A Comment on Fast Neutrinos

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Widespread surprise about the evidence of possibly faster-than-light neutrinos is the product of longtime belief in Einstein's Special Relativity Theory (SRT), which prohibits anything physical (*i.e.* containing mass, or energy, or information) from moving faster than light speed c. But even before the neutrinos, there was already unease because of the distant correlations that seem inherent in Quantum Mechanics (QM): these are prohibited in SRT. So the fast neutrinos are not unique in giving reason to wonder about the proper status of SRT.

So what could be wrong with SRT? I personally most mistrust Einstein's Second Postulate, which makes the signal speed in SRT the same thing as the light speed in Maxwell's theory for electromagnetism, and so evidently the same constant c with respect to any observer. This idea about signal speed has often been questioned, although not yet in a really convincing way, probably because the questioning hasn't been accompanied with a generally acceptable modernization of, or alternative to, SRT.

I am personally most interested in examining Einstein's Second Postulate from a mathematical perspective, because that approach could lead immediately to a potentially acceptable modernization of SRT. Here are some points that seem worth noting at the outset:

1) Observe that the Second Postulate expresses a kind a multiplicity in SRT, similar to the duality that exists in QM, but very much stronger. The SRT multiplicity allows a countable

infinity of observers, whereas the QM duality needs only two: one for the particle, and one for the wave. It was hard to swallow the duality in QM, and it ought to be very much harder to swallow the infinite multiplicity in SRT.

2) Recall that the Second Postulate was intended to capture a requirement that Maxwell seemed to imply. Maxwell's four first-order coupled differential equations for electric (E) and magnetic (B) fields together certainly imply two second-order un-coupled wave equations for E and B fields alone. And the wave equations certainly determine the propagation speed for infinite plane wave solutions. But infinite plane waves do not a signal make! An infinite plane wave contains infinite energy, but a signal has to contain only finite energy. Otherwise, it would never finish its travel to its receiver. So it might not make sense to take a characteristic that is defined for an infinite plane wave, and apply it to a point-like entity that can serve as a signal.

3) What has been done historically is to think about infinite plane waves along with infinitesimal amplitude factors, to create point-like entities by doing Fourier integrals. That is how we get Dirac delta functions, and Heaviside step functions. Such entities are called 'generalized functions', meaning they lack the usual mathematical property of normal functions, 'uniform convergence'. They are mathematically tricky: in response to a reasonable question, they can yield more than one answer, making the choice between answers seem arbitrarily.

So what could we do instead? Here are some ideas to guide the search for an approach:

1) Recall that differential equations always offer a family of possible solutions, and that real world problems always involve particular boundary conditions that have to be fit. We always construct the particular solution we want by making a combination of possible solutions to fit the boundary conditions.

2) Note that a signal is not a self-sufficient thing; it has to have a source, and it has to have a receiver. So to model a signal mathematically, we can involve not only Maxwell's equations, to describe its evolution, but also its source and its receiver, to define its extent. We can require a mathematical function representing a signal to be zero at those boundaries.

3) Anticipate that a realistic solution needs to have three parts. The first part is the main part, traveling from the source to the receiver. The other two parts travel in the opposite direction, one to maintain the zero boundary condition at the source, and the other to maintain the zero boundary condition at the receiver. The solution we want is the sum of these three parts, evaluated just within the domain between the source and the receiver.

Here are some guidelines for exploiting those ideas:

1) Observe that Maxwell's equations imply that the wave travel direction for each solution part is determined by the cross product of the electric field (E) and magnetic field (B) assigned to it. So concentrate in the E fields, and let the B fields follow accordingly to give the propagation direction required.

2) Note that all three parts of the solution have to be initialized with field pulses. Let all pulses have the same Gaussian shape. Let the E pulse for the main part of the solution be positive, and let it be located just after the source, on the path to the receiver.

3) To provide E-field cancellation at the source, let E pulse for the second part of the solution be negative, and locate it just before the source. To provide cancellation at the receiver, let the E pulse for the third part of the solution be negative, and locate it at double distance after the receiver.

Here are details about the evolution of the initial pulses under the action of Maxwell's first-order differential equations for fields:

1) They develop waveforms. As the differential operators in Maxwell's field equations work on the Gaussian E (and B) pulses, they generate higher and higher order Hermite polynomials multiplying the Gaussians. The resulting functions look just like wavelets.

2) The waveforms not only travel but also spread, just like water waves from a stone cast into a moving river. For an electromagnetic signal, waveform spreading happens because the cross products of various E's and B's direct some energy forward, and some energy back.

3) The separations between zero crossings remain very similar, no matter how many zero-crossings develop. The wavelets appear to have half wavelength equal to the width of the original Gaussian.

There exist EXCEL programs and plots about all this, information available to readers who may ask about it.

Here is what I think is fair to say about signal speed: It is a complicated story, and a single number *c* does not capture the story. The waveform is changing shape, and developing additional peaks, so what is 'the' speed? The least we can say about it is:

1) At the beginning of the propagation process, the zero boundary condition at the receiver has no significant effect. If the propagation speed must be characterized with a single number, it has to be *c* relative to the source.

2) At the end of the propagation process, the zero boundary condition at the source has no significant effect. If the propagation speed must be characterized with a single number, it has to be *c* relative to the receiver.

3) In the middle of the propagation process, neither zero boundary condition is more important than the other. If the propagation speed must be characterized with a single number, it

has to be *c* relative to a system including both the source and the receiver, with its center located midway between them.

If we adopt this rather complicated story in place of Einstein's Second Postulate, we avoid the problem of infinite multiplicity. Signal propagation speed is always *c* with respect to something physical that is definitely identifiable.

And we get a different SRT:

1) It doesn't have *c* as a speed limit for material bodies, like neutrinos.

2) It doesn't have frame-dependent time, and doesn't generate paradoxes.

3) It doesn't have Lorentz transformations, but rather Galilean transformations.

To some readers, that last point may seem a little upsetting. It was believed at the turn of the 20th century that Maxwell's equations could not be reconciled with Galilean transformations, and in fact demanded Lorentz transformations. But that assessment now turns out to be untrue. It was the result of having for tensor analysis only an incompletely developed notation, such that one could not properly write down a transformation that was not space-time symmetric.

It is possible to complete the tensor picture today, and see that Maxwell's equations impose no demand whatsoever concerning what kind of coordinate transformations physics can use. That conclusion seems right and just, inasmuch as Maxwell's equations are indeed tensor equations, and tensor analysis as a mathematical technique aims to render statements that are 'coordinate free', meaning independent of the choice of coordinate frame.

In conclusion, regardless of what the neutrinos did do or didn't do, I say there are good mathematical reasons to revisit SRT and modernize it. It was always a bit too glamorous, and we ought to be wary about too much glamour in the physics theories on offer - even today.