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HYPOTHESIS OF TACHYONIC NEUTRINOS*

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Anomalies observed in the electron energy spectrum in tritium decay are expected if electron (anti)neutrino is a tachyon; in particular anhancement of counts near the end point leading to negative values for the electron antineutrino mass squared. Since the tachyonic neutrino field is an eigenstate of the helicity operator, the hypothesis of tachyonic neutrinos offers a natural explanation of the V–A structure of the weak leptonic current. Our "educated guess" for the mass of a hypothetical tachyonic neutrino is ≈ 5 eV.

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1. Introduction

The hypothesis of tachyonic neutrinos deserves attention as being motivated by results of recent tritium decay experiments which are so far the most widely used kinematical method of direct determining the mass squared of the electron antineutrino, $m^2_{\nu_e}$ [1–10]. In tritium decay, $^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$, a value of the electron antineutrino mass squared, $\xi = m^2_{\nu_e}$, may be determined by fitting the electron kinetic energy spectrum near the end point with the formula:

$$\frac{d\Gamma}{dE} \sim p(E_{\max} - E)\sqrt{(E_{\max} - E)^2 - \xi}\,, \qquad (1)$$

where E and p denote electron energy and momentum and $E_{\max}$ – maximal energy (corresponding to a kinetic energy $T_{\max} \approx 18570$ eV). In cited experiments (Table I) the fitted values of ξ come out negative.

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TABLE I

Recent results for the electron antineutrino mass squared. The first uncertainty is statistical, the second systematic.

$\xi = m^2_{\nu_e}\,[\mathrm{eV}^2]$			Year	Ref.
-22	$\pm$	17$\pm$ 14	1996	[2]
-20.6	$\pm$	5.8	1996	[3]
-130	$\pm$	20$\pm$ 15	1995	[4]
-22	$\pm$	4.8	1995	[5]
-39	$\pm$	34$\pm$ 15	1993	[6]
-31	$\pm$	75$\pm$ 48	1993	[7]
-24	$\pm$	48$\pm$ 61	1992	[8]
-65	$\pm$	85$\pm$ 65	1991	[9]
-147	$\pm$	68$\pm$ 41	1991	[10]

High resolution of spectrometers used in the latest experiments [1–6] allowed to discover an effect, hereafter referred to as the *end point effect*, which is ilustrated in Fig. 1. It is an excess of counts in the vicinity of the end point of the electron energy spectrum. It is present in measurements from LLNL [4], Troitsk [3,5] and Mainz [2]. Both latter groups performed new measurements in 1997 and their preliminary results have been already pre-

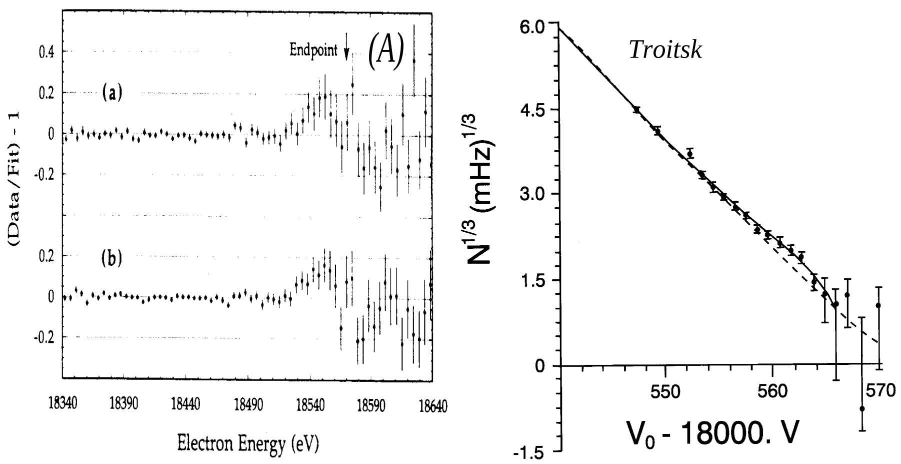

Fig. 1. Ratio of measured and fitted ($\xi = 0$) spectra from the LLNL experiment (from [4]); linearized (cube root) integral electron energy spectrum measured in the Troitsk experiment, dashed line drawn for massless ($\xi = 0$) neutrino (from [5]).

sented [1] but a detailed analysis is due later in the year. Another anomaly, below denoted as the *slope effect*, has also been reported by the Mainz [2,6] and Troitsk [3,5] groups. It has been described as a rise in the counting rate in the region further below the end point (often called a 'missing component'). A majority of this effect seen in the Troitsk data has been recently explained as due to trapping and rescattering decay electrons [3] [1].

In general one might expect that such anomalies result from insufficient understanding of the apparatus (*e.g.* a missing correction) or are manifestations of unpredicted effects of physical as well as other origin. While the *slope effect* awaits further investigation using the 1997 data, the *end point effect*, being well established experimentally, is not explained on neither grounds until now. Studies have demonstrated that it could not originate from mistreatment of molecular effects [11, 14].A manifestation of statistical effects near the end of the physical region was also considered [15, 16]. In view of this situation, one is tempted to take into account also unconventional explanations [17,18] and the hypothesis of tachyonic neutrinos is one of them.

In what follows the term 'neutrino' stands for 'electron neutrino' or 'antineutrino'. Parameter κ in the relation: $E^2 - \overline{p}^2 = -\kappa^2$ is called *tachyonic mass*, in distinction to the notion of *mass* of a slower than light particle in the relation: $E^2 - \overline{p}^2 = m^2$. We use the following symbols: total particle energy – E; kinetic energy – T; theoretical end point energy – $E_{\max}$, $T_{\max}$.

2. Theory of spin–$\frac{1}{2}$ tachyons

A tachyon is a particle which moves with a velocity always greater that c, relative to any reference frame. Tachyons, when described within the framework of the Einstein–Poincaré (EP) relativity, violate causality since this theory is applicable for slower than light (massive) and light-like (massless) particles only. Recently a unitary (causal) theory of tachyons [19–21] was proposed by Rembieliński. This theory does not invalidate nor modify the EP theory of relativity for massive and light-like particles. It was shown that tachyons can be correctly described using a different synchronisation, namely that of Chang–Tangherlini (CT). Invariance of the notion of the instant-time hyperplane [22, 23] is preserved in the CT synchronization and in consequence notion of causality is universal so space-like trajectories are physically admissible too. The price is the more complicated form of the Lorentz transformations incorporating transformation rules for velocity of a distinguished (preferred) reference frame. *The EP and CT descriptions are entirely equivalent for time-like and light-like trajectories; however a con-*

[1] Soon after the Neutrino'96 conference in Helsinki at which the effect was confirmed; explanation was already inserted to the Proceedings.

sistent description of tachyons is possible only in the CT scheme. A very important consequence is that if tachyons exist then the relativity principle is broken, *i.e.* there exists a preferred frame of reference, however the Lorentz symmetry is preserved.

In Refs. [19–21] a fully consistent, Poincaré covariant quantum field theory of tachyons is given. In particular, the elementary tachyonic states are labelled by helicity. In the case of the fermionic tachyon with helicity $\frac{1}{2}$ the corresponding free field equation reads:

$$\left(\gamma^5 \left(i\gamma\partial\right) - \kappa\right) \psi = 0 \,, \tag{2}$$

where the bispinor field ψ is simultaneously an eigenvector of the helicity operator with eigenvalue $\frac{1}{2}$ [20, 21] and the γ-matrices differ from the standard ones (see [21]). In the massless limit, $\kappa \to 0$, the theory of Rembieliński gives the Weyl's theory.

3. Beta decay with a tachyonic electron neutrino

The amplitude squared, $|M|^2$, for a β decay $(n \to p^+ + e^- + \bar{\nu}_e)$ with a tachyonic electron antineutrino, can be derived (on the tree level) directly from the lepton-hadron part of the effective Fermi weak-interaction Lagrangian:

$$\mathcal{L}_{\mathcal{I}} = -G_F j_\mu J^\mu, \tag{3}$$

where j_μ and J^μ denote leptonic and hadronic currents, respectively. However, under the condition that in the limit of zero neutrino mass the leptonic current takes the standard V–A form, there are two natural choices, which are denoted *helicity* and *chirality* coupling. Namely, one can choose the corresponding part of the leptonic current in the form:

$$\bar{u}_e \gamma^\mu w \quad \text{(helicity coupling)} \tag{4}$$

or

$$\bar{u}_e \gamma^\mu \tfrac{1}{2}(1-\gamma^5) w \quad \text{(chirality coupling)}, \tag{5}$$

respectively, where w is the tachyonic neutrino field. Detailed formulae may be found in Refs. [26, 27]. We derive results in a reference frame being at rest relative to the preferred frame; some consequences of a non-negligible velocity with respect to the preferred frame are discussed in Sec. 5.

Differential electron energy spectra in the vicinity of the endpoint, corresponding to decays with a massive, massless and tachyonic neutrino, are shown in Fig. 2(a). A distinctive detail in both tachyonic cases is the almost step – like termination of spectra at $T = T_{\max}$. The spectrum $(d\Gamma/dE)$

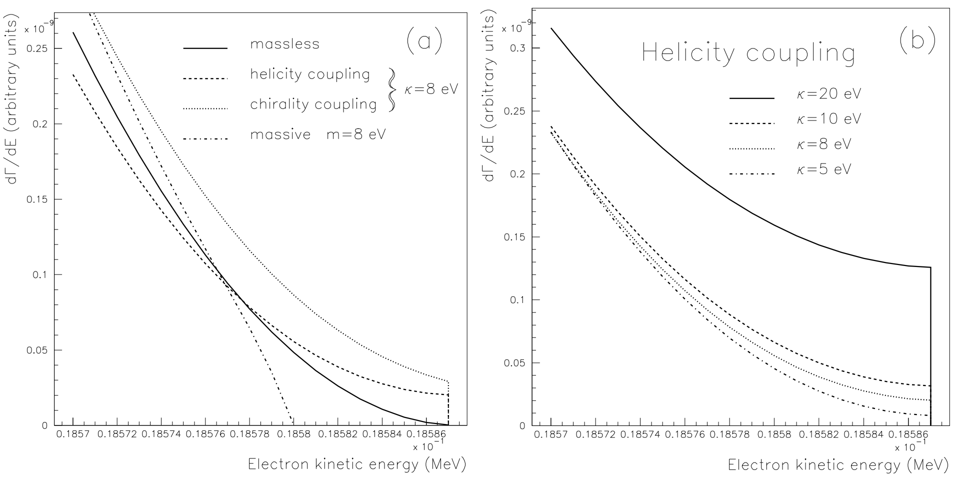

Fig. 2. (a) — Differential electron energy spectra in the vicinity of the end point, for tritium decay with: a tachyonic antineutrino of mass $\kappa = 8$ eV, massless neutrino and massive neutrino of mass $m = 8$ eV; (b) — as above for a tachyonic electron antineutrino with helicity coupling, for a range of tachyonic masses, κ.

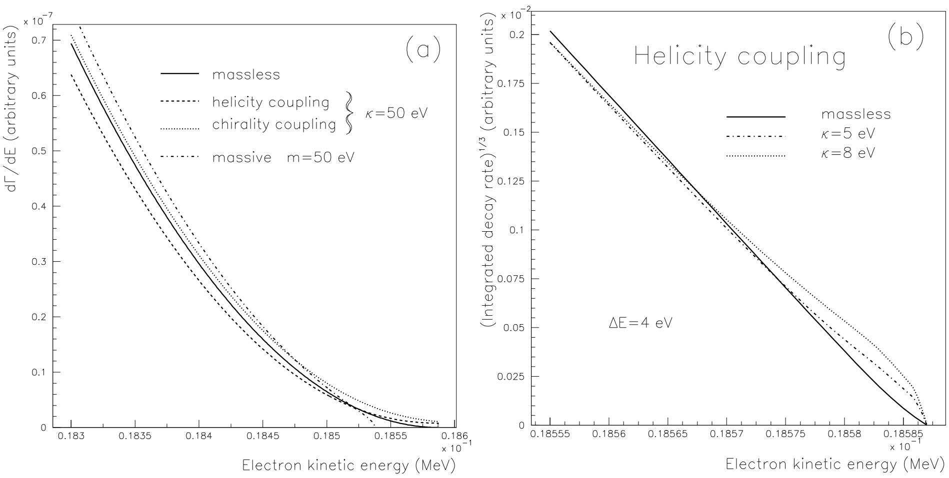

Fig. 3. (a) Differential electron energy spectrum in a wider range of energy near the end point; (b) linearized (cube root) integral electron energy spectrum with folded experimental resolution function.

decreases from the step value to zero over an interval of energy of order 10^{-3} eV. The magnitude (height) of the step depends on the choice of coupling as well as on the value of κ, as can be seen in Fig. 2(a), (b). Differential electron energy spectra in a wider range of energy are shown in Fig. 3(a) (calculated for m, $\kappa = 50$ eV in order to display a pronounced effect). Spectra corresponding to a massless and tachyonic neutrino with helicity coupling differ at lower energies and magnitude of this effect depends on the value of κ (difference between a massless and tachyonic neutrino with chirality coupling is much smaller). These differences in shapes (and slopes) of spectra at lower energies are, in turn, at origin of the *slope effect* seen in the experimental data.

4. *Effects* in the electron energy spectrum

The step — like termination of the tachyonic spectrum allows to explain additional counts in the vicinity of the end point. For the purpose of a qualitative comparison with the published measurement of the Troitsk experiment [5] we integrated the differential electron spectra with the appropriate experimental resolution function ($\Delta E = 4$ eV). The resulting linearized (cube root) electron energy spectrum near the endpoint is shown in Fig. 3(b). We observe a striking similarity of the predicted behaviour with the bump – like structure observed in the Troitsk data (Fig. 1) (in our calculation we did not account for the final state energy spectrum).

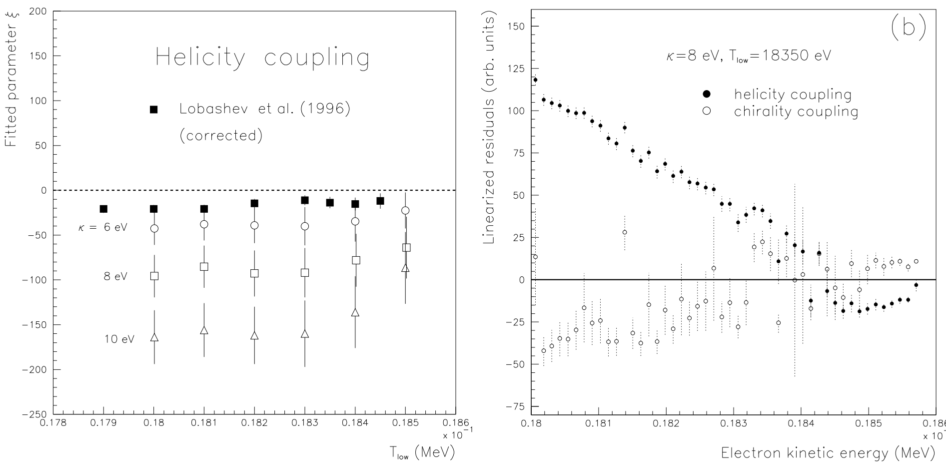

Fig. 4. (a) — Dependence of fitted values of ξ on the lower limit of fit, $T_{\rm low}$, for spectra generated with different values of tachyonic antineutrino mass, κ (shown are Troitsk data corrected for electron rescattering); (b) — linearized (root squared) residuals for the sample with $\kappa = 8$ eV; the zero line corresponds to a spectrum fitted with $\xi = 0$ and $T_{\rm low} = 18350$ eV;

In order to simulate an analysis similar to that of the Mainz and Troitsk groups, we have generated samples of tritium decays with tachyonic electron antineutrinos of different masses κ, in the energy range 18000 eV <

$T < T_{\rm max}$, according to amplitudes calculated with helicity and chirality couplings. We fitted the generated electron energy spectra with function (1), over energy intervals with variable lower limits, $T_{\rm low}$. Resulting values for parameters ξ and T_0, fitted in the range $T_{\rm low} < T < T_{\rm max}$, as a function of $T_{\rm low}$, are presented in Fig. 4(a). All values of ξ come out negative; those from the Troitsk experiment [3], recently corrected for electron rescattering, are also shown. From this figure we estimate the value of the tachyonic electron neutrino mass, κ, to be ≈ 5 eV. Following further the analysis procedure of experimental groups, we fitted our data with the massless neutrino spectrum for $T_{\rm low} = 18350$ eV, varying only two parameters: normalization and the end point energy, T_0. Linearized (root squared) residual spectra, extrapolated down to $T = 18000$ eV, are shown in Fig. 4(b) for helicity and chirality couplings. We observe an artificial effect of a rising counting rate further below the end point, in a pattern similar to that found in measurements [2, 5]; this is so for the case of helicity (but not chirality) coupling. In view of the tachyonic hypothesis the effect of 'missing component' is an artefact of the fitting procedure.

5. Preferred frame and time dependent effects on Earth

An interesting property of amplitudes for processes involving tachyonic neutrinos, in particular a beta decay, is their dependence on the velocity vector of the preferred frame. On the grounds of cosmological considerations one might expect that a frame, in which the cosmic microwave background radiation (CMBR) is isotropic, is a natural candidate for the preferred frame. In such a case results derived in previous sections are sufficiently precise because the Solar System is almost at rest relatively to the CMBR [2]. However neither there is evidence in favour of this choice nor any other possibility is excluded.

Consider a certain configuration of the final state particles momenta in a beta decay which occurs in a reference frame moving with velocity $\vec{v}$ with respect to the preferred frame. The maximal kinetic energy of the electron, $T_{\rm max}$, depends on $\beta = |\vec{v}|/c$ and $\cos\ \omega$, where ω is the angle between neutrino momentum and $\vec{v}$:

$$T_{\rm max}(\beta, \cos\ \omega) = T_{\rm max} - \Delta T_{\rm max}(\beta, \cos\ \omega)\,, \tag{6}$$

where

$$\Delta T_{\rm max}(\beta, \cos\ \omega) = \frac{\kappa\beta \cos\ \omega}{\sqrt{1-\beta^2\cos^2\ \omega}}. \tag{7}$$

Momenta of the final state particles are aligned at the end point and thus the angle ω may be expressed by the angle corresponding to the electron. If

[2] velocity deduced from the dipole anisotropy in temperature is about 350 km/s [25]

the electron spectrum is measured in a spectrometer in which electrons are moving to a good accuracy along the spectrometer axis, the angle between this axis and $\vec{v}$ in general changes with time due to Earth's rotation. Thus, according to (6), one could expect day-night variations of $T_{\rm max}$. If we identify the preferred frame with CMBR ($\beta \approx 10^{-3}$) we obtain $\Delta T_{\rm max} < 10^{-2}$ eV for the tachyonic electron neutrino mass of 5 eV, *i.e.* an effect undetectable at present. If however the velocity of the preferred frame were large ($\beta > 0.1$), the variation of the end point energy might be of order eV.

6. Summary and conclusions

The electron energy spectrum from tritium decay with a tachyonic neutrino ends with a step, in distinction to that for a massless or massive neutrino. This feature explains excess of counts observed in the vicinity of the end point in all recent experiments. Our prediction for the shape of this excess shows a high similarity as compared to experimental data [5]. Results of an analysis performed on simulated data show that rising counting rate at lower energies is not of a physical origin, being an artefact of the fitting procedure. If neutrinos were tachyons then a conclusion fundamental for the theory of weak interactions would follow. Since the tachyonic neutrino field is an eigenvector of the helicity operator with the eigenvalue $\frac{1}{2}$ [21], therefore **helicity coupling offers a natural explanation of the V–A structure of the weak leptonic current**. Basing on Troitsk results (Fig. 4) we estimate the value of the tachyonic antineutrino mass to be ≈ 5 eV.

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