Weak neutrinos–matter interactions due to contraction of Lepton Sector of the Electroweak Model

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New Trends in High Energy Physics
Crimea, September 3-10, 2011

Outline

- Neutrino: main experimental properties.
- The Standard Electroweak Model.
- The Modified Model.
- Conclusion

Neutrino: main experimental properties

- During the last century many elementary particles was discovered and study. One of these the neutrino was theoretically introduced by W. Pauli in 1930 under analysis of neutron beta decay

$$n \to p + e + \nu$$

- The name neutrino was given by E. Fermi a little later.
- The electron neutrino was experimentally verified in 1956.
- The muon neutrino was discovered in 1962.
- The last one tau neutrino was detected in 1975.
- According to the Standard Electroweak Model there are only three sorts of neutrinos (1989).

- All neutrinos are stable. They are weak and gravity interacted particles.
- For a long time neutrino was considered as massless particle. But recently experimental indications appeared that neutrino has very small mass

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For comparison: electron mass

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The Standard Electroweak Model

- **First phenomenological theory of the weak interactions (the theory of beta decay) was developed by E. Fermi in 1934.**
- Weak interactions for low energies are characterized by the Fermi constant G_F. This constant is determined by experimental measurements and turn out to be very small $G_F = 10^{-5}\frac{1}{m_p^2} = 1,17 \cdot 10^{-5}\ GeV^{-2}$.
- Modern theory, which unified weak and electromagnetic interactions, was suggested in 1968 by S. Weinberg, S.L. Glashow, A. Salam and is known as the Standard Electroweak Model.
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- The Standard Model is important to theoretical and experimental particle physics because of its success in explaining a wide variety of experimental results.
- Due to this model the W- and Z-bosons was predicted and experimentally observed at the end of the last century. Higgs boson is now searched at the LHC.
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- Elementary particles content of the Standard Model.
  Gauge bosons:

$$\gamma \text{ (photon)}, \; W^{\pm} \text{ (charged weak bosons)},$$

$$Z^0 \text{ (neutral weak boson)}.$$

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix}, \quad \begin{pmatrix} c \\ s \end{pmatrix}, \quad \begin{pmatrix} t \\ b \end{pmatrix} \in C_2.$$

Leptons:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}, \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}, \quad \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix} \in C_2.$$

- The Lagrangian of the model is given by the sum:

$$L = L_B + L_Q + L_L$$

of the boson L_B, of the quark L_Q and of the lepton L_L Lagrangians

- and is invariant under the action of the gauge group $SU(2) \times U(1)$ in C_2

$$\begin{pmatrix} z_1' \\ z_2' \end{pmatrix} = \begin{pmatrix} \alpha & \beta \\ -\bar{\beta} & \bar{\alpha} \end{pmatrix} \begin{pmatrix} z_1 \\ z_2 \end{pmatrix}, \quad |\alpha|^2 + |\beta|^2 = 1.$$

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$$L_{L,e} = L_l^\dagger i\tilde{\tau}_\mu D_\mu L_l + e_r^\dagger i\tau_\mu D_\mu e_r - h_e[e_r^\dagger(\phi^\dagger L_l) + (L_l^\dagger \phi)e_r],$$

- where $L_l = \begin{pmatrix} \nu_l \\ e_l \end{pmatrix} \in C_2$ is the $SU(2)$-doublet, e_r is the $SU(2)$-singlet, h_e is constant, $\tau_0 = \tilde{\tau}_0 = 1$, $\tilde{\tau}_k = -\tau_k$, τ_μ are the Pauli matrices, $\phi \in C_2$ are the matter fields and e_r, e_l, ν_l are the two component Lorentzian spinors.
- First and second terms in $L_{L,e}$ describe free movement of left and right fermions and their interactions with gauge fields.
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- The covariant derivatives of the lepton fields are given by the formulas:

$$D_\mu e_r = \partial_\mu e_r + ig' A_\mu e_r \cos\theta_w - ig' Z_\mu e_r \sin\theta_w,$$

$$D_\mu L_l = \partial_\mu L_l - i\frac{g}{\sqrt{2}}\left(W_\mu^+ T_+ + W_\mu^- T_-\right) L_l -$$

$$-i\frac{g}{\cos\theta_w} Z_\mu \left(T_3 - Q\sin^2\theta_w\right) L_l - ieA_\mu Q L_l,$$

- where $T_k = \frac{1}{2}\tau_k, k = 1,2,3$ are the generators of $SU(2)$,
  $T_\pm = T_1 \pm iT_2$,
  $Q = Y + T_3$ is the generator of electromagnetic subgroup $U(1)_{em}$,
  $Y = -\frac{1}{2}\mathbf{1}$ is the hypercharge of the left leptons,
  $e = \frac{gg'}{\sqrt{g^2+g'^2}}$ is the electron charge and $\sin\theta_w = \frac{e}{g}$.

- The new gauge fields

$$W_\mu^{\pm} = \frac{1}{\sqrt{2}}\left(A_\mu^1 \mp i A_\mu^2\right), \quad Z_\mu = \frac{1}{\sqrt{g^2+g'^2}}\left(g A_\mu^3 - g' B_\mu\right),$$

$$A_\mu = \frac{1}{\sqrt{g^2+g'^2}}\left(g' A_\mu^3 + g B_\mu\right)$$

- are expressed through the fields

$$A_\mu(x) = -ig\sum_{k=1}^{3} T_k A_\mu^k(x), \quad B_\mu(x) = -ig' B_\mu(x),$$

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- The next two lepton generations (muon and muon neutrino, τ-lepton and τ-neutrino) are introduced in a similar way.
- Full lepton Lagrangian is the sum:

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Modified Model

- **In the Standard Electroweak Model the gauge group $SU(2) \times U(1)$ acts in the boson, lepton and quark sectors, i.e. for the lepton fields**

$$\begin{pmatrix} \nu_e' \\ e' \end{pmatrix} = \begin{pmatrix} \alpha & \beta \\ -\bar{\beta} & \bar{\alpha} \end{pmatrix} \begin{pmatrix} \nu_e \\ e \end{pmatrix}, \quad |\alpha|^2 + |\beta|^2 = 1.$$

- Let us consistently rescale the group $SU(2)$ and field space C_2 in the lepton sector by the parameter $j \in R$

$$\begin{pmatrix} j\nu_e' \\ e' \end{pmatrix} = \begin{pmatrix} \alpha & j\beta \\ -j\bar{\beta} & \bar{\alpha} \end{pmatrix} \begin{pmatrix} j\nu_e \\ e \end{pmatrix}, \quad |\alpha|^2 + j^2|\beta|^2 = 1.$$

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- The left lepton fields are now as follows

$$\begin{pmatrix} j\nu_e \\ e \end{pmatrix}, \begin{pmatrix} j\nu_\mu \\ \mu \end{pmatrix}, \begin{pmatrix} j\nu_\tau \\ \tau \end{pmatrix} \in C_2(j).$$

- They are obtained from those of the Standard Model by multiplication of the neutrino fields on parameter j

$$\nu_e \to j\nu_e, \quad \nu_\mu \to j\nu_\mu, \quad \nu_\tau \to j\nu_\tau.$$

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- Substitution $\beta \to j\beta$, induces another ones for $su(2)$ algebra generators

$$T_1 \to jT_1, \quad T_2 \to jT_2, \quad T_3 \to T_3.$$

- As far as the gauge fields take their values in Lie algebra, we can rescale the gauge fields instead of transforming the generators, namely:

$$A_\mu^1 \to jA_\mu^1, \;\; A_\mu^2 \to jA_\mu^2, \;\; A_\mu^3 \to A_\mu^3, \;\; B_\mu \to B_\mu.$$

- Indeed, due to commutativity and associativity of multiplication by j

$$g(j) = \exp\left\{A_\mu^1(jT_1) + A_\mu^2(jT_2) + A_\mu^3 T_3\right\} =$$

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- Above transformations of the neutrinos and gauge fields give rise to the lepton Lagrangian

$$L_{L,e}(j) = e_l^\dagger i\tilde{\tau}_\mu \partial_\mu e_l + e_r^\dagger i\tau_\mu \partial_\mu e_r - e e_l^\dagger \tilde{\tau}_\mu A_\mu e_l + \frac{g\cos 2\theta_w}{2\cos\theta_w} e_l^\dagger \tilde{\tau}_\mu Z_\mu e_l -$$

$$-g'\cos\theta_w e_r^\dagger \tau_\mu A_\mu e_r + g'\sin\theta_w e_r^\dagger \tau_\mu Z_\mu e_r - m_e[e_r^\dagger e_l + e_l^\dagger e_r] +$$

$$+j^2 \left\{ \nu_l^\dagger i\tilde{\tau}_\mu \partial_\mu \nu_l + \frac{g}{2\cos\theta_w} \nu_l^\dagger \tilde{\tau}_\mu Z_\mu \nu_l + \right.$$

$$\left. + \frac{g}{\sqrt{2}} \left[\nu_l^\dagger \tilde{\tau}_\mu W_\mu^+ e_l + e_l^\dagger \tilde{\tau}_\mu W_\mu^- \nu_l \right] \right\} = L_{e,b} + j^2 L_{\nu,f}.$$

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- Lagrangian $L_{e,b}$ describe free movement of left and right electrons as well as their interactions with gauge fields and electron mass.

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- We put $\phi = \phi^{vac} = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \end{pmatrix}$ in $L_{L,e}$ and denote the electron mass as $m_e = \frac{h_e v}{\sqrt{2}}$.
- Next lepton generation fields are transformed in a similar way:

$$\nu_{\mu,l} \to j\nu_{\mu,l}, \quad \nu_{\tau,l} \to j\nu_{\tau,l}, \quad \mu_l \to \mu_l, \quad \tau_l \to \tau_l,$$

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- The lepton Lagrangian is the sum:

$$L_L(j) = L_{L,e}(j) + L_{L,\mu}(j) + L_{L,\tau}(j) = L_{L,b} + j^2 L_{L,f},$$

where each term has the structure of $L_{L,e}(j)$ with the mass $m_q = \frac{h_q v}{\sqrt{2}}, \quad q = e, \mu, \tau$.

- We put $\phi = \phi^{vac} = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \end{pmatrix}$ in $L_{L,e}$ and denote the electron mass as $m_e = \frac{h_e v}{\sqrt{2}}$.
- Next lepton generation fields are transformed in a similar way:

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$$L(j) = L_B + L_Q + L_L(j) = L_r + j^2 L_\nu$$

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The mathematical interpretation of the parameter j

- **To understand the meaning of the parameter j let us consider the limit $j \to 0$ in the action of $SU(2;j)$ on the space $C_2(j)$**

$$\begin{pmatrix} j\nu_e' \\ e' \end{pmatrix} = \begin{pmatrix} \alpha & j\beta \\ -j\bar{\beta} & \bar{\alpha} \end{pmatrix} \begin{pmatrix} j\nu_e \\ e \end{pmatrix}, \quad |\alpha|^2 + j^2|\beta|^2 = 1.$$

- In this limit (or for $j = \iota,\ \iota^2 = 0$) the unitary group $SU(2;j)$ is contracted to the motion group $E(2)$ of the Euclid plane.
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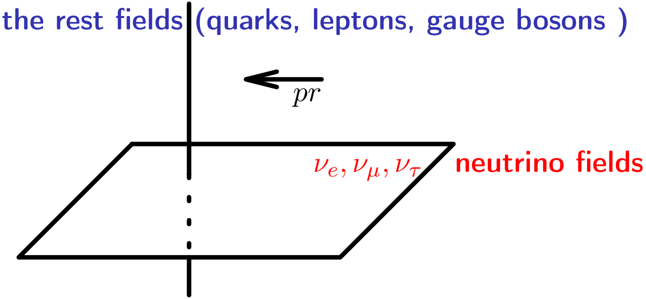

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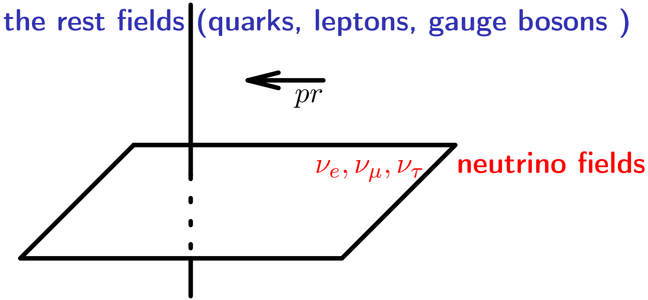

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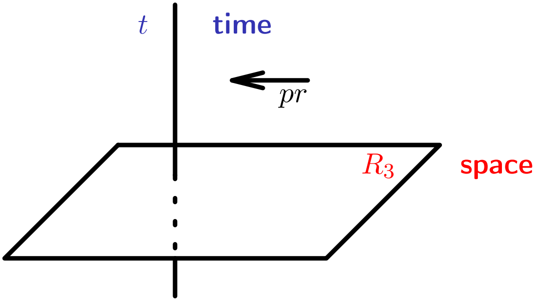

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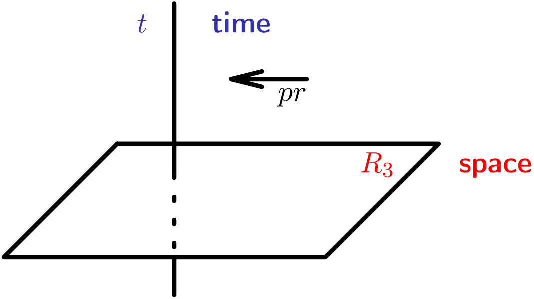

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The physical interpretation of the parameter j

- The space-time of the special relativity is transformed to the nonrelativistic space-time when dimensionfull contraction parameter — velocity of light c — tends to infinity and dimensionless parameter $\frac{v}{c} \rightarrow 0$.
- From the neutrino part Lagrangian

$$j^2 L_{\nu,f} = j^2 \left\{ \nu_l^\dagger i \tilde{\tau}_\mu \partial_\mu \nu_l + \frac{g}{2\cos\theta_w} \nu_l^\dagger \tilde{\tau}_\mu Z_\mu \nu_l + \right.$$

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- Therefore probability amplitudes for weak current interactions, which include such vertexes, for example

$$\nu_\mu e^- \to \nu_e \mu^- \text{ or } \nu_\mu e^- \to \nu_\mu e^- \text{ (elastic scattering)}$$

are multiplied by the same factor j^2.

- But these amplitudes have Fermi constant G_F as a factor.
- This makes it possible to connect dimensionless parameter j^2 with Fermi constant G_F, if one introduces the dimensionfull constant $G_0 = \frac{1}{m_p^2}$, where $m_p \approx 1\ GeV$ is the proton mass.
- Then we can compare both factors

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- If we suppose that parameter j depend on neutrino energy in an appropriate manner, then contraction procedure can be connected with the dependence of neutrino-matter cross-section on neutrino energy, which is decreased when neutrino energy go down.

Conclusion

The suggested model explain the very weak neutrinos-matter interactions on the level of classical fields with the help of contraction of the gauge group in the lepton sector of the Standard Electroweak Model, leaving the invariance group in the boson and quark sectors untouched.

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The very small Fermi constant is represented

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by the contraction parameter, which is small by implication.

Thank you for your attention.