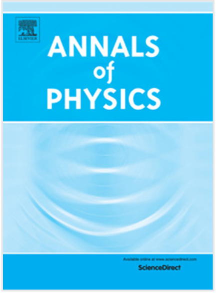

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Chiral transformations of spin-1 mesons in the non-symmetric vacuum

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A new sort of chiral transformations for spin-1 states is obtained as a result of a linearized diagonalization of πa_1 mixing in the effective meson Lagrangian. Using this symmetry argument, we argue that there is no physical distinction between such theory and the theory in which a covariant nonlinear diagonalization is used instead. As an illuminating example, the Nambu – Jona-Lasinio type model with the broken $SU(2)\times SU(2)$ chiral symmetry in the one-quark-loop approximation is considered.

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I. INTRODUCTION

The chiral transformations of meson fields are well established both for linear and nonlinear realizations of a Lie group [1–9]. It is also known that when the symmetry is spontaneously broken the chiral Lagrangians with spin-1 mesons contain a cross term $\vec{a}_\mu\partial^\mu\vec{\pi}$, i.e. the axial-vector $\vec{a}_\mu$ and pseudoscalar $\vec{\pi}$ fields mix [3]. As a consequence, one should diagonalize the free part of the Lagrangian by introducing a physical axial-vector field $\vec{A}_\mu$. In particular, the non-diagonal term $\vec{a}_\mu\partial^\mu\vec{\pi}$ can be eliminated by a linearized transformation $\vec{a}_\mu=\vec{A}_\mu+c\partial_\mu\vec{\pi}$ [10–13]. This conventional replacement, however, ruins the transformation law of the axial-vector field. Because of that, in the literature, the linearized transformation is considered to be a source of all sorts of apparent symmetry breakings [14].

In fact, to elliminate the πa_μ mixing, one can use the nonlinear transformation $\vec{a}_\mu=\vec{A}_\mu+\vec{\xi}_\mu$ [3, 7, 14, 15], where the formal series for $\vec{\xi}_\mu$ (in powers of meson fields) starts with a derivative $c\partial_\mu\vec{\pi}$. Additionally, one can always arrange that $\vec{\xi}_\mu$ transforms as the axial-vector field $\vec{a}_\mu$. Such a diagonalization affects the interaction part of the Lagrangian introducing new vertices but conserves the transformation properties of the spin-1 fields. One can describe this situation by saying that the chiral dynamics protects the transformation laws of spin-1 fields from changes in the non-symmetric vacuum.

Actually there are no valid field theoretical objections to the following alternative idea: subject to a linearized diagonalization which does not affect the interaction part of the Langrangian, the chiral transformation laws of spin-1 fields undergo changes that leave the Lagrangian invariant. To pursue this idea one should find a suitable choice of meson fields and their transformations (induced by the chiral group on them), and show invariance explicitly. If the problem has a solution, we can claim that the chiral symmetry of the Lagrangian is preserved. The statement made in [14] is somehow too frustrating and is based most probably on the assumption that the indicated problem does not have any solution. Here we show that it does (see also [16]). This proves that the linearized transformation does not lead to chiral symmetry breaking, although it changes the chiral transformation properties of the axial-vector and vector fields in the non-symmetric ground state. We find an infinitesimal form of these transformations and show that all group properties are fulfilled.

To find the chiral transformation laws of meson fields in the non-symmetric vacuum it is instructive to use a Nambu–Jona-Lasinio Lagrangian which includes both spin-0 and spin-1 $SU(2)_L\times SU(2)_R$ symmetric four-quark interactions. This Lagrangian undergoes symmetry breaking. The symmetric phase is unstable because the minimum of the effective potential occurs for a non-zero value of a scalar field. The model relates both phases and gives a solid tool for our study of the symmetry aspects in question. Indeed, after some standard redefinitions, one can track the chiral transformation properties of the fields starting from fundamental quarks in the Wigner-Weyl phase and up to the meson quark-antiquark bound states in the Nambu-Goldstone phase.

The outline of the paper is as follows. The effective quark Lagrangian with $SU(2)_L\times SU(2)_R$ symmetric four-quark interactions is presented in Section II. Here we introduce the auxiliary bosonic variables and obtain their transformation properties as a consequence of transformation laws of fundamental quarks. Section III is devoted to the computation of an effective potential. It gives an unified description of all possible ground states of the model. In Section IV we discuss the solution of the πa_μ mixing problem, showing that the linearized diagonalization leads to new chiral transformation laws of spin-1 fields. This section contains the main result of our paper. In Section V the meson effective Lagrangian is obtained in the one-quark-loop approximation. In Section VI we give support to the correctness of the above new chiral transformation laws by applying them to the effective meson Lagrangian. We show explicitly that the interaction part of the effective meson Lagrangian is invariant under the chiral transformations found. The divergence of the axial-vector current is calculated and the standard PCAC relation is obtained. In Section VII we compare the Lagrangian obtained with the results of other approaches and show that on the mass shell all of them are equivalent. We summarize our results in Section VIII. Finally, in the Appendix A we collect some useful formulae and our conventions describing a Wick rotation