The velocity of neutrinos

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Recently, the OPERA neutrino experiment at the underground Gran Sasso Laboratory has measured the velocity of neutrinos from the CERN CNGS beam over a baseline of about 730 km. The experiment shows that neutrinos can have *superluminal* velocities. This result could, in principle, be taken as a clear violation of the Special Relativity. However, it will be show here that neutrinos can actually travel at velocities faster than light speed, without violating Special Relativity.

Key words: Neutrino mass, Neutrino interactions, Special relativity.
PACS: 14.60.Pq, 13.15.$^{+}$g, 03.30.$^{+}$p.

The mass of the *electron neutrino* (ν_e) is usually measured using the beta decay. The continuous spectrum of beta decay electrons terminates at a maximal energy, which depends on the neutrino mass and on the emitting nucleus type. Because of the way that the neutrino mass affects the electron energy spectrum, the measured quantity is the *square* of the neutrino mass. All recent measurements show that the *neutrino mass squared* is *negative* [1]. However, the square root of a negative number is an *imaginary number*. Thus, the measurements suggest that the *electron neutrino has an imaginary mass*. Assuming that the neutrino has no *real mass*, and considering that the *imaginary momentum* has a *real* value, i.e., $L_{(im)} = I_{(im)}\omega_{(im)} \equiv S_{(real)}$ and $p_{(im)} = M_{g(im)}V_{(im)} \equiv p_{(real)}$, we can infer that the neutrino is an *imaginary particle* with a measurable property; *the square of its imaginary mass*.

The OPERA neutrino experiment [2] at the underground Gran Sasso Laboratory (LNGS) was designed to perform the first detection of neutrino oscillations. Recently, it was reported that the OPERA neutrino experiment had discovered neutrinos with velocities greater than the light speed [3]. The neutrinos in question appear to be reaching the detector 60 nanoseconds faster than light would take to cover the same distance. That translates to a speed 0.002% higher than $c = 299{,}792{,}458$ m.s^{-1} (the speed upper limit for *real particles* in the *real* spacetime).

The quantization of velocity shows that there is a speed upper limit, $c_i > c$, for *imaginary particles* in the *real* spacetime (real Universe)*. This means that Einstein's speed limit (c) not applies to imaginary particles propagating in the real spacetime. Theoretical predictions show that $c_i \approx 10^{12}\, m.s^{-1}$ [4]. Consequently, the imaginary particles, such as the neutrinos, can reaches velocities faster than light speed. Therefore, in the case of imaginary particles, we must replace c in the *Lorentz transformation* by $C_{(im)} = c_i i$ in order to generalize the equations of Special relativity. Thus, the *imaginary* kinetic energy of *imaginary particles*, for example, is written in the following form:

$$K_{(im)} = \left(m_{i(im)} - m_{i0(im)}\right)C_{(im)}^2 = \left(\frac{1}{\sqrt{1-\frac{V_{(im)}^2}{C_{(im)}^2}}} - 1\right) m_{i0(im)}C_{(im)}^2 =$$

$$= \left(\frac{1}{\sqrt{1-\frac{V^2}{c_i^2}}} - 1\right) m_{i0(im)}C_{(im)}^2$$

where $m_{i0(im)}$ is the *imaginary mass* of the particle at rest. The expression above shows

* The speed upper limit for *real particles* in the *imaginary* spacetime is C, because the relativistic expression of the mass shows that the velocity of *real* particles cannot be larger than C in *any space-time*.

that the imaginary particle has a *real* velocity V. This means that imaginary particles propagating in the real spacetime can be detected. This is the case, for example, of the neutrinos with $V > c$ observed in the OPERA neutrino experiment.

Note that the *imaginary kinetic energy* of the particle is what gives to the neutrino its real velocity $\left(K_{(im)} \to V\right)$. This solves therefore, the problem of how the neutrino propagates in the space.

In addition, we can conclude that in the neutrino-electron reactions, mediated by the Z particle, the neutrino does not enter as a real mass but as a *real* angular *momentum* (spin ½). The real mass of the neutrino is null, but the *real* angular *momentum* and the *imaginary* angular *momentum* of the neutrino are not null. The *real* angular *momentum* of the neutrino, $S_{(real)}$, derives from its *imaginary* angular *momentum*, according to the following relation: $I_{(im)} = I_{(im)}\omega_{(im)} \equiv S_{(real)} = \sqrt{s(s+1)}\hbar$.

References

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