Hypothesis about semiweak interaction and experiments with solar neutrinos

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A hypothesis about the existence of semiweak interaction of electronic neutrinos with nucleons mediated by exchange of massless pseudoscalar bosons is stated. Owing to approximately 10 collisions of a solar neutrino with nucleons of the Sun, the fluxes of left- and right-handed solar neutrinos at the Earth surface are approximately equal, and their spectrum is changed in comparison with the one at the production moment. Good agreement is demonstrating between the calculated and experimental characteristics of the processes with solar neutrinos: $^{37}\text{Cl} \rightarrow ^{37}\text{Ar}$, $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$, $\nu_e e^- \rightarrow \nu_e e^-$, and $\nu_e D \rightarrow e^- pp$.

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The model of neutrino oscillations, which is appealed to explain the discrepancy between the predictions of the standard solar model for the rates of a number of processes caused by solar neutrinos and the results obtained in appropriate experiments, has not gained the desirable completeness in spite of significant time of its existence. Such a completeness would mean we should be able to show in particular: here is the formula for the probability that a solar neutrino remains electronic at the Earth surface, depending on its energy and such-and-such parameters; and here are the summary results, calculated on the basis of oscillation model, for the rates of the processes investigated in experiments (see, for example, the review [1] and references therein). In this situation, an alternative opinion about the mentioned discrepancy seems quite pointful.

We believe, that the solution to the solar neutrino problem is being provided by logically clear methods of the classical field theory combined with an additional hypothesis about the existence of semiweak interaction of electronic neutrinos with nucleons ($u$- and $d$-quarks) mediated by exchange of massless pseudoscalar bosons.

At that we consider that the neutrino of each sort is described, similarly to the electron, by a bispinor representation of the proper Lorentz group, and its field obeys the Dirac equation. We note that all solutions with positive energy of the massless free Dirac equation, of which two (left-handed and right-handed) can be taken for basic ones, describe various states of the same neutrino. If there is external scalar or pseudoscalar field interacting with the neutrino, then the left and right spinors of neutrino wave vector will both have nonzero values.

The different kinds of hypothetical interactions involving neutrino were considered repeatedly. One of them, proposed by us [2], was connected with a hypothetical massless axial photon. Now we can assert with sufficient confidence, not going into detail, that it is impossible to solve the solar neutrino problem by means of the axial photon as an interaction carrier. In parallel to this, an assumption about interaction of a hypothetical massless scalar with Majorana neutrino was expressed [3]. Only exceedingly faint interaction of such a scalar with others fermions was admitted, practically neither affecting the results of Eotvos type experiences nor the value of the electron magnetic moment and, thereby, nor the solar neutrino spectrum.

So, we suppose, that there exists a massless pseudoscalar boson $\varphi_{ps}$, whose interaction with an electronic neutrino, a proton and a neutron is described by the following Lagrangian

$$\mathcal{L} = g_{ps\nu_ee^+} \bar{\nu}_e \gamma^5 \nu_e \varphi_{ps} + g_{psNp} \bar{p} \gamma^5 p \varphi_{ps} - g_{psNn} \bar{n} \gamma^5 n \varphi_{ps}, \quad (1)$$

or by a similar Lagrangian with $u$- and $d$-quarks instead of proton $p$ and neutron $n$. 

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We intend neither to maintain, nor to deny the possibility to identify the boson $\varphi_{ps}$ with the Peccei–Quinn axion, but we take into account the unsucessfulness of experimental search for the axion when postulating the masslessness of the introduced boson. The pseudo-scalar boson $\varphi_{ps}$ is considered not interacting with the electron because it is impossible to fulfil simultaneously the three conditions: the values of coupling constants of this boson with the electronic neutrino and the electron should be of the same order; the neutrino produced in the center of the Sun with the energy of the order 1 Mev should undergo at least one collision with some electron of the Sun; the contribution of such a boson to the value of the electron magnetic moment should not exceed the uncertainty limits admissible by the standard theory and experiments [4]. We do not exclude that the interaction of boson $\varphi_{ps}$ with neutrinos of different sorts ($\nu_e$, $\nu_\mu$, and $\nu_\tau$) is nonuniversal, i.e., characterized by different coupling constants.

The differential cross-section of the elastic scattering of the left- or right-handed electronic neutrino with initial energy $\omega_1$ on a rest nucleon with mass $M$, obtained on the basis of Lagrangian (1), is given by expression

$$d\sigma = \frac{(g_{ps\nu}g_{psN})^2}{32\pi M\omega_1^2} d\omega_2,$$

where $\omega_2$ is the scattered neutrino energy, which, as it results from the energy-momentum conservation law and from the formula (2), can take evenly distributed values in interval

$$\frac{\omega_1}{1 + 2\omega_1/M} \leq \omega_2 \leq \omega_1.$$

The total cross-section of the elastic $\nu_eN$-scattering found from relations (2) and (3) is

$$\sigma = \frac{(g_{ps\nu}g_{psN})^2}{16\pi M^2} \cdot \frac{1}{(1 + 2\omega_1/M)}$$

and, consequently, the mean free path of the solar neutrino before its collision with any nucleon practically does not depend on the energy $\omega_1$ because its maximal value is about 16 MeV [5].

The first consequence of the interaction (1) is that at each collision with a nucleon caused by an exchange of axial boson, the neutrino changes its handedness from left to right and vice versa. We take into account that solar neutrinos are produced in different areas distanced from each other by 0.1 up to 0.3 solar radius on the average (this and other information about solar neutrinos is taken from the review [5]), and that, anyhow, they undergo different number of collisions with nucleons before escaping from the Sun. Then it seems reasonable to consider that, at an average number of collisions of the order of 10, the fluxes of left- and right-handed solar neutrinos at the Earth surface are approximately equal. As the contributions from right-handed neutrinos to the processes at low energies are extremely small (see, for example, the initially $P$-invariant model of the electroweak interactions [6]) the flux of the effective (left-handed) neutrino arriving at the Earth is approximately twice less than that expected in the absence of any interaction acts after their production in the Sun.

The second consequence of the interaction of the solar neutrino with a nucleon resulting from relations (2) and (3) is the neutrino energy decrease, on the average, by the value of

$$\Delta\omega_1 = \frac{\omega_1^2}{M} \cdot \frac{1}{1 + 2\omega_1/M}$$

in comparison with the initial energy. The formula (5) shows that the relative single-shot change in the energy $\Delta\omega_1/\omega_1$ for solar neutrinos from decays of $^8B$ (their average energy equals 6.7 MeV) playing the dominant role in transitions $^{37}Cl \rightarrow ^{37}Ar$ is by one order higher than that for $p-p$-neutrinos (their maximal energy equals 0.423 MeV) giving the most essential contribution.
to transitions $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$. This conclusion together with the first consequence gives clear qualitative understanding of the features of experimental results with chlorine and gallium.

When calculating the rates of a number of processes caused by solar neutrinos, we adhere to the most simple scenario. The only free parameter of the considered model is the effective number $n_0$ of collisions of a neutrino with nucleons, which occur from the production to the exit of this neutrino from the Sun, with $n_0$ being independent from the neutrino initial energy. We suppose that this number affects the solar neutrino spectrum keeping intact the proportion between the different handedness states at the exit from the Sun. Regarding the methods acceptable for calculations (say, in FORTRAN, as we did it), we have considered two variants to describe the energy distribution of neutrinos, having fixed initial energy $\omega_i$, after $n_0$ collisions with nucleons. In the first variant, the energy attributed to a neutrino after each collision is equal to the mean value of the kinematic interval (3), so that we have sequentially for zero, one, ..., $n_0$ collisions

$$\omega_{0,i} = \omega_i, \quad \omega_{1,i} = \frac{1 + \omega_{0,i}/M}{1 + 2\omega_{0,i}/M}, \quad \ldots, \quad \omega_{n_0,i} = \frac{1 + \omega_{n_0-1,i}/M}{1 + 2\omega_{n_0-1,i}/M}. \quad (6)$$

In the second variant, it is assumed that, as a result of each collision with a nucleon, the neutrino energy takes one of the two limiting values of the interval (3) with equal probability and, by that, after $n_0$ collisions the initial level of energy $\omega_i$ turns into a set of $n_0 + 1$ binomially distributed values which elements are listed below:

$$E_{1,i} = \omega_i, \quad E_{2,i} = \frac{E_{1,i}}{1 + 2E_{1,i}/M}, \quad \ldots, \quad E_{n_0+1,i} = \frac{E_{n_0,i}}{1 + 2E_{n_0,i}/M}. \quad (7)$$

Both variants yield close results. As the second variant is more comprehensible in its logical plan than the first, we use it everywhere, except for calculating the rate of the deuteron disintegration process $\nu_e D \rightarrow e^- pp$ where there is a problem of overflow of the fortran program stack.

Let us turn now to specific experiments on registration of solar neutrinos.

The first experiment of this type [7] has consisted in studying the process $\nu_e + ^{37}\text{Cl} \rightarrow e^- + ^{37}\text{Ar}$, having the threshold energy 0.814 MeV. Now the experimental rate of such transitions is considered equal to $2.56 \pm 0.16 \pm 0.16$ SNU (1 SNU is $10^{-36}$ captures per target atom per second) [8]. At the same time, theoretical calculations based on the standard solar model (SSM) give though different, but significantly greater values, for example: $7.9 \pm 2.6$ SNU [5] and $8.5 \pm 1.8$ SNU [9].

We take from Refs. [5], [10], and [11] the tabulated values of a number of quantities which are necessary to us for calculating the rates of transitions $^{37}\text{Cl} \rightarrow ^{37}\text{Ar}$ and $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$ induced by solar neutrinos.

We use the dependence of the cross-section of the process of neutrino absorption by chlorine on the neutrino energy $E$, presented in the table IX and partly in the table VII of Ref. [5], and we assign for this cross-section a linear interpolation in each energy interval. We note the strong enough dependence of the mentioned cross-section on energy $E$ (expressed below in MeV) [12]: $\sigma^{Cl}(E) \sim E^{2.85}$, if $E \in [1, 5]$, and $\sigma^{Cl}(E) \sim E^{3.7}$, if $E \in [8, 15]$. Therefore it is necessary to expect, that the decrease in energy of solar neutrinos as a result of their collisions with nucleons will affect the rate of $^{37}\text{Cl} \rightarrow ^{37}\text{Ar}$ transitions stronger than the rate of elastic neutrino-electron scattering.

The energy values of the neutrino from $^8\text{B}$, spreading from 0 to about 16 MeV, are given in the table of Ref. [10] in the form of set $\omega_i = i\Delta_i$, where $i = 1, \ldots, 160$, $\Delta_i = 0.1$ MeV, and their distribution is expressed through probability $p(\omega_i)$ of that neutrinos possess energy in an interval $(\omega_i - \Delta_i/2, \omega_i + \Delta_i/2)$. Each of the energy distributions in the interval [0, 1.73] MeV for neutrinos from $^{15}\text{O}$ and in the interval [0, 1.20] MeV for neutrinos from $^{13}\text{N}$ is presented.
in tables of Ref. \[1\] for 84 points, and the distribution for neutrinos from \textit{hep} is given in the table of Ref. \[3\] for 42 values of energy in the interval \([0, 18.8]\) MeV. The energy spectrum of neutrinos from \(^7\)Be has two lines \(\omega_1^{\text{Be}} = 0.862\) MeV (89.7\%) and \(\omega_2^{\text{Be}} = 0.384\) MeV (10.3\%), and from \textit{pep} has one line \(\omega_1^{\text{pep}} = 1.442\) MeV. For solar neutrino fluxes at the Earth surface, the values (in units of \(\text{cm}^{-2}\text{s}^{-1}\)) presented in Ref. \[9\] are taken: \(\Phi(8\text{B}) = 5.79 \times 10^6(1 \pm 0.23)\), \(\Phi(\text{\textit{Be}}) = 4.86 \times 10^6(1 \pm 0.12)\), \(\Phi(15\text{O}) = 5.03 \times 10^6(1_{-0.03}^{+0.43})\), \(\Phi(\text{\textit{pep}}) = 1.40 \times 10^6(1 \pm 0.05)\), \(\Phi(13\text{N}) = 5.71 \times 10^6(1_{-0.33}^{+0.37})\), \(\Phi(\text{\textit{hep}}) = 7.88 \times 10^3(1 \pm 0.16)\). For all that in the calculations, we use only the average values of the fluxes without involving uncertainty into any estimations or conclusions.

In view of the assumption that the fluxes of the left-handed neutrino at the Earth surface are equal to half of the above-mentioned fluxes, the formulas for calculating the contributions to the rate of transitions \(^{37}\text{Cl} \rightarrow ^{37}\text{Ar}\) caused by neutrinos from \(^8\text{B}\) and \(^7\text{Be}\) can correspondingly be presented in the form

\[
V(^{37}\text{Cl} | \text{B}) = 0.5 \Phi(8\text{B}) \sum_{n=1}^{160} \Delta B p(\omega_i^{\text{B}}) \sum_{n_0+1}^{n_0+1} \frac{n_0!}{2^{n_0}(n-1)!(n_0+1-n)!} \sigma^{\text{Cl}}(E_{n,i}^{\text{B}}), \tag{8}
\]

\[
V(^{37}\text{Cl} | \text{Be}) = 0.5 \times 0.897\Phi(7\text{Be}) \sum_{n=1}^{n_0+1} \frac{n_0!}{2^{n_0}(n-1)!(n_0+1-n)!} \sigma^{\text{Cl}}(E_{n,i}^{\text{Be}}), \tag{9}
\]

where energy values \(E_{n,i}^{\text{B}}\) and \(E_{n,i}^{\text{Be}}\) are given by the formula \(\Phi\), in which the quantity \(\omega_i\) needs to be set equal to \(\omega_i^{\text{B}}\) and \(\omega_i^{\text{Be}}\) accordingly. The contributions from neutrinos from \(^{15}\text{O}\), \(^{13}\text{N}\), and \textit{hep} are calculated by a formula similar to \(\Phi\), and the contribution from \textit{pep} does by a formula similar to \(\Phi\).

Before we proceed to calculations using formulas of the type \(\Phi\) with nonzero value of the number of neutrino-nucleon collisions \(n_0\), we check how much are the results, obtained with using the tabulated and interpolated values for the cross-section \(\sigma^{\text{Cl}}(E)\) under the condition of free motion of neutrinos in the Sun, close to what are obtained in Ref. \[5\] on the basis of more precise calculations, though at slightly different spectra and flux values. This comparison is reflected in table 1.

We find that the rate of transitions \(^{37}\text{Cl} \rightarrow ^{37}\text{Ar}\) calculated within the framework of interaction \(\Phi\) agrees with the experimentally measured one if the number of neutrino-nucleon collisions \(n_0\) is \(13 \pm 3\), when the rate of transitions equals to \(2.55^{+0.27}_{-0.24}\) SNU. The calculations concerning all of the discussed below processes give in their integrity the best agreement with experimental results if \(n_0 = 10\), and, therefore, this number is present in table 1 and in the rest of the paper.

| Table 1. The rate of transitions \(^{37}\text{Cl} \rightarrow ^{37}\text{Ar}\) in SNU. |
|---|---|---|---|---|---|---|
|   | \(^8\text{B}\) | \(^7\text{Be}\) | \(^{15}\text{O}\) | \textit{pep} | \(^{13}\text{N}\) | \textit{hep} |
| SSM \[5\] Interpolations, no interactions | 6.1 | 1.1 | 0.3 | 0.2 | 0.1 | 0.03 | 7.9 |
| Interaction \(\Phi\), \(n_0 = 10\) | 6.21 | 1.05 | 0.35 | 0.22 | 0.09 | 0.02 | 7.94 |

Let us turn now to the process \(\nu_e + ^{71}\text{Ga} \rightarrow e^- + ^{71}\text{Ge}\) having the threshold energy 0.233 MeV. The latest experiments have given the following values for the rate of this process: \(65.4^{+3.1}_{-3.0}^{+2.6}_{-2.8}\) SNU \[13\] and \(62.9^{+6.0}_{-5.9}\) SNU \[14\]. From the theoretical results, which are worthy mentioning, we note two: \(132^{+20}_{-17}\) SNU \[5\] and \(131^{+12}_{-10}\) SNU \[9\].

We use the neutrino energy dependence of the cross-section of the process with gallium \(\sigma^{\text{Ga}}(E)\) presented in the table II of Ref. \(\Phi\), and interpolate it inside the each interval by a
linear function. In addition to the information written above on the neutrino fluxes, some data about neutrinos from $p$-$p$ is still required. The tabulated energy spectrum of such neutrinos, available in Ref. [11], spreads from 0 to 0.423 MeV and is given by a set of 84 points. The flux of solar neutrinos from $p$-$p$ at the Earth surface is taken equal to $\Phi(pp) = 5.94 \times 10^{10} (1 \pm 0.01) \text{ cm}^{-2}\text{s}^{-1}$ [9].

We calculate the contributions to the rate of transitions $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$ brought by solar neutrinos from $p$-$p$, $^8\text{B}$, $^{15}\text{O}$, $^{13}\text{N}$, and $\text{hep}$, with the formula similar to (8), and the contributions brought by two lines of $^7\text{Be}$ and by one line of $\text{pep}$, with the formula similar to (9). The results of calculations are presented in table 2.

| p-p | $^7\text{Be}$ | $^8\text{B}$ | $^{15}\text{O}$ | $^{13}\text{N}$ | $\text{pep}$ | $\text{hep}$ | Total |
|-----|--------------|--------------|----------------|----------------|-------------|-------------|-------|
| SSM [5] | 70.8 | 34.3 | 14.0 | 6.1 | 3.0 | 0.06 | 132 |
| Interpolations, no interactions | 69.8 | 34.9 | 14.0 | 5.7 | 3.4 | 2.9 | 0.05 | 130.7 |
| Interaction (1), $n_0 = 10$ | 34.7 | 17.2 | 5.0 | 2.8 | 1.7 | 1.4 | 0.02 | 62.8 |

The fact that the theoretical value of the rate of transitions $^{71}\text{Ga} \rightarrow ^{71}\text{Ge}$ at $n_0 = 10$ agrees with the above-mentioned experimental values is an important evidence, firstly, in favour of our assumption about the approximate equality of the fluxes of the left- and right-handed solar neutrinos at the Earth surface and, secondly, in favour of the consequence (5), resulting from Lagrangian (1), about decreasing the relative neutrino energy change at a single-shot collision with decreasing energy.

Let us turn to consideration of the process of elastic scattering of solar neutrinos on electrons $\nu_e e^- \rightarrow \nu_e e^-$, taking into account the conditions and the results of experiments at Super-Kamiokande [15]–[17] and at the Sudbury Neutrino Observatory (SNO) [18]–[21].

The differential cross-section of elastic scattering of the left-handed neutrino with initial energy $\omega$ on a rest electron with mass $m$ is given by the formula (see, for example, Ref. [22])

$$
\frac{d\sigma_{\nu e}}{dE} = \frac{2G_F^2 m}{\pi} \left[ g_L^2 + g_R^2 \left( 1 - \frac{E - m}{\omega} \right)^2 - g_L g_R \frac{m(E - m)}{\omega^2} \right] \equiv f_{\nu e}(\omega, E),
$$

where $E$ is the energy of the recoil electron. For the scattering of the electronic neutrino, we have in the Weinberg–Salam model of electroweak interactions

$$
g_L = \frac{1}{2} + \sin^2 \theta_W, \quad g_R = \sin^2 \theta_W,
$$

where it is necessary to set $\sin^2 \theta_W = 0.231$.

On the basis of the energy-momentum conservation law, we obtain that the recoil electron can get the energy $E$ if the energy $\omega$ of the incident neutrino satisfies the condition

$$
\omega \geq \frac{E - m + \sqrt{E^2 - m^2}}{2} \equiv h_{\nu e}(E).
$$

At setting up an experiment on the elastic neutrino-electron scattering, it is considered that a distinction between the true energy $E$ of the recoil electron and its reconstructed (effective) energy $E_{\text{eff}}$ is given by the Gaussian probability density

$$
P(E_{\text{eff}}, E) = \frac{1}{\sigma \sqrt{2\pi}} \exp \left[ -\frac{(E_{\text{eff}} - E)^2}{2\sigma^2} \right],
$$
where the parameter $\sigma$, being a function of the energy $E$, depends on the features of an experimental set-up.

Since in all of the discussed experiments the lower limit $E_c$ for the reconstructed energy $E_{\text{eff}}$ is introduced, and it is not less than 3 MeV, then the observable events are practically completely generated by the solar neutrinos from $^8\text{B}$, while the contribution from neutrinos from $\text{hep}$ is very small. The contribution to the rate of the scattering of neutrinos from $^8\text{B}$ on electrons, when the reconstructed energy $E_{\text{eff}}$ belongs to the interval from $E_k$ up to $E_{k+1}$ $(E_k \geq E_c)$, is calculated according to the formula

$$V(\nu_e \mid B \mid [E_k, E_{k+1}]) = 0.5\Phi(8\text{B}) \int_{E_k}^{E_{k+1}} dE_{\text{eff}} \int_{1\text{ Mev}}^{16\text{ Mev}} dE \left[P(E_{\text{eff}}, E) \right]$$

$$\times \left[ \sum_{i=1}^{160} \Delta B p(\omega_i^B) \sum_{n=1}^{n_0+1} \frac{n_0!}{2^{n_0(n-1)}!(n_0+1-n)!} f_{\nu e}(E_{n,i}^B, E) \theta(E_{n,i}^B - h_{\nu e}(E)) \right], \quad (14)$$

where $\theta(x)$ is the Heaviside step function. The contribution from neutrinos from $\text{hep}$ is found by the similar formula. The result of this or that experiment and, also, the theoretical calculation on the basis of the formula (14) are expressed through the effective (either observable, or equivalent) flux of neutrinos from $^8\text{B}$, $\Phi_{\text{eff}}(8\text{B})$, which do not undergo any changes between the production place in the Sun and the experimental apparatus on the Earth. Connection between such a result or calculation and the effective flux is given by the following relation

$$V(\nu_e \mid B + \text{hep} \mid [E_c, 20\text{ MeV}]) = \Phi_{\text{eff}}^{\nu_e}(8\text{B}) \int_{E_c}^{20\text{ MeV}} dE_{\text{eff}} \int_{1\text{ Mev}}^{16\text{ Mev}} dE \left[P(E_{\text{eff}}, E) \right]$$

$$\times \left[ \sum_{i=1}^{160} \Delta B p(\omega_i^B) f_{\nu e}(\omega_i^B, E) \theta(\omega_i^B - h_{\nu e}(E)) \right]. \quad (15)$$

Let us notice here, that the Gaussian distribution (13) has essential influence on the bin $[E_k, E_{k+0.5\text{ MeV}}]$ distribution (14) of the rate of $\nu_e$-scattering events and has only small influence on the value of the effective neutrino flux found from equality (15).

Some details of the experiments and of our calculations concerning the elastic scattering of solar neutrinos on rest electrons are presented in table 3, where $T = E - m$, the quantities $E_c$, $E$, and $T$ are given in MeV, and the fluxes are expressed in units of $10^6$ cm$^{-2}$s$^{-1}$.

| References | $E_c$ | $\sigma$ | $\Phi_{\text{eff}}^{\nu_e}(8\text{B})$ | $\Phi_{\text{eff}}^{\nu_e}(8\text{B})$ |
|------------|------|---------|-------------------------------|-------------------------------|
| SK III [17] | 5.0  | -0.123 + 0.376\sqrt{E} + 0.0349E | 2.32 ± 0.04 ± 0.05 | 2.32 |
| SK II [16]  | 7.0  | 0.0536 + 0.520\sqrt{E} + 0.0548E | 2.38 ± 0.05 + 0.15 | 2.07 |
| SK I [15]   | 5.0  | 0.2468 + 0.1492\sqrt{E} + 0.0690E | 2.35 ± 0.02 ± 0.08 | 2.32 |
| SNO III [21]| 6.5  | -0.2955 + 0.5031\sqrt{T} + 0.0228T | 2.35 + 0.21 ± 0.15 | 2.08 |
| SNO IIB [20]| 6.0  | -0.131 + 0.383\sqrt{T} + 0.0373T | 2.35 ± 0.22 ± 0.15 | 2.17 |
| SNO IIA [19]| 6.0  | -0.145 + 0.392\sqrt{T} + 0.0353T | 2.21 + 0.31 ± 0.10 | 2.17 |
| SNO I [18]  | 5.5  | -0.0684 + 0.331\sqrt{T} + 0.0425T | 2.39 + 0.24 ± 0.12 | 2.24 |

Let us dwell now on the process of deuteron desintegration by solar neutrinos caused by the weak charged current interactions, $\nu_e D \rightarrow e^- pp$. The needed differential cross-section of this process, $d\sigma_{cc}/dE \equiv f_{cc}(\omega, E)$, as a function of energy $\omega$ of the incident left-handed electronic neutrino and the energy $E$ of the produced electron is found in the tabulated form on a Website [24], which has resulted from the field-theoretical analysis of the $\nu D$-reaction presented in
where the energy value \( \omega \) taken equal to similar to (15).

In the works by Super-Kamiokande and SNO collaborations, this question, however, was not put in an evident view and by that had no experimental solution. In the paper [15] containing the most detailed description of the data processing, the solar neutrino flux is extracted from the likelihood function, and the authors say about one of the quantities \( Y_i \) entering into this function: "\( Y_i \) represent the expected fraction of signal events in the \( i \)th energy bin". Thus, in the processing of the experimental results on \( \nu e \)-scattering, the shape of the event rate distribution in the recoil electron energy expected in the standard solar model is laid from the beginning.

The results of the SNO collaboration experiments and of our calculations are presented in table 4, to which the comments made to table 3 also apply.

| References | \( E_c \) | Experimental \( \Phi_{\text{eff}}^{(8B)} \) | Eq. (11), \( \Phi_{\text{eff}}^{(8B)} \) |
|------------|---------|-----------------|-----------------|
| SNO III [21] | 6.5 | \( 1.67^{+0.03+0.00}_{-0.04-0.08} \) | 1.63 |
| SNO II B [20] | 6.0 | \( 1.68^{+0.06+0.08}_{-0.06-0.09} \) | 1.75 |
| SNO II A [19] | 6.0 | \( 1.59^{+0.08+0.06}_{-0.07-0.08} \) | 1.75 |
| SNO I [18] | 5.5 | \( 1.76^{+0.06+0.09}_{-0.05-0.09} \) | 1.85 |

Noting good enough agreement between the results of our calculations and the results of experiments concerning the effective neutrino fluxes which correspond to the events of elastic \( \nu e \)-scattering and the reaction \( \nu_e D \to e^- pp \), we draw attention to the fact that the difference between theoretical values of the effective fluxes describing the two processes is due to the change in the shape of the solar neutrino spectrum because of their collisions with the nucleons of the Sun.

It is possible in principle to provide an answer to the question of the change of the spectrum shape of solar neutrinos from \( ^8B \) by an experimental measurement of the event rate distribution for the process \( \nu_e e \to \nu_e e \) or \( \nu_e D \to e^- pp \) in the energy of the scattered or produced electrons. In the works by Super-Kamiokande and SNO collaborations, this question, however, was not put in an evident view and by that had no experimental solution. In the paper [15] containing the most detailed description of the data processing, the solar neutrino flux is extracted from the likelihood function, and the authors say about one of the quantities \( Y_i \) entering into this function: "\( Y_i \) represent the expected fraction of signal events in the \( i \)th energy bin". Thus, in the processing of the experimental results on \( \nu e \)-scattering, the shape of the event rate distribution in the recoil electron energy expected in the standard solar model is laid from the beginning.
We find another evidence for this in Ref. [27], containing a correction of two mistakes made in Ref. [17]. One of them concerns "uncertainties... based on the Monte Carlo simulation $^{3}$B solar neutrino events", and the matter of the other is: "The energy dependence of the differential interaction cross-section between neutrinos and electrons was accidentally eliminated". The correction of the mentioned mistakes should not have influenced in any way the event rate distribution in the energy of the recoil electrons if it had the purely experimental origin. But by comparing table A.1 from Ref. [27] with table VI from Ref. [17], we detect that, along with the decrease in the "expected rate" in every energy bin, there is also a simultaneous decrease in the "observable rate". So, the distributions in the energy bins of the "observable rate" of $\nu e$-events at all positions of the Sun as presented in the tables of Refs. [15]--[17] have no value for theoretical conclusions as they reflect only what was initially laid in them and passed through fitting the likelihood function.

Let us note in addition that the final electron energy distributions for the $\nu D$- and $\nu e$-processes presented in the table XXII of Ref. [28] show, over vivid irregularities, almost full identity in their shapes for the phase I and phase II of the SNO experiment. An opinion is free or involuntarily formed, that this identity has no purely experimental origin and comes from using in both phases the same programs for distributing the full number of events among the energy bins.

We have still left without detailed consideration the process of deuteron desintagration $\nu D \rightarrow \nu np$ caused by neutral currents of a neutrino, which is investigated in SNO experiments. Within the framework of our hypothesis about the existence of the interaction described by Lagrangian (1), the amplitude of this process, along with the standard item corresponding to exchange of $Z$-boson, contains also an item corresponding to exchange of the massless pseudoscalar boson $\varphi_{ps}$. One of the factors, in which the last item decomposes, represents the pseudoscalar bilinear form made up of wave functions of the bound and unbound proton–neutron states. In the first approximation, this bilinear form expressed through one-nucleon bilinear forms vanishes because the interaction constants of the pseudoscalar boson with the proton and the neutron (as well as $u$- and $d$-quarks) have opposite values in Lagrangian (1). The problem of including the mass difference between the proton and neutron and radiative corrections in the description of the pseudoscalar boson $\varphi_{ps}$ interaction with a deuteron seems difficult to solve.

Let us find the value of the constant $g_{ps\nu}g_{psN}$ starting from the point that the electronic neutrinos during their movement in the Sun undergo a small number (of order of 10) of collisions with nucleons. Using the density values of the Sun matter varying with the distance from the Sun center as tabulated in Ref. [5], we find that a tube of 1 cm$^2$ cross-section spearing spreading from the center to the periphery of the Sun contains 1.5 $\times$ $10^{12}$ grams of matter and, consequently, 8.9 $\times$ $10^{35}$ nucleons. From here, and on the basis of relation (4) and the assumption that a neutrino passes in the Sun through 0.7 to 0.9 of the amount of matter in the mentioned tube before colliding with a nucleon, we obtain

$$\frac{g_{ps\nu}g_{psN}}{4\pi} = (3.2 \pm 0.2) \times 10^{-5}.$$  \hspace{1cm} (18)

Thus, the product of constants of the postulated interaction of a massless pseudoscalar boson with electronic neutrinos and nucleons is by several orders of magnitude smaller than the constants of electromagnetic and weak interactions, respectively $\alpha$ and $g^2/4\pi$. Therefore, the postulated interaction could be named superweak. However, by virtue of that the total cross-section of such a neutrino-nucleon interaction at a low energy, as it is the case for solar neutrinos, is much smaller than that of the standard weak interaction via $Z$-boson exchange, we prefer to call the postulated interaction semiweak.

It is surprising and wonderful, that some aspects of the short-term Brownian motion of a neutrino in the inhomogeneous but spherically symmetric Sun medium manifesting themselves
in a number of experiments, allow so simple and efficient mathematical and physical description as it is stated above.

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