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ON A NONMINIMAL GAUGE INTERACTION OF A SCALAR FIELD IN D=2+1 CHERN-SIMONS-MAXWELL THEORY

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The consequences of spontaneous symmetry breaking are considered in a model, describing nonminimal gauge interaction of a scalar field (analogous to that of spin-1/2 particle with anomalous magnetic momentum). It is shown that the gauge field Chern-Simons term can be generated as a result of symmetry breaking if it was not initially present in the action and, at the same time, the Maxwell term can be canceled by symmetry breaking corrections.

9 refs.

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Латинский С.М., Сорокин Д.П. О неминимальном калибровочном взаимодействии скалярного поля в D=2+1 теории Черна-Саймонса-Максвелла: Препринт ХФТИ 91-12, Харьков, 1991, 6 с.

Рассмотрены последствия спонтанного нарушения симметрии в модели, описывающей неминимальное калибровочное взаимодействие заряженного скалярного поля (аналогичное взаимодействию частицы со спином 1/2, обладающей аномальным магнитным моментом). Показано, что в результате спонтанного нарушения симметрии может генерироваться Черн-Саймоновское действие для калибровочного поля и, в то же время, Максвелловский член может исчезнуть в результате компенсирующих вкладов, возникающих при спонтанном нарушении симметрии.

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The Chern-Simons-Maxwell (CSM) theory [1] attracts a great deal of attention due to its connection with problems of topological field theory [2], anyon statistics and spin [3], high temperature superconductivity [4], and other effects in the field theory and solid state physics.

The various aspects of the theory has been intensively discussed in the literature including the phenomenon of spontaneous symmetry breaking and its influence on CSM system [5,6]. It was shown, for example, that in a theory with pure Chern-Simons (CS) action the Higgs effect converts non-dynamical gauge vector field into topologically massive helicity 1 photon state [5]. At the same time, when the conventional Maxwell kinetic term is also present in theory's action, the spontaneous symmetry breaking results in two vector field states with opposite helicities and different masses [6].

In present note we consider the consequences of spontaneous symmetry breaking in a model, describing nonminimal gauge interactions of a charged scalar field. It will be shown that the CS term can be generated as a result of symmetry breaking phenomenon if it was not present in the action from the beginning and, on the contrary, the Maxwell term can be canceled by symmetry breaking corrections. If the CS term is initially present in the theory, a "spin-flip" effect can take place in spontaneously broken phase which manifests in changing of the sign of vector field helicity associated with the sign of the CS term.

In the Appendix the group-theoretical approach to connect the CS term with the conventional mass term is discussed.

One of the motivations to introduce the nonminimal gauge interaction in the form considered below is its natural appearance in the generalized model of relativstic particles, based on the twistor approach [7]. It also has the similarity with the anomalous magnetic momentum term for spin 1/2 particle.

So we start with reminding of the notion of anomalous magnetic momentum of spin 1/2 particle and discussion of its peculiarities in D=2+1 space-time dimensions.

The Dirac equation for charged spinor field with anomalous magnetic momentum interacting with abelian gauge field $A_m(x)$ has the

form $$[(\partial_m + iA_m)\gamma^m - \frac{l}{2}F_{mn}\gamma^m\gamma^n]\Psi(x) = 0 \qquad (1)$$

Where γ^m are D=2+1 Dirac matrices (m=0,1,2 and the metric signature is chosen to be (+,-,-)), $F_{mn}= \partial_m A_n - \partial_n A_m$ being the field stress tensor and l is a parameter of length dimension, which characterizes the value of magnetic momentum. A_m has the dimension of l^{-1} and the gauge coupling constant e (which is hidden into A_m) has the dimension of $l^{-1/2}$. In D=2+1 γ^m satisfy the relation $\gamma^m\gamma^n=g^{mn}- i\varepsilon^{mnl}\gamma_l$, which allows one to rewrite eq.(1) in a following way:

$$(\partial_m + iA_m + i\frac{l}{2}\varepsilon_{mnl}F^{nl})\gamma^m\psi = 0 \ . \qquad (2)$$

Thus to take into account the gauge interaction, caused by anomalous magnetic momentum of a particle in D=2+1 one has to add the dual vector $F_m=\varepsilon_{mnl}F^{nl}$ to the gauge field potential A_m. This procedure can be applied to scalar fields $\Phi(x)$ as well, for which the equation of motion takes the form

$$(\partial_m + iA_m + i\frac{l}{2}F_m)^2\Phi(x) = 0. \qquad (3)$$

The action, from which the eq.(3) can be obtained is written as follows

$$S = \int d^3x[|(\partial_m + iA_m + i\frac{l}{2}F_m)\Phi|^2 - V(|\Phi|^2) + \theta\varepsilon^{mnl}A_m\partial_n A_l - \frac{1}{4e^2}(F_{mn})^2] \qquad (4)$$

where $V(|\Phi|^2)$ potential of a Higgs type has been taken into account, Φ has the dimension of $l^{-1/2}$ and θ is a dimensionless parameter, proportional to a gauge field topological mass and coupling constant ratio [1] in unbroken symmetry phase. It seems interesting to make a group-theoretical explanation of the connection between topological (Chern-Simons) and conventional mass

terms, which we reproduce in the Appendix.

One can rewrite action (4) in the following form

$$S = \int d^3x [|(\partial_m + lA_m)\Phi|^2 - V(|\Phi|^2) + \frac{1}{2} l F_m j^m$$
$$+ (\theta + l|\Phi|^2)\varepsilon^{mnl} A_m \partial_n A_l - (1/4e^2 - l^2|\Phi|^2/2)(F_{mn})^2]. \quad (5)$$

(where $j^m = i(\Phi^* \partial_m \Phi - \Phi \partial_m \Phi^*)$ is a free scalar field current) and notice that nonminimal interaction terms contribute to the CS and Maxwell terms. It is essential, that the contribution to the latter one occurs with the opposite sign. One can see, that nonminimal interaction survives even when the charge of Φ is equal to zero.

When the vacuum expectation value of Φ is nonzero ($\langle\Phi\rangle = \mu$) and the gauge symmetry is spontaneously broken (this is indeed the minimum of the Hamiltonian in the long-wave approximation to which consideration we restrict ourselves) the effective vectorfield action takes the form

$$S = \int d^3x [-(\frac{1}{4} - \frac{l^2}{2}\mu^2 e^2) F_{mn}^2 + e^2(\theta + l\mu^2)\varepsilon^{mnl} A_m \partial_n A_l + (e\mu)^2 A_m A^m], \quad (6)$$

where the vector field redefinition, $A_m \to A_m/e$, has been made. The analysis of the action (6) allows one to draw the following conclusions. The contribution to the Maxwell term leads to rescaling of coupling constant. And if the CS term was not initially present in the theory ($\theta = 0$) we see, that it appears as a result of spontaneous symmetry breaking. The generation of the CS term by radiative corrections in scalar electrodynamics with spontaneously broken parity was considered previously in [8].

There are two critical points of the symmetry breaking parameter μ^2, in which the dynamics of vector field is drastically changed.

One of them is $\mu^2 = 1/(2l^2 e^2)$, where the Maxwell term disappears from (6) and we obtain the theory, discussed in refs. [5]. Note,

that for $\mu^2>1/(2l^2e^2)$, Maxwell term acquires the wrong sign, which leads to the nonunitarity of the theory in this sector.

The another critical point is $\mu^2=-\theta/l$, where the CS term vanishes and the conventional massive vector field action is restored. It is just in this point "spin-flip" effect takes place: because of the absence of correlation between θ and l signs we get opposite vector-field helicities, depending on whether $\mu^2>-\theta/l$ or $\mu^2<-\theta/l$.

Outside the critical points action (6) describes two vector field states with the opposite helicities and different masses [6].

It ought to be stressed, that the model discussed above should be considered as an effective theory, which is valid in the long-wave approximation and for small values of l parameter.

It would be interesting to realize to what extent this model or any its modification (for example, taking into account terms with higher l's powers) can lead to consistent renormalizable quantum field theory.

It seems also interesting to study spin-statistical properties of the field $\Phi(x)$ in connection with possible appearance of anyons [3], as well as to look for vertex-type solutions [9] and possible applications to describe physical effects in solid-state physics.

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Appendix.

Here we would like to make a remark on how one can understand the connection between topological (CS) and conventional mass terms for vector field from group-theoretical point of view.

If it is proved, that the CSM theory describes massive vector states then one can impose on A_m the Lorentz condition $\partial_m A^m=0$ to extract the corresponding physical degrees of freedom and consider

$A_m(x)$ as the irreducible representation of the $D=2+1$ Poincare group. The Poincare algebra (M_{mn}, P_l) in $D=2+1$ has two principal Casimir operators $P_l^2 = m^2$, $(1/2)\,\varepsilon^{mnl} M_{mn} P_l = sm$, where m and s being a particle mass and helicity respectively. Thus, to describe physical states with definite m and $s=\pm 1$ $A_m(x)$ must satisfy the following conditions :

$$(P_l^2 - m^2)A_m = 0, \qquad (i)$$

$$\frac{1}{2}(\varepsilon^{ikl} M_{ik} P_l)A_m = sm\, A_m \qquad (ii)$$

where $P_l = i^{-1}\partial/\partial x^l$, and $(M_{ik})_{mn} = i(g_{im}g_{kn} - g_{in}g_{km})$ for vector representation of the Poincare group. Substituting this operator realization into eq.(ii) and multiplying both its sides by A_m one immediately gets the relation

$$\varepsilon^{mnl} A_m \partial_n A_l = sm\, A_m A^m,$$

which presents the correspondence between the topological and conventional mass terms.

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О НЕМИНИМАЛЬНОМ КАЛИБРОВОЧНОМ ВЗАИМОДЕЙСТВИИ СКАЛЯРНОГО ПОЛЯ В Д = 2+I ТЕОРИИ ЧЕРНА-САЙМОНСА-МАКСВЕЛЛА

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