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THE CURRENT STATUS OF THE NEUTRINO PHYSICS SOLUTIONS OF THE SOLAR NEUTRINO PROBLEM

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S.T. Petcov * †
Scuola Internazionale Superiore di Studi Avanzati,
and Istituto Nazionale di Fisica Nucleare, Sezione di Trieste,
I-34014 Trieste, Italy

Abstract

The current status of the two-neutrino vacuum oscillation, matter-enhanced transition, spin-flavour precession, and the neutrino decay solutions of the solar neutrino problem is briefly reviewed.

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† Permanent address: Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria.

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Scuola Internazionale Superiore di Studi Avanzati, and Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, I-34013 Trieste, Italy, and Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria.

The current status of the two-neutrino vacuum oscillation, matter-enhanced transition, spin-flavour precession, and the neutrino decay solutions of the solar neutrino problem is briefly reviewed.

Below we show graphically the current status of the two-neutrino vacuum oscillation, matter-enhanced transition, and resonance spin-flavour precession solutions of the solar neutrino problem [1,2]. We comment also on the status of the solar neutrino decay hypothesis. The new data input in the corresponding analyses are the most recent results of the GALLEX experiment [3].

1. VACUUM OSCILLATIONS OF SOLAR NEUTRINOS

Fig. 1a. Regions of values of the two-neutrino vacuum oscillation parameters Δm^2 and $\sin^2 2\theta$ allowed at 90% C.L. (solid line) and 95% C.L. (dashed line) by the solar neutrino data in the case of vacuum $\nu_e \leftrightarrow \nu_{\mu(\tau)}$ oscillations of solar neutrinos. Shown are the results [4] of an extended χ^2-analysis based on data from 84 runs of the Homestake experiment [1], 15 runs of the GALLEX–I experiment [3], and from 13 three-month time interval measurements of Kamiokande–II collaboration [5]. The standard solar model predictions of Bahcall and Pinsonneault [2] have been used in the χ^2-analysis. The regions allowed by the mean event rate data only of the indicated experiments are considerably larger [4]. (For details and references to previous studies see ref. [4].)

Similar study has been performed for solar neutrino oscillations into sterile neu-

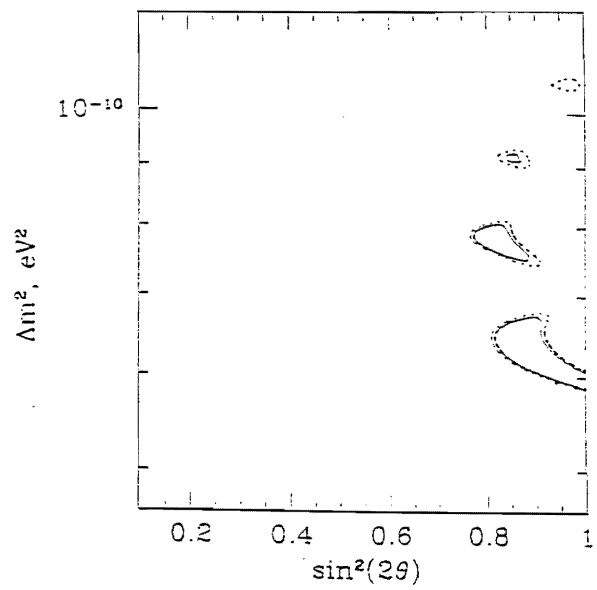

Fig. 1a

trino in vacuum [4]: $\nu_e \leftrightarrow \nu_s$. The χ^2- analysis of the currently reported mean event rates in the Homestake, Kamiokande, GALLEX and SAGE [6] detectors, based on the Bahcall–Pinsonneault theoretical predictions, rules out the two-neutrino $\nu_e \leftrightarrow \nu_s$ oscillations as a solution of the solar neutrino problem at 98% C.L., with the uncertainties in the theoretical predictions included in the analysis [4]. The run by run Homestake, Kamiokande–II and GALLEX–I data are less restrictive in the case of $\nu_e \leftrightarrow \nu_s$ oscillations: the results of the corresponding

χ^2−analysis [4] are shown in Fig. 1b.

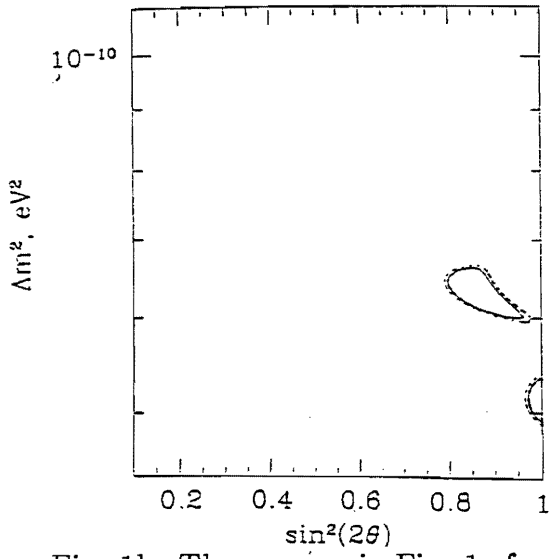

Fig. 1b. The same as in Fig. 1a for solar neutrino oscillations into sterile neutrino in vacuum: $\nu_e \leftrightarrow \nu_s$.

2. THE MSW SOLUTIONS

The MSW solutions, corresponding to ν_e transitions into an active neutrino, $\nu_e \rightarrow \nu_{\mu(\tau)}$, are depicted in Figs. 2a and 2b. The allowed regions of values of Δm^2 and $\sin^2 2\theta$ are shaded in black. The results shown were obtained by using the Homestake, Kamiokande, SAGE (1992), and the GALLEX–I + GALLEX–II data, and the simple method of overlapping of the regions allowed by the data of each of the four experiments, with uncertainty of 1 s.d. (Fig. 2a) and 2 s.d. (Fig. 2b) included in the data. (For details concerning the analysis and extensive list of references see ref. [7].) The results shown in Fig. 2b are conservative: the χ^2−analyses of the data typically give smaller allowed regions at 95% C.L., unless one includes rather large uncertainties in the theoretical predictions in the analysis.

3. RESONANCE SPIN-FLAVOUR PRECESSION (RSFP)

The possibility of RSFP of solar neutrinos in the magnetic field of the Sun is being discussed in connection with the suggested time variations of the signal in the Homestake experiment [1], in (anti)correlation with the solar activity (associated with the 22 year solar cycle). The RSFP mechanism

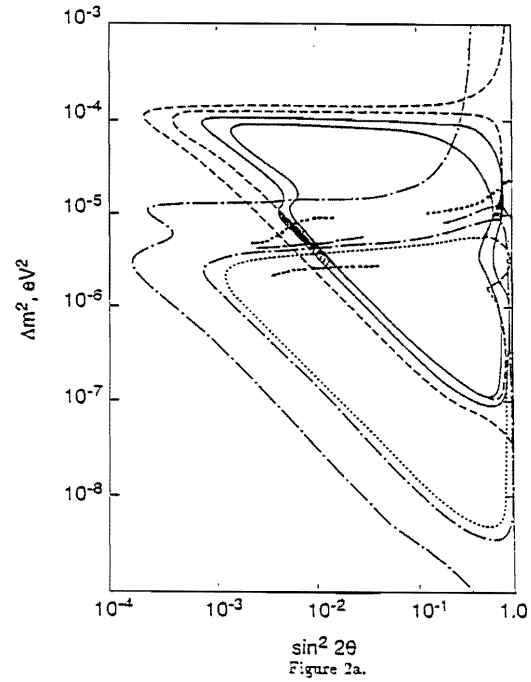

Figure 2a.

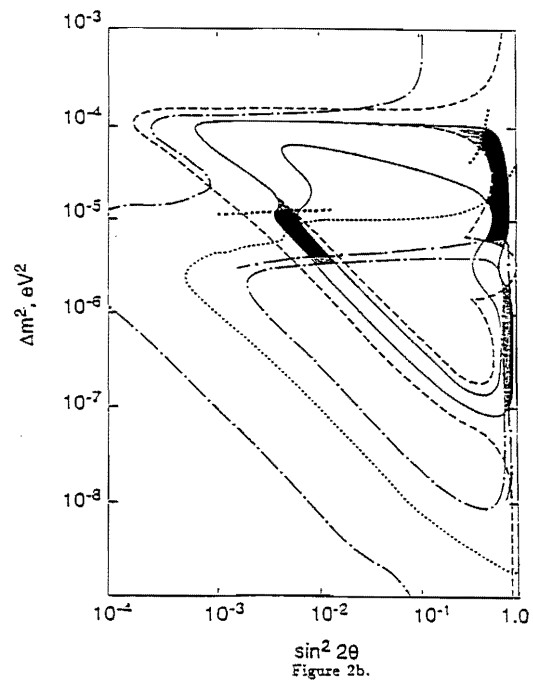

Figure 2b.

can be effective if ν_e has a sufficiently large magnetic moment or transition moment of magnetic dipole type, μ. The results of a study [8] of the simplest case of RSFP of $\nu_\odot$ (absence of lepton mixing in vacuum, two-neutrino $\nu_e \rightarrow \bar{\nu}_{\mu(\tau)}$ conversion due to a $\nu_{eL} - \bar{\nu}_{\mu R(\tau R)}$ transition moment μ, no inner magnetic field in the Sun, convective zone

magnetic field changing only its magnitude (but not its shape) with the change of the solar activity) are shown in Fig. 3.

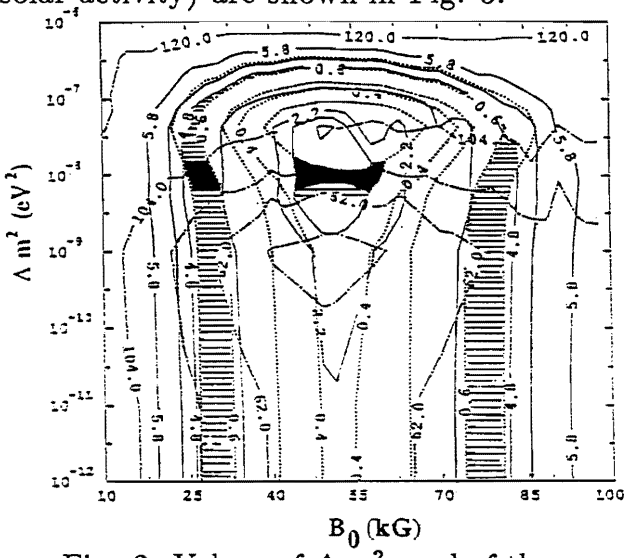

Fig. 3. Values of Δm^2 and of the maximal value B_0 of the solar convective zone magnetic field in the periods of minima and maxima of solar activity, for which one obtains a description of the solar neutrino data, including the suggested time variation of the Homestake event rate (the areas shaded in black). The results shown were obtained [8] for a triangle–type magnetic field distribution in the solar convective zone, and for $\mu = 10^{-11}$ μ_B, μ_B being the Bohr magneton. (For further details and a rather complete list of references see [8].)

4. THE ν–DECAY HYPOTHESIS

The simplest possibility corresponds to ν_e being a mixture of two neutrinos ν_1 and ν_2 with definite but different masses, the heavier of which decays into the lighter one with emission, e.g., of a massless scalar particle (see, e.g., ref. [9] and the articles quoted therein). The depletion of the solar ν_e flux depends on two parameters: the decaying neutrino lifetime, τ, and the lepton mixing angle θ. Using the results of the detailed study performed in ref. [9] and shown graphically in Fig. 4, and the most recent GALLEX results [3] one can conclude that the neutrino decay hypothesis in its simplest version is ruled out at least at 95% C.L. by the current solar neutrino data.

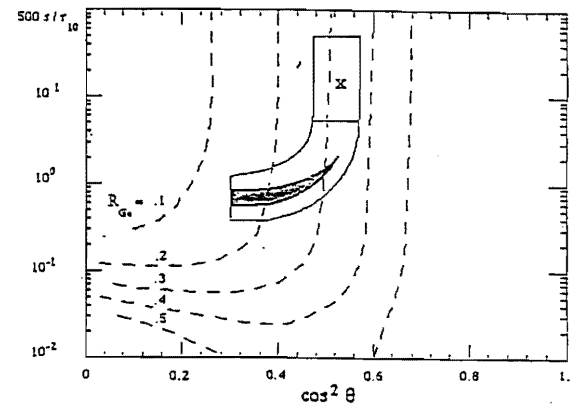

Fig. 4. Values of τ_{10} (a 10 MeV neutrino lifetime) and $\cos^2\theta$ allowed by accelerator, SN1977A, and Homestake and Kamiokande data (inside the solid line). The region denoted by X is excluded for $\nu_e - \nu_{\mu(\tau)}$ mixing. Shown are also contours of a given predicted suppression, R_{Ge}, of the signal in the Ga-Ge experiments. The most recent GALLEX result reads [3]: $R_{Ge} = 0.66 \pm 0.12$.

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