ON THE POSSIBLE UNIVERSAL NEUTRINO INTERACTION

Translated and reprinted from Pis'ma ZhETF (JETP Lett.) **16**, no. 11, pp. 621–624 (1972)

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Much attention in elementary particle physics has been paid recently to the possible degeneracy of vacuum and the respective spontaneous breaking of various symmetries. The most direct consequence of the vacuum degeneracy is the appearance of zero-mass particles, the so-called Goldstone particles [1].

Of all the presently known elementary particles, only neutrinos, photons, and gravitons have zero mass. The last two, however, correspond to gauge fields and do not require apparently the vacuum degeneracy for their description. Therefore, a neutrino is the only particle, whose existence can be directly related to the vacuum degeneracy.

The purpose of this study is to point out that the hypothesis that a neutrino is the Goldstone particle leads to a definite form of the interaction of a neutrino both with other neutrinos and with all other particles. The interaction is fully defined by a single phenomenological coupling constant and is universal in this sense.

To determine the type of a symmetry, whose spontaneous violation causes the degeneracy of vacuum and the corresponding properties of a neutrino as the Goldstone particle, let us consider the symmetry properties of the equation for a free neutrino

$$i\sigma_\mu \frac{\partial}{\partial x_\mu}\,\psi = 0. \qquad (1)$$

This equation is invariant with respect to the Poincaré group, chiral transformations, and shifts in the spinor space, i.e., with respect to transformations of the form

$$\psi \to \psi' = \psi + \zeta,$$

$$x \to x' = x, \qquad (2)$$

where ζ is a constant spinor that anticommutes with ψ.

We retain the character of the transformations of x_μ and ψ under transformations of the Poincaré group and replace transformations (2) by the transformations

$$\psi \to \psi' = \psi + \zeta,$$

$$\psi^+ \to \psi^{+\prime} = \psi^+ + \zeta^+,$$

$$x_\mu \to x'_\mu = x_\mu - \frac{a}{2i}\,(\zeta^+\sigma_\mu\psi - \psi^+\sigma_\mu\zeta). \qquad (3)$$

The resultant structure with ten commuting and four anticommuting parameters has the structure of a group[2] and is the only possible generalization of (2) without introducing additional group parameters.

The constant a in transformations (3) is arbitrary and has the dimension of length raised to the fourth power. We postulate that the equations for a neutrino with regard for the interaction are invariant under transformations (3). We assume also that the interaction terms contain the minimum number of field derivatives which is compatible with the invariance requirement.

To construct the phenomenological action integral under the foregoing assumptions, it suffices to use the following differential forms which are invariant under transformations (3):

$$\omega_\mu = dx_\mu + \frac{a}{2i}\,(\psi^+\sigma_\mu d\psi - d\psi^+\sigma_\mu\psi). \qquad (4)$$

The action integral invariant under transformations (3) and those of the Poincaré group is given by

$$S = \frac{1}{a}\int \omega_0\,\Lambda\omega_1\,\Lambda\omega_2\,\Lambda\omega_3, \qquad (5)$$

where the symbol Λ stands for an external product. Expression (5) corresponds to a certain four-dimensional invariant volume in the space of group parameters.

While determining the 4-volumes, the action integral (5) can be written, by specifying the function $\psi = \psi(x)$, in the more usual form as

$$S = \frac{1}{\sigma}\int |W| d^4x. \qquad (6)$$

Here, $|W|$ is the determinant of the matrix W,

$$W_{\mu\nu} = \delta_{\mu\nu} + \sigma T_{\mu\nu},$$

[2] Lie groups with commuting and anticommuting parameters were recently considered by Berezin and Kats in [2].

$$T_{\mu\nu} = \frac{1}{2i}(\psi^+\sigma_\mu\partial_\nu\psi - \partial_\nu\psi^+\sigma_\mu\psi). \quad (7)$$

It follows from (6) and (7) that the action integral as a function of the tensor T takes the form

$$S = \int \Bigg[\frac{1}{\sigma} + T_{\mu\mu} + \frac{a}{2}(T_{\mu\mu}T_{\nu\nu} - T_{\mu\nu}T_{\nu\mu} +$$

$$+\frac{a^2}{3!}\sum_p (-1)^p T_{\mu\mu}T_{\nu\nu}T_{\rho\rho} +$$

$$+\frac{a^3}{4!}\sum_p (-1) T_{\mu\mu}T_{\nu\nu}T_{\rho\rho}T_{\sigma\sigma}\Bigg] d^4x, \quad (8)$$

where the symbol $\sum_p$ stand for a sum over all the permutations of the second indices in the products of the tensors T.

The term with $T_{\mu mu}$ corresponds to the kinetic terms, and the terms with products of two, three, and four tensors T describe interactions, in which four, six, and eight fields, respectively, participate. The degrees of the field derivatives in the interaction terms are determined by the number of factors T.

The neutrino interaction with other fields can be determined in a manner that is invariant with respect to transformations (3). Thus, for example, the action integral for a Dirac particle is given by

$$S = \int \Bigg[R_{\mu\mu} + a(R_{\mu\mu}T_{\nu\nu} - R_{\mu\nu}T_{\nu\mu}) + \frac{a^2}{2}\sum_p (-1)^p \times$$

$$\times R_{\mu\mu}T_{\nu\nu}T_{\rho\rho} + \frac{a^3}{3!}\sum_p (-1)^p R_{\mu\mu}T_{\nu\nu}T_{\rho\rho}T_{\sigma\sigma} +$$

$$+ m\bar{\phi}\phi|W|\Bigg] d^4x, \quad (9)$$

where

$$R_{\mu\nu} = \frac{1}{2i}(\bar{\phi}y_\mu\partial_\nu\phi - \partial_\nu\bar{\phi}y_\mu\phi), \quad (10)$$

and the tensor T and the determinant $|W|$ are defined in (7). Weak interactions can be included in the scheme under consideration by introducing the gauge fields for the approximate unitary symmetry group of the neutrino and other leptons. In this case, the electromagnetic interaction for charged leptons is introduced simultaneously. The weak and electromagnetic interactions are switched on simultaneously by the well-known mechanism of spontaneous breaking of the unitary-group symmetry [3]. In the zero-lepton-mass limit, the unitary symmetry is exact. To obtain the action integral for the leptons in the unitary-symmetry limit, it suffices to regard the spinor products in (3), (4), and (7) as invariant products of unitary multiplets. It is also possible to add the terms for leptons with opposite chiralities to formulas (3), (4), and (7). In this case, the unitary groups for states with different chiralities need not necessarily coincide. The gauge fields can be introduced into the action integral generalized in such a manner covariantly with respect to transformations (3). The gravitational interaction can be introduced into the scheme analogously, by introducing the gauge fields corresponding to the Poincaré group. We note that if we introduce also gauge fields corresponding to transformations (3), then, as a consequence of the Higgs effect [4], a massive gauge field with spin 3/2 arises, whereas the Goldstone particles with spin 1/2 vanish.

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Received October 13, 1972

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Dmytro Vasyl'ovych Volkov was the outstanding physicist-theoretician, Full Member of the National Academy of Sciences (NAS) of Ukraine (1988), winner of the International W. Thirring's prize (1997). He is the founder of a scientific school in the theory of elementary particles. From 1956 till 1996, he worked at Kharkov Institute of Physics and Technology (now National Scientific Center "Kharkov Institute of Physics and Technology" of the NAS of Ukraine); during 1967–1996, he was Head of a laboratory of Kharkov Institute of Physics and Technology. The scientific papers by D.V. Volkov were devoted to problems of quantum electrodynamics (scalar quantum electrodynamics, generalization of quantum statistics – parastatistics), theory of Regge poles [1], theory of higher symmetries and spontaneous vacuum transitions in the dual models of elementary particles, development of the method of phenomenological Lagrangians and its applications to the theory of elementary particles and condensed-matter physics [3]. D.V. Volkov proposed and constructed a generalized model which unified the internal symmetry group of Goldstone particles with the Poincaré group. He proposed a new type of the symmetry of bosons and fermions – supersymmetry [2] which is a basis for the construction of modern unified theories of fundamental interactions; developed a local generalization of the supersymmetry – supergravity [4]. D.V. Volkov proposed and constructed the twistor-like approach to superstrings and superbranes which is a key ingredient in the covariant quantization of these relativistic objects.

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