Superluminal Neutinos in Matter and Causality

Barry D.O. Adams
Barry.David.Adams@gmail.com

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Abstract

In the presence of a strong electric or magnetic field, quantum field theory modify the speed of light. We see that the same effect can explain the recent observation of neutrinos travelling faster than the speed of light in the vacuum from the CERN collider to the OPERA neutrino detector in Gran Sasso. We investigate the causality of the situation, and show that a form of electrical induction between very fast moving bodies will prevent closed timelike loops from occuring.

1 Superluminal Neutrinos

In August 2011, researcher at the OPERA neutrino detector in Gran Sasso [1], released shocking an shocking experiment result, that muon neutrinos travelling the 730 km from the CERN large hadron collider, arrived at there detected some 58 nanoseconds faster than would be expected if they travelled at the speed of light in a vacuum. The neutrinos seemed to travel at a velocity faster than light by a fractional part $2.48*10^{-5}$. Such a measurement is at first site, contria to Eisteins special and general theories of relavity. But secondary measurements with sharper pulses of neutrinos seem to confirm the results, moreover the results seemed to fit with earlier measurements from Fermilab to MINOS [2], which however were not greater than the statistic uncertainity in the measurements. While it might be wise to wait for further confirmation of the measurements, which might be produced at T2K in Japan or Fermilab before believing that relavity is violated, it would also be wise to investigate what theories might allow for this measurement.

Relavity but not quantum field theory, might allow superlumnal particles called tachyons provided that the masses of such particles are purely imaginary, i.e. with negative mass squared. A Tachyonic explaination of the faster than light neutrinos does not seem viable however. Measurements of neutrino travelling from the SN1987a Supernova seemed no faster than light. Tachyons would [3] emit cherenkov radiation and rapidly lose they energy. Further Tachyons would move slower, closer to light speed (from above), the higher their energy. Where as OPERA seemed to measure the speed

increase as independent of energy. In this paper we look at a different mechanism for the faster than light neutrino travel that is limited to occuring only in matter. Quantum Electrodynamics seems to vary the speed of light depending upon the energy density of vacuum and any fields in the vacuum, the effect slows light for positive energy density, and speeds it negative energy density. In example of negative energy density is the Scarnhorst effect [4] in the Casmir Vacuum between two conducting plates. Lattore, Pascual and Tarrach [5] show that in all situation the speed of light is modified to.

$$v = 1 - \frac{44}{135}\alpha^2 \frac{\rho}{m_e^4}$$

Where $c = \hbar = 1$, α is the fine structure constant i.e. the strength of the electromagnetic force, rho is the energy density of the Vacuum and m_e is the mass of the electron.

Let us assume that the neutrino interacts which another force similar to the electromagnetic force. We have investigated such a force [8] and find that not only would it have to date remained unnoticed but it also might generate the dark energy of the universe. Such a force would have its own force carrier, and the speed of this force carrier would be the limiting speed of neutrinos. In the vacuum the speed of this force carrier would be equal to that of ordinary light. As it was shown by Anber and Donoghue [7] that all force carriers have equal speed in the vacuum. In matter the electromagnetic force is dominant but this however would not effect the neutrinos. If the neutrino charge is conserved we can see from that the nucleons in matter must also be charged under this force, and to cancel out these charged the would need to be a sea of low energy neutrinos in matter. The sea would be compressed by the dominant E-M force leading to an negative energy density in the field the neutrino is charged under. The Lattore formule would again operate leading to.

$$v = 1 - \frac{44}{135}\alpha_\nu^2 \frac{\rho_v}{m_v^4}$$

Because the mass of the neutrino is so very small, at least less than 60 milli-electron volts, and the speed increase for neutrinos could be quite large. If this is the cause of OPERA results, we would see the speed of the neutrinos varying only with the type of material between the source and detectors, in fact we would find the speed varying directly with density of the medium.

2 Closed timelike loops and Superluminal Propagation

Let us look at the causality in the case where some particles are allowed to travel faster in matter than the speed of light in the vacuum. In some reference frames the particles would appear to travel backwards in time, this

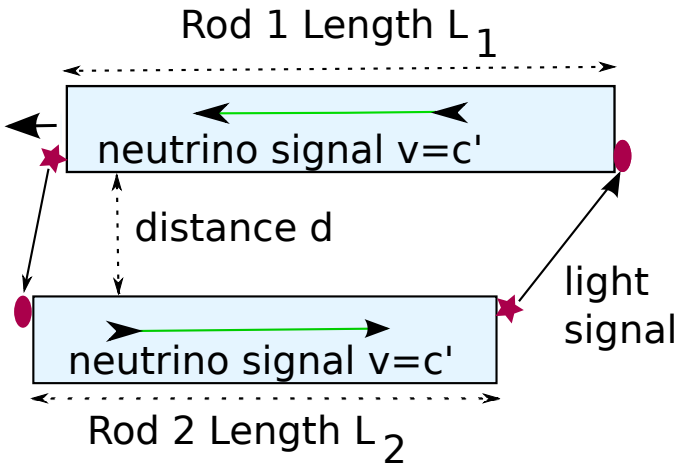

Figure 1: CTC with Superluminal Propagation in Matter

is upsetting for causality but may not be fatal for a theory. What would however make a theory unphysical would be a closed timelike loop, i.e. the existance of any path for a signal that allows the signal to return to its sender before the time of transmission. Such a loop would result in either a paradox, such as the sender choosing not to send the signal if it has already receiver, (was the signal sent or not, neither answer is may be true), or in the build up of infinite energy, where the signal goes round the loop an infinite number of time, each time be added to by the sender.

Where superluminal propagation is limited to certain particles (here neutrinos) inside matter, the minimum situation with the potential for causality violation is show in figure 1. Two rods lengths L_1 and L_2 in motion relative to each other, transport signals via superluminal neutrinos inside the rods, the speed of the neutrinos in the rod is taken to be c'. At each end of the rod, these signal are converted to or from ordinary light travelling at its usual speed c in the vacuum. Let us start the transmission on the left side of rod 2 which we choose to be motionless, and arrange rod 1, passing at high velocity to have its ends next to the ends of rod 1 at the times of its receiving or emitting a signal, thus minimising the signals time in ordinary space.

Begin with a neutrino emission from LHS of Rod 2, at time 0, event 1. Let us write the space time coordinates of signal as (x,y,z,t),

$$E_1 = (0, 0, 0, 0)$$

The neutrino travels thought rod 1, at speed c' and reaches the end, at event 2

$$E_2 = (L_2, 0, 0, \frac{L_2}{c'})$$

At the end, let a have placed a transceiver that absorbs the neutrino signal

and emits a light signal towards the passing Rod 1, which is received at the end of Rod 1, at Event 3, and is converted to neutrinos travelling leftwards though Rod 1 again.

$$E_3 = (L_2, d, 0, \frac{L_2}{c'} + \frac{d}{c})$$

The relavistic frame for Rod 1 is given by a Lorentz Transform so that,

$$t' = \gamma(t - \frac{Vx}{c^2})$$

$$x' = \gamma(x - vt)$$

So from the view point of Rod 2, the neutrino signal passing through Rod 1 takes,

$$t' = \gamma \left[\frac{L_1}{c'} - \frac{VL_1}{c^2} \right]$$

Arriving at the left side of Rod 1, at Event 4

$$E_4 = (0, d, 0, \frac{L_2}{c'} + \frac{d}{c} + \gamma\frac{L_1}{c'} - \gamma\frac{VL_1}{c^2})$$

In order to have the end of Rod 1, to be directly next to the beginning of Rod 2 at Event 4, we need its length to be

$$\Delta x = L_2 = \gamma \left(L_1 - V\frac{L_1}{c'} \right)$$

or

$$L_1 = \frac{L_2}{\gamma} \left(1 - \frac{v}{c'} \right)^{-1}$$

Thus minimising the signal time back to the orgin again via light to Event 5.

$$E_5 = (0, 0, 0, 2\frac{d}{c} + L_2 \left[\frac{1}{c'} + \frac{c^2 - Vc'}{c^2(c' - V)} \right]$$

We see event E_5 occurs before the E_1 if

$$d < \frac{L_2}{2} \left[\frac{Vc' - c^2}{c(c' - v)} - \frac{c}{c'} \right] \tag{1}$$

We note the CTC can only occur for very high velocity passing rod 1,

$$V > 2\frac{c'c^2}{c^2 + c'^2}$$

We have demostrated that for standard relavity neutrinos travelling superluminally in matter may lead to a paradox. Thus this mean that OPERA

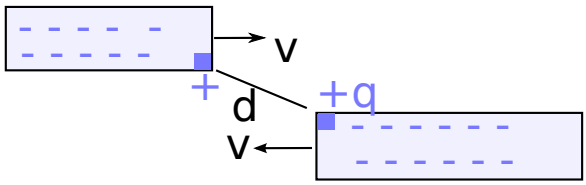

Figure 2: Rods with charged ends at high velocity

measurement must be wrong? There is a loop hole in the argument, if nature prevents superluminal propagation when they near each other at high velocity. In the next section we will show that rod travelling at high velocity will induce strong electric fields inside themselves. This will lead to a positive field energy inside the rods, end any superlumality for the neutrinos inside them.

3 Induction between Rods at High Velocity

Consider two Rods nearing each other at high velocity. In general fluctation in charge may occur, this is for example the origin of Van der Waals force between atoms. Here we show at high velocities, this effect is very much amplified by relavity. We will figure the energies of due to any charges at the ends of rods, with balances opposite charges at there centers from reference frame where the Rods are travelling with equal and opposite velocities V towards each other. The over all velocity measured between one Rod and the other is then.

$$V_b = \frac{2V}{1 + V^2/c^2}$$

We consider a charge on the edge of the Rod, q, to be balanced by an image charge in the center of the rod for simplicity. The energy for a charge q, in the corner of either rod is,

$$E_{11} = E_{22} = \gamma(V)\frac{1}{2\pi\epsilon_R}\frac{q^2}{L}$$

Between the rods, and including the magnetic part of the electrostatic force, the energy is,

$$E_{12} = -\frac{1}{4\pi\epsilon_0}\frac{q^2}{r}\gamma(V_b) - \frac{1}{4\pi\epsilon_0}.\frac{q^2 V_b^2 \gamma(V_b)}{c^2 r}$$

So the total energy is,

$$E = \frac{q^2}{4\pi\epsilon_0}.\left[\frac{2\gamma(V)}{\epsilon L} - \frac{\gamma(V_b)}{r}\left(1+\frac{v^2}{c^2}\right)\right]$$

Lets differentiate the energy by the charge,

$$\frac{dE}{dq} = \frac{q}{4\pi\epsilon_0}.\left[\frac{2\gamma(V)}{\epsilon L} - \frac{\gamma(V_b)}{r}\left(1+\frac{v^2}{c^2}\right)\right]$$

Let I be the inner part of the above equation, and we also find that $\gamma(V_b)$ is

$$\gamma(V_b) = \frac{c^2+v^2}{c^2-v^2}$$

$$I = \frac{1}{2\epsilon L}\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - \frac{1}{r}\frac{(c^2+v^2)^2}{c^2(c^2-v^2)}$$

Whenever I is less than zero, charges will not build up on the rods, however when I is greater than zero, the rods will induce a large electric charge between them. One can see that at high velocity, this charging becomes very strong. This then would lead to large fields inside the rods with positive energy values. In the begin section we saw that is was existance of a negative energy in the field interacting between neutrino that gave rise to there superluminal behaviour. When two rods pass close to each other and travel at high velocities relative to each other, the induced charges lead to a positive field energy, and the neutrinos will no longer travel superlumally. Thus induction leads to a chronology protection for neutrinos in the universe.

4 Conclusion

We have show that if superluminal propagation of neutrinos occurs in matter, closed timelike loops might be possible. However for our particular model where neutrinos gain there superluminality due to a negative energy density of some fifth force between neutrinos, causality will survive in all cases, since when materials come close togther at high velocity a positive energy density will be induced in the materials. This mechanism applies only where neutrinos interact under a fifth force. And it is this force that both enables superluminal propagation but prevents it where closed time like loop might appear.

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