame in equation (64). The interesting thing about this number is that it is completely independent of the velocity of the medium. That is just another way of saying that no matter what the velocity of the frame, all observers will always measure exactly the same phase shift.

Notice that k is a very large number since L is measured in meters and the wavelength is measured in hundreds of nanometers. This number is not measurable by the interferometer. It is only able to measure *differences* in phase. Fortunately it is the difference between the orthogonal and parallel phase shifts that we are interested in. We will now repeat the above procedure to determine the phase shift for the orthogonal direction.

5.2 Time delay and phase with the light beam orthogonal to velocity

When the light beam is orthogonal to the velocity of the laboratory, no contraction occurs and the length of the RB remains at its rest length of L . Since the individual wavelets are moving through the RB at an angle, the time that it takes for an

individual wavelet to travel through the block is determined by the component of its velocity that is parallel to the normal line.

This is obtained from equation (52):

$$c_{n0\perp} = \frac{c}{n\gamma}. \quad (67)$$

Of course, it propagates a distance L in this direction at this speed. Since the velocity of the laboratory is orthogonal to the RB, this is also the velocity of a wave relative to the RB. The total time for a wave to propagate through the RB is

$$\Delta t_{0\perp} = \frac{L}{c_{n0\perp}} = \frac{Ln\gamma}{c}. \quad (68)$$

During this same time, the unrefracted beam is propagating at speed c but not exactly orthogonal. Its velocity in the orthogonal direction is also given by equation (52), but with $n = 1$, since it is moving through vacuum:

$$c_{n0u\perp} = \frac{c}{\gamma}. \quad (69)$$

The distance that the unrefracted beam travels in this time is

$$\Delta x_{0u\perp} = \frac{c}{\gamma} \Delta t_{0\perp} = \frac{c}{\gamma} \frac{Ln\gamma}{c} = Ln. \quad (70)$$

The difference between the two distances is

$$\Delta x_{\perp} = \Delta x_{0u\perp} - \Delta x_{0\perp} = nL - L = L(n - 1). \quad (71)$$

We divide this by the wavelength in the orthogonal direction to get the total phase shift:

$$k_{\perp} = \frac{L}{\lambda_{i0\perp}} (n - 1). \quad (72)$$

For calculating $\lambda_{i0\perp}$ we must again account for the longer wavelength due to the slowing of the frequency source. While there is no Doppler shift orthogonal to a moving source, we must consider the change in wavelength due to the angle at which it is propagating in the rest frame. So

$$\lambda_{i0\perp} = \lambda_i \gamma \cos \theta_{i0\perp}. \quad (73)$$

Since this wavelength is measured in vacuum while the wave is moving at velocity c , from equation (69), we see that

$$\cos \theta_{i0\perp} = \frac{c/\gamma}{c} = \frac{1}{\gamma}. \quad (74)$$

Thus, $\lambda_{0\perp} = \lambda_i$ and the total phase shift in wavelengths from equation (72) becomes

$$k_{\perp} = \frac{L}{\lambda_i} (n - 1). \quad (75)$$

Comparing this to the phase shift for the parallel case in equation (66), we see that they are identical. We have now proven mathematically that regardless of whether or not the experiment is performed in vacuum or in a refractive medium there is no difference in phase between the two orientations — it will always be a null experiment.

6 Numerical values of Cahill’s predictions

Cahill, on the other hand, predicted that there will be a measurable phase difference. Cahill predicts in his equation (11) in [1] that the time difference between the two paths will approximate to his equation (12). Again using a “C” in the subscripts to indicate Cahill’s predictions, his time difference is

$$\Delta t_C \approx Ln (n^2 - 1) \left(\frac{\beta^2}{c} \right). \tag{76}$$

But this is for a two-way experiment. Our experiment is a one-way measurement. Cahill’s one-way time in the parallel direction through the refractive block is derived from his equations (1) and (2):

$$\Delta t_{0\parallel C} = \frac{Ln}{c} \left(\frac{1}{\gamma(1 - n\beta)} \right). \tag{77}$$

His time in the orthogonal direction is given in his equation (8) in [1]:

$$\Delta t_{0\perp C} = \frac{Ln}{c} \left(\frac{1}{\sqrt{1 - n^2\beta^2}} \right). \tag{78}$$

Both of these times are as measured in the rest reference frame and represent the total time between a wavelet entering the refractive block until it exits.

According to Cahill, the speed of light in the refractive material is approximately c/n in both cases and Fresnel drag is insignificant. In the orthogonal case, from his Figure 1 (b) this requires that the direction of the wave is actually at an angle that satisfies the equations

$$\left. \begin{aligned} \sin \theta_{r0\perp C} &= \frac{vn}{c} \\ \cos \theta_{r0\perp C} &= \sqrt{1 - \left(\frac{vn}{c} \right)^2} = \sqrt{1 - n^2\beta^2} \end{aligned} \right\}. \tag{79}$$

Therefore the distances traveled in the parallel and orthogonal directions during the times of equations (77) and (78) are respectively

$$\left. \begin{aligned} \Delta x_{0\parallel C} &= \frac{c}{n} \Delta t_{0\parallel} = \frac{L}{\gamma(1 - n\beta)} \\ \Delta x_{0\perp C} &= \frac{c}{n} \Delta t_{0\perp} \cos \theta_{r0\perp} \\ &= L \left(\frac{1}{\sqrt{1 - n^2\beta^2}} \right) \sqrt{1 - n^2\beta^2} = L \end{aligned} \right\}. \tag{80}$$

On the other hand, the distances traveled by the light in the unrefracted paths in these times are

$$\left. \begin{aligned} \Delta x_{0u\parallel C} &= c \Delta t_{0\parallel} = \frac{Ln}{\gamma(1 - n\beta)} \\ \Delta x_{0u\perp C} &= c \Delta t_{0\perp} \cos \theta_{i0\perp} = \frac{Ln}{\gamma} \left(\frac{1}{\sqrt{1 - n^2\beta^2}} \right) \end{aligned} \right\}. \tag{81}$$

For each direction, respectively, the differences between the refracted and unrefracted lengths are

$$\left. \begin{aligned} \Delta x_{\parallel C} &= \Delta x_{0u\parallel C} - \Delta x_{0\parallel C} = \frac{L}{\gamma(1 - n\beta)} (n - 1) \\ \Delta x_{\perp C} &= \Delta x_{0u\perp C} - \Delta x_{0\perp C} = L \left(\frac{n}{\gamma \sqrt{1 - n^2\beta^2}} - 1 \right) \end{aligned} \right\}. \tag{82}$$

Using equation (65) for the parallel incident wavelength (orthogonal incident wavelength is unchanged), we can convert these distances to wavelengths:

$$\left. \begin{aligned} k_{\parallel C} &= \frac{\Delta x_{\parallel C}}{\lambda_{i0\parallel C}} = \frac{L}{\gamma \lambda_i (1 - n\beta)} (n - 1) \sqrt{\frac{1 + \beta}{1 - \beta}} \\ k_{\perp C} &= \frac{\Delta x_{\perp C}}{\lambda_{i0\perp C}} = \frac{L}{\lambda_i} \left(\frac{n}{\gamma \sqrt{1 - n^2\beta^2}} - 1 \right) \end{aligned} \right\}. \tag{83}$$

The total phase shift predicted by Cahill’s equations is the difference between these two values, which simplifies to

$$\Delta k_C = \frac{L}{\lambda_i (1 - n\beta)} \left(n - \beta - \frac{n}{\gamma} \sqrt{\frac{1 - n\beta}{1 + n\beta}} \right). \tag{84}$$

In this experiment

$$L = 1 \text{ m} \quad n = 1.33 \quad \lambda_i = 650 \text{ nm}. \tag{85}$$

Cahill claims that the original MM experiment measured a velocity of about 360 km/sec. Thus,

$$v = 3.6 \times 10^5 \Rightarrow \beta = 0.0012. \tag{86}$$

Substituting all these values into equation (84) gives us the phase shift that Cahill predicts for this experiment:

$$\Delta k_C = 1421 \text{ wavelengths}. \tag{87}$$

This is an enormous phase difference which would easily be detected by this experiment if it existed.

7 Results of experiment

The present experiment is capable of measuring phase differences with a resolution of about 0.1 wavelengths. The phase shift was measured between a north-south orientation and an east-west orientation each hour for 12 hours. Had there been any significant velocity difference in any direction, one or more of these measurements would have been able to detect it.

The peak phase difference (after averaging) was measured to be 0.1 wavelengths at 10 a.m. This is within the error tolerance of the experiment and is therefore not statistically different from zero. After averaging the 10 measurements at each time, the measured phase shifts in wavelengths are graphed in Figure 8.

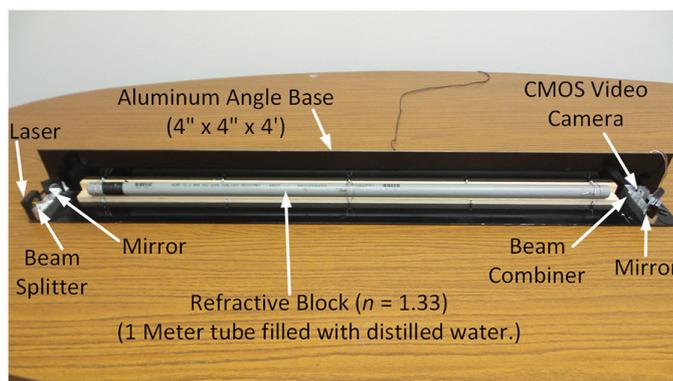


Fig. 9: Overview of interferometer system.

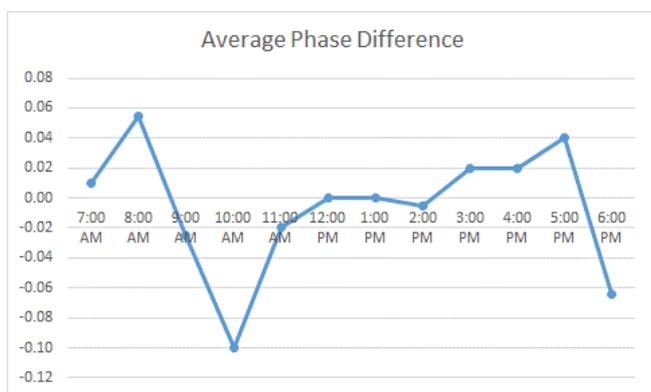


Fig. 8: Measured phase shift.

The results of this experiment are the “final arbiter” and clearly rule in favor of the derivation in this paper and against Cahill’s derivation. The measured phase shifts are 4 orders of magnitude less than those predicted by Cahill and they are within the measurement tolerances of the null prediction of this paper. We can conclude that the mathematical derivations in this paper are correct and that it is impossible to detect the absolute velocity of the earth using MM type experiments regardless of the index of refraction of the medium used.

8 Description and procedures of experiment

Figures 9, 10 and 11 show actual annotated photographs of the interferometer system used in the experiment. It is arranged according to the layout shown in Figure 1. Not shown in these pictures are two polarizers — one at the output of the laser and one at the input to the camera. These were rotated relative to one another to attenuate the light to just the right brightness so that the camera image was optimized for visualization of the fringe pattern. Without them the image was too bright and the camera’s CMOS detector bloomed to an all-white image.

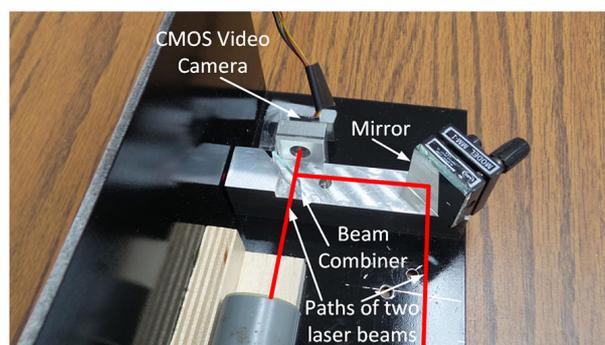


Fig. 10: Closeup of camera/detector end.

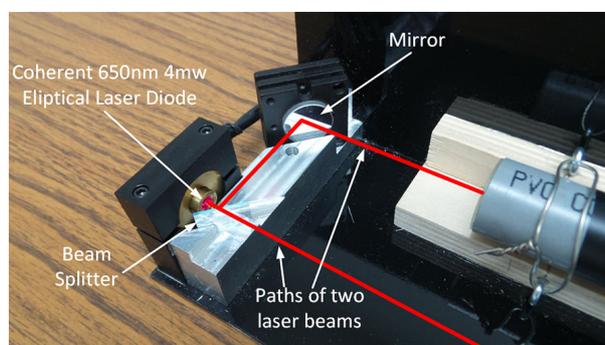


Fig. 11: Closeup of laser diode end.

8.1 Measurement considerations

The fringe shifts are measured by displaying the output of the camera on a computer monitor. Figure 12 shows the camera output plus two drafting triangles that were placed on the monitor as references to assist in measuring fringe movement.

The entire system is mounted on a 4-foot (1.22 m) aluminum base that is painted black. The thermal expansion coefficient of aluminum causes it to expand about 29 μm per degree C. That is 45 wavelengths of light per degree C or about one half wavelength for each hundredth of a degree C.



Fig. 12: Fringe pattern output from camera.

An even larger sensitivity occurs due to the fluctuations in barometric pressure which change the index of refraction of the air. Because of this extreme sensitivity to temperature and pressure, there is a constant drifting of the fringe patterns that must be taken out of the measurement.

To minimize the thermal drift, the following mitigating techniques were employed:

1. The entire interferometer was placed inside a cardboard tubular shipping container and sealed on both ends.
2. The system was allowed to warm up and reach a stable temperature prior to making any measurements.
3. The measurements were taken inside a room with no outside walls or windows.
4. The heating and air conditioning system was turned off so that only slow, convection heating from outside the building could affect the temperature inside the room.
5. A 4 foot wooden dowel was used to rotate the system so that human body temperature was kept away from the system.
6. The system was rotated very slowly (about 30 seconds for a 90 degree rotation) to minimize the cooling and pressure effects of the air flow.

By doing all of these things, the drift was reduced to significantly less than 1 fringe per minute (probably mostly due to barometric pressure drift), which was easy to remove from the measurements.

Mechanical disturbances were minimized by placing the system on pillows and attaching it to a rotatable platform with a bungee cord pressing it into the pillows. The platform is made from an aluminum trailer hitch-mounted cargo carrier with the hitch attachment removed. The platform was mounted to the base of a rotating office chair (after removing the seat) so that it could be rotated very smoothly and with little effort. The pillows prevented any residual vibrations of the platform from propagating to the interferometer. The result is that almost no vibrations affected the fringes so they were very easy to follow as they drifted slowly across the screen.



Fig. 13: Complete system with vibrational and thermal mitigation.

Figure 13 shows the system after employing these temperature and vibration mitigating techniques. The interferometer is sealed inside the tubular cardboard shipping container with the camera output coming through a small hole in the back of the container into the monitor.

8.2 Measurement procedure

To improve accuracy and resolution, 10 measurements were made at 1 hour intervals for 12 hours – which corresponds to 10 measurements every 15 degrees of earth's rotation for 180 degrees total rotation. The measurements were performed in Longmont, Colorado between 7 am and 6 pm on September 22 and 23, 2015. The following procedure was used:

1. Turn on the system and let it warm up for 2 hours.
2. At the top of each hour, position the system in a north-south orientation.
3. Place the edge of a triangle in the middle of the fringe nearest to the center of the screen.
4. Very slowly rotate the system clockwise 90 degrees until it reaches an east-west orientation. (about 30 seconds)
5. Estimate the movement of the fringe to the nearest 0.1 wavelength – including any drift that occurred. Record this as phase 1.
6. Reposition the edge of the triangle in the middle of the center fringe.
7. Very slowly rotate the system counterclockwise to return to the north-south orientation.
8. Estimate the movement of the fringe to the nearest 0.1 wavelength – including any drift that occurred. Record this as phase 2.
9. Repeat steps 2 to 8 until 10 pairs of phase 1 and phase 2 measurements have been recorded.
10. Wait until the top of the next hour and repeat steps 2 to 9 until data for 12 hours have been recorded.

After all data were recorded, the phase shift of each measurement was calculated as

$$PhaseShift = \frac{1}{2} (Phase1 - Phase2). \tag{88}$$

This removes any drift from the measurement because it will be constant in both phases.* For example, suppose *Phase1* includes a real shift of *k* and a drift of *d*. Then when returning, *Phase2* will measure a real shift of $-k$ and the same drift *d*. The phase shift recorded will be

$$PhaseShiftR = \frac{(k + d) - (-k + d)}{2} = k. \tag{89}$$

This was done for each of the 10 measurements at each hour. The 10 measurements for each hour were averaged. This improves the resolution of the final answer and averages out drift errors due to each “slow” rotation not being exactly the same amount of time. These results are tabulated in Table 1 and were graphed earlier in Figure 8.

Time	Average Phase Shift
7:00	0.01
8:00	0.06
9:00	-0.03
10:00	-0.10
11:00	-0.10
12:00	0.00
13:00	0.00
14:00	-0.01
15:00	0.02
16:00	0.02
17:00	0.04
18:00	-0.06

Table 1: Measured phase shifts.

9 Conclusions

We have now shown both mathematically and experimentally that Michelson-Morely-type interferometer experiments cannot detect the absolute speed of the earth through space regardless of the medium through which the light is propagating. This experiment and the accompanying mathematical analysis show that the conspiracy between Mother Nature and light is complete. They have conspired to make it impossible to detect our absolute speed using light signals.

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*The rate of change of the temperature and the pressure are assumed to be nearly constant over the 1 minute required to take each measurement.

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References

1. Cahill R.T., Kitto K. Michelson-Morley Experiments Revisited and the Cosmic Background Radiation Preferred Frame. *Apeiron*, April 2003, v. 10(2), 104–117.
2. Cahill R.T. The Michelson and Morley 1887 Experiment and the Discovery of Absolute Motion. *Progress in Physics*, 2005, v. 1(3), 25–29.
3. Cahill R.T. A New Light-Speed Anisotropy Experiment: Absolute Motion and Gravitational Waves Detected. *Progress in Physics*, 2006, v. 2(4), 73–92.
4. Cahill R.T. Absolute Motion and Gravitational Effects. *Apeiron*, 2004, v. 11(1), 53–111.
5. Roberts T.J. An Explanation of Dayton Miller’s Anomalous “Ether Drift” Result. arXiv: physics/0608238.