A Chiral Lagrangian Framework for Scalar Mesons

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The experimental and theoretical status of the light scalar mesons is summarized, and the main aspects of their inclusion into a non-linear chiral Lagrangian framework of refs. [1,2,3,4] is briefly discussed.

Scalar mesons play important roles in low-energy QCD, and are at the focus of many theoretical and experimental investigations. Scalars are important from the theoretical point of view because they are Higgs bosons of QCD and induce chiral symmetry breaking, and therefore, are probes of the QCD vacuum. Scalars are also important from a phenomenological point of view, as they are very important intermediate states in Goldstone boson interactions away from threshold, where chiral perturbation theory is not applicable. There are 9 candidates for the lowest-lying scalar mesons ($m < 1$ GeV): $f_0(980)$ [I=0] and $a_0(980)$ [I=1] which are well established experimentally [5]; $\sigma(560)$ or $f_0(400-1200)$ [I=0] with uncertain mass and decay width [5]; and $\kappa(900)$ [I=1/2] which is not listed but mentioned, in PDG 2000 [5]. The $\kappa(900)$ is only observed in some theoretical models. It is known that a simple $q\bar{q}$ picture does not explain the properties of these mesons. Different theoretical models that go beyond a simple $q\bar{q}$ picture have been developed, including: MIT bag model [6], $K\bar{K}$ molecule [7], unitarized quark model [8], QCD sum-rules [9], and chiral Lagrangians [1,2,3,4].

Chiral Lagrangians, the main focus of this article, provide a powerful framework for studying scalars probed in different Goldstone boson interactions ($\pi\pi$, πK, $\pi\eta$,...) away from threshold [1,2,3,4]. In this approach, a description of scattering amplitudes which are, to a good approximation, both crossing symmetric and unitary is possible. To construct scattering amplitudes, all contributing intermediate resonances up to the energy of interest are considered, and only tree diagrams (motivated by large N_c approximation) are taken into account. In this way, crossing symmetry is satisfied, but the constructed amplitudes should be regularized. The regularization procedure in turn unitarizes the scattering amplitude. Finally, by fitting the resulting scattering amplitude to experimental data, the unknown physical properties

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(mass, decay width, ...) of the light scalar mesons can be extracted. A $\sigma(560)$ and a $\kappa(900)$ are required in order to describe experimental data on $\pi\pi$ and πK scattering amplitudes, respectively. Therefore, this approach suggests the existence of a scalar meson nonet, N, below 1 GeV (containing $\sigma(560)$, $f_0(980)$, $\kappa(900)$, and $a_0(980)$). Rewriting the Lagrangian in terms of N involves terms that mix the two isosinglet combinations $(N_1^1 + N_2^2)/\sqrt{2}$ and N_3^3. This mixing can be parametrized in terms of an a priori unknown scalar mixing angle, the value of which can be determined by requiring consistency with different available experimental data. It is shown in [2] that

$$\begin{pmatrix} \sigma \\ f_0 \end{pmatrix} = \begin{pmatrix} \sim 0.94 & \sim -0.34 \\ \sim 0.34 & \sim 0.94 \end{pmatrix} \begin{pmatrix} N_3^3 \\ \frac{N_1^1+N_2^2}{\sqrt{2}} \end{pmatrix}$$

This is closer to a 4-quark assignment for the lowest-lying scalars, and therefore, agrees with a non $q\bar{q}$ nature of these light scalars.

The next-to-lowest scalars (1 GeV $< m <$ 2 GeV) are: $K_0^*(1430)$ [I=1/2], $a_0(1450)$ [I=1], $f_0(1370)$, $f_0(1500)$, $f_J(1710)$ [I=0], and are all listed in [5]. These states are generally believed to be closer to $q\bar{q}$ objects, except $f_0(1500)$ which is believed to contain a large glue component and therefore a good candidate for the lowest scalar glueball state. Within the chiral Lagrangian framework described above, the properties of the next-to-lowest-lying scalar nonet which includes $K_0^*(1430)$ [I=1/2] and $a_0(1450)$ [I=1] can also be studied. Some puzzling features on their mass and decay widths can be explained based on a mixing mechanism between underlying $q\bar{q}$ and $qq\bar{q}\bar{q}$ nonets [4].

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