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INTERACTION OF GOLDSTONE NEUTRINO WITH ELECTROMAGNETIC FIELD

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1. Starting from the representation of the neutrino as a Goldstone particle, we have constructed in [1] a phenomenological action integral, invariant against the expanded Poincare group and containing anticommuting parameters. This integral describes the universal interaction of the neutrino with itself and with an arbitrary fermion field. The interaction of the neutrino with other fields, particularly with the electromagnetic field, is also universal and is determined by the same constant $a = \ell^4$.

The gauge-invariance requirements together with the required invariance with respect to the expanded Poincare group determine uniquely the form of this interaction. It turns out that the action integral contains only a term quadratic in the electromagnetic field, whereas terms linear in the electromagnetic field are forbidden by the considered invariance requirements. The invariant action integral, containing a minimum number of derivatives of the fields, can be written in this case in the form of the ratio

$$S = \int \frac{D(A_\mu\, dx^\mu)\,\Lambda\omega^\nu\,\Lambda\omega^\rho\, D(A_\alpha\, dx^\alpha)\,\Lambda\omega^{\nu'}\Lambda\,\omega^{\rho'}}{\epsilon_{\mu\nu\rho\lambda}\,\omega^\mu\,\Lambda\,\omega^\nu\Lambda\omega^\rho\,\Lambda\omega^\lambda}\, g_{\nu\nu'}\, g_{\rho\rho'}\,, \qquad (1)$$

where D denotes the outer differential, Λ the outer product [2], and $A_\mu(x)$ the electromagnetic potential. The differential forms ω^μ are defined in [1].

In the more customary notation, the action integral (1) takes the form

$$S = \int \left[-\frac{1}{4} F_{\mu\nu}F^{\mu\nu} + a\, F_{\mu\nu}F^{\mu\rho}\, T^\nu_\rho + \dots \right] d^4x\,, \qquad (2)$$

where

$$T^\mu_\nu = \frac{i}{2}\left(\psi^*\, \sigma^\mu\, \frac{\partial \psi}{\partial x^\nu} - \frac{\partial \psi^*}{\partial x^\nu}\sigma^\mu\, \psi \right),$$

and the dots correspond to the omitted terms containing higher powers of the spinor fields and of the coupling constants.

It follows from (2) that the process

$$\gamma + \gamma \to \nu + \bar{\nu}$$

which is forbidden in the ordinary theory of weak interactions [3], is possible in the Goldstone-neutrino model. It is easy to obtain expressions for the differential and total cross sections of this process

$$\frac{d\sigma}{dt} = \frac{a^2}{8\pi\, 16}\left[st + 3t^2 + 4\frac{t^3}{s} + 2\frac{t^4}{s^2}\right] , \tag{3}$$

$$\sigma(s) = \frac{a^2}{80\pi} s^3 . \tag{4}$$

The cross section (4) is similar to the cross section for the scattering of light by light at low energies [4].

2. From the estimated upper limit of the loss of solar energy by emission of neutrino pairs [5] we can obtain a limitation on the constant a, similar to the one obtained in [6].

Using (4), we obtain the following expression for the neutrino luminosity

$$Q_\nu = \frac{\ell^8 c^2 \hbar}{\rho} \frac{\Gamma(7)\Gamma(6)\zeta(7)\zeta(6)\, 2^8}{400\pi^5}\left(\frac{T}{\hbar c}\right)^{13} , \tag{5}$$

where $\rho \sim 140$ g/cm^3 is the density at the center of the sun, T = 1.3 keV is the temperature, $\Gamma(n)$ is the Gamma function, and $\zeta(n)$ is the Riemann Zeta function. Putting $Q_\nu \sim 2$ erg/g-sec [5] we obtain a limitation on ℓ:

$$\ell \lesssim 10^{-12} \text{ cm}. \tag{6}$$

It should be noted that a characteristic feature of the universal interaction of the Goldstone neutrino is the presence of high powers of the derivatives of the fields in the interaction Lagrangian; this causes a rapid growth of the cross section with energy. At a definite stage of stellar evolution, when there is a high density of high-energy photons, the universal interaction of the Goldstone neutrinos can therefore play the fundamental role in the cooling of the star. It would be of interest to consider the influence of this interaction during the early stage of expansion in the hot-universe model.

3. We note that a stronger limitation on the coupling constant ℓ can be obtained from the data of the 1967 CERN neutrino experiment on elastic scattering of muonic neutrinos by protons. An upper limit was obtained for this process in the form [7]

$$R = \frac{\sigma(\nu_\mu p \to \nu_\mu p)}{\sigma(\nu_\mu n \to \mu^- p)} \lesssim 0{,}24 .$$

From the Lagrangian of [1], which describes the interaction of the neutrino with the fermion, we obtain an expression for the differential cross section

$$\frac{d\sigma(s,t)}{dt} = \frac{a^2}{16\pi}\left[(s - m^2)^2 + (s - 2m^2)t + \frac{s}{s - m^2} t^2\right]. \tag{7}$$

Integrating (7) with respect to the kinetic energy of the protons from 150 to 500 MeV and averaging over the spectrum of the incident neutrinos [8] in the region from 1 to 4 GeV, we obtain for ℓ the value

$$\ell \lesssim 10^{-15} \text{ cm}.$$

This value is already quite close to the weak-interaction length

$$\ell_w = \sqrt{G} \sim 0.66 \cdot 10^{-16} \text{ cm.}$$

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INFLUENCE OF LOW-FREQUENCY OSCILLATIONS ON TRANSPORT PROCESSES ACROSS A MAGNETIC FIELD

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The author has shown in an earlier paper [1] (see also [2, 3]) that the presence of low oscillations of the potential in a plasma can lead to a noticeable increase of the transport coefficients across a strong magnetic field. This is connected with the "mixing" [4] that results from the deviation of the drift trajectories of the particles from magnetic surfaces (or from constant-pressure surfaces).

The cited papers, however, considered only a two-dimensional case, when the perturbation potential does not depend on one of the coordinates[1]. In the present article we get rid of this limitation and analyze the influence exerted on the transport across a strong magnetic field by low-frequency three-dimensional potential oscillations (e.g., drift waves). We confine ourselves here to a qualitative theory, which explains easily the physical picture of the phenomena in question, on one hand, and gives sufficiently satisfactory quantitative description of the process, on the other.

We consider a plasma cylinder situated in a longitudinal (B_z) and azimuthal ($B_\phi = \theta B_z$) magnetic fields, in which there propagates a potential wave of the form

$$\Phi = \Phi_0(r, \eta - v_0 t)\exp i[k_\perp \eta + k_\parallel \zeta - \omega' t], \tag{1}$$

where $\zeta = z + \theta r\phi$ is the coordinate along the force line, $\eta = r\phi - \theta z$ is the transverse coordinate, $\omega' = \omega + k_\perp v_0$, $v_0 = -c(E_r/B)$ is the velocity of the azimuthal rotation of the plasma in a constant (ambipolar) radial electric field E_r, and ω is the frequency of the oscillations in a coordinate system in which the plasma is at rest[2]. We assume that the magnetic field is strong enough so

[1] Thus, in [1, 2] the potential was independent of the longitudinal coordinate of the torus, and in [3] it was constant along the line $k_y y + k_z z$ = const.

[2] To abbreviate the notation, we assume here that $\theta \ll 1$.