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LEFT-RIGHT COMPONENTS OF BOSONIC FIELD AND ELECTROWEAK THEORY

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It is shown that the notion of «chirality» in the theory with fundamental mass has a more universal meaning and is applicable not only to fermion but also to boson fields. In the framework of this approach the Higgs sector of the standard model should include apart from the «left» isotopic doublets of scalar fields the «right» scalar singlets as well. Possible experimental consequences of this proposal are shortly discussed.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Левые и правые компоненты бозонного поля и электрослабая теория

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Показано, что в теории с фундаментальной массой понятие «киральности» имеет более универсальный смысл и применимо не только к фермионным, но и к бозонным полям. В рамках этого подхода хиггсовский сектор стандартной модели помимо «левых» изотопических дублетов скалярных полей должен включать также «правые» скалярные синглеты. Кратко обсуждаются возможные экспериментальные следствия этого предположения.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

I. In the Glashow — Salam — Weinberg standard model of electroweak interactions based on the $SU(2)\otimes U(1)$ gauge group, the Higgs scalar, like left and right chiral projections of quarks and leptons, is an $SU(2)$ doublet. However, the notion of chirality doesn't have meaning when applied to boson fields. So the model seems to us to be inconsistent in this point.

We would like to draw attention to the existence of such a formulation of quantum field theory (QFT) when the quantum number «chirality» has a more general and universal meaning than just the eigenvalue of the γ^5 matrix. The new notion of chirality is being spread now not only to fermion fields but to bosonic ones,too. It gives us an opportunity to extend the Higgs sector of the standard model by introducing into consideration separately «left» H_L and «right» H_R scalar fields. Possible experimental consequences are shortly discussed.

II. The formulation of QFT [1—5] mentioned here contains a new high energy scale M that has the simple geometrical meaning. This is the curvature radius of the De Sitter p-space

$$p_0^2 - \mathbf{p}^2 - p_5^2 = -M^2 \tag{1}$$

replacing the Minkowski p-space in the theory. The low energy-momentum region corresponding to the standard theory is identified with the flat limit of the surface (1)

$$|p_0|, |\mathbf{p}| << M, \quad |p_5| \cong M. \tag{2}$$

In the coordinate representation (1) is replaced by a free 5-dimensional equation (the so-called «fundamental equation»)

$$\left[\frac{\partial^2}{\partial x_\mu \partial x^\mu} - \frac{\partial^2}{(\partial x^5)^2} - M^2\right]\varphi(x, x^5) = 0 \tag{3}$$

to be universal for the fields of any tensor type. However, for the spinor ones $\psi(x, x_5)$, besides (3), the 5-dimensional Dirac equation is also fulfilled

$$(\partial_L \Gamma^L + M)\psi(x, x^5) = 0, \tag{4}$$

where Γ^K are five 4×4 matrices with anticommutation relations $\{\Gamma^K, \Gamma^L\} = 2g^{KL}$; $K, L = 0, 1, 2, 3, 5$, $\mathrm{diag}\, g = (+1, -1, -1, -1, -1)$, $\Gamma^5 = i\gamma^5$. All information about the fields $\varphi(x, x^5)$ and $\psi(x, x^5)$ and their interactions is contained in the initial data $(\varphi(x, 0), \partial\varphi/\partial x^5\,(x, 0))$ and $\psi(x, 0)$ for which an adequate Lagrange formalism has been constructed in [1—2]. We consider the corresponding field theory naturally including a new universal constant M as a basis for describing high energy processes under $E \gtrsim M$ beyond the scope of standard model.

When passing to the standard theory as $M \to \infty$, equation (4) turns into

$$(\partial_5 \Gamma^5 + M)\,\psi(x, x^5) = 0 \tag{5}$$

and $\psi(x, x^5)$ reads

$$\psi(x, x^5) = \frac{1+\gamma^5}{2}\psi(x, 0)\, e^{-iMx^5} + \frac{1-\gamma^5}{2}\psi(x, 0)\, e^{iMx^5}. \tag{6}$$

Thus, the ordinary «left» and «right» spinor fields corresponding to different eigenvalues of the γ^5 matrix are amplitudes of the phase multipliers $e^{\pm iMx^5}$.

An analogous definition of chiral fields can be introduced in the bosonic case if the asymptotics of solutions of Eq. (5), when $M \to \infty$, is written in the form like (6). For this purpose let us put

$$\frac{1}{2}\left(\varphi(x, x^5) + i\frac{\partial}{\partial x^5}\varphi(x, x^5)\right) \equiv \varphi_1(x, x^5),$$
$$\frac{1}{2}\left(\varphi(x, x^5) - i\frac{\partial}{\partial x^5}\varphi(x, x^5)\right) \equiv \varphi_2(x, x^5) \qquad (7)$$

and introduce the doublet $\Phi(x, x^5)^T = (\varphi_1(x, x^5), \varphi_2(x, x^5))$. Then, from (3) it follows that

$$\frac{\partial}{\partial x^5}\Phi(x, x^5) = i\left[\sigma^3\left(M - \frac{\Box}{2M}\right) - i\sigma^2\frac{\Box}{2M}\right]\Phi(x, x^5), \qquad (8)$$

where $\Box = \dfrac{\partial^2}{\partial x_\mu \partial x^\mu}$ and σ^2, σ^3 are the Pauli matrices. Thus, if $M \to \infty$,

$$\Phi(x, x^5) = \frac{1 + \sigma^3}{2}\Phi(x, 0)\,\mathrm{e}^{-iMx^5} + \frac{1 - \sigma^3}{2}\Phi(x, 0)\,\mathrm{e}^{-iMx^5}. \qquad (9)$$

One can see, comparing (6) and (9), that σ^3 plays the role of the γ^5 matrix, and the components $\varphi_1(x, x^5)$ and $\varphi_2(x, x^5)$ of the doublet $\Phi(x, x^5)$ can be considered as scalar «left» and «right» fields analogous to left and right chiral projections ψ_L and ψ_R of the spinor field.

III. Following the Glashow — Salam — Weinberg model we place left scalar fields into isotopic doublets and consider right spinors and scalars as isosinglets. It is natural to identify left scalar doublets with Higgs fields and assign to them the proper value of hypercharge $Y = 1$. The occurrence of right scalar singlets is beyond the scope of the standard model. Meanwhile two essentially different cases are possible — charged and uncharged fields.

Let us discuss the properties of charged right singlets marked by H_R^+ and H_R^- according to the sign of their charge. First of all particles of that type could be clearly observed in experiments at electron-positron colliders in the processes $e^+e^- \to \gamma \to H_R^+ H_R^-$ or $e^+e^- \to Z_0 \to H_R^+ H_R^-$. For example, the cross-section of the first process beyond the threshold is about 1/4 of the section of the process $e^+e^- \to \gamma \to \mu^+\mu^-$ [6]. So far as charged scalar particles were not yet observed, their mass must not be less than half the neutral vector boson mass. Interactions of $H_R^\pm$ with quarks and leptons and also with vector W-bosons appear sufficiently weak as the corresponding interaction terms are absent in the Lagrangian of the theory.

The prediction of uncharged right scalar particles H_R^0 also seems interesting. From the Gell - Mann - Nishidgima relation one can infer that such particles have zero hypercharge and very weakly interact with the other matter. They resemble in this respect right neutrinos ν_R with which they can be coupled in the Yukawa manner

$$f \bar{\nu}_R^c \nu_R H_R^0 + \text{h.c.}, \tag{10}$$

where f is a constant and $\bar{\nu}_R^c$ is the spinor charge conjugated to ν_R. If H_R^0 gets nonzero vacuum expectation value, these interactions give rise to Majorana masses of right neutrinos and lepton number nonconservation. The corresponding Goldstone boson was called the majoron [7]. This circumstance is used in a number of generalizations of the standard electroweak model, in the Glashow work [8], for example, where a suggested model describes both the solar neutrino deficit and the existence of the so-called 17-keV neutrino revealed by Simpson [9].

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