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Neutrino dispersion relation changes due to radiative corrections as the origin of faster-than-light-in-vacuum propagation in a medium

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Abstract

Radiative corrections to the dispersion of neutrinos in nonstandard vacuum may give rise to "boosts" in their speed. This could explain recent experimental evidence by the OPERA collaboration, as well as the null result indicated by the supernova 1987A (SN 1987A) measurements of neutrino and photon arrival times.

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The speed of light in a medium [1] or under certain geometric constraints [2–6] may be decreased by radiative corrections with respect to vacuum values. "Diagrammatically speaking" [7–9], i.e., in terms of perturbative quantum field theory, a quantum travels through the vacuum ether medium [10] through partly "splitting up" into, and recombining from virtual particles. Thus, intuitively speaking, it may not be too unreasonable to conceive such a particle spending "some of its existence" in these virtual particle states. As many of these virtual particles, although off shell, are massive, this may temporarily decelerate a massless, or almost massless quantum like a neutrino as it traverses a nonvacuum medium such as the matter crossed in the OPERA experiment [11].

At the same time, this may explain why for neutrinos from a cosmic source, the coincidence in time with the optical sighting of the source has been consistent with a neutrino speed comparable to the speed of light in vacuum [12]. Because in the case of a distant supernova event, the vacuum medium traversed by both types of quanta has been identical for both particle types – the cosmic neutrinos and photons registered on Earth – respectively.

Thus, any change of vacuum polarization, such as finite boundary conditions, or increased or decreased pair production, alters the susceptibility of the vacuum ether medium for carrying quanta, and thus results in a change of the velocity of these particles. Analogue situations have been investigated for magnetic fields [13–15] and finite temperatures [16]. A vacuum polarization-induced index of refraction *smaller than one* was reported by Scharnhorst [2–4] and Barton [5, 6] in an attempt to utilize the reduced vacuum polarization in the Casimir vacuum [17] between two conducting parallel plates. Moreover, trans-vacuum-speed metamaterials [18–22] as well as negative refractive indices in gyrotropically magnetoelectric media [23] have been suggested.

One of the possibilities which have been discussed recently [1] is the immersion of photons into a vacuum ether medium "occupied" by electrons or positrons [1]. In such an environment, the Pauli exclusion principle would "attenuate" pair creation, thereby reducing the polarization of the medium, resulting in a reduced index of refraction as well as in an increase of the velocity of light.

The lowest order change to the radiative correction associated with the vacuum polarization of the photon can be written as [8, 24, 25]

$$\Delta\mathbf{\Pi}_{\mu\nu}(k^2) = -\left(g_{\mu\nu}k^2 - k_\mu k_\nu\right)\frac{2\alpha}{3\pi}\log\frac{\varepsilon_F}{m}. \tag{1}$$

Here m stands for the electron rest mass and ε_F denotes the cutoff associated with the filled electron or positron modes. Let ϵ_μ stand for the vacuum polarization. Then an effective mass term can be introduced [26–28]

$$M(k) = \epsilon^\mu \mathbf{\Pi}_{\mu\nu}(k)\epsilon^\nu \tag{2}$$

such that the eigenvalue equation is

$$\mathbf{k}^2 + M(k) = (k^0)^2, \tag{3}$$

where $k^\mu = (\mathbf{k}, k^0 = \omega)$; and

$$|\mathbf{k}| \approx \omega - \frac{1}{2\omega} M(k). \tag{4}$$

The index of refraction may be defined by

$$n(\omega) = \frac{|\mathbf{k}|}{\omega} \approx 1 - \frac{1}{2\omega^2} M(k). \tag{5}$$

Hence the change of the refractive index is given by

$$\Delta n(\omega) \approx -\frac{\alpha}{3\pi\omega^2} (\epsilon^\mu k_\mu)^2 \log \frac{\varepsilon_F}{m}. \tag{6}$$

The group velocity is given by [4, Equ. (2)] $v_{gr} = c/n_{gr}$ with $n_{gr}(\omega) = n(\omega) + \omega\left[\partial n(\omega)/\partial\omega\right]$, which, for transversal waves, turns out to be $n(\omega)$. As a result, the speed of photons in such a medium $c/(1 - \Delta n) \approx c + \Delta c$ exceeds the velocity of light in vacuum by $\Delta c = c\Delta n$. Thereby it should always be kept in mind that group velocities, like phase velocities and energy velocities, in general are not signal velocities; hence group velocities exceeding the vacuum speed of light c does not contradict relativity [29–31].

In summary we have discussed field theoretic options for the "speedup" of ultrarelativistic particles beyond the speed of light barrier in the presence of suitable media which cause a reduction of polarizability and radiative corrections. These considerations do neither represent the possibility to circumvent relativistic causality, because no *ad hoc* "willable" superluminal information or paradoxical time travel will be rendered [32]; nor are they inconsistent with the present formalism of relativity theory or the theory of quantized fields; on the contrary they can be taken as a demonstration of the relativistic formalism [33, 34]. They would not even make necessary the standard SI conventionalization of the constancy of the speed of light [35]; with the possible addendum of referring to this the velocity of light in a particular type of rather idealized vacuum.

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