Constraints on decay plus oscillation solutions of the solar neutrino problem

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We examine the constraints on the nonradiative decay of neutrinos from the observations of solar neutrino experiments. The standard oscillation hypothesis among three neutrinos solves the solar and atmospheric neutrino problems. The decay of a massive neutrino mixed with the electron neutrino results in the depletion of the solar neutrino flux. We introduce neutrino decay in the oscillation hypothesis and demand that decay does not spoil the successful explanation of solar and atmospheric observations. We obtain a lower bound on the ratio of the lifetime over the mass of \( \nu_2 \), \( \tau_2/m_2 > 22.7 \text{s}/\text{MeV} \) for the Mikheyev-Smirnov-Wolfenstein solution of the solar neutrino problem and \( \tau_2/m_2 > 27.8 \text{s}/\text{MeV} \) for the vacuum oscillation solution (at 99\% C.L.).

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I. INTRODUCTION

Solar neutrino experiments with chlorine [1], gallium [2], and water Cherenkov detectors [3,4] show unequivocally that there is a deficit of \( \nu_e \) at the Earth compared to the predictions of the standard solar model [5]. It is commonly accepted that vacuum oscillations (VOS) or matter induced Mikheyev-Smirnov-Wolfenstein (MSW) conversions, with a large mixing angle (LMA) or small mixing angle (SMA), can account for the deficit of solar neutrinos. The available experimental results not only allow a test of neutrino oscillation hypothesis but also offer the possibility of constraining new physics, e.g., the neutrino magnetic moment [6], neutrino decay, flavor changing neutral currents, etc. Here we will be concerned with neutrino decay in the context of neutrino oscillations. The possibility of solving the solar neutrino problem only through neutrino decay in vacuum was raised in [7] and ruled out mainly owing to the fact that the lower energy pp neutrinos observed in gallium experiments are less suppressed compared to higher energy \(^7\text{Be}\) and \(^8\text{B}\) neutrinos observed in chlorine experiments. The suppression in the neutrino flux caused by the solar matter induced decay to Majoron plus neutrino has correct energy dependence [8] but the required fast rates cannot easily be obtained in the standard scenario without conflicting with other constraints [8]. The oscillation plus vacuum decay scenario has been studied more recently in a two-generation model in [9,10]. A field theoretic analysis of decay in the oscillation scenario was done in [11]. These studies were prior to results from the SNO [4,12]. In [13] the Super-Kamiokande spectrum data were used in a two-generation analysis for obtaining bounds on neutrino lifetime. The recent SNO charged current (CC) [4] and SNO neutral current (NC) [12] results provide further information which can be used to constrain the neutrino lifetime. The SNO CC data in combination with earlier data from Super-Kamiokande [3] can be used to separate the flux of the electron neutrino from that of other active flavors. This additional information provided by the SNO can be quite useful in probing new physics as we will demonstrate. In addition, the SNO NC rates directly measure the total probability of \( \nu_e \) conversion to active flavors. This probability is 1 in the absence of decay and sterile neutrinos. Decay reduces it from 1. Thus SNO NC rates directly provide information on decay. In the light of this, we study in this paper the three-generation model of neutrino oscillation plus decay including the recent SNO [4,12] result in our analysis.

Radiative decays of neutrinos are severely constrained by laboratory experiments and a variety of astrophysical and cosmological observations [see references in the Particle Data Group (PDG) review [14]]. However, constraints on nonradiative decays are much less stringent. Constraints on nonradiative decays, like \( \nu_2 \rightarrow \nu_1 (\bar{\nu}_1) + J \), have been set from the detection of \( \bar{\nu}_e \) from SN1987a at IBM and Kamiokande II [15]. In the case of a large mixing angle fast decay cannot be ruled out as in this case the \( \bar{\nu}_e \) content of \( \nu_1 \) and \( \nu_2 \) is the same [15]. If one were to consider neutrino decay into a sterile neutrino plus a Majoron as we do in the present paper then the active neutrino flux would be halved in the case of fast decay. However, since the initial neutrino flux is not certain (with the same precision as, say, the solar neutrino flux) fast decay of neutrinos cannot be ruled out from SN1987a observations. For a relatively heavy unstable neutrino, one can apply the argument that decay products contribute to the energy density of the universe and thus obtain a limit [16]. However, for masses of the order of 1 eV or less, there is no limit on the lifetime. Solar neutrino data constrain nonradiative neutrino decay in this mass regime.

We examine the scenario where the neutrinos from the Sun are depleted due to nonradiative decays like Majoron emission decays \( \nu_2 \rightarrow \nu_1' + J \), where the \( \nu_1' \) state is sterile. We assume that the lowest mass neutrino \( \nu_1 \) is stable,