Dynamical Chiral Symmetry Breaking on the Light Front

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Abstract

A method of describing the dynamical chiral symmetry breaking (DχSB) on the light front (LF) is exemplified in the chiral Yukawa model which is closely related to the NJL model.

1. Question – How does a trivial LF vacuum allow DχSB to occur?

In the light-front (LF) formalism [1], quantization is performed with $x^+ = (t+z)/\sqrt{2}$ being time instead of t. Then, the vacuum becomes very simple due to kinematical reason and in some cases is equivalent to the Fock vacuum defined perturbatively. However, when we try to apply this formalism to QCD, this most desired property itself raises a question because it seems to contradict the usual QCD vacuum with rich structure. Among various "vacuum physics," the dynamical chiral symmetry breaking (DχSB) is of special importance for hadron physics at low energy. Therefore we investigate how DχSB is described on the LF using very familiar example – the NJL model. For more details, see our recent paper [2, 3].

2. Answer – Importance of longitudinal zero modes of fermion bilinears

As for spontaneous symmetry breaking in scalar models, we know that an important role is played by a longitudinal scalar zero mode (ZM), which is not a dynamically independent field in the DLCQ (Discretized Light-Cone Quantization) approach. Indeed we have a constraint relation for the ZM, the so-called "zero-mode constraint (ZMC)," and a nonzero condensate is accessible only through a nontrivial (nonperturbative) solution to the ZMC. Can we apply this method to the NJL model? Of course the NJL model does not possess scalar fields as fundamental degrees of freedom, but the idea can be applied to the model

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once we introduce auxiliary fields for the fermion bilinears $\bar{\Psi}\Psi, \bar{\Psi}i\gamma_5\Psi$ and further raise them to dynamical variables. Thus, we consider the chiral Yukawa model, which reproduces the NJL model in the infinitely heavy mass limit of scalars.

The ZMC of the chiral Yukawa model is very complicated but we can exactly solve it in classical theory. As a result we can explicitly construct the chiral charge and so on. In quantum theory, however, to solve the ZMC is extraordinary difficult because the equation to be solved is now an operator equation and we must consider the problem of operator ordering. In actual calculation, we discuss with fixed operator ordering. For the purpose of describing the broken phase within our framework, it is necessary to deal with the ZMC *nonperturbatively* in a *quantum* treatment. Since we do not have much space, let us give a brief summary of our results. A thorough discussion is in Ref. [2].

1. First of all, we find that in the lowest order of $1/N$ expansion (N is the number of fermions), the ZMC becomes the gap equation for a chiral condensate. When we identify the lowest ZMC with the gap equation, a careful treatment of infrared divergence is required. To choose a nontrivial solution of the gap equation corresponds to working in the broken phase.

2. The coexistence of triviality of null-plane chiral charge $Q_5^{\rm LF}|0\rangle = 0$ and nonzero chiral condensate $\langle 0|\bar{\Psi}\Psi|0\rangle \neq 0$ is realized because the transformation law of the fields change in the broken phase. That is, $[Q_5^{\rm LF}, \bar{\Psi}i\gamma_5\Psi] \neq 2i\bar{\Psi}\Psi$ but it gives a consistent result $\langle 0|[Q_5^{\rm LF}, \bar{\Psi}i\gamma_5\Psi]|0\rangle = 0$.

3. Masses of the scalar and pseudoscalar bosons are obtained from the poles of their propagators. The Gell-Mann, Oakes, Renner relation for the pseudoscalar boson (pion) is explicitly checked.

4. We can derive the PCAC relation and understand the nonconservation of the chiral charge is due to a divergent behavior of the pseudoscalar zero mode in the chiral limit.

In Ref. [3], we consider the NJL model without introducing auxiliary fields. There, we have a complicated constraint equation for the bad component of fermion and find that it plays the same role as that of the ZMC.

References

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