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The Possibility of Neutrinos Detected as Tachyons

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Abstract: Recent measurements on electron neutrinos suggest that they might have an imaginary rest mass. This paper shows that they have a possibility being emitted from the atomic nucleus as a faster-than-light (FTL) particle called a tachyon.
Key Words: faster-than-light, tachyon, neutrino.

Table of Symbols

ψ： wave function of the moving particle
ψ_*： wave function of the particle in a FTL state
α： proper acceleration of the particle
c： light speed
p： momentum of the particle
p_*： momentum of the particle in a FTL state
E： energy of the particle
$\hbar$： Planck's constant divided by 2π
m_o： rest mass of the particle
T penetration probability of particles through the light barrier
L： size of the atomic nucleus
Λ： traveling distance of the particle in a FTL state

INTRODUCTION

The rest mass of neutrinos has been assumed to be zero. However recent measurements on electron neutrinos suggest that they might have an imaginary rest mass [1]. This means that they are faster-than-light (FTL) particles, which were named tachyons by G. Feinberg [2]. The purpose of this paper is to examine the possibility of electron neutrinos being emitted from the atomic nucleus as a tachyon.

WAVE EQUATION FOR THE PARTICLE MOVING INSIDE THE ATOMIC NUCLEUS

Supposing that the elementary particle moving inside the nucleus satisfies the equation described as

$$\psi(x,t) = A \cdot \exp\left[-i\left(\frac{E}{\hbar}t - \frac{p}{\hbar}x \right) \right] \quad , \tag{1}$$

where ψ is a wave function, A is an arbitrary constant and $\hbar$ is a Planck's constant divided by 2π [3]. E and p are energy of the particle and its momentum given by

$$E = \frac{m_o c^2}{\sqrt{1 - v^2 / c^2}} \quad , \tag{2}$$

$$p = \frac{m_o v}{\sqrt{1 - v^2 / c^2}} \quad , \tag{3}$$

where m_o is a rest mass of the particle.

From Eq.(1), we can obtain the relation given by

$$i\hbar \frac{\partial \psi}{\partial t} = c\sqrt{p^2 + m_o^2 c^2}\,\psi \quad . \tag{4}$$

When the moving particle inside the nucleus turns its direction as shown in Figure 1, Eq.(4) can be rewritten as

$$\frac{\partial \psi}{\partial p} = -i\frac{c}{m_o \alpha \hbar}\sqrt{p^2 + m_o^2 c^2}\,\psi \quad , \tag{5}$$

by using the proper acceleration α given by

$$p = m_o \alpha (t - t_o) \quad . \tag{6}$$

where t_o is the time when the particle is accelerated [4]. The solution of Eq.(5) can be given by

$$\psi = C \cdot \exp\left[-i\frac{c}{m_o \alpha \hbar}\left(\frac{p}{2}\sqrt{p^2 + m_0^2 c^2} + \frac{m_o^2 c^2}{2}\log(p + \sqrt{p^2 + m_o^2 c^2}\right)\right] \quad , \qquad (7)$$

where C is an arbitrary constant.

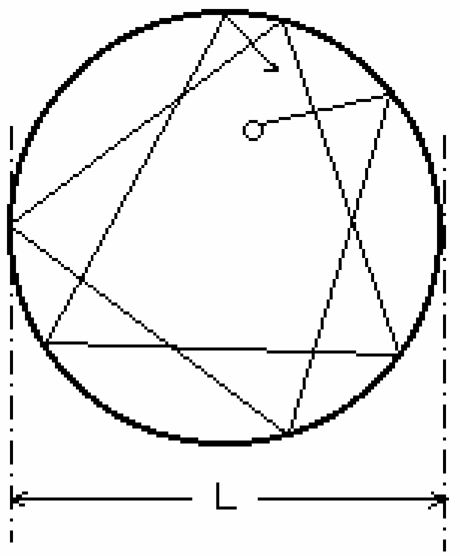

Figure 1. Moving particle inside the nucleus.

If the velocity of the particle inside nucleus almost equals the light speed, the velocity of the particle remains almost the same when it is accelerated. So the wave equation for the moving particle inside the nucleus can be approximated as follows by inserting Eq.(3) into Eq.(7).

$$\psi = C \cdot \exp\left[-i\frac{m_o c^3}{2\alpha\hbar}\left(\frac{cv}{c^2 - v^2} + \log\left(m_o c\sqrt{\frac{c+v}{c-v}}\right)\right)\right] \quad . \qquad (8)$$

For the velocity beyond the light speed, Eq. (8) can be rewritten as

$$\psi_* = C \cdot \exp\left[-i\frac{m_o c^3}{2\alpha\hbar}\left(\frac{cv}{c^2 - v^2} + \log\left(m_o c\sqrt{\frac{v+c}{v-c}}\right)\right)\right]\exp\left[-\frac{\pi m_o c^3}{4\alpha\hbar}\right] \quad , \qquad (9)$$

where ψ_* is a wave function of the particle in a FTL state.

From the uncertainty principle given by $\Delta p \cdot L \approx \hbar$, the proper acceleration of the particle moving inside the atomic nucleus can be roughly estimated as

$$\alpha = \frac{1}{m_o}\frac{\Delta p}{\Delta t} \approx \frac{c\hbar}{m_0 L^2} \quad , \qquad (10)$$

where L is a size of the atomic nucleus.

According to the WKB approximation [5], the penetration probability through the light barrier for the highly accelerated particle can be estimated by

$$T \approx \frac{|\psi_*|^2}{|\psi|^2} = \exp\left[-\frac{\pi}{2}\frac{m_o^2 c^2 L^2}{\hbar^2}\right] . \qquad (11)$$

POSSIBILITY OF THE NEUTRINO EMITTED FROM THE ATOM AS A TACHYON

By the uncertainty principle of the momentum, the velocity of the particle moving inside the atomic nucleus can be estimated from the relation [6] shown as

$$\frac{m_o v}{\sqrt{1 - v^2 / c^2}} \approx \frac{\hbar}{L} . \qquad (12)$$

From which, we have

$$v \approx c - \frac{c}{2}\frac{m_o^2 c^2 L^2}{\hbar^2} , \qquad (13)$$

for the light particle when satisfying $m_o cL / \hbar << 1$.

According to the uncertainty principle, it is considered that the particle penetrated through the light barrier is permitted to maintain the FTL state temporarily shown by supposing that energy of the penetrated particle through the light barrier is conserved, the particle moving inside the atomic nucleus satisfies

$$E^2 - p^2 c^2 = m_o^2 c^4 \ \text{(in a non-FTL state)}, \qquad (14)$$

and

$$E^2 - p_*^2 c^2 = m_*^2 c^4 \ \text{(in a FTL state)}, \qquad (15)$$

where p_* is the momentum of the particle and m_* is an absolute value of the particle's rest mass in a FTL state.

If we let $\Delta p_* = p - p_*$, we have

$$(m_*^2 - m_o^2) c^2 = 2 p \Delta p_* - \Delta p_*^2 . \qquad (16)$$

Then it is seen that the FTL particle has an imaginary mass temporarily according to the uncertainty principle.

For the case when $m_* >> m_o$, Δp_* can be approximated as

$$\Delta p_* = \frac{\hbar}{L}\left(1 - \sqrt{1 - \frac{m_*^2 c^2 L^2}{\hbar^2}}\right) \approx \frac{m_*^2 c^2 L}{2\hbar} , \qquad (17)$$

from $\Delta p \approx \hbar / L$, when satisfying $m_* cL/\hbar << 1$. From the conversation of energy of the particle through the light barrier shown as

$$\frac{m_o c^2}{\sqrt{1-v^2/c^2}} = \frac{m_* c^2}{\sqrt{v_*^2/c^2 - 1}} \quad , \tag{18}$$

we have

$$v_* \approx c + \frac{c}{2}\frac{m_*^2 c^2 L^2}{\hbar^2} . \tag{19}$$

The uncertainty relation for the tachyon can be given by

$$\Delta p_* \cdot \Delta t \approx \frac{\hbar}{v_* - v_o} \quad , \tag{20}$$

where v_* and v_0 is are velocities before and after the measurement [7].

From Eq.(17),(19) and (20), the time interval of the particle emitted from the atomic nucleus traveling in a FTL state can be given as

$$\Delta t \approx \frac{4\hbar^4}{m_*^4 c^5 L^3} \tag{21}$$

if we let $v_o \approx c$. From which, the traveling distance of the particle emitted from the atomic nucleus as a tachyon can be estimated as

$$\Lambda = v_* \Delta t \approx \frac{4\hbar^4}{m_*^4 c^4 L^3} \tag{22}$$

Hence it is seen that the light particle emitted from the nucleus has the possibility to travel in a tachyonic state within a finite length according to the uncertainty principle.

CALCULATION OF EXPERIMENTAL DATA FOR THE ELECTRON NEUTRINO

The square of the electron neutrino rest mass measured for tritium β decay, ^3H decay and β decay by many researchers are shown in Table 1 below.

Table 1. Experimental data of electron neutrino.

No.	Nuclear Reaction	Experiment $(eV)^2$	$i\overline{m}_*$ (Kg)	Λ (m)	Ref.
1	Tritium β decay	-24 ± 48	$i8.72\times10^{-36}$	1.06×10^{13}	[8]
2	Tritium β decay	-39 ± 34	$i1.11\times10^{-35}$	4.03×10^{12}	[9]
3	^3H decay	-65 ± 85	$i1.43\times10^{-35}$	1.46×10^{12}	[10]
4	β decay	-147 ± 68	$i2.16\times10^{-35}$	2.81×10^{11}	[11]
5	Tritium β decay	-130 ± 20	$i2.03\times10^{-35}$	3.60×10^{11}	[12]

The square of the electron neutrino rest mass implies that it has an imaginary rest mass shown in Table 1, where $\overline{m}_*$ is the mean value of the electron neutrino rest mass. Figure 2 shows the penetration probability through the light barrier when we let $L \approx 10^{-14}$ m. If the particles rest mass satisfies $m_* >> m_o$, the probability for the particle being emitted from the atomic nucleus in a FTL state becomes almost a unity as shown in the figure below.

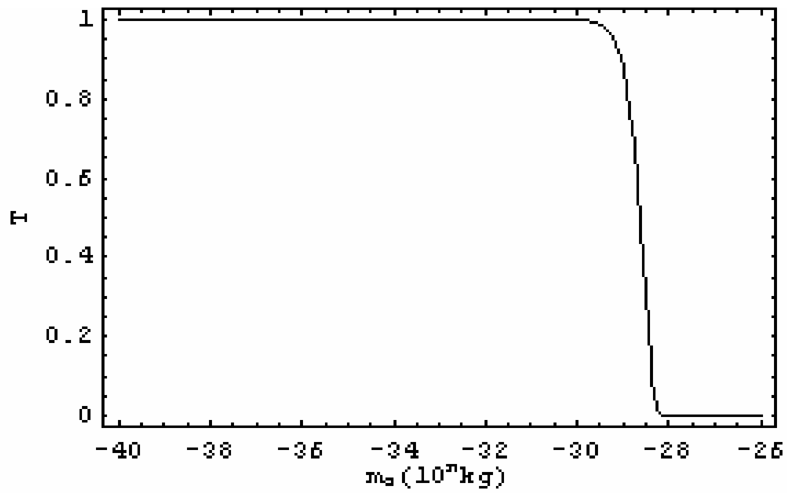

Figure 2. Probability of the particle being emitted from the atomic nucleus in a FTL state.

The traveling distance in a FTL state can be calculated by Eq. (22), which is also shown in Tabel.1. From these results, it is considered that electron neutrinos can be detected as a tachyon near the source as observed at the experiments, however the distance between the source and the detector is much larger than the distance between the Earth and the Sun, which equals about 1.5×10^{11} m, they can be observed as an ordinary particle which has a real rest mass.

CONCLUSION

In this paper, the possibility of the neutrino being emitted from the atomic nucleus as a tachyon has been discussed and the theoretical analysis done gives the result that electron neutrinos can be detected as tachyons near their source.

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