Testing a Sound Postulate

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Abstract

The Michelson-Morley (MM) experiment, foundational in challenging classical understandings of light propagation, played a crucial role in the development of special relativity. This paper re-examines this pivotal experiment from a new perspective, investigating the equivalence between optical and audio interferometry. By generalising the events within a MM interferometer, the study proposes a method to test if audio waves exhibit relativistic properties or not. This exploration of optical and acoustic analogy aims to deepen our understanding of wave mechanics and relativity, offering novel insights into relativistic experimental physics.

Keywords— Michelson-Morley, wave equation, special relativity

1 Introduction

The wave equation [1] is a powerful mathematical tool with applications spanning numerous fields in both classical and modern physics. Initially derived to describe vibrations in strings and sound waves, its utility extends to electromagnetic waves, fluid dynamics, and quantum mechanics. Its universality lies in its ability to describe how disturbances propagate through various media, whether tangible or abstract, providing a unified framework for understanding oscillatory and wave-like behavior across disciplines.

The Michelson-Morley experiment [2], conducted in 1887 by Albert A. Michelson and Edward W. Morley, is one of the most significant experiments in the history of physics. It was designed to detect variations in the speed of light as the Earth moved through space, which, according to classical physics, should have occurred if light propagated through a medium. Using an interferometer, the experiment aimed to measure differences in light travel times along perpendicular arms, assuming Earth's motion would affect the speed of light along each path. However, the experiment produced a null result, indicating no detectable difference in the speed of light, regardless of Earth's motion. This outcome directly challenged the prevailing theories and eventually contributed to the development of Einstein's theory of special relativity [3], which postulates the constancy of the speed of light in all inertial reference frames.

In their work, *Why Not a Sound Postulate* [4], Cheng and Read ask the question: given that both sound waves and optical waves are governed by similar wave equations, should we not expect to observe relativistic effects within the audio domain as well? The question is indeed intriguing and the arguments below propose an experimental method to test this hypothesis through an acoustic equivalent of the MM experiment.

1.1 Methodology

Let us investigate and generalise the geometry and sequence of events within a MM interferometer into the acoustic domain following the steps below:

1. We examine two flat triangles [3] that are relevant to the discussions at hand.
2. We show that the triangles discussed above form a template for the geometry and sequence of events within a MM interferometer.
3. We generalise the MM experiment's null result to create a theoretical interferometer having infinite equal length arms i.e. an IAI.
4. We consider a thought experiment involving travelling waves that reflect and interfere with each other within the confines of a circular boundary. Further, we establish that our thought experiment generates an event sequence equivalent to the IAI we have earlier theorised.
5. We debate a physical implementation of our thought experiment and how it may be employed to test the validity of a sound postulate.

2 Euclidean Geometry

On a flat surface, we draw any angle θ at origin Q bounded by two equal length line segments $QB = QB' = h$. We join points B and B' to points A and C such that the line segment AC is perpendicular to QB and centred at Q. We will restrict our arguments to the domain $x < h$. Fig. 1 illustrates.

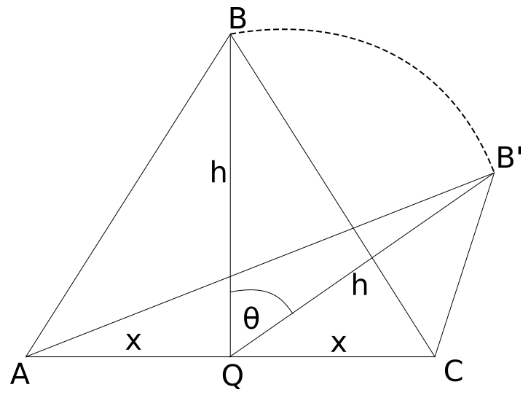

Figure 1: Triangles ABC and $AB'C$ rendered on a flat surface.

From fig. 1, we posit the following:

1. If $x > 0$, physical measurements will verify the theoretical statement $AB + BC \neq AB' + B'C$ remains true for all $\theta \neq 0, \pi, 2\pi ...$
2. If $x > 0$, physical measurements will verify the theoretical statement $\angle AB'Q \neq \angle QB'C$ remains true over all $\theta \neq 0, \pi/2, \pi ...$
3. Since h is constant, curve BB' will take the form of a circle as $0 \leq \theta \leq 2\pi$ independent of x.

3 A Template of the MM Experiment

Now we turn to theoretical aspects of relativistic optical interferometry to demonstrate that the geometry and sequence of events within an MM interferometer always templates to that of fig. 1.

3.1 Frames of Reference

Consider two imaginary euclidean reference frames that are in relative motion with respect to each other. Let us arbitrarily assume one of these frames is at rest and the other moves with some velocity v with respect to the rest frame. Accordingly we refer to fig. 1 and declare,

1. A rest frame I_0 centered at point Q.
2. A moving frame I_1 that translates from point A to point C with some velocity v relative to rest frame I_0.

3.2 Geometry and Sequence of Events

Now let us consider the structure of an MM interferometer [2](see fig. 2). By fixing $\angle B_1'QB_2' = \pi/2$, line segments QB_1' and QB_2' form the arms of the interferometer. Mirrors B_1 and B_2 are aligned perpendicular to their respective arms. The apparatus may be rotated about its source and consequently each arm subtends its own angle θ measured from a perpendicular to line segment AC. Let us affix moving frame I_1 to the source of the interferometer. Now let us imagine this interferometer moving through space under inertial rules such that,

1. v remains constant ($AQ = QC$).
2. The interferometer orientation (θ) with respect to line segment AC remains constant.

Reference frame I_1 (affixed to the source) translates with constant velocity v from point A to point C. From the perspective of the rest frame I_0, a discrete event cycle begins with the source at point A marking the simultaneous emission of a pair of photons (wavelength=λ). As the entire apparatus moves with some constant ($AQ = QC$) velocity v relative to origin Q along line segment AC, the photons are emitted at point A, reflect from mirrors B_1 and B_2 to finally arrive simultaneously (in phase with each other) at point C. This geometry and sequence of events remains true over all possible orientations of an MM interferometer [5] and over all $0 \leq v < c$ where c represents the velocity of light in free space [6].

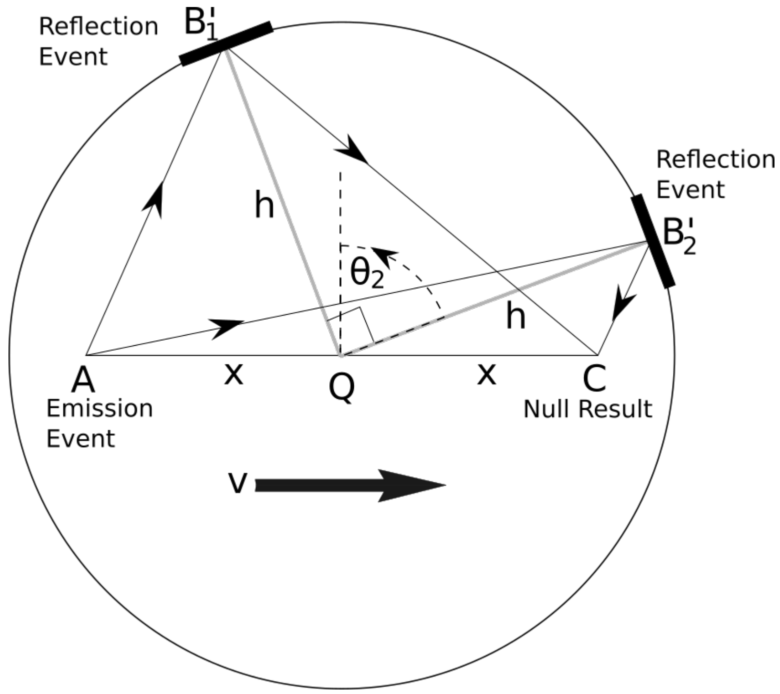

Figure 2: Geometry of the Michelson-Morley experiment depicting the general case $v \neq 0$ and $\theta_i \neq 0, \pi/2, \pi....$ Point Q is chosen as the origin. Only the events within the interferometer that are relevant to relativistic discussion are shown. Independent of the orientation of the interferometer, we find triangle $AB_i'C$ is a generalisation of triangle $AB'C$ in fig. 1. It is evident from the diagram that h and x in fig. 1 are equivalent in magnitude to c and v in the MM experiment and that curve BB' will take the form of a circle of radius h about point Q. By setting $v = 0$ ($x = 0$), the figure represents the observational perspective of moving frame I_1. By setting $v > 0$ ($x > 0$), the figure represents the observational perspective of rest frame I_0.

4 Constructing an Interferometer with Infinite Arms

In our analysis of the MM experiment, we are only interested in positions in space where physical interaction events are occurring. Therefore, consider the following:

1. In a traditional MM interferometer, the physical structure of the arms are real but irrelevant to the event sequence; the arms serve only to keep the mirrors in inertial motion and do not themselves merit theoretical consideration. Therefore, in theory, we readily ignore the arms altogether.
2. We also recognise that in the MM experiment, the mirrors retain practical relevance only during reflection events, thus we may choose to ignore their existence during the emission and result events.
3. By similar arguments, in theory, the interferometric source needs our consideration only during the emission and result events.

4.1 Merging Geometries Over Origin Q

With the above considerations in mind, imagine n independent discrete cycles of an MM interferometer (arm length = h) moving with some velocity v with respect to rest frame I_0. It has been experimentally confirmed [5] that each of these cycles would render a null result independent of v and the orientation of the interferometer (θ) with respect to the line of relative motion.

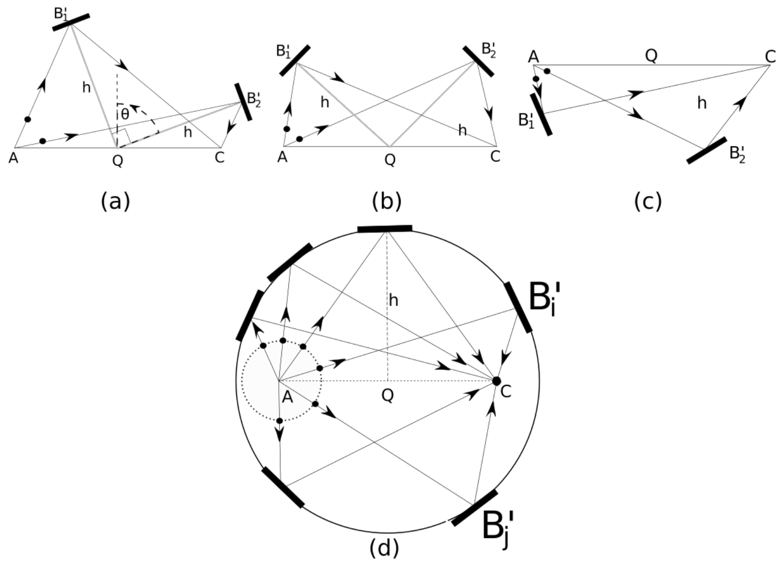

Figure 3: Merging Geometries. The figure shows 3 runs (a), (b) and (c) of a standard MM interferometer moving with relative velocity $v \approx 2/3c$ as observed from the perspective of rest frame I_0. The orientation of the interferometer θ is unique for each run. Were it possible to conduct these n runs simultaneously, it is reasonable to predict (i) each discrete cycle would manifest its respective null result at its respective point C and (ii) since all the runs were conducted at the same relative velocity v, we posit that all these null results will be manifested simultaneously. Therefore rest frame I_0 may superimpose these n runs (see figure (d)) over origin Q so as to generate a composite image and will predict a combined, simultaneous null result at point C. The triangles AB'_iC depicted in the figure (d) are a generalisation of triangle $AB'C$ in fig. 1. In the figure (d), we have ignored the mirrors during the emission and result events and also the source during reflection events. The arms are ignored altogether.

Now let us superimpose these n cycles of the MM interferometer as described in fig. 3 and argue further : were it physically possible to construct an apparatus with not 2, or 4 or 8 but rather an infinite number of arms, this apparatus would take the form of a wheel-and-spoke design with each spoke being interrogated by a single photon. Since the MM null result is independent of θ, we refer to fig. 3 and argue that this apparatus too must render a combined null result at point C independent of relative velocity and orientation with respect to the line of relative motion. This IAI theoretical construct generalises the notion of two arms (and two mirrors), each oriented at some angle θ, into an infinite number of arms (i.e. over all $0 \leq \theta \leq 2\pi$), each terminated at a point mirror. Since the arms are infinite in number, this circle of point mirrors takes the form of a continuous circle of radius h about point Q. By selecting point Q as origin, rest frame I_0 is assured that this circle of reflection remains fixed in space over all $0 \leq v < c$. Lastly, at the instant of emission (see fig. 3(d)), the role of two photons in the MM experiment is generalised into a two dimensional equivalent of Einstein's spherical wave [3]. Let us refer to this thought process as generalising a standard MM interferometer over all $0 \leq \theta \leq 2\pi$. Thus the geometry and sequence of events within a theoretical IAI are as follows:

1. The emission of an isotropic wave [3] at point A.
2. Reflection events from an infinite number of point mirrors, all of which are located on a continuous circle of radius h about point Q.
3. A combined, simultaneous null result at point C.

4.2 A Thought Experiment

Imagine an ideal homogeneous flat surface S1 enclosed by an ideal rigid boundary of geometrically circular shape (radius = h) and capable of transporting a travelling wave of the form,

$$\frac{1}{c^2}\frac{\delta^2 y}{\delta t^2} = \frac{\delta^2 y}{\delta x^2} \tag{1}$$

where the terms are as follows:

1. x (m) represents the displacement of the measurement point from the origin of the wave measured along the direction of travel,
2. c (m/s), a constant, represents the velocity of the wave measured along the direction of travel,
3. y (m) represents the instant displacement of surface S1 measured perpendicular to its equillibrium state.
4. t (s) represents the time elapsed since the instant that the wave was created.

From directly above, we may project fig.1 onto S1 without distortion such that the boundary of S1 is defined by curve BB', a circle of radius h about point Q. It is reasonable to agree that surface S1 supports the geometry of fig. 1 over all $0 \leq \theta \leq 2\pi$ and $0 \leq x < h$.

We choose any point A on S1 and disturb the equilibrium causing an isotropic [7] [3] sinusoidal wave (wavelength = λ) to emanate from that point and travel outwards at constant velocity c. As this primary wave expands, its wavefront will interact with S1's boundary generating innumerable secondary waves as it does so. Each reflection event along curve BB' generates its own isotropic [7] wave. Let us invoke the following assumptions to debate the nature of the interference pattern at point C:

1. The wave we generate originates from a single point and travels according to eq. 1.
2. λ remains constant in accordance with the law of conservation of energy [8].
3. Reflections are instantaneous and lossless.

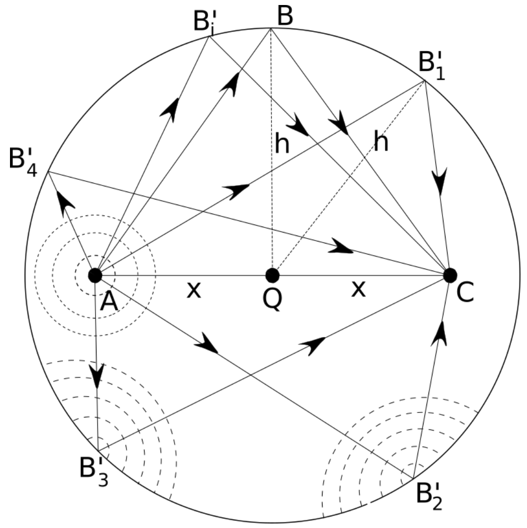

Figure 4: A single isotropic sinusoidal wave is emitted from point A and reflects from the circular boundary generating innumerable secondary wavefronts. We predict (a) if $x = 0$, (i) every wave that is created will expand equally in all directions and the wave velocity c in the medium will remain constant and (ii) reflection events from any two points B'_i and B'_j occur at the same instant in time and (b) by setting $x > 0$, (i) every wave will expand isotropically, c will remain constant and (ii) the reflection events from B'_i and B'_j will be separated in time except if the line joining B'_i and B'_j is perpendicular to AC. In the figure, we see $x \approx 2h/3$ and readily agree that (i) the reflection event from B'_2 must occur *after* the reflection event from B'_3 and (ii) reflection events from B'_1 and B'_2 are simultaneous. We consider these predictions further in sec. 5.

4.3 Practical Implications

Let us now define a physical implementation of the theoretical IAI described in sec. 4.

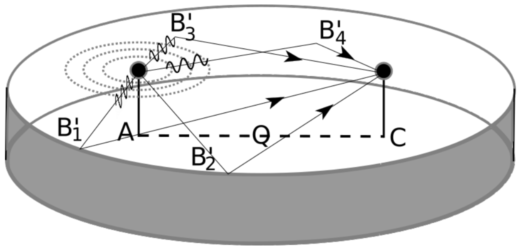

Figure 5: A Physical IAI setup. When viewed from directly above, the geometry and sequence of events within a physical IAI experiment is equivalent to fig. 4 and the triangles AB'_iC are a generalisation of triangle $AB'C$ in fig. 1. The waveforms depicted in the image represent pressure variations in the medium.

An isotropic source of audio waves is placed at some random point A within a circular shaped reflective boundary of arbitrary radius h. An isotropic audio receiver is placed diametrically opposite (point C). By energising the system, we may test if this IAI setup will generate events and manifest relativistic effects equivalent to the MM experiment. The presence of these effects would confirm that sound waves also exhibit relativistic properties.

4.4 Estimating Relative Velocity

Given the geometry of the sequence of events within the IAI, let us estimate the relative velocity between frames I_0 and I_1. Recall from fig. 2 that v and c in the MM experiment are equivalent to x and h in the IAI thought experiment. Thus if a practical IAI experiment employs ambient air as the medium, c is known [9] and determining relative velocity between I_0 and I_1 does not require a clock. Therefore the relative velocity between frames I_0 and I_1 may be obtained by measuring rod alone,

$$v \approx \frac{x}{h} 336 (m/s) \tag{2}$$

4.5 Observational Perspectives in the IAI experiment

From a practical viewpoint, let us discuss the method of realising the observational perspectives of both the rest frame (I_0) and the moving frame (I_1). Curiously, the IAI apparatus does not itself move with respect to origin Q. A human experimenter may follow the procedure below to generate audio events equivalent to those experienced by either the rest frame I_0 [10] or moving frame I_1 (i.e. the co-moving observer [11]) of a single cycle in an MM interferometer:

1. To reveal the observational perspective of moving frame I_1, we select points A and C to coincide with point Q. This creates the geometry of fig. 4 such that $x = 0$. In this special case frames I_0 and I_1 are coincident and at rest with respect to a human experimenter over the full emission-reflection-result cycle.
2. To reveal the observational perspective of rest frame I_0, we choose points A and C such that $0 < x < h$. See also fig. 4 such that $x > 0$. In this general case of the IAI experiment, the human experimenter continues to remain affixed to origin Q and recognises an imaginary moving frame I_1 translate with velocity v from point A to point C within the observed time interval t of the emission-reflection-result cycle.

5 Do Sound Waves Exhibit Relativistic Properties?

Let us consider the various temporal and spatial effects associated with a relativistic interferometry experiment [4], and introspect how the IAI apparatus may be employed to detect if these effects are equivalently manifested in the audio domain.

5.1 Postulates of Special Relativity

1. *The laws of physics are equal in all frames of reference* [3]. This postulate flows directly from symmetry in nature [7]. Since the IAI experiment is a natural one, it follows that this postulate is satisfied.
2. *Light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body* [3]. This counter-intuitive property of light waves is equivalently satisfied in the IAI thought experiment for we readily predict (refer fig. 4) that independent of x, i.e. from the perspective of either rest frame I_0 or moving frame I_1, all the wavefronts will be isotropic [3] and all the waves will travel according to eq. 1 with equal and constant velocity c, where c represents the velocity of sound in the medium. Figure 6 elucidates the method to test the audio domain for physical conformity with this 2nd postulate.

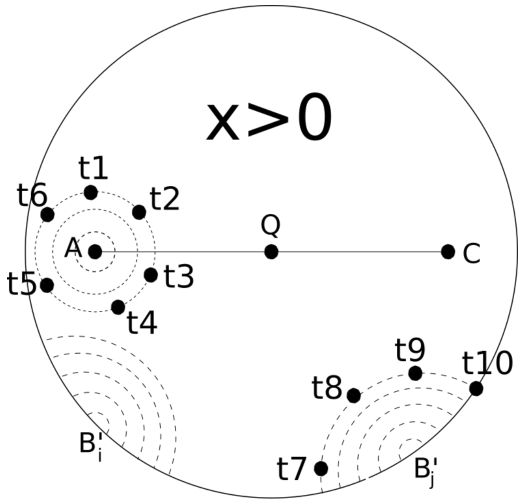

Figure 6: Testing the 2nd Postulate. Audio receiver units are placed on arcs of circles around point A and B'_i to record the instant of interaction with the waves as shown. If $t_1 = t_2 = t_3 = t_4 = t_5 = t_6$ and $t_7 = t_8 = t_9 = t_{10}$ then by sec. 5.1(2), the 2nd postulate is satisfied.

5.2 Simultaneity of Relativity

Recall from fig. 1 that if $\theta \neq 0$ then in both IAI and MM experiments, points B and B'_i are separated in space from the perspective of both resting and moving observers. Therefore we may refer to fig. 4 and predict for both experiments:

1. If $x = 0$ (the perspective of moving frame I_1) then all the reflection events from the circular boundary occur simultaneously.
2. If $x > 0$ (the perspective of rest frame I_0) then reflection events from any two points B'_i and B'_j occur simultaneously only if $\sin\theta_i = \sin\theta_j$ i.e. only if the line segment $B'_iB'_j$ is perpendicular to AC (see fig. 4). In cases where $x > 0$ and $\sin\theta_i \neq \sin\theta_j$, the two reflection events are separated in time. The temporal separation observed by rest frame I_0 is proportional to x/h and the physical distance between B_i and B_j measured *along* the line of relative motion. This difference in temporal observational perspectives between two frames in relative motion with each other is recognised as that of distant simultaneity [12] in the optical domain. Figure 7 elucidates.

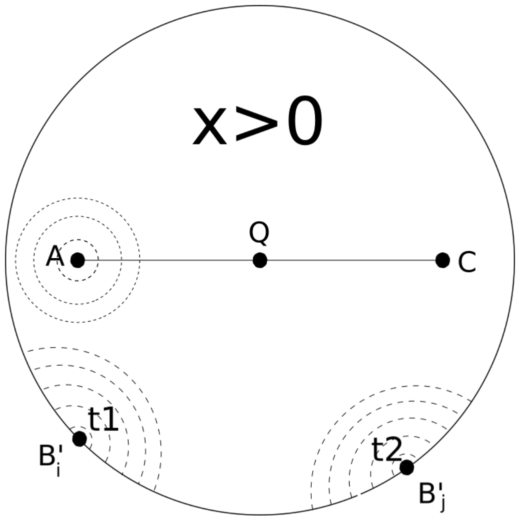

Figure 7: Testing distant simultaneity. Audio receiver units record the instant of reflection from two spatially displaced positions B_i and B_j. Should sonic waves exhibit relativistic properties, then the effect known as distant simultaneity may be confirmed by comparing t_1 and t_2. If $t_1 = t_2$ and the line joining B_i to B_j is found perpendicular to AC, then it is confirmed that distant simultaneity is manifested in sound waves. Sec. 5.2 (2) refers. It may be noted here that the event sequence and geometry in Einstein's thought experiment discussing distant simultaneity [13] is a special case of the IAI thought experiment where the line joining B_i' and B_j' is parallel to AC.

5.3 Null Result

Whether or not this apparatus will render a null result may be determined by signal analysis of the final received waveform at point C. If this signal bears experimentally acceptable resemblance to the original emitted waveform, we may conclude that this apparatus too renders a null result equivalent to the MM interferometer.

5.4 Reflection Geometry

Assuming the acoustic IAI apparatus renders a null result at point C then rest frame I_0 would also recognise that if $\theta \neq 0, \pi/2, \pi..$ (Refer fig. 1), the angles of incidence ($\angle AB'Q$) and reflection ($\angle QB'C$) are *unequal*. The same is true in the case of the MM interferometer. In an optical astronomical scale experiment [14], this relativistic spatial effect (as observed at point A or point C) is known as stellar aberration [15] and is proportional to v/c (x/h in the IAI experiment) and $\sin 2\theta$. Since the IAI event sequence and geometry is a generalisation of the MM interferometer over all $0 \leq \theta \leq 2\pi$, this relativistic spatial effect may be evidenced in the audio domain by a null result followed by physical measurements of triangle $AB_i'C$ in fig. 4.

5.5 Comparision with Wave Theory

From the relavistics effects described above, it is evident that the application of wave theory to fig. 4 is compatible with both the postulates of special relativity and with distant simultaneity. However, a null result and it's consequent aberration in reflection geometry would be in conflict with the predictions of wave theory.

5.6 Lorentz Contraction and Time Dilation

Cheng and Read, citing the example of Langevin clocks, posit that under Poincare invariant conditions, these relativistic effects may also be manifested equivalently in the audio domain [4]. Assuming a null result in the acoustic IAI setup described, these effects would be manifested as follows in experimental cases where $x > 0$:

1. Rest frame I_0 would observe a physical "shortening" [3] of the apparatus *along* the AC direction.
2. Rest frame I_0 would observe the time duration between emission and result events to be elongated

Both these effects would be proportional to the acoustic equivalent of the lorentz factor [3],

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \tag{3}$$

where c represents the velocity of sound in the medium.

6 Conclusion

In their paper, Cheng and Read explore the broad historical and philosophical aspects of relativity theory whereas this work adopts a more nose-to-the-ground approach to investigate the question they have posed. Undoubtedly, the manifestation of relativistic effects in sound waves opens many exciting avenues for theoretical and practical study particularly in the aqueous domain. Therefore the experiment proposed above is presented for scrutiny to further the investigation of Cheng and Read's intriguing question of a "sound postulate".

7 Statements and Declarations

The author has no competing interests to declare that are relevant to the content of this article. There are no data associated with this article.

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