Interaction of solar neutrinos with the cosmic background

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(Submitted 21 September 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **37**, No. 2, 115–118 (20 January 1983)

Annihilation of solar neutrinos by cosmic-background electron antineutrinos into pairs of axial photons and Compton scattering of cosmic-background axial photons by solar neutrinos can appreciably attenuate the flux of solar neutrinos at the earth's surface. Starting from the experimental results for ^{37}Cl, predictions are given for the forthcoming experiments for ^{71}Ga and ^{115}In.

PACS numbers: 96.60.Kx, 94.40.Ht, 13.10. + q, 25.30.Pt

The solar neutrino problem—the disagreement between the theoretical predictions of the standard solar model and between experimental results for ^{37}Cl (Ref. 1)—exists for about 20 years. The assumption of neutrino oscillations arising in connection with this problem has not yet been established experimentally. The validity of the hypothesis of instability of the electrion neutrino,[3] proposed in order to solve the problem of solar neutrinos, is also not clear. It is expected that experiments for ^{71}Ga (Ref. 4) and for ^{115}In (Ref. 5) will clarify a great deal in this respect.

In this paper we propose another approach to the solution of this problem. The starting point for us is the assumption[6] that there exists an axial electromagnetic field B_ρ interacting with the neutrino:

$$\mathcal{L}_{int} = i g_e \bar{\nu}_e \gamma_\rho \gamma_5 \nu_e B_\rho + i g_\mu \bar{\nu}_\mu \gamma_\rho \gamma_5 \nu_\mu B_\rho + \ldots \tag{1}$$

On its way to the earth a solar neutrino, due to the interaction (1), can collide with a cosmic-background neutrino, antineutrino, and axial photons. As is well known, the cosmic background of each kind of (anti-) neutrino has a temperature $T = 1.9$ K and density $n = 110$ particles cm^{-3} for each polarization. Because of thermal equilibrium, the cosmic axial-photon background has the same temperature and density. The density of cosmic-background particles in the energy range from ω_2 to $\omega_2 + d\omega_2$ is determined by the Fermi-Bose distributions

$$n(\omega_2)d\omega_2 = C\left[\exp\left(\frac{\omega_2 - \mu}{kT}\right) \pm 1\right]^{-1} \omega_2^2 d\omega_2 , \tag{2}$$

where C is a normalizing factor, the plus sign is for fermions, the minus sign is for bosons, and μ is the chemical potential, which in the first approximation can be set equal to zero.[7]

We shall examine the separate interaction processes between the solar neutrinos and the cosmic background.

The annihilation of solar neutrinos with momentum k (energy ω_1) and a cosmic-background electron antineutrino with momentum k_2 (energy ω_2) into a pair of axial photons with momenta k'_1 and k'_2 (energies ω'_1 and ω'_2) is described by the square of the matrix element

$$|M|^2 = \frac{(2\pi)^8 g_e^4}{4\omega_1\omega_2\omega'_1\omega'_2}\left[\frac{(k_1k'_2)}{(k_1k'_1)} + \frac{(k_1k'_1)}{(k_1k'_2)}\right] . \tag{3}$$

In calculating the corresponding cross section, there arises the question of eliminating the divergence of the integral which occurs because the particles participating in the process have no mass. We ensure the finiteness of this cross section and that of other cross sections by a kinematic limitation:

$$-(k_1k'_1) \geqslant \lambda^2, \quad -(k_1k'_2) \geqslant \lambda^2 . \tag{4}$$

The origin of the dimension parameter in axial dynamics, the magnitude of λ, and the validity of relations (4) will not be analyzed in this paper.

We obtain the following cross section for the expected annihilation, averaged over orientations of the momenta of the cosmic-background antineutrinos:

$$\sigma_A = \frac{\pi\beta_e^2}{\omega_1\omega_2}\left(\ln^2\frac{\omega_1\omega_2}{e\lambda^2} + 1\right), \qquad \beta_e = g_e^2/4\pi . \tag{5}$$

Compton scattering of a cosmic-background axial photon with energy ω_2 by a solar neutrino with energy ω_1 corresponds to the cross section ($\omega_0 \gg \omega_2$)

$$\sigma_k\ (0 \leqslant \omega_1' \leqslant \omega_0) = \frac{\pi\beta_e^2}{2\,\omega_1\omega_2}\left[\ln^2\frac{\omega_0\omega_2}{\lambda^2} + \ln\frac{\omega_1}{\omega_1-\omega_0} + \frac{\omega_0^2}{\omega_1^2}\ln\frac{(\omega_1-\omega_0)\omega_2}{\lambda^2} - \frac{\omega_0}{\omega_1} - \frac{\omega_0^2}{2\,\omega_1^2}\right]. \qquad (6)$$

Here ω_1' indicates the energy of the electron neutrino in the final state.

As numerical calculations show, $\ln \omega_1\omega_2/\lambda^2$ for $\omega_1 \sim 1$ MeV and $\omega_2 \sim kT$ is not less than 250. For this reason, we do not present the cross sections for annihilation of solar neutrinos by cosmic-background electron antineutrinos into a neutrino–antineutrino pair and for elastic scattering of solar neutrinos by cosmic-background (anti-) neutrinos of all kinds, which are proportional to the first power of the logarithm and lead to a small change in the transformation rates of atomic elements.

From Eqs. (5), (6), and (2) it follows that at the earth's surface the flux Φ of electron neutrinos with energies above threshold for atomic transformations is:

$$\Phi(\omega_1) = \Phi_0(\omega_1)\exp(-\omega/\omega_1), \qquad (7)$$

where Φ_0 is the flux given by the standard solar model, while the energy ω is determined by the relation

$$\frac{0{,}8\, n L\, \pi\beta_e^2}{kT\,\omega}\ln^2\frac{kT\ 1\,\mathrm{MeV}}{\lambda^2} = 1, \qquad (8)$$

where L is the distance from the sun to the earth.

The standard solar model for transformation of ^{37}Cl into ^{37}Ar gives the rate 7.6 ± 3.3 SNU (3σ is the error), while the experimental figure is 2.1 ± 0.3 SNU (1σ is the error).[1] In our numerical calculations we used the shape of the spectrum of solar neutrinos from separate sources from Ref. 1; the energy dependence of the cross sections $\sigma(\nu_e{}^{37} \to e^{-37}\mathrm{Ar})$ and $\sigma(\nu_e{}^7\mathrm{Li} \to e^{-7}\mathrm{Be})$ from Ref. 8. We find that $\omega = 10.5 \pm 3.2$ MeV (1σ is the error) and from (8)

$$\beta_e \ln\frac{kT\ 1\mathrm{MeV}}{\lambda^2} = (3{,}1 \pm 0{,}5)\cdot 10^{-2}. \qquad (9)$$

Since $\beta_\mu \leqslant 0.9\times 10^{-4}$ (see Ref. 9), under the condition that $\beta_\mu = \beta_e$ we have $kT\,1\,\mathrm{MeV}/\lambda_2 \gtrsim 3.4\times 10^2$.

Our predictions are presented in the last column of Table I (in Table I, N is the number of types of neutrinos and the error is three standard deviations).

The proposition that the electron neutrino is unstable[3] (with lifetime 48 ± 11 s at 1 MeV) and the proposition that solar neutrinos interact with the cosmic background give identical results for atomic transformations. The difference between the neutrino interaction of the form (1) of Ref. 3, $\bar{\nu}_e\nu_i\,\phi, \bar{\nu}_e\nu_i\phi_1\phi_2, \bar{\nu}_e\nu_i\bar{\nu}_j\nu_j (i, j \neq e)$, can in principle be resolved with the help of two experiments. In the decays $K[\pi] \to \nu X$, where X are undetected particles, the muon spectrum must be increasing if $X = \nu\phi$ or $\nu +$ is an axial photon,[9] and decreasing if $X = \nu\phi\phi$ or $\nu\bar{\nu}\nu$.[11] The number of events with single electrons (positrons), created during scattering of a beam of muonic neutrinos by nu-

TABLE I.

Target	Rate of transitions (SNU)		
	Standard solar model	Neutrino oscillations[10] ($N = 4$)	Interaction with cosmic background. Neutrino instability
^{7}Li	46.3 ± 14.1	11.6 ± 3.5	5.7 ± 3.0
^{71}Ga	$106^{+12.5}_{-8.7}$	$26.5^{+3.1}_{-2.2}$	0.5 ± 0.2
^{115}In	700 ± 65	175 ± 16	1.4 ± 0.7

cleons, could give evidence for an excess of nonmuonic neutrinos in the beam compared to the computed admixture of electron neutrinos from K-meson decay.

I am deeply grateful to A. M. Baldin for a discussion and for support of this work.

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