MIPA Insight: Journal of Science, Technology, Education, and Mathematics
https://journal.innoscientia.org/index.php/mipainsight/index
ISSN **3063** *(online)*

Volume 1, Nomor 2, Tahun 2024
Hal. 65-69

MASSIVE NEUTRINOS AS INTERMEDIARIES IN SCALAR FIELD DECAY

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ABSTRAK

Neutrino merupakan partikel fundamental yang memiliki sifat unik dan sulit dideteksi karena tidak mengalami interaksi elektromagnetik. Dalam penelitian ini, model yang digunalkan adalah Model Simetri Kiri-Kanan dan Medan Skalar Ekstra. Fokus penelitian ini adalah analisis peluruhan medan skalar χ_L di sektor kiri yang dimediatori oleh neutrino masif right-handed ν_R . Peluruhan ini menghasilkan dua fermion (ℓ_L dan $\overline{q_L}$) dan medan scalar ϕ_L. Laju peluruhan proses ini sebanding dengan pangkat lima massa medan skalar χ_L dan berbanding terbalik dengan pangkat empat massa neutrino ν_R .Hasil peluruhan menyumbangkan entropi ke sektor kiri, memanaskan sektor tersebut, dan memicu ketidakseimbangan suhu antara sektor kiri dan kanan.

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ABSTRACT

Neutrinos are fundamental particles that have unique properties and are difficult to detect because they do not experience electromagnetic interactions. In this study, the models used are the Left-Right Symmetry Model and Extra Scalar Fields. The focus of this study is the analysis of the decay of the scalar field χ_L *in the left sector mediated by the right-handed massive neutrino* ν_R*. This decay produces two fermions (*ℓ_L and $\overline{q_L}$*) and the scalar field* ϕ_L*. The decay rate of this process is proportional to the fifth power of the mass of the scalar field* χ_L *and inversely proportional to the fourth power of the neutrino mass* ν_R*. The decay results contribute entropy to the left sector, heating the sector and triggering a temperature imbalance between the left and right sectors.*

Keywords: *Left-Right Symmetry, Neutrino, Scalar Fields, Decay Rates*

INTRODUCTION

Neutrino is a particle that still holds many mysteries. Initially, the neutrino was a hypothetical particle proposed by Wolfgang Pauli in 1930 to explain the problem of beta decay energy. Pauli proposed neutrino particles as particles with intermediate spin, no charge, and tiny mass, which are produced together with electrons but escape detection [1]. Furthermore, Enrico Fermi developed a quantum theory to explain beta decay [2]. In 1956, Clyde Cowan and Frederick Reines conducted an experiment based on the neutrino-proton interaction that produced positrons and neutrinos. This experiment proved the existence of neutrinos [3]. Neutrinos have unique properties; namely, they are challenging to detect because they do not experience electromagnetic interactions. Neutrinos can also be mediators in an interaction. Research conducted by Ananthanarayan and Minskowski Andreviewed the interaction of electron scattering into W^- bosons mediated by massive neutrinos[4]. Research conducted by [5] reviewed the mechanism of muon-electron conversion mediated by neutrinos. This finding shows the opportunity to understand new phenomena.

The Extension of the Standard Model allows for new consequences or phenomena. One extension of the Standard Model is the Left-Right Symmetry Model with Extra Scalar Fields. This model is characterized by the tera group $SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$. The proposed particles are divided into two sectors, namely, the left sector and the right sector. In this model, it is necessary to analyze interactions involving additional scalar fields with massive neutrinos as mediators.

METHODS

This study is theoretical in nature. Possible scalar interactions are identified through an analysis of the Higgs Potential. The interaction terms within the Higgs Potential are illustrated using Feynman diagrams. Subsequently, the interaction probability is determined using the Feynman rules within the framework of Toy Theory [6]. The decay rate, on the other hand, is calculated using the Golden Rule, as expressed in Equation (1).

$$\Gamma = \frac{S}{2\hbar}\int |\mathcal{M}|^2 (2\pi)^4 \delta^4(p_1 - p_2 - \cdots - p_n) \times \prod_{j=2}^{n} 2\pi\delta\left(p_j^2 - m_j^2 c^2\right)\theta\left(p_j^0\right)\frac{d^4 p_j}{(2\pi)^4} \qquad (1)$$

.

RESULTS AND DISCUSSIONS

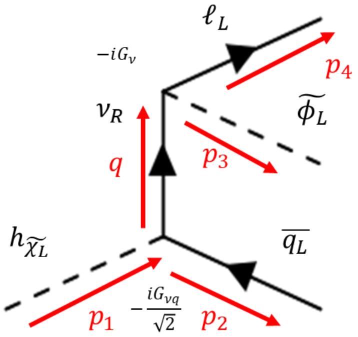
The Left-Right Symmetry Model with Extra Scalar Field consists of two sectors, namely the left sector, which is the real sector and the right sector. The particles in the left sector are Standard Model particles with additional right-handed neutrinos and additional scalar fields. While in the left sector, the particles are pairs of particles in the right sector. Symmetry breaking based on this model occurs in two stages of symmetry breaking. The first symmetry breaking is spontaneous symmetry breaking, which occurs when the temperature of the universe is around d10^4 GeV *[7].* At this time, the tera group $SU(3) \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_Y$ is broken into the Standard Model tera group$SU(3) \otimes SU(2)_L \otimes U(1)_Y$. The left and right sectors are still symmetrical in terms of temperature and number of particles. The mass of photons in both sectors is also zero. The second symmetry breaking occurs when the scalar field

ϕ_L and the scalar field ϕ_R take the vacuum expectation value VEV at the temperature of the universe about 10^2 *GeV.* The symmetry breaking occurs in the tera group $SU(3) \otimes SU(2)_L \otimes U(1)_{B-L}$ to the tera group $SU(3) \otimes U(1)_{em}$.

In this study, the destruction that occurs in the first stage is reviewed. At this stage, the scalar fields $\eta, \xi, \chi_L, \chi_R, \rho$ and ω take their VEV values. The Yukawa Lagrangian terms reviewed in this study are shown by Equation (2)

$$-G_\nu \overline{\ell_L} \phi_L \nu_R - G_{\nu q} \overline{\nu_R} \widetilde{\chi_L} q_L \tag{2}$$

The combination of the two Yukawa terms shows the decay of the scalar field χ_L decaying into a doublet $\overline{q_L}$ and ℓ_L and a scalar field ϕ_L with a massive neutrino mediator ν_R or through the process $h_{\widetilde{\chi_L}} \rightarrow \overline{q_L} + \widetilde{\phi_L}$. Consider the decay process $(c.9) h_{\widetilde{\chi_L}} \rightarrow \overline{q_L} + \widetilde{\phi_L} + \ell_L$ via ν_R whose external and internal momenta are shown in Figure 1.



$(c.39) h_{\widetilde{\chi_L}} \rightarrow \overline{q_L} + \widetilde{\phi_L} + \ell_L$

Figure 1 Feynman Decay Diagram $\boldsymbol{h_{\widetilde{\chi_L}} \rightarrow \overline{q_L} + \widetilde{\phi_L} + \ell_L}$

The probability amplitude of the square of this decay is given by Equation (3)

$$\boldsymbol{M^2 = \frac{G_\nu^2 G_{\nu q}^2}{m_{\nu_R}^4} [2(p_1 \cdot p_2)(p_1 \cdot p_2) - 2(p_1 \cdot p_4)(p_2 \cdot p_2) + (p_2 \cdot p_4)(p_2 \cdot p_2)} \\ \boldsymbol{-(p_1 \cdot p_1)(p_4 \cdot p_2)]} \tag{3}$$

Based on the centre of energy-momentum framework, the assumption of the state of each particle is given by Equation (4)

$$\begin{aligned} p_1 &= (m_{\chi_L}; 0) \\ p_2 &= (E_2, \mathbf{p_2}) \\ p_3 &= (E_3, \mathbf{p_3}) \\ p_4 &= (E_4, \mathbf{p_4}) \end{aligned} \tag{4}$$

The scalar field χ_L decays into three relativistic particles so that Equation (5) is obtained

$$\begin{gathered}
p_1 \cdot p_1 = m_{\chi_L}^2 \\
p_2 \cdot p_2 = p_3 \cdot p_3 = p_4 \cdot p_4 = 0 \\
p_1 \cdot p_2 = m_{\chi_L} E_2 \\
p_1 \cdot p_4 = m_{\chi_L} E_4
\end{gathered} \tag{6}$$

Equation (6) is substituted into Equation (3) to obtain the quadratic decay probability amplitude shown by Equation (7)

$$M^2 = \frac{G_\nu^2 G_{\nu q}^2 m_{\chi_L}^4}{\mathrm{m}_{\nu'}^4} \left[\frac{2E_2E_4}{m_{\chi_L}^2} + \frac{E_3}{m_{\chi_L}} - \frac{1}{2} \right] \tag{7}$$

The rate of the decay process into three particles is shown by Equation (8)

$$d\Gamma = \frac{\mathrm{M}_{(c.9)}^2}{2m_{\chi_L}} \left(\frac{d^3\mathbf{p_2}}{(2\pi)^3 2|\mathbf{p_2}|} \right) \left(\frac{d^3\mathbf{p_3}}{(2\pi)^3 2|\mathbf{p_3}|} \right)$$

$$\left(\frac{d^3\mathbf{p_4}}{(2\pi)^3 2|\mathbf{p_4}|} \right) \times (2\pi)^4 \delta^4 (p_1 - p_2 - p_3 - p_4) \tag{8}$$

It is assumed that the decay particle, namely the scalar field $\widetilde{\phi_L}$ moves in the opposite direction to the other two particles, namely $\overline{q_L}$ and ℓ_L. The scalar field $\widetilde{\phi_L}$ gets kinetic energy of $\frac{1}{2} m_{\chi_L}$, while the other two particles get the rest. The final result of the decay rate is shown by Equation (9)

$$\Gamma = \frac{11 \boldsymbol{G_\nu^2 G_{\nu q}^2} m_{\chi_L}^5}{24(8\pi)^3 m_{\nu_R}^4} \tag{9}$$

The addition of right-handed neutrinos to this model results in a new phenomenon. Right-handed neutrinos are hypothesized to have existed when the early universe was created with massive mass. These neutrinos have the uniqueness that they can interact as mediators. One of the interactions is the decay of the scalar field χ_L in the left sector, producing two fermions and one scalar field in the left sector through massive neutrinos. The decay of this scalar field has a minimal probability because, based on Equation (9), The decay rate of this process is proportional to the fifth power of the mass of the scalar field χ_L and inversely proportional to the fourth power of the neutrino mass ν_R. This decay of the scalar contributes entropy to the left sector so that the temperature of the left sector becomes hotter than the right sector. The scalar field ϕ_L resulting from the decay of χ_L is the Higgs scalar field of the Standard Model; this field obtains a VEV value at the second spontaneous symmetry breaking stage. The scalar field ϕ_L was discovered experimentally in 2012 [8]. The temperature imbalance between the left and right sectors is related to the phenomena of matter-antimatter asymmetry, Big Bang nucleosynthesis and cosmic microwave background.

CONCLUSION

The massive right-handed neutrino ν_R mediates the decay of the scalar field χ_L into a fermion doublet $\overline{q_L}$ and ℓ_L and the scalar field ϕ_L. The decay rate of this process is proportional to the fifth power of the mass of the scalar field χ_L and inversely proportional to the fourth power of the neutrino mass ν_R.

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