Contraction of Lepton Sector of Electroweak Model Can Explain the Neutrino-Matter Interactions

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Outline

- **Neutrino: main experimental properties.**
- Semi-Riemannian geometry and group contractions.
- The Standard Electroweak Model
- Modified Model
- Conclusion

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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).

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- 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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- The vanishingly small interaction with matter especially for low energies distinguishes neutrinos from other elementary particles. The attenuation length of neutrino in water is about 100 light years.
- The second remarkable experimental fact is that neutrinos cross-section increases with the energy. For energies greater than $1\,GeV$ this dependence is linear.
- We want to explain both facts with the help of group contraction.
- More precisely, the modification of the Standard Electroweak Model shall be suggested, where the boson and quark sectors are the same as in the Standard Model, but the lepton sector is invariant with respect to the gauge group $SU(2;j) \times U(1)$, where j is a small dimensionless parameter.

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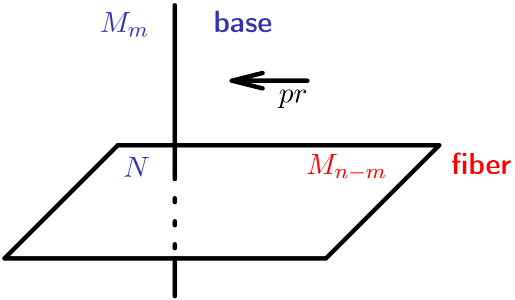
Semi-Riemannian geometry and group contractions

Semi-Riemannian geometry V_n^m is defined by a smooth fibration $pr: M_n \mapsto M_m$, with the **base** M_m and the **fiber** $M_{n-m} = pr^{-1}(N)$, $N \in M_m$.



- Only those geometrical objects which are consistent with this projection can be regarded, in particular, only the following coordinate transformations

$$\left\{ \begin{array}{l} x^{\mu'} = f^{\mu'}(x^1, \ldots, x^m), \\ x^{i'} = f^{i'}(x^1, \ldots, x^m, x^{m+1}, \ldots, x^n) \end{array} \right. ,$$

with the standard conditions on the smoothness and Jacobian. Here and below $\alpha, \beta = 1, \ldots, n,$ for all coordinates, $\mu, \nu = 1, \ldots, m$ for coordinates in the base and $i, k = m+1, \ldots, n$ for coordinates in the fiber.

- In the base M_m a nondegenerate (pseudo)Riemannian metrics is defined whose components depend only on base coordinates $g_{\mu\nu}(x^1, \ldots, x^m)$.
- In the fibers M_{n-m} also a nondegenerate (pseudo)Riemannian metrics $g_{ik}(x^1, \ldots, x^n)$ is defined but its components depend on all coordinates M_n.
- In order to equalize the number of metrics components of the fiber geometry and the (pseudo)Riemannian one the additional metrics components are introduced

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- Denoting $D^{\alpha'}_{\beta} = \partial_{\beta} x^{\alpha'}$, we can write down the matrix of coordinate transformations as

$$(D^{\alpha'}_{\beta}) = \left(\begin{array}{cc} (D^{\mu'}_{\nu}) & 0 \\ (D^{i'}_{\nu}) & (D^{i'}_{k}) \end{array} \right), \quad \det(D^{\mu'}_{\nu}) \neq 0, \, \det(D^{i'}_{k}) \neq 0. \tag{1}$$

- The metric (flag)tensor

$$(g_{\alpha\beta}) = \left(\begin{array}{cc} g_{\mu\nu} & g_{\mu k} \\ g_{i\nu} & g_{ik} \end{array} \right)$$

of semi-Riemannian space V_n^m is transformed under admissible transformations (1) by the formulas

$$g_{\mu'\nu'} = g_{\mu\nu} D^{\mu}_{\mu'} D^{\nu}_{\nu'}, \quad g_{i'k'} = g_{ik} D^{i}_{i'} D^{k}_{k'},$$

$$g_{\mu'i'} = g_{\mu i} D^{\mu}_{\mu'} D^{i}_{i'} + g_{ki} D^{k}_{\mu'} D^{i}_{i'},$$

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- In order to avoid terminological misunderstanding let us stress that the fibering pr has nothing to do with the principal bundle, where some group acts on the fiber.
- In the last approach something similar to a tangent space $(dx^1, \ldots, dx^n)$ is built on the space $(x^1, \ldots, x^n)$ and then unified object $(x^1, \ldots, x^n, dx^1, \ldots, dx^n)$ is regarded as having base $(x^1, \ldots, x^n)$ and fiber $(dx^1, \ldots, dx^n)$.
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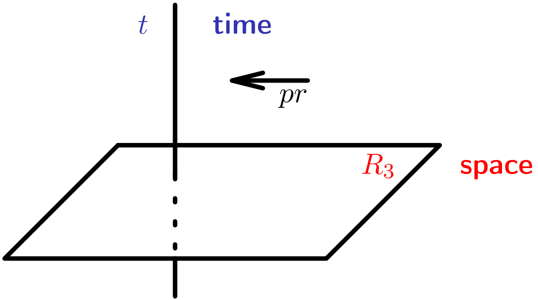
- Very simple and most known example of the semi-Riemannian (or more exactly semi-Euclidean) geometry is the Galilei space-time of classical physics with 1D base, which is interpreted as time axis t, and 3D fiber, which is interpreted as space R_3.



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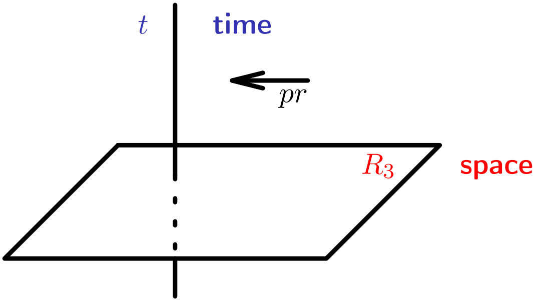

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Semi-Riemannian geometry and group contractions

- In the previous sections semi-Riemannian geometry was constructed for real objects as the structure consistent with fiberig.
- At the same time geometry of this sort can be realized with the help of nilpotent objects.
- In particular, semi-Riemannian space can be obtained from Riemannian space by multiplying fiber coordinates by nilpotent unit

$$\iota x^{m+1}, \ldots, \iota x^n,$$

where $\iota \neq 0$, $\iota^2 = 0$, division $\frac{a}{\iota}$ is defined only for $a = 0$, but $\frac{\iota}{\iota} = 1$.

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- Above transformation induce contraction of the invariance group. For example, under substitution $z_1 \rightarrow \iota z_1$ complex space C_2 turn into the fiber space $C_2(\iota)$ with 1D base $\{z_2\}$ and 1D fiber $\{z_1\}$.
- The space $C_2(\iota)$ has two hermitian forms: one in the base $\bar{z}_2 z_2 = |z_2|^2$ and one in the fiber $\bar{z}_1 z_1 = |z_1|^2$.
- Both forms can be unified in a single expression

$$z^{\dagger} z(j) = j^2 |z_1|^2 + |z_2|^2,$$

where $z^{\dagger} = (j\bar{z}_1, \bar{z}_2)$, and parameter j takes two values: $j = 1, \iota$.

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- The unitary group $SU(2;j)$ is defined as the transformation group

$$z'(j) = \begin{pmatrix} jz'_1 \\ z'_2 \end{pmatrix} = \begin{pmatrix} \alpha & j\beta \\ -j\bar{\beta} & \bar{\alpha} \end{pmatrix} \begin{pmatrix} jz_1 \\ z_2 \end{pmatrix} = u(j)z(j),$$

$$\det u(j) = |\alpha|^2 + j^2|\beta|^2 = 1, \quad u(j)u^\dagger(j) = 1$$

of the space $C_2(j)$, which keep the hermitian form $z^\dagger z(j) = inv$ invariant.
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- But in this case the deep mathematical matter connected with the conception of fiber space and semi-Riemannian geometry is hidden.
- When a limit case of a physical system resulting from the contraction of invariance group is studied, then for the perfect representation of its properties it is necessary to take into account both complementary approaches to the group contraction.

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The Standard Electroweak Model

- **First phenomenological theory of the weak interaction (the theory of beta decay) was developed by E. Fermi in 1934.**
- 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.
- This model is a gauge theory with the gauge group $SU(2) \times U(1)$, which act in the boson, lepton and quark sectors.
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- 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.
- At the same time the grave disadvantage of the Standard Model is the presence more then fifteen free parameters.
- But among these there is not such parameter, which a priori can be regarded as a small one and can be connected with the very rare interaction neutrinos with matter.

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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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- As far as L_B and L_Q are not changed we concentrate our attention on the lepton Lagrangian, which for the first lepton generation is written in the form:

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

- 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.
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- 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, $\tau_0 = \tilde{\tau}_0 = \mathbf{1}$, $\tilde{\tau}_k = -\tau_k$, 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.
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- 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 $U(1)_{em}$, $Y = -\frac{1}{2}1$ is the hypercharge of the left leptons, $e = \frac{gg'}{\sqrt{g^2+g'^2}}$ is the electron charge and $\sin\theta_w = \frac{e}{g}$.

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- **The gauge fields**

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

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

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- **In the Standard Electroweak Model the gauge group $SU(2) \times U(1)$ acts in the boson, lepton and quark sectors, i.e. it is the invariance group of the boson L_B, lepton L_L and quark L_Q Lagrangians.**
- We consider a model where the group $SU(2) \times U(1)$ acts only in the boson and quark sectors, whereas the group $SU(2; j) \times U(1)$ acts in the lepton sector.
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- **The main idea** is that **lepton fields belong to the fiber space** $C_2(j)$ and are 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 transformation of the neutrino fields

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

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

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

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

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

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

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

- Lagrangian $j^2 L_{e,f}$ describe free neutrino and its interactions with electron and gauge fields.
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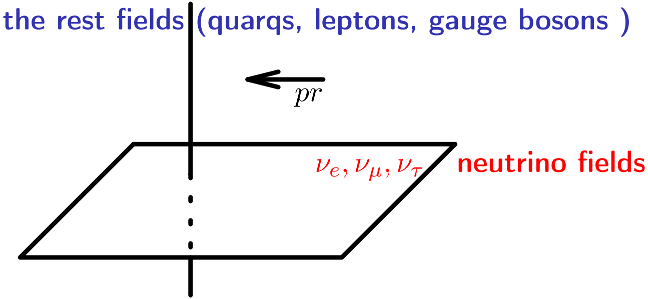
- From geometrical point of view in the limit $j \to 0$ or for $j = \iota$ the neutrino fields are in the fiber and does not act on the rest fields, which are in the base.



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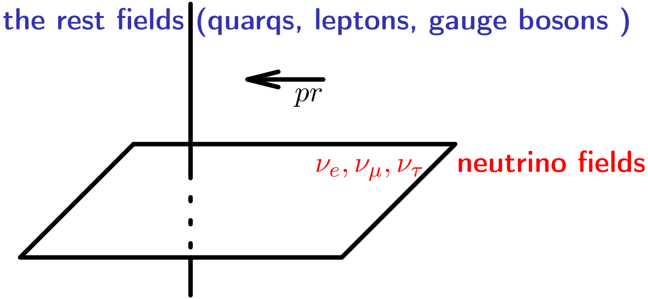

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- In general, ideal mathematical constructions are physically realized approximately with some errors.
- Suppose that contraction parameter j is small, but different from zero. The full Lagrangian of the model

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

is split in two parts:

- the Lagrangian L_ν, which includes neutrino fields along with their interactions with gauge and lepton fields and
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- It is well known, that the space-time of the special relativity is transformed to the nonrelativistic space-time when dimensionfull contraction parameter — velocity of light c — tends to the infinity and dimensionless parameter $\frac{v}{c} \to 0$.
- 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 $G_F = 10^{-5}\frac{1}{m_p^2} = 1,17 \cdot 10^{-5}\, GeV^{-2}$.
- Probability amplitude for weak current interactions which include two neutrino fields for example

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

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$$G_F = j^2 G_0$$

and one can approximate the minimal value of the dimensionless parameter as $j^2{}_{min} \approx 10^{-5}$, when energy is measured in GeV.

- The linear dependence of the neutrinos cross-section for energies $\approx 1\ GeV$ is directly coupled with the multiplication of the probability amplitude for weak current interactions by the factor j^2.

- So the suggested model explain both experimental facts in the neutrino-matter interactions.
- Let my remained that limit transition $c \to \infty$ in special relativity was resulted in the notion of group contraction by E.P. Wigner and E. Inönü (1953).
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Conclusion

In the Standard Electroweak Model all fields (gauge, quarks, leptons) belong to the same space C_2.

The replacement of C_2 by the 3D spherical space S_3 in boson sector eliminates Higgs boson.

(NAG, arXiv:0705.4575v1, arXiv:1009.1456v2, J. Phys.: Conf. Ser., 2008, v.128, 012005; 2011, v.284, 012033.)

The replacement of C_2 by the space $C_2(j)$ in lepton sector explain neutrino properties for low energies already at classical level.

(NAG, Komi SC Scientific Reports №512, Syktyvkar, 2010; arXiv:1010.5512v3.)

What about the replacement of C_2 in quark sector

$$C_2 \to ?$$

This is the open question.

Thank you for your attention.