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MASS, ELECTRIC CHARGE AND OSCILLATIONS OF NEUTRINO

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Half a century has passed from the moment neutrino has been discovered but still there are no answers to some questions:

- Does neutrino possess any mass?
- How many types of neutrino exist?
- Is this a stable elementary particle or unstable one?

We could add one more question:

- Does neutrino possess any charge?

But the eldest question is that of its mass. There are experimental restrictions for the maximum value of neutrino mass:

$$m_{\nu_e} \lesssim 35 \text{ eV}^{/1/}, \qquad m_{\nu_\mu} \lesssim 0.57 \text{ MeV}^{/2/}. \tag{1}$$

From cosmological data one can obtain the upper limit for the sum of light neutral lepton masses

$$\sum_i m_i < 40 \text{ eV}^{/3/}.$$

The present paper discusses the above-mentioned questions from the points of view of the modern experimental status of elementary particle physics.

The main subject of this paper is formulation of the following regularities confirmed by elementary particle data available.

I. In the free state all the neutral particles with mass at rest different from zero, are unstable.

II. In the free state a stable particle with mass at rest unequal to zero (protons, electrons and their antiparticles) possess an electric charge (γ-quanta, being related to stable particles at present, possess a mass at rest, equal to zero).

The hypothesis about the proton unstability which is considered within SU(5) symmetry does not contradict (II).

There arise from I and II the following possibilities:

a) If we suppose the neutrino charge to be equal to zero, and neutrino mass at rest different from zero, then neutrino is an unstable particle;

b) If neutrino possesses a mass at rest different from zero, and it is a stable particle, then neutrino should have an electric charge different from zero.

Charged neutrino can also decay. However, modern physics knows that only mass is a charge carrier. Thus, after a series of possible decays, there should be left stable charged neutrinos. From the theoretical and experimental points of view of elementary particle physics the hypothesis about the zero mass and charge of a neutrino is less contradictory. Recently, there have appeared in cosmology theoretical papers showing preference to the hypothesis about a small mass ($\lesssim 30$ eV) of neutrino. In this case one may better describe the structure of the Universe.

On the assumption that neutrino mass is not equal to zero (A) or neutrino mass and charge are not equal to zero (B) we may obtain very interesting and unusual consequences.

Consider these possibilities in more detail:

A) Neutrino possesses mass m_ν but it does not possess any charge. In this case, following from I, neutrinos should decay till there remain only massless ones. If charged particles occur in the course of decay, then they finally should stop to decay and remain stable (see II). The conservation laws of isospin and strangeness are known to be violated by the interaction of the decaying type. It can be supposed that the conservation law of lepton number is also violated by the interaction of the decaying type. From this hypothesis the following reaction may be written down/4/:

$$\nu_1 \to \nu_2 + \nu_3 + \nu_4 , \tag{2a}$$

$$\nu_1 \to \gamma + \nu_i , \tag{2b}$$

where $\nu_{1,2,3,4}$ are neutrinos with different masses. ν_2, ν_3, ν_4 may appear with zero masses then the decay of ν_1 is immediately stopped.

Interactions, responsible for (2a,2b) decays, can be chosen in the usual form, and matrix elements may be written down as follows:

$$M = \frac{g_1}{\sqrt{2}} [\bar{\nu}_1 \gamma_\alpha (1+\gamma_5) \nu_2][\bar{\nu}_3 \gamma_\beta (1+\gamma_5) \nu_4] , \tag{3a}$$

$$M = \frac{g_2}{\sqrt{2}} \bar{\nu}_2 \sigma_{\alpha\beta} \nu_1 F_{\alpha\beta} , \tag{3b}$$

where g_1 and g_2 are coupling constants responsible for (2a,2b) decays, correspondingly. If such decays do exist, the constants g_1 and g_2 may be defined from experimental data*.

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*In the S.Petcov's paper (N.Phys., 1977, C25, p.641) the life-time of neutral unstable neutrino was calculated within modern theory approach.

Really, if we measure the ratio

$$\frac{\nu_\mu + n \to e^- + p}{\nu_\mu + n \to \mu^- + p}, \tag{4}$$

we can arrive to some conclusions concerning the coupling constant g_1 assuming that mass ν_μ predominates over mass ν_e. Ratio (4) is different from zero, the appearance of electrons can be explained either completely or partly by the emergence of ν_e in the beam ν_μ, as a result of the ν_μ decay. Since the commonly known spectrum of elementary particles is discrete, it is natural to suppose that spectrum of neutral neutrino is discrete too.

Within I and II and a neutrino decay hypothesis the process of neutrino beam oscillations /5/ should be looked at quite differently. Oscillations are possible when neutrinos possess different masses.

Let us restrict ourselves to the case of the existence of ν_μ and ν_e neutrinos only and assume for a certainty that

$$m_{\nu_\mu} > m_{\nu_e} \quad (m_{\nu_\mu} \neq 0,\ m_{\nu_e} = 0).$$

Then the following decays are possible:

$$\nu_\mu \to \nu_e + \nu_e + \nu_e, \tag{5a}$$

$$\nu_\mu \to \nu_e + \gamma. \tag{5b}$$

The intensity of muonic neutrino I_{ν_μ} without taking account of oscillations during $t = \frac{R}{v_\nu}$, where R is a distance from the source ν_μ to the place of observation, and v_ν - a velocity of a beam of the ν_μ, will decrease to:

$$I_{\nu_\mu}(R) = I_{\nu_\mu}(0) \cdot e^{-\Gamma_{\nu_\mu} \cdot \frac{R}{v_\nu}}. \tag{6}$$

Here Γ_{ν_μ} is the total width of the ν_μ decay. Assume that the change of the intensity of stable neutrino ν_μ due to oscillations follows the law /5/

$$I_{\nu_\mu}(R) = \frac{1}{2} I_{\nu_\mu}(0) [1 + \cos 2\pi \frac{R}{L}], \tag{7}$$

where L is the oscillation length.

With decay (6) taken into account we obtain (at $R \ll L$):

$$I_{\nu_\mu}(R) = \frac{1}{2} I_{\nu_\mu}(0) \cdot e^{-\Gamma_{\nu_\mu} \cdot \frac{R}{v_\nu}} [1 + \cos 2\pi \cdot \frac{R}{L}]. \tag{8}$$

If the region of neutrino production is large (or comparable with L) then after averaging over it and at a maximum angle of mixing we shall obtain:

$$I_{\nu_\mu}(R) \approx \frac{1}{2} I_{\nu_\mu}(0) \cdot e^{-\Gamma_{\nu_\mu} \cdot \frac{R}{v_\nu}} .$$

With $L \ll R$ the law of a beam intensity change of muonic neutrino will be more complicated, as each time anew there should be introduced an exponential decay, as soon as on the account of oscillations its intensity decreases to zero and then gradually increases.

Thus with I, II and a neutrino decay hypothesis the interpretation of experiments on oscillations appears to be not simple, for there may be various correlations between $I_{\nu_\mu}(0)$ and $I_{\nu_\mu}(R)$.

From all this it follows that the problem of neutrino mass, possible neutrino decays and oscillations, should be solved by placing detectors in space so that they might distinguish the oscillation behaviour of a neutrino beam from an exponential decay (for example with the help of three detectors: the initial (fixed), which is near the muonic neutrino source, the final (fixed or unfixed) one, positioned at a considerable distance from the initial detector, and the third, moving one, placed between the initial and final detectors).

Consider possibility B:

Neutrino is a stable particle, possessing an electric charge. This possibility is unusual. One may consider different versions:

1) The conservation law of an electric charge is violated in the process of decay;

2) An electric charge of a neutron in a bound state in a nucleus is unequal to that of a neutron in a free state;

3) The conservation law of an electric charge is fulfilled strictly in all the phenomena and in this case either *α*) in the decay $n \to p + e + \tilde{\nu}$ the absolute quantity of a proton charge is precisely equal to an electron one and $\tilde{\nu}$ carries away the precise charge of a neutron, or *β*) in the decay $n \to p + e + \tilde{\nu}$ a neutron charge is equal to zero; and the $\tilde{\nu}$ – charge, to the difference of a proton and electron charges; or *γ*) in the decay $n \to p + e + \tilde{\nu}$ neutron charge is not equal to zero and the absolute quantity of a proton one is not equal to the electron charge, and the $\tilde{\nu}$ carries away a charge, equal to the difference of neutron, proton and electron charges.

Any of *α*)–*γ*) may be realised in Nature, for conservation laws of electric, electronic, muonic and baryonic charges do not allow one to conclude that absolute quantities of electron and proton charges are equal, but they have opposite signs, and electric charges of electron and muon are equal and the neutron charge is exactly equal to zero /6/.

Further, we shall discuss only one of the versions: the conservation law of an electric charge is fulfilled strictly and a neutrino charge is precisely equal to zero.

Hence we arrive at quite definite conclusions. Experimental data (see, e.g., refs. /6,7/) point that a difference of proton and electron absolute electric charges $\lesssim 10^{-19}$ of an electron electric charge. Then from a neutrino decay $n \to p + e + \tilde{\nu}$ it follows that a neutrino charge is small and equal to $\sim 10^{-19} e$ (in the assumption that a neutrino charge is equal to zero).

Other methods of measuring the neutrino charge $q(\nu)$ give the following estimates: /6/:

a) from scattering data of reactor neutrinos on electrons (in the assumption of the absence of neutral currents)

$$q(\nu_e) \lesssim 3 \cdot 10^{-10} e,$$

b) from astrophysical data:

$$q(\nu_e) < 2 \cdot 10^{-14} e \ \ (\text{for } m_\nu = 0),$$

$$q(\nu_e) < 7 \cdot 10^{-12} e \ \ (\text{for } m_\nu = 1 \text{ MeV}).$$

For a muonic neutrino /6/ from data on π -meson production $q(\nu_\mu) < 3 \cdot 10^{-5}$ e (in the assumption that neutral currents are absent).

Let us note that the absolute value of charge e is measured with an accuracy to $\sim 10^{-7}$ e.

With a value of a neutrino charge 10^{-10} e and estimations of electron neutrino masses adduced (see formula (1)) the ratio e/m (in units of e/m for electrons) is:

$$\frac{10^{-10} e}{35 \text{ eV}} \approx \frac{e}{m} \cdot 10^{-6} . \tag{9}$$

From this, one can evaluate the energy loss of a neutrino beam, for example, on bremsstrahlung in different matters. If for average losses on electron radiation formulas (14.9), (14.10) and (17.2) /8/ are used, the ratio R of radiative losses of electron neutrino to those of an electron, moving with the same velocity, is:

$$R = \left(\frac{m_e}{m_\nu}\right)^2 \cdot \left(\frac{q(\nu)}{e}\right)^4 . \tag{10}$$

Substituting into (10) values (1) and (9) we obtain:

$$R \sim 10^{-30}. \tag{11}$$

Ratio (11) is strongly changed depending on accepted values of neutrino electric charge. Thus, if we substitute the value 10^{-7} e for 10^{-10} e, the ratio R will increase to 10^{-18}, instead of 10^{-10} e the quantity 10^{-19} e is taken, the ratio will decrease to 10^{-66}.

If we use a neutrino beam with a density of 10^{10} neutrinos instead of a singular neutrino, then such a beam for $q(\nu) = 10^{-10}$ e will have energy losses equal to 10^{-20} of a singular electron one.

Thus, if a singular electron with an energy of 5 GeV loses 1 GeV for radiation in a substance, then the 5 GeV neutrino beam with a density of 10^{10} in the same substance will lose an energy of 10^{-11} eV (for $R \sim 10^{-30}$). However, while most probably a singular electron emits only one or two hard γ quanta, a neutrino beam will emit very many soft ones. In all the cases neutrino electromagnetic radiation appears to be very small compared to electron or any other commonly known particle radiation. Wave lengths of such radiation are very long and the radiation itself has some features of a quasistable electromagnetic field, filling the cosmic space. So, if a practically constant electromagnetic field exists in our Galaxy then one may try to estimate an average value of neutrino charge if we know the full number of neutrinos, that have passed through the Galaxy during the whole period of its existence.

There is another interesting possibility of observing a neutrino charge. Radiative matter, the nucleus of which undergoes β-decay, is placed into an envelope.

The envelope absorbs all the radiation, except for charged $\tilde{\nu}$, which carry an electric charge through the envelope. Thus inside the envelope there should be accumulated an electric charge with an opposite sign to the $\tilde{\nu}$ charge. The charge inside the envelope may be measured in different ways.

The importance of experiments on the discovery of a neutrino charge is apparent, as the establishment of the fact of the charge existence will lead us to the radical breaking of our world outlook on nature of the microworld and various phenomena both on the Earth and in space too on the essence of electricity.

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