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The Photonic Revolution:

The Implications of Superluminal Speed of Light

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***Abstract*:**

In the current review, the implications of experiments, on superluminal and subluminal light propagation, in various types of artificially prepared optical media, have been analyzed and discussed in detail. In addition, the theoretical interpretations of the reported experimental results, which are being put forward within the framework of several physical theories, in this field, have been thoroughly examined. Subsequently, it has been concluded that, even though the two leading interpretations, on the basis of the hypothesis of quantum tunneling and the Sommerfeld-Brillouin-Stenner hypothesis, might facilitate the integration of the above experimental results, into the prevailing physical paradigms, neither hypothesis could possibly encourage further inquiries into the far-reaching implications of those experiments, or assist in finding the actual physical mechanisms behind them.

Keywords:

Superluminal speed of light; anomalous dispersion, Wang experiment; phase velocity; multiple reflections; Stenner experiment; group velocity; Nimtz experiment; subluminal speed of light;

refractive media; Hau experiment; quantum tunneling; fast-light media; EPFL experiment.

Introduction:

No doubt that the discovery of superluminal light propagation, in artificially prepared dispersive media, which has been stumbled upon, serendipitously, over and over again, in research laboratories, across the world, since the beginning of the twenty-first century, is extraordinary, to say the least; not only in terms of uncovering new and important aspects of nature; but also because of the many very serious problems that such a monumental finding poses to Einstein's special theory of relativity, in accordance with which no numerical value of any velocity (***v***), in the entire universe, can be greater than the numerical velocity value of (***+299792458 meter per second***), or less than the same numerical velocity value of (***-299792458 meter per second***); i.e.,

$$\left[-299792458 \text{ ms}^{-1}\right] \le v \le \left[+299792458 \text{ ms}^{-1}\right]$$

where the speed value (***299792458 meter per second***) is the conventional numerical value of the intrinsic muzzle speed of light (***c***), in the vacuum of space, which has been officially adopted by the General Conference on Weights and Measures (*CGPM*), in 1983 [***Ref. #15***].

From a historical perspective, however, it abundantly clear that, since its initial formulation, in 1905, the staunch opponents as well as the stalwart proponents of Einstein's special theory of relativity have been keenly aware of the theoretical possibility of superluminal speeds of light, propagating in optical media with refractive indices less than unity, the so-called '*fast-light*' media [***Ref. #9***].

As a matter of fact, the aforementioned cosmic speed limit, in particular, has been all but demolished, and almost dead on arrival, right from the start, due to none other than the immediate outcome of the very same experiment of Armand Hippolyte Louis Fizeau, which Albert Einstein, himself, imagined it, somehow, to be "*an experimentum crucis in deciding between the Newtonian velocity addition law, which is based on absolute time, and the velocity addition law consistent with Special Theory of Relativity, which is based on the relativity of time*" [***Ref. #16***].

For example, if an optical medium is assumed to be in uniform linear motion, relative to the frame of reference, in which the measuring observer is at rest, as in the widely published case of the Fizeau experiment [***Ref. #17***], then the speed of incident light rays, emitted by a stationary source of light, in the laboratory, as measured by the observer, can be computed by using the Fresnel equation, below:

$$c' = \frac{c}{n'} = \left(\frac{c}{n}\right) \pm v\left(1 - \frac{1}{n^2}\right)$$

where (c') is the speed of the light rays, as measured in the laboratory; (n') is the refractive index of the moving optical medium; (n) is the refractive index of the same optical medium, when it's at rest, relative to the same laboratory; and (v) is the speed of the optical medium, relative to the frame of reference of the laboratory, in which the measuring observer is at rest.

And accordingly, if it assumed, as a given, the following set of data:

$$\begin{aligned} c &= 299792458 \text{ ms}^{-1} \\ v &= 00.99c \\ n &= 01.0003 \end{aligned}$$

it can be readily shown that light rays traveling in the same direction, inside the optical medium of air, under normal conditions, at sea level, do, indeed, achieve a superluminal speed $\{c'\}$, with respect to the stationary observer, in the reference frame of the laboratory, as calculated below:

$$\begin{aligned} c' &= 299880543.85339902 \text{ ms}^{-1} \\ c' &\approx (1.00029382) \times c \end{aligned}$$

where (c) stands for the intrinsic muzzle speed of light, in empty space.

And so, now, the crucial question, which should be raised, within the present context, is this:

Is it theoretically true that Einstein's special theory of relativity, as widely believed, is totally incompatible with the notion of superluminal light propagation, under all conceivable circumstances?

As usually taught and routinely interpreted, in physics departments, around the world, Einstein's special theory of relativity is being supposed to have been solely built upon these two basic postulates:

- The first postulate, in accordance with which the laws of physics are the same and having their simplest form in all frames of reference, in uniform linear motion, relative to each other.
- The second postulate, in accordance with which the speed of light, in a vacuum, is the same for all observers, regardless of their motion, relative to the emitting body.

On closer inspection, however, it's quite clear that none of the mathematical equations of Einstein's special theory of relativity is, in any way, consistent with its second postulate; except the following formula, for the composition of velocities [***Ref.*** *#3*]:

$$V = \frac{v + w}{1 + vw/c^2}$$

where (V) denotes the vector sum of the velocity vector (v) and the velocity vector (w).

For instance, even though it's generally claimed that the very same set of mathematical equations labeled as '*Lorentz transformation*' — which had been previously derived, in a tentative manner, by Hendrik Lorentz, on the basis of the stationary aether theory — can be deduced, axiomatically, from the two postulates, above, within the framework of Einstein's special theory of relativity, these mathematical equations of this so-called '*Lorentz transformation*', as listed below:

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}; \quad y' = y;$$

$$z' = z; \quad t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}.$$

not only are essentially impossible, logically and mathematically, to be derived, somehow, from Einstein's two postulates [***Ref. #18***], but also they break outright Einstein's second postulate, in every inertial frame of reference, both superluminally as well as subluminally, at the same time:

1. If the light rays are moving directly in the direction of the inertial reference frame's velocity vector (v), then their relative velocity resultant (c'), measured by observers, from inside that inertial frame of reference, as predicted by the Lorentz transformation, must, always, be subluminal, in accordance with the following mathematical equation:

$$c' = \frac{c}{1 + v/c}$$

   where (c) is equal to (*299792458 meter per second*).

2. If the light rays are moving directly in the opposite direction to that of the inertial reference frame's velocity vector (v), then their relative velocity resultant (c''), measured by observers, from inside that inertial frame of reference, as predicted by the Lorentz transformation, must, always, be superluminal, in accordance with the following mathematical equation:

$$c'' = \frac{c}{1 - v/c}$$

   where (c) is equal to (*299792458 meter per second*).

3. If the light rays are moving transversely at right angles to the direction of the inertial reference frame's velocity vector (v), then their relative velocity resultant (c'''), measured by observers, from inside that inertial frame of reference, as predicted by the Lorentz transformation, must be, always, luminal, in accordance with the following mathematical equation:

$$c''' = c$$

where (c) is equal to (*299792458 meter per second*).

And that is because the Lorentz transformation is nothing more than the algebraic implementation of the hypothesis of length contraction and the hypothesis of time dilation, which have been invented, primarily, in order to explain away the reported null result of the Michelson-Morley experiment — not by rendering the speed of the experimental beam, in every direction, equal to the intrinsic muzzle speed of light (c), in free space — but rather, by making the sum of the two flight times of the first experimental light beam, in the longitudinal direction, exactly equal to the sum of the two flight times of the second experimental light beam, in the transversal direction.

In brief, therefore, it can be concluded, with absolute certainty, that the second postulate of the special theory of relativity, in its current wording — i.e., the speed of light, in a vacuum, is the same for all observers, regardless of their motion, relative to the light source — has never, really, been made use of, by Albert Einstein, anywhere, in his 1905 paper entitled "***On the Electrodynamics of Moving Bodie***s"; except, of course, in the construction of this one single general algebraic equation, for computing the composition of velocities:

$$V = \frac{\sqrt{\left(v^2 + w^2 + 2vw\cos(\alpha)\right) - \left(vw\sin(\alpha)/c\right)^2}}{1 + vw\cos(\alpha)/c^2}$$

in which (α) stands for the angle between the two velocity vectors (v & w).

So, why, on Earth, did Albert Einstein choose to invent and then to put his seemingly '*next-to-useless*' second postulate, at the very top of his special theory of relativity, in the first place?

Apparently, there were two main reasons behind that:

I. Albert Einstein seemed to have incorrectly deduced from the tentatively constructed transformation, within the framework of the stationary aether theory, by Hendrik Lorentz, that the hypothesis of length contraction and the hypothesis of time dilation would make the speed of light, in every direction, within the moving co-ordinate system, equal to its intrinsic muzzle speed (c). While, in reality, those two hypotheses can only render the numerical sums of flight times of round trips, by light beams, over equal distances, in every direction, inside the moving co-ordinate system, precisely equal and fully identical to each other, in all respects.

II. In addition, Albert Einstein was, in all probability, compelled to place his second postulate, at the very top of his special theory of relativity, by the obvious fact that most of the listed mathematical formulas, in the aforementioned 1905 article of his, must break down, if the following condition is true:

$$v \geq c$$

as far as the motion of material objects is concerned. And even though Hendrik Lorentz, Joseph Larmor, and Herbert Ives, in all likelihood, accepted, without further ado, the break down of most of the mathematical equations of their theories, under the above condition, as well, Albert Einstein appeared, on the contrary, to dislike mathematical singularities, so much so that if there were axioms, for preventing the appearance of the gravitational singularity, he would, most certainly, have placed them, at the very top of his general theory of relativity, regardless of whether they were logically consistent with the rest of its conceptual framework, or not.

It should be noted, nonetheless, that the second postulate of Einstein's special theory of relativity — in spite of its somewhat wrongheaded insistence on that the maximum cosmic speed limit has to be exactly equal to the symbolic value of (c) — doesn't, actually, assign any specific numerical value to it. And this, necessarily, implies that the intrinsic muzzle speed of light (c), in the vacuum, can, within the framework on his theory, possibly, have any value, anywhere, within the numerical range below:

$$-\infty < c < +\infty$$

without causing any serious problem, for the physical theory, under investigation.

Let's assume, for a moment, that the second postulate of the special theory of relativity, holds good. But the numerical value of the real cosmic speed limit (c_{real}) is twice as large as the current numerical value of (c). However, only a handful of extremely rare physical objects, in the universe, can emit light rays with the intrinsic muzzle speed (c_{real}). What will the most resourceful members of the worldwide relativity community, do, if one of such rare sources of light is discovered?

At first glance, it seems reasonable to suppose that, in such a scenario, the worldwide relativity community would, first and foremost, make sure, the following algebraic relationship:

$$c_{real} = 2 \times c = 599584916 \text{ m/s}$$

does, indeed, hold true.

And then and only then, the worldwide relativity community should reclassify the old (c) as distinctly '*subluminal*', and embark, immediately, on readjusting everything and carrying out the relatively tedious and immense task of recalculating every old (β_{old}), in Einstein's special theory of relativity, in terms of the new (β_{new}), as dictated by this very simple mathematical relationship:

$$\beta_{new} = \tfrac{1}{2}\beta_{old} = v/c_{real} = \tfrac{1}{2}(v/c)$$

in accordance with which one new (β_{new}) is equal to half old (β_{old}).

In any event, it's highly likely that, as long as one and only one numerical value is assigned to the intrinsic muzzle speed of light, in the vacuum, Einstein's theory of special relativity can, in principle, be reworked out, pretty quickly, and with no trouble, to speak of, at all.

It goes without saying, however, that if the intrinsic muzzle speed of light, in a vacuum, has two or more numerical values, at the same time, then, for certain — unless all but the fastest one are demoted and treated as those of light in air, water, etc.— Einstein's special theory of relativity must encounter a potentially endless series of very significant problems, among the most daunting and exceptionally challenging of which have, undoubtedly, to be the following:

i. If the intrinsic muzzle speed of light, in a vacuum, has, simultaneously, two or more numerical values, the calculations of linear momentum, angular momentum, rest energy, kinetic energy, time dilation, length contraction, ... etc., on the basis of Einstein's theory of special relativity, would definitely lead to highly conflicting results, become next to useless, and ultimately fail.

ii. If the intrinsic muzzle speed of light, in a vacuum, has two or more numerical values, at the same time, then calculations, within the framework of Einstein's theory of general relativity, are going to produce conflicting results, as well, and to become worse than useless, and utterly fail.

iii. If the intrinsic muzzle speed of light, in a vacuum, has, concurrently, two or more numerical values, it would lead to the multiplicity of Minkowski spacetime, in Einstein's special theory of relativity. And that, in itself, is going to be the ultimate theoretical catastrophe, unless some creative members of the relativity community, worldwide, stumble, somehow, upon a viable method, for nesting all of them, one at a time, inside of each other, like boxes in a box prank.

iv. If the intrinsic muzzle speed of light, in a vacuum, has two or more numerical values, at once, it would lead to the multiplicity of pseudo-Riemannian manifold, in Einstein's general theory of relativity. And this, for sure, would have to be the worst cosmological calamity, since the days of Claudius Ptolemy, unless some members of the worldwide relativity community come up with a creative way, for placing them, one by one, inside of each other, like Matryoshka dolls.

However, two or more coexisting numerical values of the intrinsic muzzle speed of light, in empty space, cannot, under any circumstances, cause the unmitigated disaster — viz., mixing up the physical relationships between causes and effects in the universe — which have continued to scare the hell out of the relativity community, across the globe, since the days of Arnold Johannes Wilhelm Sommerfeld and Léon Nicolas Brillouin [***Ref. #9***]. And that is because the hypothetical disaster, in question, is bound to vanish, as soon as the fundamental distinction between the order of causes and effects, related to physical objects, and the order of causes and effects, related to optical images of physical objects, is made explicitly crystal clear.

1. Experiments on the Propagation of Light:

Recent experiments, on the propagation of light, can be divided into two major categories:

- The subluminal category, which includes all experiments, related to the measurements of subluminal speeds of light, such as the Hau experiment, in which a subluminal speed of (*17* *meter per second*) has been measured [***Ref. #19***].

- The superluminal category, which includes all experiments, related to the measurements of superluminal speeds of light, such as, for example, the Nimtz experiment, in which Mozart's 40th Symphony has been sent to a microwave receiver, at a superluminal speed of (*4.7 x c meter per second*) [***Refs #4 & #6***].

Judged on their scientific and technological merits, these two categories of experiments, on the propagation of light, are equally important. In addition, their significant commercial potential makes the superluminal category, along with the subluminal category, very attractive targets, for patent applicants and invention hunters. Can you imagine how much NASA and ESA are going be more than willing to pay for speedy and superluminal telecommunications, in order to be able to communicate, in near real time with distant space probes, throughout the solar system and beyond?

But,still such impressive jackpot prospects, regrettably, do tend, more often than not, to hinder rather than to facilitate the replication of experiments, on superluminal and subluminal speeds of light, due to the omission of relevant specifications, concerning the instruments as well as the actual experimental setups, from the published reports, which are usually sprinkled with nonsensical hypotheses and misleading interpretations of all sorts. And so, perhaps, certain basic aspects of this very important subject will remain, indefinitely, shrouded in mystery, thanks to old-fashioned trade secrecy.

Theoretically speaking, experiments, on the subluminal propagation of light, represent no obvious threat to prevailing physical theories; since the experimental reported results, in this regard, can be handled, quite easily, and conceptually treated, in the same way as experiments, on propagation of light, in air, water, glass, diamond, silicon, germanium, et cetera.

However, it is worth pointing out that, in point of fact, a few experiments, in the subluminal category, have come much closer to the hypothetical phenomenon of '*frozen waves of light*', which was, for some unspecified reason, being deemed, by none other than Albert Einstein, himself, to be paradoxical and totally incompatible with the basic tenets of his own special theory of relativity [***Ref. #11***].

To give an example, if two or three bicycle drivers travel, in the same direction, alongside the experimental beam, in the Hau experiment, with the speed of (*17 meter per second*), relative to the laboratory, then with the right equipment, they could, probably, spot trains of light waves, frozen in time, and frozen in space, as well.

By contrast, the superluminal category's experiments are, indeed, revolutionary; and their reported results pose an immediate and clear threat to Einstein's theory of special relativity, in particular, and to a lesser extent, to most theories of the present physical paradigm, in general.

The following is a short list of the superluminal category's most crucial experiments:

1. ***The Nimtz Experiment:***

   In the Nimtz experiment, a famous symphony of Mozart is encoded on a microwave beam and transmitted to a receiver at 4.7 times the intrinsic muzzle speed of light, in free space [***Refs #4 & #6***]. And as such, it amounts — if it is successfully replicated — to straightforward and convincing experimental falsification of ongoing theoretical attempts at redefining the cosmic speed limit of Einstein's theory of special relativity as the cosmic speed limit of information rather than the cosmic speed limit of moving physical objects.

2. ***The Ranfagni Experiment:***

In the Ranfagni experiment, pulses of reflected microwaves observed to be traveling, in air, at 5-10 per cent faster than the intrinsic muzzle speed of light, in empty space **[Ref. #1]**. And consequently — if it is successfully repeated — the supposition that superluminal speeds of light are possible only inside artificial optical materials would be experimentally discredited, for good. And moreover,if microwave pulses are, indeed, able to travel, at superluminal speeds, in open air, it would be, very likely, that light rays, in general, are capable of retaining their gained speeds, and more than able, to travel, at superluminal speeds, in the vacuum of space, as well.

3. ***The Wang Experiment:***

In the Wang experiment, which was carried out, by Wang et al, a laser pulse has been observed to travel, through gas-filled cells, with a whopping superluminal speed of more than 300 times the intrinsic muzzle speed of light, in the vacuum of space [***Ref.*** *#7*].

4. ***The Stenner Experiment:***

In the Stenner experiment, which was designed and carried out by Stenner et al, in order to investigate the so-called '*velocity of information*', a refractive index of (-19 ± 0.8) has been inferred [***Ref.*** *#2*]. However, according to the experimental physicist — Günter Nimtz, even though the reported results of their experiment are, pretty accurate and correct, their interpretation of those reported experimental results is arbitrary and misleading [***Ref. #20***].

5. ***The EPFL Experiment:***

In this experiment, a team of researchers from the Ecole Polytechnique Fédérale de Lausanne (EPFL) has successfully demonstrated, subluminal speeds of light, as well as superluminal speeds of light, inside fiber optics, for the first time [***Ref. #5***].

6. ***The Keaveney Experiment:***

In the Keaveney experiment, the refractive index of high density rubidium (*Rb*) vapor, in a gaseous atomic nanolayer, has been measured; and where a subnanosecond optical pulse was observed to advance by (>100 *ps*) over a propagation distance of (*390 nm*), corresponding to a group index (n_g) equal to about $\{-(1.0 \pm 0.1) \times 10^5\}$ [***Ref. #13***].

7. ***The NIST Experiment:***

In this experiment — on the four-wave mixing of superluminal pulses — in which both the injected and generated pulses, involved in the process, propagate with negative group velocities; it was reported, by T. Ryan et al, that the generated pulse's peak exited the 1.7 centimeter long medium 50 nanoseconds earlier than if it had propagated, at the intrinsic muzzle speed of light, in the vacuum of space [***Refs #12 & #14***].

2. Theoretical Interpretations:

It is to be expected, of course, from the outset, that — as far as the seven experiments, above, are concerned — various physical theories, in this specific field, would, in all likelihood, lead to distinctly different interpretations of the very same reported experimental results, with regard to superluminal light propagation, along with subluminal light propagation, as well:

I. Maxwell's Electromagnetic Theory:

As the final and best up-to-date version of the classical wave theory, Maxwell's electromagnetic theory has, at its disposal, several primary mechanisms, for interpreting the reported results of the aforementioned experiments, and explaining away subluminal light propagation, as well as superluminal light propagation, in a variety of optical media:

- Variation of refractive index with temperature:
  This particular mechanism — in accordance with which the refractive index of an optical medium decreases, as the temperature of the optical medium increases; and vice versa — allows Maxwell's electromagnetic theory to explain away the increasing speed of light, in that optical medium, with increasing temperature; and the reverse is true [***Ref. #23***].

- Variation of refractive index with pressure:
  This mechanism — by means of which the refractive index of some optical media, such as silicate glass, increases, with pressure; while the refractive index of other optical media, such as diamond decreases with pressure — enables Maxwell's electromagnetic theory to explain away the decrease of the speed of light, in the former, as well as the increase of the speed of light, in the latter [***Ref. #24***].

- Variation of refractive index with density:
  This special mechanism — on the basis of which the refractive index of the medium increases, as the density of the medium increases; and vice versa — let Maxwell's electromagnetic theory explain away the decrease of the speed of light, with the increasing density of optical media; and the other away around [***Ref. #25***].

- Variation of refractive index with motion:
  The Fresnel drag coefficient is the special mechanism, by means of which the Maxwell's electromagnetic theory is capable of explaining away the observed variation of the speed of light with the magnitude as well as the direction of the velocity vector (v) of various optical media, through which light is propagating; as calculated by using the following mathematical formula:

$$c' = \frac{c}{n'} = \left(\frac{c}{n}\right) \pm v\left(1 - \frac{1}{n^2}\right)$$

where (c') is the speed of the light rays, as measured in the laboratory; (n') is the refractive index of the moving optical medium; (n) is the refractive index of the same optical medium, when it's at rest, relative to the same laboratory; and (v) is the speed of the optical medium, relative to the frame of reference of the laboratory, in which the measuring observer is at rest.

- Variation of μ_0 and ε_0 with aether density:
  This is a universal mechanism, which allows, in principle, Maxwell's electromagnetic theory to easily explain away any measured amount of superluminal light propagation, by decreasing, indefinitely, the magnetic permeability(μ_0) and the electric permittivity (ε_0), with increasing luminiferous aether's density. And conversely, it allows the same theory to explain away, with relative ease, any measured amount of subluminal light propagation, by increasing, indefinitely, the magnetic permeability(μ_0) and the electric permittivity (ε_0), with decreasing luminiferous aether's density; as illustrated by the following mathematical formal, for computing, on the basis of Maxwell's electromagnetic theory, the intrinsic muzzle speed of light (c):

$$c = \sqrt{\frac{1}{\mu_0 \varepsilon_0}}$$

  where μ_0 is the magnetic permeability of luminiferous aether; and ε_0 is the electric permittivity of luminiferous aether [***Ref. #22***].

II. The Theories of Lorentz, Larmor, & Ives:

The aether theories of Hendrik Lorentz, Joseph Larmor, and Herbert Ives have been built, right from the start, upon the framework of Maxwell's electromagnetic theory, with the sole objective of explaining away the anomalous result of the Michelson-Morley experiment [***Ref. #26***].

And it must follow, therefore, that the three aether theories of Lorentz, Larmor, and Ives have, for all intents and purposes, inherited, by definition, the aforementioned primary mechanisms of Maxwell's electromagnetic theory, for interpreting the reported results of the listed experiments, on subluminal light propagation, as well as superluminal light propagation, in all optical media, artificial or otherwise.

III. Einstein's Special Theory of Relativity:

As in the case of the three aether theories of H. Lorentz, J. Larmor, and H. Ives, Einstein's special theory of relativity is widely supposed to have been founded upon the framework of Maxwell's electromagnetic theory, with the single purpose of explaining away the anomalous result of the Michelson-Morley experiment.

Nonetheless, the special theory of relativity can neither inherit, nor utilize, directly or indirectly, any of the primary physical mechanisms of Maxwell's electromagnetic theory, for interpreting the reported results of the aforementioned experiments, on subluminal light propagation, as well as superluminal light propagation, in all optical media, artificial and non-artificial alike. That is mainly because, during the construction of his special theory of relativity, Albert Einstein took, in passing, the fateful decision of replacing the luminiferous aether with the vacuum of space. And although, at first glance, the luminiferous aether and the vacuum of free space may appear very similar to each other, in many respects, it's generally taken for granted that the luminiferous aether has varying actual density. But, obviously, the vacuum of space cannot, even in principle have the slightest trace of density, at all. And since each and every one of the mentioned mechanisms of Maxwell's electromagnetic theory has been based squarely upon the presumed density of the luminiferous aether, Einstein's theory of special relativity has been excluded and forbidden, from the very beginning, from making use of any of them.

And subsequently, the early proponents of Einstein's special theory of relativity, including, of course, its originator — Herr Einstein himself, have been left with no choice but to try setting up as best they could the makeshift procedures, below, for interpreting the reported results of various experiments, on subluminal light propagation, as well as superluminal light propagation, in all sorts of optical media:

1. The variations of refractive indices with temperature, pressure, and density have to be determined, in a tentative manner — through trial and error — in the physics lab.

2. The variations of refractive indices with the motion of optical media can be calculated, in advance, by making use of Einstein's equation, for the addition of velocities, as long as the magnitude of the velocity vector (v) remains less than the magnitude of the velocity vector (c):

$$\frac{c}{n'} = \frac{(c/n) \pm v}{1 \pm (v/nc)}$$

   where (n') is the refractive index, relative to the laboratory's reference frame; and (n) is the refractive index, relative to the moving optical medium's own reference frame.

3. The reported results of all experiments, on superluminal propagation of light, in artificially manufactured optical media, have to be explained away, by the Sommerfeld-Brillouin-Stenner method of interpretation [***Ref. #11***], according to which electromagnetic radiation is supposed, in theory, to simultaneously have the phase velocity (c_p), along with the group velocity (c_g):

   — The phase velocity (c_p) is defined as the velocity, at which a point of fixed phase propagates in an optical medium, and obtained by using the following mathematical equation:

$$c_p = \frac{c}{\sqrt{1 - (f_c^2 / f^2)}}$$

   where (f_c) is the cutoff frequency; (f) is the wave frequency; and the phase velocity (c_p) can have any numerical value, between (*299792458 meter per second*) and infinity.

   — And likewise, the group velocity (c_g) is defined as the velocity, at which information travels, in an optical medium, in accordance with this mathematical equation:

$$c_g = c\left(\sqrt{1 - (f_c^2 / f^2)}\right)$$

   where (c_g) can have any numerical value, between (*0*) and (*299792458 meter per second*).

And correspondingly, based on the Sommerfeld-Brillouin method, the mathematical relation, below, is always assumed to hold true:

$$c_g \leq c \leq c_p$$

where (c) is equal to (*299792458 meter per second*).

IV. The New-source Emission Theory:

If it's assumed that, in the aforementioned experiments, the initial laser beams have been able to set the optical media in motion, then the new-source emission theory of W. Ritz, J. G. Fox, and R. Waldron can, very easily, employ its *'new-source'* principle, as shown below, in order to explain away, at once, the reported experimental results, in the case of subluminal light propagation, as well as in the case of superluminal light propagation:

- In the case of light beams, propagating in an optical medium, in the same direction as that of the velocity vector (v), the moving optical medium, in question, becomes a new light source, for the incident light beams whose velocity resultant (c') can be obtained, through the use of the following mathematical formula:

$$c' = \frac{c}{n'} = \frac{cn + v\left(n^2 - 1\right)}{n^2}$$

where (n') denotes the refractive index of the moving optical medium, and can be computed by inserting the numerical value of the standard refractive index (n) and the standard density (ρ) of the same optical medium, into Laplace's formula [***Ref.** #27*]:

$$\frac{n'^2 - 1}{p'} = \frac{n^2 - 1}{\rho}$$

in which (ρ') is the density of the moving optical medium.

- In the case of light beams, propagating in an optical medium, in the opposite direction to that of the velocity vector (v), the moving optical medium, in question, becomes a new light source, for the incident light beams whose velocity resultant (c') can be obtained, through the use of the following mathematical formula, below:

$$c'' = \frac{c}{n''} = \frac{cn - v\left(n^2 - 1\right)}{n^2}$$

where (n'') denotes the refractive index of the moving optical medium, and can be computed by inserting the numerical value of the standard refractive index (n) and the standard density (ρ) of the same optical medium, into the following Laplace's formula:

$$\frac{n''^2+1}{p''}=\frac{n^2+1}{\rho}$$

in which (ρ'') is the density of the moving optical medium.

V. The Elastic-Impact Emission Theory:

The elastic-impact emission theory of Isaac Newton, J. J. Thomson, and O. M. Stewart has four primary mechanisms, for explaining way the reported results of the listed experiments, on subluminal light propagation, as well as superluminal light propagation, in artificially made optical media:

i. If the experimental light beams, upon emerging from an optical medium, retain their subluminal velocity, in empty space, then the mechanism of multiple reflections of light by the receding layers of the optical medium, in question, can be employed, in the calculation of the subluminal velocity resultant (c'_N), in accordance with this mathematical equation:

$$c'_N = c - 2v(N)$$

where (N) stands for the number of reflections from the receding layers (*1, 2, 3, ..., N*).

ii. If the experimental light beams, upon emerging from an optical medium, retain their superluminal velocity, in empty space, then the mechanism of multiple reflections of light, by the approaching layers of the optical medium, under investigation, can be employed, in the computation of the superluminal velocity resultant (c''_N), in accordance with this equation:

$$c''_N = c + 2v(N)$$

where (N) stands for the number of reflections from the approaching layers (*1, 2, 3, ..., N*).

iii. If the experimental light beams, upon emerging from an optical medium, lose their subluminal velocity, in empty space, then their velocity resultant (c'), in that optical medium, can be calculated, through the use of the following mathematical formula:

$$c' = \frac{c}{n'} = \frac{cn - v\left(n^2-1\right)}{n^2}$$

where (n') is the refractive index of the moving optical medium, and can be computed by inserting the numerical value of the standard refractive index (n) and the standard density (ρ) of the same optical medium, into the following Laplace's formula:

$$\frac{n'^2+1}{\rho'}=\frac{n^2+1}{\rho}$$

in which (ρ') is the density of the moving optical medium.

iv. If the experimental light beams, upon emerging from an optical medium, lose their superluminal velocity, in empty space, then their velocity resultant (c''), in that optical medium, can be obtained, by using the mathematical formula, below:

$$c''=\frac{c}{n''}=\frac{cn+v\left(n^2-1\right)}{n^2}$$

where (n'') is the refractive index of the moving optical medium, and can be computed by inserting the numerical value of the standard refractive index (n) and the standard density (ρ) of the same optical medium, into the following Laplace's formula:

$$\frac{n''^2-1}{\rho''}=\frac{n^2-1}{\rho}$$

in which (ρ'') is the density of the moving optical medium.

3. The Stenner Experiment:

As mentioned earlier, in the present discussion, this experiment has been designed and carried out, by Stenner et al, for the main goal of investigating, in detail, the supposition that "*the information velocity is less than or equal to the speed of light in vacuum*", within the context of Einstein's theory of special relativity, with regard to superluminal propagation of light [***Ref. #2*** **&** ***Ref. #9-a***].

It should be noted, however, that the new notion of '*information velocity*', in itself, is nothing more than a simple implementation of the old notion of '*cosmic speed limit*', as previously defined within the framework of Einstein's special theory of relativity, into the Sommerfeld-Brillouin method of interpretation [***Ref. #11***], on the basis of which electromagnetic radiation is hypothesized to have two kinds of velocities — the phase velocity (c_p) and the group velocity (c_g) — at the same time.

At the start of their published report, M. D. Stenner et al have defined the group velocity (c_g) as the velocity of the pulse peak of "*a collection of elementary sinusoidal waveforms*", each with a distinct frequency (ω), in accordance with the following mathematical formula:

$$c_g = \frac{c}{n + \omega dn/\omega} | \omega - \omega_0 = \frac{c}{n_g}$$

where (n_g) is the group index; (ω_0) is the central frequency of the wave packet, and ($dn/d\omega$) is the dispersion of an optical material.

By all appearances, the above redefinition of the old concept of '*cosmic speed limit*', in terms of the new concept of '*information speed*' seems to imply, necessarily, replacing the old version of Einstein's second postulate—i.e., the speed of light in the vacuum is the same for all observers regardless of their motion relative to the emitting body — with its new information-age version — i.e., the speed of information (carried by light) in the vacuum is the same for all observers regardless of their motion relative to the source of the encoded information onto the light of the emitting body — in order to make it much easier, for Einstein's theory of special relativity, to explain away the frequently reported results of lab experiments, on superluminal light propagation, in artificially assembled optical media.

And subsequently, M. D. Stenner and his team carried out their experiment, on superluminal propagation of light, in the hope of finding out whether the new notion of information velocity (c_i) satisfies the highly desirable condition, below:

$$c_i = c$$

which is presumably required, for keeping the chain of cause and effect intact, within the framework of Einstein's special theory of relativity; or, on the contrary, it fulfills the following adverse condition:

$$c_i = c_g$$

in which the numerical value of the group velocity (c_g), sometimes, becomes larger than the numerical value of the intrinsic muzzle speed of light, in free space, (c) of (*299792458 meter per second*).

Here is a brief summary of the experiment of M. D. Stenner and his team of professional physicists:

1. In the experiment of M. D. Stenner et al, on superluminal light propagation, it has been assumed, from outset, that, for a typical optical material, there are narrow spectral regions, where the mathematical relationship, below:

$$\frac{dn}{d\omega} < 0$$

   always holds good, and results in anomalous dispersion and superluminal group velocity (c_g).

2. A laser-driven potassium vapor has been used to obtain a negative refractive index (*ng*); i.e.,

$$n_g = -19 \pm 0.8$$

   which entails, necessarily, a positive and minute fractional refractive index, and points to a highly superluminal regime and large advancement for a smooth Gaussian-shaped pulse.

3. It has been taken for granted, by Stenner's team of experimental physicists, that any sort of information, encoded on an optical pulse, by creating a point of non-analyticity, must always travel,with propagation speed — through the laser-driven potassium vapor — equal to, or less than, but no greater than the intrinsic muzzle speed of light (c) of (*299792458 meter per second*), in the vacuum, regardless of the other velocities associated with that pulse.

4. Two identical optical pulses have been employed to estimate the location of the point of non-analyticity, by turning on the pulse amplitude, above the noise floor of the detection instruments, to a high (*1*) value, or low (*0*) value, near the Gaussian peak and for the remainder of the pulse. The moment, when a decision is made to switch between the two symbols, has been conjectured, by the experimenters, to be the point of non-analyticity.

5. It has also been assumed, by M. D. Stenner et al, in the same published report, that the detection time of information is later than the time when information is available at the detector; and this detection latency of (Δt) depends on the characteristics of the optical medium, the shape of the symbols, the detection algorithm, the noise in the detection, and the bit error rate (*BER*) threshold.

6. The purpose of the current experiment is to make the detection latency of (Δt) as small and as similar as possible, for both vacuum and advanced pulses. But achieving the following limit:

$$\Delta t \to 0$$

has been deemed impossible, on the assumption that it would require the use of infinite amount of energy, as well as unrealistic optimal shape symbols.

7. An integrate-and-dump matched filter technique has been employed to determine the bit error rate (*BER*), for vacuum and advanced pulse pairs. A (*BER*), in the range between (*–40 ns*) and (*–25 ns*), has been obtained.

8. By placing the detection threshold at the value, below:

$$BER = 0.1$$

the difference in detection time, for the vacuum and the advanced pulse pairs, has been achieved.

9. And subsequently, it has been concluded, by M. D. Stenner and his team, that the information detection time for pulses propagating, through the fast-light medium. is longer than the detection time for the same information, propagating through the vacuum, even though the group velocity (c_g) is presumed to have a numerical value, within the highly superluminal regime, for the fast-light optical medium under investigation.

10. And finally, a mathematical model, based upon Maxwell's equations, has been reported to be fully analyzed, in order to gain insight, about the detection latency. And eventually, the related observations have been deemed to be consistent with Einstein's theory of special relativity, in

the case of the investigated optical medium, within which the group velocity (c_g) is believed to be highly superluminal.

Although the Stenner experiment, as summarized above, is, technically, one of the best experiments, on superluminal propagation of light, the published interpretation of its actual results, by M. D. Stenner himself and his team of physicists, does show, at first sight, clear weaknesses and shortcomings:

A) The explicit verbal definition of group velocity of light, in the published experimental report — as the velocity of the pulse peak of a collection of elementary sinusoidal waveforms each with a distinct frequency — is somewhat arbitrary, vague, and clearly different from the implicit mathematical definition of group velocity of light — as the inverse of the derivative of the wavenumber with respect to angular optical frequency — in the very same experimental report.

B) Neither the explicit verbal definition, nor the implicit mathematical definition, in the mentioned experimental report, can, in any way, prevent the assignment of the measured numerical value of (n_g), in the Stenner experiment, to the alternative and equally valid definition of the group velocity of light — as the velocity with which the envelope of a pulse propagates in a medium — which would definitely undermine whole interpretation that has been put forward, by M. D. Stenner and his team, in the aforementioned experimental report.

C) The expression of the measured superluminal group velocity (c_g), exclusively, in terms of the negative exponent (-19 ± 0.8) of the fractional refractive index ($n < 1$), without any direct reference, anywhere in the published experimental report, to the actual base of that negative exponent, seems to strongly suggest an intentional effort, on the part of the Stenner's team, to shield the hardcore proponents of Einstein's theory of special relativity from the agony of having to watch its second postulate being smashed, over and over again, in the lab, by the enormous speed values of superluminal propagation of light, in a laser-driven potassium vapor.

D) Redefining Einstein's cosmic speed limit, which explicitly prohibits all material objects, from moving, anywhere in the universe, at any speed larger numerically, even by an infinitesimal amount, than the intrinsic muzzle speed of light (c) of (*299792458 meter per second*), in a vacuum, in terms of the proposed speed of information, imprinted naturally or artificially on emitted light rays, appears to represent nothing more than an anthropomorphic instant of naively projecting the idiosyncrasies of the current digital age, on the physical world.

E) Historically; the cosmic speed limit — the theoretical prohibition on the superluminal motions of all material objects, in the entire universe — has been imposed, within the framework of Einstein's theory of special relativity, for the sole purpose of preventing the appearance of the mathematical singularity of the relativistic factor gamma (γ), under the following condition:

$$[v = c] \Rightarrow \left[\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-0.5} = \infty \right]$$

where (v) stands for the speed of the material object. That is the only justification for it. As for the fundamentally philosophical notion of '*relativistic causality*', it is, by all accounts, flexible enough to coexist with almost everything, including, of course, speeds of physical objects equal exactly to (*299792458 meter per second*), as well as speeds of material objects much larger than (*299792458 meter per second*), and all the way to infinity.

F) It's quite possible, however, that propagation speeds of light beams greater than (*299792458 meter per second*) would, anyhow, render the currently employed techniques, for encoding information on light beams, partially or totally ineffective; and might, as well, scramble and corrupt encoded data, on them prior to gaining such higher speeds. And so, it may, be wiser, on the part of experimental physicists and others, to wait a bit longer, than to rush and make the hasty conclusion that information cannot travel at any speed greater than the numerical value of the intrinsic muzzle speed of light, in empty space, of {c = *299792458 meter per second*}.

G) Unless it is demonstrated, experimentally, beyond reasonable doubt, that the detection latency of encoded information, along with the reaction time for momentum and energy delivery, must increase, indefinitely, with increasing numerical values, for propagation light speeds, greater than the conventional numerical value of (*299792458 meter per second*), the conjecture of the practical impossibility of encoding data on superluminal beams cannot be justified.

H) The assumption that the vapor-cell portion of the path, for a pulse propagating through the cells, is equivalent to the portion of the path, for a pulse propagating through the vacuum, when lasers are tuned far from the atomic resonance, is clearly arbitrary; since no portion of the path, for any pulse propagating through free space, has been tested, in the experiment, under discussion.

I) The interpretation of the reported experimental results, concerning superluminal light propagation, as outlined in the aforementioned Stenner experimental report, has not taken into consideration the important finding of the Nimtz experiment, in which the 40^{th} Symphony of Mozart has been encoded, on microwave beams, and transmitted at the superluminal speed of {*(4.7) X* (*299792458 meter per second*)}.

Nevertheless, the above interpretation, by O. M. Stenner et al, despite its theoretical shortcomings, is an important step towards the integration of the comparatively extraneous notion of superluminal light propagation, into the current physical paradigms, which may help, in the long run, to promote and facilitate further research projects, in this new field.

4. Concluding Remarks:

Certainly, from a historical perspective, it's an accepted fact that the notion of subluminal propagation of light has been a mainstream idea, for a long time, and easily manageable, through diverse and well-established procedures, by almost every physical theory, in this particular field.

By comparison, not only there are no time-tested operational procedures, alluded to or hint at anywhere in the published physics literature, for handling properly the notion of superluminal light propagation, within the current physical paradigms, but also the very concept of superluminal propagation of light, in itself, has been considered, for years, by the physics community, as a whole, to be unphysical, troublesome, and totally inconsistent with the second postulate of Einstein's theory of special relativity.

Nevertheless, taking into consideration the reported results of the experiments that have been continued to be carried out, in the lab, regularly, since the turn of the century, and up to now, it's fair to say that as long as the phenomenon of superluminal propagation of light remains boxed, in artificially prepared fast-light media, theoretical interpretations, grounded in quantum tunneling and Sommerfeld-Brillouin-Stenner fine distinction, between the phase velocity (c_p) and the group velocity (c_g) of electromagnetic radiation, are, more likely than not, going to assist most, if not all, conventional theories of the mainstream physical paradigm to learn, slowly but surely, to live with it.

Notwithstanding their plausibly important role, in enhancing the conceptual flexibility and cognitive adaptability of physical theories, the theoretical interpretations, in question, which have been built, exclusively, upon the hypothesis of quantum tunneling and the Sommerfeld-Brillouin-Stenner fine distinction, between the phase velocity (c_p) and the group velocity (c_g) of light, do, actually, seem to have undesirable and discouraging effects on the empirical side of the potentially significant discovery of the phenomenon of superluminal propagation of light, in the man-made fast-light media.

To begin with, neither the Sommerfeld-Brillouin-Stenner hypothesis, as expounded above, nor the hypothesis of quantum tunneling of photons — i.e., the suppositional ability of photons to pass through seemingly impassable barriers at random — could, reasonably, be expected, under the best of circumstances, to inspire too much of technological inventiveness, or to ignite a heck of a lot of practical ingenuity; since these two hypotheses can't hardly possess the minimal coherence and the nominal internal consistency of a working scientific hypothesis; let alone a fertile and inspiring one.

One common feature of the published reports, regarding the experiments, on superluminal light propagation, that have been conducted, so far, is the absence of any mention of any attempt at verifying experimentally and checking whether or not the experimental light beams retain their superluminal speeds, upon existing the artificially prepared fast-light media, and passing through regular optical media, such as air, water, and glass. And that is, highly likely, because the postulated notion of negative refractive index, in the Sommerfeld-Brillouin-Stenner hypothesis, might have led the experimenters to hastily make the sweeping and possibly faulty generalization that light beams have to behave, in exactly, the same way, in optical media of refractive indices less than one, and in optical media of refractive indices greater than one, as well.

Likewise, the hypothesis of quantum tunneling doesn't encourage any further experimental verification, in this regard, either; since in accordance with which the whole process of superluminal light propagation, in fast-light media, amounts, from start to finish, in the final analysis, to nothing more than a simple shortcut, through what have been conjectured, in advance, to be impenetrable potential energy barriers.

All in all, leaving aside the two technically uninspiring interpretations of the hypothesis of quantum tunneling and the Sommerfeld-Brillouin-Stenner hypothesis, the experimental verification of whether or not a light beam maintains its superluminal speed, upon traveling from a fast-light medium, such as the laser-driven potassium vapor, to a regular optical medium, such as air, can, in principle, have only one of no more than three possible outcomes, in these three scenarios:

(a) If the experimental light leaves a fast-light medium — whose refractive index is less than unity — enters a regular optical medium — whose refractive is greater than unity— as well as it's, experimentally, verified that the numerical value of its superluminal speed stays unaltered and exactly the same, then this, without a shred of doubt, will be, by far, the best possible outcome, as far as the potential practical and industrial applications of the discovery of superluminal light propagation, in the highly dense rubidium (*Rb*) vapor, in gaseous atomic nanolayers, the laser-driven potassium vapor, fiber optics, photonic crystals, and the like, are concerned.

(b) If the experimental light leaves a fast-light medium — whose refractive index is less than unity — and enters a regular optical medium — whose refractive is greater than unity— and it's, experimentally, confirmed that a significant part of the numerical value of its superluminal speed remains unchanged and at work, then this remaining portion of the numerical value of its superluminal speed will be, less than optimal, but still a good outcome, as far as the expected technological and practical prospects of the discovery of superluminal light propagation, in artificial optical media of fractional refractive indices, are concerned.

(c) If the experimental light leaves a fast-light medium — whose refractive index is less than unity — enters a regular optical medium — whose refractive is greater than unity— and it's, experimentally, verified that the numerical value of its superluminal speed has been wiped out and completely lost, then this, definitely, will be, on all accounts, the most sterile, by far, and the worst of all possible outcomes, as far as the potential technical and and industrial benefits of the discovery of superluminal light propagation, in fast-light light media, are concerned.

It should be obvious, however, that if, at some time, in the future, light rays, immediately, after emerging from fast-light media, are verified, experimentally, to have, indeed, retained their superluminal speeds in air, water, diamond, or empty space, then the hypothesis of quantum tunneling, the Sommerfeld-Brillouin-Stenner hypothesis, Einstein's cosmic speed limit, and the second postulate of the special theory of relativity will all have — theoretically speaking— to undergo major changes, and endure deeply brutal modifications, just to barely survive, and avoid being thrown, into the dustbin.

In any case, the serendipitous discovery of superluminal light propagation, in fast-light media, is an important empirical finding, in this particular branch of physics. And it might, as well, revolutionize the entire scientific discipline of physics, if it's proved, beyond doubt, one day, that the experimental light beams are more than able to keep their '*gain-assisted*' superluminal speeds, in free space.

REFERENCES:

1. ***Down To Earth***
   "*Quest for speed*"

2. ***Stenner, M. D., et al:***
   "*The Speed of Information in a Fast-light Optical Medium*"

3. ***Einstein, A.***,
   "*On the Electrodynamics of Moving Bodies*".

4. ***Weiss, P.,***
   "*Light pulses flout sacrosanct speed limit*"

5. ***ScienceDaily:***

"*Light that travels…faster than light*"

6. ***John G. Cramer:***
"*Tunneling through the Lightspeed Barrier*"

7. ***Physicsworld:***
"*Laser smashes light-speed record*"

8. ***Glanz, J.,***
"*Light Exceeds Its Own Speed Limit, Or Does It?*"

9. ***Duke Physics:***
a.) "*The Fast-Light Debate*"
b.) "*Introduction to the Information Velocity*"

10. ***MathPages:***
"*Phase, Group, and Signal Velocity*"

11. ***John D. Norton:***
"*Chasing a Beam of Light*"

12. ***First Light:***
"*NIST Researchers Develop New Way to Generate Superluminal Pulses*"

13. ***Keaveney et al:***
"*Maximal Refraction and Superluminal Propagation in a Gaseous Nanolayer*"

14. ***T. Ryan et al:***
"*Stimulated Generation of Superluminal Light Pulses via Four-Wave Mixing*"

15. ***Historical context of the SI:***
"Unit of length (meter)"

16. ***Anthony Maers et al:***
"*The Fizeau Experiment: Experimental Investigations of the Relativistic Doppler Effect*"

17. ***Fizeau, H.;***
"*On the Effect of the Motion of a Body upon the Velocity with which it is Traversed by Light*"

18. ***Paul Marmet:***
"*Incompatibility between Einstein's Relativity and Lorentz's Equations*"

19. ***Hau et al:***
"*Light speed reduction to 17 metres per second in an ultracold atomic gas*"

20. ***Günter Nimtz:***
"*Letter: Faster than light?*"

21. ***LightMachinery:***
"*Temperature Coefficient of the Refractive Index*"

22. ***wikiHow:***
"*How to Derive the Speed of Light from Maxwell's Equations*"

23. ***Ansys:***
"*Temperature dependent refractive index models*"

24. ***R. M. Waxler et al:***
"*Effect of Hydrostatic Pressure on the Refractive Indices of Some Solids*"

25. ***Wikipedia:***
"*Atmospheric refraction*"

26. ***Roberto Lalli:***
"*Anti-Relativity in Action*"

27. ***Cambridge Core:***
"*The Relation between Refractive Index and Density*"

Related Papers:

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