**Article**

# Superluminal Neutrinos?

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**Abstract**

In view of the claims and counter claims about superluminal neutrinos, we revisit considerations of temporal order in relativistic effects, taking into account Heisenberg's Uncertainty Principle. We discuss the consequences.

In the context of the debate on superluminal neutrinos, we consider some ultra relativistic effects. Let us in particular investigate the Quantum Mechanical effect on special relativity. Following Weinberg [1] let us suppose that in one reference frame $S$ an event at $x_2$ is observed to occur later than one at $x_1$, that is, $x_2^0 > x_1^0$ with usual notation. A second observer $S'$ moving with relative velocity $\vec{v}$ will see the events separated by a time difference

$$x_2^{'0} - x_1^{'0} = \Lambda_\alpha^0(v)(x_2^\alpha - x_1^\alpha)$$

where $\Lambda_\alpha^\beta(v)$ is the "boost" defined by the usual Lorentz transformation,

$$x_2^{'0} - x_1^{'0} = \gamma(x_2^0 - x_1^0) + \gamma\vec{v}\cdot(x_2 - x_1)$$

This will be negative, that is, the order would be reversed if,

$$v \cdot (x_2 - x_1) < -(x_2^0 - x_1^0) \tag{0.1}$$

We now quote from Weinberg [1]:
"At first sight this might seem to raise the danger of a logical paradox. Suppose that the first observer sees a radioactive decay $A \to B + C$ at $x_1$, followed at $x_2$ by absorption of particle $B$, for example, $B + D \to E$. Does the second observer then see $B$ absorbed at $x_2$ before it is emitted at $x_1$? The paradox disappears if we note that the speed $|v|$ characterizing any Lorentz transformation $\Lambda(v)$ must be less than unity, so that (0.1) can be satisfied only if

$$|x_2 - x_1| > |x_2^0 - x_1^0| \tag{0.2}$$

"However, this is impossible, because particle $B$ was assumed to travel from $x_1$ to $x_2$, and (0.2) would require its speed to be greater than unity, that is, than the speed of light.

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To put it another way, the temporal order of events at $x_1$ and $x_2$ is affected by Lorentz transformations only if $x_1 - x_2$ is spacelike, that is,

$$\eta_{\alpha\beta}(x_1 - x_2)^\alpha (x_1 - x_2)^\beta > 0$$

whereas a particle can travel from $x_1$ to $x_2$ only if $x_1 - x_2$ is timelike, that is,

$$\eta_{\alpha\beta}(x_1 - x_2)^\alpha (x_1 - x_2)^\beta < 0''$$

All this is well known in the theory of special relativity. In Quantum Theory, however there is a complication: the spacetime coordinates are not so precisely known, due to the Uncertainty Principle, unless we lose all information about the momentum (or velocity) and energy. To quote Weinberg again,
"In consequence there is a certain chance of a particle getting from $x_1$ to $x_2$ even if $x_1 - x_2$ is spacelike, that is, $|x_1 - x_2| > |x_1^0 - x_2^0|$. To be more precise, the probability of a particle reaching $x_2$ if it starts at $x_1$ is nonnegligible as long as

$$(x_1 - x_2)^2 - (x_1^0 - x_2^0)^2 \leq \frac{\hbar^2}{m^2} \tag{0.3}$$

where $\hbar$ is Planck's constant (divided by $2\pi$) and $m$ is the particle mass. (Such space-time intervals are very small even for elementary particle masses; for instance, if $m$ is the mass of a proton then $\hbar/m \sim 10^{-14} cm$ or in time units $6 \times 10^{-25} sec$. Recall that in our units $1 sec = 3 \times 10^{10} cm$.) We are thus faced again with our paradox; if one observer sees a particle emitted at $x_1$, and absorbed at $x_2$, and if $(x_1 - x_2)^2 - (x_1^0 - x_2^0)^2$ is positive (but less than $\hbar^2/m^2$), then a second observer may see the particle absorbed at $x_2$ at a time $t_2$ before the time $t_1$ it is emitted at $x_1$".
To put it another way, the temporal order of causally connected events cannot be inverted in classical physics, but in Quantum Mechanics, the Heisenberg Uncertainty Principle leaves a loop hole. To quote Weinberg again:
"There is only one known way out of this paradox. The second observer must see a particle emitted at $x_2$ and absorbed at $x_1$. But in general the particle seen by the second observer will then necessarily be different from that seen by the first. For instance, if the first observer sees a proton turn into a neutron and a positive pi-meson at $x_1$ and then sees the pi-meson and some other neutron turn into a proton at $x_2$, then the second observer must see the neutron at $x_2$ turn into a proton and a particle of negative charge, which is then absorbed by a proton at $x_1$ that turns into a neutron. Since mass is a Lorentz invariant, the mass of the negative particle seen by the second observer will be equal to that of the positive pi-meson seen by the first observer. There is such a particle, called a negative pi-meson, and it does indeed have the same mass as the positive pi-meson".
In other words, Relativistic Quantum Mechanics as seen above throws up the fact that every particle has an anti-particle and this also saves the temporal order from reversing.
As can be seen from the above, the two observers $S$ and $S'$ see two different events, viz.,

one sees, in this example the protons while the other sees neutrons. Moreover, this is a result stemming from (0.3), viz.,

$$0 < (x_1 - x_2)^2 - (x_1^0 - x_2^0)^2 (\leq \frac{\hbar^2}{m^2}) \qquad (0.4)$$

in Quantum Theory. The inequality (0.4) points to a reversal of time instants $(t_1, t_2)$ as noted above. However, as can be seen from (0.4), this happens within the Compton wavelength or Compton time.

There is another way of looking at (0.4) which becomes relevant in view of the current claims and counter claims about superluminal neutrinos. There is a non zero probability for a particle to acquire superluminal velocities, within the Compton scale. This in any case is very small. However the neutrino, because of its low mass would have a higher value of this scale. Taking its mass to be $\sim 10^{-8}$ times the electron mass, we conclude that the neutrino could be superluminal within an interval of about $10^{-15}$ seconds.

There is however one way in which this conclusion can be avoided. We must remember that the above is within the background of the point spacetime. If instead spacetime is fuzzy, that is we cannot clearly define spacetime pointsm, at least within a small interval like the Compton scale, then the superluminal conclusion from (0.4) need not hold. Indeed this fuzzy feature was pointed out by Dirac in connection with his electron equation [2]. Later Wigner and Salecker [3] argued that indeed the concept of time measurement itself breaks down at the Compton scale.

So we are lead to a spacetime in which there are fuzzy or minimum spacetime intervals. This has been studied in detail by the author and others [4, 5]. We then have the so called Snyder-Sidharth energy momentum relation [6, 7, 8, 9]

$$E^2 = p^2 + m^2 + \alpha l^2 p^4 \qquad (0.5)$$

where as was shown $\alpha > 0$ for fermions and $< 0$ for bosons. Equation (0.5) shows that the usual relativistic energy momentum relation acquires an extra term, that is there is an extra energy for fermions. This has been discussed in detail in the literature. One way in which it can be interpreted is [10] that fermions get an extra momentum or energy. Specializing to the case of neutrinos, this can also be interpreted as the neutrinos getting a slightly greater velocity than in the usual theory. In any case the effect is greater for neutrinos than other fermions because of their much smaller mass, or equivalently, their larger Compton wavelength $l$.

# References

[1] Weinberg, S. (1972). *Gravitation and Cosmology* (John Wiley & Sons, New York), p.61ff.

[2] Dirac, P.A.M. (1958). *The Principles of Quantum Mechanics* (Clarendon Press, Oxford), pp.4ff, pp.253ff.

[3] Salecker, H. and Wigner, E.P. (1958). *Quantum Limitations of the Measurement of Space-Time Distances Physical Review* Vol.109, No.2, January 15 1958, pp.571-577.

[4] Sidharth, B.G. (2008). *The Thermodynamic Universe* (World Scientific), Singapore.

[5] Sidharth, B.G. (2005). *The Universe of Fluctuations* (Springer, Netherlands).

[6] Glinka L.A. (2008). *Apeiron* 2, April 2008.

[7] Sidharth, B.G. (2008). *Found. Phys.*,38(1), 2008, pp.89ff

[8] Sidharth, B.G. (2004). *Int.J.Th.Phys.*, 43(9),2004,1857-1861.

[9] Sidharth, B.G. (2008). *Found Phys.*, 38(8), 2008,pp.695-706.

[10] Sidharth, B.G. *arXiv.1201.09315* January 2012.