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Are Goldstone Neutrinos Responsible for the Solar Neutrino Puzzle?

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We propose that the solar neutrino puzzle may be partially due to emission of Goldstone neutrinos resulting from a spontaneous breakdown of supersymmetry. An oscillation of the Goldstone neutrinos and a photon–neutrino coupling also result.

1. INTRODUCTION

The solar neutrino puzzle, namely, the discrepancy between the observed and the predicted capture rate in ^{37}Cl, has become the source of many exotic solutions modifying the physics and astrophysics of the Sun. One such theory ascribes the discrepancy to neutrino oscillations. Recently, Bahcall et al. (1980) have analyzed the uncertainty in the current best estimate of the theoretical value of the neutrino capture rate, which is 1.5 solar neutrino units. This uncertainty gives a range for the ratio of predicted to observed capture rates of 4.0–2.6. This is a strong constraint on the model of neutrino mixing. Thus, a current problem is whether the solar neutrino problem can be entirely due to neutrino oscillations. It should be pointed out that the ^{37}Cl experiment is not ideally suited to studying neutrino oscillation because of uncertainties in the prediction of the relatively small ^{8}B neutrino flux. Table I illustrates the neutrino flux calculation using some typical physical hypotheses on solar models (Bahcall, 1978). In the present paper we propose a new idea on neutrino oscillation. This oscillation has previously been explained on the basis of a spontaneous breakdown of global supersymmetry, and in such a model neutrinos always remain massless. They may also been shown to be coupled to photons, leading to a theory of photon–neutrino weak coupling (Bandyopadhyay,

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TABLE I

Model/source	pp	pep	^{7}Be	^{8}B	^{13}N	^{15}O
Standard	6.1	1.5E−2	3.4E−1	3.2E−4	2.6E−4	1.8E−2
Low z	6.3	1.6E−2	1.4E−1	5.4E−5	1.2E−3	4.3E−4
Homogenized	6.45	1.6E−2	1.44E−1	8E−5	7.2E−3	7.2E−3
Only pp and pep	6.45	1.6E−2	0	0	0	0
CNO	0	0	0	0	3.38	3.38
Neutrino oscillations (R_{osc} 1/3)	2	5E−3	1.1E−1	1.1E−4	9E−3	6E−3
Neutrino decay	0	0	0	0	0	0

1968). We here propose rather that a fraction of the neutrinos coming from the Sun are exotic neutrinos in the sense that they originate because of a spontaneous breakdown of supersymmetry in the Sun. Thus these neutrinos evade standard detection apparatus. They do not participate in the $^{37}\mathrm{Cl}+\nu \rightarrow {}^{37}\mathrm{Kr}$ reaction by which solar neutrino flux has been measured, nor they will be detected by the forthcoming experiments involving ^{115}In. In the following section we explain how Goldstone neutrinos emerge in nature, construct a theory of neutrino oscillation of different type, and discuss how photon–neutrino interactions result. In conclusion, we present arguments in favor of an explanation of the solar neutrino problem in terms of Goldstone neutrinos.

2. GOLDSTONE NEUTRINOS AND NEUTRINO OSCILLATION

It has long been known that the addition of a real, irreducible, self-coupling internal symmetry to a supersymmetric Lagrangian produces a Goldstone potential for the spontaneous breakdown of internal symmetry along discrete canonical directions, the supersymmetry remaining exact (O'Raifeartaigh, 1975). The emergence of a Salam–Strathdee Goldstone supermultiplet seems to be an illustrious effect of this subject (Salam and Strathdee, 1975). This was first observed in an $SU(2)\otimes SU(2)$-invariant supersymmetric Lagrangian where the scalar superfield multiplet belonged to the real representation (3,3) of the $SU(2)\otimes SU(2)$ satisfying the reality condition $\phi^{ia} = (\phi^{ia}_{+})^{*}$. The genuine Goldstone solution was found to preserve the supersymmetry, and the superfield broke into three pieces belonging to the representation $I=0$, 1, and 2 of the unbroken $SU(2)$. The isovector piece with the mass $M = 0$ became the Goldstone supermultiplet containing a Majorana spinor and two spin zero particles.

We present a phenomenology associated with such a Goldstone multiplet. An important remark, however, is in order. There exist broken supersymmetric theories in which chiral symmetry does not survive and such theories are more acceptable candidates for the broken world. In that case the existence of massless color octet quarks implies the existence of additional light ($\lesssim 1$ GeV) unstable hadrons with large ($\gtrsim 10$ μb) production cross section, but experiments rule out their existence if they have lifetime greater than 10^{-10} sec (Goldman, 1978).

For the Salam–Strathdee Goldstone supermultiplet we observe that the two spin zero members are two 0^+ and 0^- leptons. The existence of spin zero leptons has previously been observed within the context of the $SU(2)\otimes SU(2)$ gauge theory, and it has been claimed that they may be responsible for the anomalous $e\mu$ events seen in the e^+e^- scattering (Ma, 1977). For a proper elucidation of what happens in our case, we propose to associate the spontaneous breakdown of supersymmetry with a spinor current. If the theory is manifestly covariant, Goldstone particles will emerge.

Let us consider an irreducible set of massive Heisenberg fields $\{\psi^\alpha\}$ and let

$$\theta^{\mu\alpha}(x) \equiv \theta^{\mu\alpha}[\psi^{(\alpha)}(x)]$$

where $\{\psi^\alpha\}$ is a set of Lorentz indices and α's are Dirac indices. We understand that it has been guaranteed that $\partial_\mu\theta^{\mu\alpha} = 0$. Now for a spontaneous symmetry breaking to be operative in the theory we should have for some α,

$$\langle 0|[\theta^{\mu\alpha}(x), \psi^{(\alpha)}(0)]|0\rangle \neq 0$$

with the vacuum defined through $\langle 0|\psi^{(\alpha)}|0\rangle = 0$. Under such conditions the Goldstone–Salam–Weinberg argument (Goldstone et al., 1962) applies to the current $\theta^{\mu\alpha_i}$, where i signifies the number of canonical directions, and particles produced in these canonical directions should transform as the component of the Majorana spinor. From such an argument, we are in a position to interpret the two spin zero members of the Salam–Starthdee Goldstone supermultiplet as two $0^\pm$ leptons. Since the supersymmetric generators are spinors with respect to the Lorentz group, to retain correct relations between spin and statistics we consider anticommutators between such generators, for example, $\{Q_\alpha, Q_\beta\} = -2\gamma^\mu_{\alpha\beta}P_\mu$ where $\alpha, \beta = 0, 1, 2,$ and 3 and the supersymmetric algebra is represented by $[P_\mu, P_\nu] = 0$, $[P_\mu, Q_\alpha] = 0$, and $[P_\mu,[P_\lambda,[P_\nu, Q_\alpha]]] = 0$. Recall now that there is a Majorana spinor member in the Salam–Starthdee Goldstone supermultiplet. It is strange at first sight that a neutrino is associated with two $0^\pm$ satellites. However, the dividend is clear if we invoke the idea of neutrino oscillation. In the past an occurrence of neutrino oscillation has been justified if in addition to ordinary weak interaction there is a lepton number nonconserving interaction (Bilenkii and Pontecorvo, 1977). Neutrinos have nonzero mass in such a concept. In the neutrino oscillation we are proposing, the Salam–Starthdee Goldstone supermultiplet exhibits a neutrino oscillation through a mechanism $\nu_e + 0^+ \rightleftharpoons \bar{\nu}_\mu + 0^-$. By this we mean that if we recognize the upper two components of the Majorana spinor member of the Goldstone supermultiplet as $\nu_e(\psi_L)$, then it is associated with 0^+, say. Thereafter, it should be recognized as $\bar{\nu}_\mu(\psi_R)$ and should be associated with 0^-. This will be effective only if the Higgs mechanism has not been operative in the theory to make the Goldstone multiplet massive. A proper assignment of lepton numbers to $0^\pm$ shows that one does not need lepton number nonconservation for neutrino oscillation. Neutrinos need not be massive now. Moreover, decays of the type $\mu \to e\gamma$ are $\mu \to 3e$ are forbidden by lepton number conservation principle. On experimental grounds it has been claimed that the search for neutrino oscillation is the only way to understand such decays (Bilenkii and Pontecorvo, 1977). Within the context of the present idea of neutrino oscillation one need not bring in lepton oscillation to understand such decays.

The Salam–Starthdee Goldstone supermultiplet is coupled to the trace of the energy momentum tensor, the present idea of neutrino oscillation should then be considered as a physical theory. Moreover, such a coupling amounts to the existence of photon–neutrino weak coupling in nature (Bandyopadhyay, 1968). Since there has been a spontaneous breakdown of global supersymmetry and the neutrino is a Majorana spinor, no trouble with the masslessness and the neutrality of photon arises. This may imply reactions of great astrophysical interest. A few of them are

$$\gamma + e^- \to e^- + \nu + \bar{\nu}$$

$$e^- + z \to e^- + z + \nu + \bar{\nu}$$

$$e^+ + e^- \to \nu + \bar{\nu}$$

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

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

and

$$\Gamma \to \nu + \bar{\nu}\,(\Gamma \to e^+ + e^- \to \gamma \to \nu + \bar{\nu})$$

3. CONCLUSION

Can the neutrinos causing the solar neutrino puzzle be Goldstone neutrinos? The most important point in this regard is that the neutrinos have to be massless. In the usual V−A theory the neutrino will stay massless in all orders, hence one need not bring in the idea of neutrino oscillation. But in theories with V−A and V+A currents higher-order weak processes will naturally bring about their masses and mixing. The masses of elementary particles seem to be of the order of 1 GeV as given by heavy quarks and leptons. The neutrino mass is so small that we find it hard to believe that they are not zero in some sense. From astronomical observations at the radio, optical, and X-ray frequencies it has been shown (Cowsik, 1977) that the lifetime of neutrinos for radiative decays divided by rest mass, τ_ν/m_ν, exceeds 10^{17} sec/eV. If one makes the further assumption that $m_\nu \geqslant 10^{-3}$ eV, then $\tau_\nu \geqslant 10^{19}$ sec. If there are other competing decays of neutrinos then

$$\frac{\Gamma_{\nu e}(\nu_e \to x + \gamma)}{\Gamma_{\nu e}(\text{total})} \leqslant 10^{-15}$$

and

$$\frac{\Gamma_{\nu\mu}(\nu_\mu \to x + \gamma)}{\Gamma_{\nu\mu}(\text{total})} \leqslant 10^{-6}$$

It is to be noted that the present idea of neutrino oscillation is different from standard oscillation ideas such as

$$\nu_e \rightleftharpoons \nu_\mu, \qquad \nu_e \rightleftharpoons \bar{\nu}_{eL}, \qquad \nu_e \rightleftharpoons \bar{\nu}_{\mu L}$$

which involve lepton number nonconservation. The present model invokes an oscillation, $\psi_L \rightleftharpoons \psi_R$, between two pairs of components of the Majorana spinor member of the Goldstone supermultiplet. But here ψ_L and ψ_R are both associated with two satellites, 0^+ and 0^-, respectively.

Thus the solar neutrino puzzle raises the question, Is there an exotic Goldstone neutrino in the game?

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