Neutrinos and the speed of light

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Abstract

While neutrino particles are being extensively studied in modern physics, researchers are still debating whether these particles travel at the speed of light. While theoretical methods suggest that this cannot be the case, experimentations have failed to show any significant difference between neutrino speed and c. In this paper, we suggest that neutrinos actually travel at the speed of light, and propose a simple theoretical approach to compute neutrino quantum states corresponding masses, using observed flavour distribution. We also introduce the idea that using imaginary masses for some of these quantum states would solve the current dead-end researchers are facing when studying the speed of neutrinos.

Introduction

In 1998, the Super-Kamiokande experiment validated the hypothesis of neutrino oscillation. This oscillation has resulted in non-zero masses being assigned to the three particles (neutrinos ε, μ, τ) and a velocity lower than the speed of light.
Indeed, this oscillation implies a «proper time» in the neutrino referential, which seems incompatible with zero mass and luminal velocity.

Previously, the 1987 observation of the flow of neutrinos from supernova SN 1987A had shown a relative difference between neutrino speed and light velocity of less than $2*10^{-9}$, and no spread in speed has yet been demonstrated between light and neutrinos.

The observed velocity of a particle is not necessarily identical to the calculated velocity for each of the quantum states of this particle, a phenomenon known as "wave function collapse". The present study explores the hypothesis that the observed neutrino velocity is actually that of light, this velocity resulting from the superposition of quantum states that do not violate the laws of relativity for a particle endowed with mass.

A calculation of neutrino mass

For a relativistic particle, the energy/velocity relationship is given by:

$$E = \frac{m}{(1-\frac{v^2}{c^2})^{\frac{1}{2}}}$$

(Mass expressed in eV).

When the velocity v is very close to c, this relationship becomes, with a very good approximation:

$$c - v = \frac{m^2 c}{2E^2} \quad (i)$$

Furthermore, the following relationships between the masses m_1, m_2 and m_3 of neutrinos have emerged from experiments (Boyd, S. Lectures of neutrinos (2019)):

$$m_1^2 - m_2^2 = 0.8*10^{-4} eV^2$$

$$|m_2^2 - m_3^2| = 23*10^{-4} eV^2$$

We have two equations for three unknowns. A third relation between the masses would solve the system.

The probability of oscillation of a neutrino with an energy E, and having travelled a distance L is [1]:

$$P(\nu_{\varepsilon} \rightarrow \nu_{\mu,\tau}) = cos^2(\theta_{13}^2)sin^2(2\theta_{12}^2)sin^2(1.27\Delta m_{12}^2\frac{L}{E}) + \frac{1}{2}sin^2(2\theta_{13}^2)$$

Over a long trajectory, the average of this probability can be calculated with [1]:
- Mean value of $sin^2(1.27\Delta m_{12}^2\frac{L}{E}) = 0.5$
- $sin^2(2\theta_{12}^2) = 0.85 +/- 0.05$
- $sin^2(2\theta_{13}^2) = 0.089 +/- 0.01$ and so $cos^2(\Theta_{13}^2) = 0.98$

This gives a probability of observing a neutrino ε with the flavour μ or τ of $0.46 +/- 0.03$.

Considering the symmetry between the flavours μ and τ, a neutrino can be observed according to the probabilities:
- Neutrino ε: 0.54
- Neutrino μ: 0.23
- Neutrino τ : 0.23

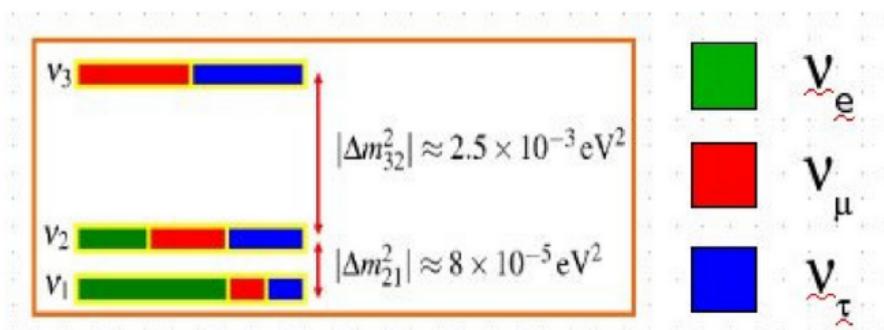

Figure 1. Flavour/mass observed distribution[1]

Moreover, considering the mass/flavour distribution in figure 1, the masses m_1, m_2 and m_3 are distributed according to the following probabilities (see appendix table 1):
- m_1: 0.44
- m_2: 0.33
- m_3: 0.23

Regardless of the observed state, the particle retains the same energy E. The velocity being related to the mass in each state by the relation (i), the hypothesis of an average velocity equal to c can be translated into:
$0.44m_1^2 + 0.33m_2^2 + 0.23m_3^2 = 0$

This hypothesis excludes the possibility of a fourth direct relationship between the neutrino masses, which is consistent with the current state of experiments. The third equation solves the system – with two solutions depending on whether $m_2^2 - m_3^2$ is positive or negative, corresponding to two different quantum states.

State A: $m_2^2 - m_3^2 > 0$

$m1 = 2.37 * 10^{-2}\ eV$
$m2 = 2.19 * 10^{-2}\ eV$
$m3 = i * 4.24 * 10^{-2}\ eV$ (Imaginary value)

State B: $m_2^2 - m_3^2 < 0$

$m1 = i * 2.21 * 10^{-2}\ eV$ (Imaginary value)
$m2 = i * 2.39 * 10^{-2}\ eV$ (Imaginary value)
$m3 = 4.19 * 10^{-2}\ eV$

It seems physically legitimate to consider that the quantity $m_2^2 - m_3^2$ can equally take both signs, either positive or negative. This is why we have retained the hypothesis that the probability wave of the neutrino is the sum of the two quantum states A and B with the same probability 1/2.

Compatibility with the current theory

On the use of imaginary masses

The use of imaginary masses as calculation intermediaries is not a novelty. This is, for example, the case in string theory (where these values are treated as instabilities requiring a new configuration of the system).

This is also the case in the calculations relating to the Higgs boson, a very real particle which has now been observed.

Compatibility with special relativity

It would be bold to say that these solutions are compatible with the theory of relativity: These calculations implicitly assume that equation (i) remains applicable for speeds higher than that of light.

The speed of light remains an impassable barrier for particles endowed with mass, but the hypothesis is to admit a "supraluminic" physics of objects of imaginary mass... it is obviously disturbing, should it be excluded a priori?

Possible theoretical and experimental confirmation

Experimental confirmation

To obtain a zero proper time on the sum of states A and B, the relativistic calculation of the neutrino's proper time leads to pose the hypothesis of a slight asymmetry of the quantity $|m_2^2 - m_3^2|$ in quantum states A and B. For an average value of $23 * 10^{-4} eV^2$, these states would take the values $+22.8 * 10^{-4} eV^2$ and $-23.2 * 10^{-4} eV^2$.

This results in a phase shift between the two quantum states, and therefore a probability oscillation over a path length of about 50 times the length L characteristic of the neutrino oscillation. Provided that neutrinos can be obtained in a sufficiently tight band of energy, this oscillation would be observable.

Additionally, recent experiments (Mertens, Susanne (2016)[2]) have found an upper bound for the sum of the three masses of around 120 meV, which is consistent with our findings (using the norm for the imaginary masses).

More directly, considering a sufficient measurement accuracy, the quantity $|m_2^2 - m_3^2|$ could be observed as taking two distinct values, separated by about $5 * 10^{-5} eV^2$ and corresponding to the two quantum states.

On the other hand, the direct detection of a velocity deviation between the neutrino and c (either above or below) seems illusory: for a neutrino with an energy as low as 1 MeV, the relative deviation with c would be of the order of 10^{-15}.

Theoretical confirmation

These solutions give a constant average speed to the neutrino and are therefore compatible with a constant helicity. This could allow a reconciliation of neutrinos with the standard model, leading to a simplification of the theory by reducing free parameters.

To date, the neutrino seems to be the only «messenger» particle of one of the four fundamental interactions (the weak interaction) to propagate at a speed smaller than c. Even if nature has accustomed us to be wary of the obvious, this situation seems "philosophically" troubling.

Appendix

Flavour/mass split	ε	μ	τ	p(m_i)
m_1	0.68	0.16	0.16	0.44
m_2	0.32	0.34	0.34	0.33
m_3	0	0.50	0.50	0.23
p(flavour)	0.54	0.23	0.23	1.00

Table 1. Distribution of masses and flavours

References

1. Boyd, S. Lectures of neutrinos (2019). https://warwick.ac.uk/fac/sci/physics/staff/academic/boyd/stuff/lec_oscillations.pdf.

2. Mertens, S. Direct neutrino mass experiments. (2016).