Mass Splitting of σ and a_0 from the Strong $U_A(1)$ Breaking

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The recent analyses of the experimental data based on the chiral symmetry suggest the existence of the low-lying nonet scalar mesons: $a_0(980)$, $\kappa(900)$, $\sigma(500)$ and $f_0(980)$ [1]. We study the low-lying nonet scalar mesons using the extended three-flavor Nambu-Jona-Lasinio (NJL) model that includes the $U_A(1)$ breaking 6-quark interaction. This model has been recently applied to study the radiative decays of the η meson and it has been shown that the η-meson mass, the $\eta \to \gamma\gamma$, $\eta \to \gamma\mu^-\mu^+$ and $\eta \to \pi^0\gamma\gamma$ decay widths are in good agreement with the experimental values when the $U_A(1)$ breaking is strong, namely, the contribution from the $U_A(1)$-breaking interaction to the dynamical mass of the up and down quarks is about 44% of that from the usual $U_L(3) \times U_R(3)$ invariant four-quark interaction [2].

We find that the strong $U_A(1)$ breaking interaction gives rise to the $300 \sim 400$ MeV mass splitting of the σ and a_0 mesons and the observed masses are reproduced reasonably well. The $U_A(1)$ breaking interaction gives rise to the flavor mixing too. We define the mixing angle θ by $\lambda^\sigma \equiv \cos\theta\lambda^8 - \sin\theta\lambda^0$, $\lambda^{f_0} \equiv \sin\theta\lambda^8 + \cos\theta\lambda^0$ (ideal mixing angle is -54.7°). We obtain the mixing angle $\theta = -77.3°$. It indicates that the σ meson has some amount of the strange quark component.

Another way of explaining the mass splitting of the σ and a_0 mesons is to introduce the $qq\bar{q}\bar{q}$ structure of the scalar meson rather than the simple $q\bar{q}$ structure [3]. In this case, the spectrum of the nonet scalar mesons is clearly understood, though the chiral property of the scalar meson is less clear. On the contrary, in the NJL model the scalar mesons are represented as the chiral partners of the pseudoscalar mesons which are the Goldstone bosons associated with the spontaneous breaking of chiral symmetry.

Since the special mass relation: $m_\sigma \simeq 2m_q$ (m_q is the constituent quark mass) holds in the NJL model, it may be better to study the scalar meson masses using the model with the different mechanism of the dynamical chiral symmetry breaking. Recently the properties of the η and η' mesons have been studied using the improved ladder Schwinger-Dyson and Bethe-Salpeter equations in which the one gluon exchange kernel with the one-loop running coupling constant is used [4]. The effect of the $U_A(1)$ anomaly has been introduced by the $U_A(1)$ breaking 6-quark flavor-mixing interaction. We are now studying the scalar meson masses in this approach and we hope we shall report our results in the improved ladder QCD too.

References

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