We examine the effects of a scalar field, coupled only to neutrinos, on oscillations among weak interaction current eigenstates. The existence of a real scalar field is manifested as effective masses for the neutrino mass eigenstates, the same for $\bar{\nu}$ as for $\nu$. Under some conditions, this can lead to a vanishing of $\delta m^2$, giving rise to MSW-like effects. We present an idealized example and show that it may be possible to resolve the apparent discrepancy in spectra required by r-process nucleosynthesis in the mantles of supernovae and by Solar neutrino solutions.

We have recently examined the possibility that, in addition to the Standard Model interactions, neutrinos interact with each other through an extremely light scalar field $\phi$. The neutrinos with mass $m_i$ couple to $\phi$ with constants $g_i$. We showed that, consistent with known phenomena, neutrino clouds could form in the early Universe, influence the evolution of structures on stellar scales, and have observable consequences. Here, we discuss a consequence of this scalar interaction that can occur whether clouds form or not.

Following the relativistic many-body theory known as Quantum Hadrodynamics (QHD), we define effective masses

$$m_j^* = m_j - g_j \phi$$

With more than one mass eigenstate, it is possible for some $m_j^*$ to become negative. The richness of the system can be demonstrated with a spherically symmetric model in which the various couplings are all equal to the same constant $g$. Consider, for simplicity, two mass eigenstates, let the vacuum mass of the heavier be denoted by $m_h$ and that of the lighter by $m_l$. In this case, the shift from the vacuum mass to the effective mass is the same for both neutrinos,

$$\Delta m = g \phi$$
\[ m_{h}^* = m_{h} - \Delta m \]  
\[ m_{l}^* = m_{l} - \Delta m \]  

For large enough shift this can lead to \( m_{l} \) becoming very negative. If

\[ m_{l}^* = -m_{h}^* \]

then

\[ m_{h}^* - m_{l}^* = 0, \]

and there is a degeneracy between the two neutrinos arising from a very different mechanism than that involved in the usual MSW effect. Since the change in the effective mass is due to a scalar interaction, it is the same for both \( \nu \) and \( \bar{\nu} \) and the degeneracy will occur at the same density, hence the same radius in a star, supernova or other object, for both.

In the presence of matter, there is also a normal MSW effect which, being an energy shift due to a vector interaction, has the opposite sign for \( \nu \) and \( \bar{\nu} \), hence degeneracies will occur at different radii.

To illustrate these points we have generated the cartoons in Figure 1 by representing the results of solving the nonlinear differential equation for the selfconsistent effective mass with a simple analytic form and assuming a linear effect for the vector MSW (clearly, this is far too simple for a real system, but the trends are correctly represented). In part A we assume no scalar field and demonstrate that the \( \bar{\nu} \) degeneracy, indicated by the shorter vertical line,
occurs at a smaller radius than the $\nu$ degeneracy, indicated by the longer vertical line. In B, we add the scalar. The middle vertical line indicates the position of the $m^2$ degeneracy ignoring the vector MSW; the outer vertical line indicates the position of the $\bar{\nu}$ degeneracy with both. The position of the $\nu$ degeneracy is shown by the inner most vertical line.

This result has possible physical implications. It has recently been shown\textsuperscript{4} that r-process nucleosynthesis in the exterior of a supernova can give a credible account for abundances, provided there is an excess of neutrons over protons. To achieve this, it is desirable to have the $\bar{\nu}$ at a higher temperature than the $\nu$ at the site of the r-process, which can be achieved through enhanced flavor transitions if the $\bar{\nu}$ transition occurs outside the $\nu$ transition\textsuperscript{4}. These authors suggest that this can be achieved by an inverted spectrum ($m_{\nu_e}$ larger than some other mass); it could also be achieved through a scalar interaction.

The extension of these considerations to three generations is straightforward and will be presented elsewhere\textsuperscript{5}.

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