THE COHERENT WEAK CHARGE OF MATTER

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Abstract. We study the long-range force arising between two aggregates of ordinary matter due to a neutrino-pair exchange, in the limit of zero neutrino mass. Even if matter is neutral of electric charge, it is charged for this weak force. The interaction is described in terms of a coherent charge, which we call the weak flavor charge of aggregated matter. For each one of the interacting aggregates, this charge depends on the neutrino flavor as

\[ Q_{\nu e}^W = 2Z - N, \]
\[ Q_{\nu \mu}^W = Q_{\nu \tau}^W = -N, \]

where \( Z \) is the number of protons and \( N \) the number of neutrons. \( Q_{\nu e}^W \) depends explicitly on \( Z \) because of the charged current contribution to \( \nu e \) elastic scattering, while the \( N \) term in the three charges comes from the universal neutral current contribution. The effective potential describing this force is repulsive and decreases as \( r^{-5} \). Due to its specific behavior on \((Z,N)\) and \( r \), this interaction is distinguishable from both gravitation and residual electromagnetic forces. As neutrinos are massive and mixed, this potential is valid for \( r \lesssim 1/m_\nu \), distances beyond which a Yukawa-like attenuation kicks in.

1 Introduction

The study of the origin of neutrino mass is one of the directions in which we can expect finding new Physics, even though its small value \((m_\nu \lesssim 1 \text{ eV})\) makes it hard to observe experimentally. As well as determining the absolute mass of the neutrino, there’s still a more fundamental question about their nature unanswered: their finite mass could be explained through a Dirac mass term (implying there is a conserved total lepton number \( L \) distinguishing neutrinos from antineutrinos, which are described by 4-component Dirac spinors) or through a Majorana one (implying that neutrinos are self-conjugate of all charges, described by 2 independent degrees of freedom).

In any case, the fact that their masses are very low stands, and we discuss here another property of neutrinos as mediators of a new force. As is well known, the processes represented in Quantum Field Theory by the exchange of a massless particle give raise to long-range interactions. An easy example is the scattering of two particles mediated by a photon, which—at tree level—describes Coulomb scattering. Our objective in this work is the application of these ideas to a process mediated by neutrinos. According to the Electroweak Lagrangian, the lowest-order process is a neutrino-pair exchange, which—since neutrinos are nearly massless—describes an interaction of long range.

2 Long-range weak interaction between aggregate matter

We are interested in obtaining the interaction potential due to a neutrino-pair exchange between two matter aggregates, say \( A \) and \( B \). In doing so, we will not...
impose any restriction on the internal structure of the aggregates—whatever
they are, we only ask them to be neutral of electric charge. Therefore, for each
aggregate, its composition is specified by two numbers: \( Z \) will represent the
number of protons and the number of electrons, which must be the same, and \( N \)
will represent the number of neutrons.

The picture is now clear. Elastic interactions of matter constituents with
neutrinos is through either \( W \) or \( Z \) exchange, as well as the aggregate structure,
determine the 1-loop neutrino-pair exchange \( AB \rightarrow AB \) elastic interaction, as
shown in Fig. 1.

The whole interaction potential between the two aggregates is given by the
Fourier Transform of the Feynman amplitude in Fig. 1. Since we are only in-
terested in the long-range part of the potential, a few simplifications can be
performed. Through rewriting the amplitude as an unsubtracted dispersion
relation, we find the long-range behavior is fully determined by its absorptive
part. In turn, the absorptive part is determined, after unitarity-cutting the
diagram in the \( t \)-channel, by a simple tree-level \( A\nu \rightarrow A\nu \) amplitude. This
tree-level calculation is straightforward—in the process, we only kept the dom-
inant contributions, neglecting both incoherent and relativistic corrections.

The analysis described above leads \( 3 \) to the interaction potential

\[
V(r) = \frac{G_F^2}{8\pi^3} \left[ (2Z_A - N_A)(2Z_B - N_B) + 2N_AN_B \right] \frac{1}{r^5}.
\]  

(1)

3 Coherent weak flavor charges

A careful reading of Eq. (1) shows the standard structure of an interaction
potential. By defining, for each of the aggregates, their weak flavor charges

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig1}
\caption{Effective neutrino-pair exchange interaction between two ag-
ggregates of matter. The blobs in the vertices represent any structure the
aggregates could have.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig2}
\caption{Weak flavor charges of the elements specified by the atomic number \( Z \), compared
to their mass \( \approx Z + N \). The isotope chosen is the one in which the \( (Z, N) \) pair lies in the
valley of nuclear stability.}
\end{figure}
as $Q^e_W = 2Z - N$ and $Q^e_W = Q^e_W = -N$, one gets the usual structure $V = (\text{coupling})^2 \times (\text{product of charges}) \times (\text{power law})$.

Indeed, this shows that, within the Standard Model, matter is charged! The values of the weak charges of all stable atoms are represented in Fig.2. At this point, we remark that the unique $(Z,N)$ dependence of these charges makes them scale with the size of the system in a different way than gravitation. Also, the fact that the charges of all elements have the same sign (for each flavor) implies that this interaction is always repulsive. These two properties may become crucial in disentangling this weak interaction from gravitation experimentally.

4 Prospects

The long-range potential obtained in this work, Eq.(1), is valid and of interest for distances between nanometers and microns. The short-distance limit comes from the requirement of having neutral (of electric charge) systems of aggregate matter, while the long-distance limit is imposed by a non-vanishing value of the absolute mass of the neutrino—indeed, the range of this interaction for neutrinos of $m \sim 0.1\ eV$ is of the order of $R \sim 1/m_\nu \sim 1\mu m$. In this region, the effective potential will become of Yukawa type instead of the pure inverse power law.

The neutrino mass dependence of the effective potential in the long-range behavior opens novel directions in the study of the most interesting pending questions on neutrino properties: absolute neutrino mass (from the range), flavor dependence and mixing (from the weak charges in the interaction) and, hopefully, with two neutrino exchange, the exploration of the most crucial open problem in neutrino physics: whether neutrinos are Dirac or Majorana particles.

Acknowledgments

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