

Hadron Resonances Within a Constituent-Quark Model

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In order to get a more realistic description of the hadron spectrum we extend a constituent-quark model by explicit mesonic degrees of freedom. The resulting system of constituent (anti)quarks, which are subject to an instantaneous confining force, and mesons, which couple directly to the quarks, is treated by means of a relativistic coupled-channel framework. It can be formally shown that the mass-eigenvalue problem for such a system is equivalent to a hadronic eigenvalue problem in which the eigenstates of the pure confinement potential (bare hadrons) are coupled via meson loops. Following this kind of approach we have calculated hadron masses and decay widths for a simple toy model.

The resonance character of hadron excitations is usually not taken into account in constituent quark models. As a consequence most of the (perturbatively) calculated partial decay widths come out too small as compared to experiment [1]. This suggests that physical hadron resonances are not just simple bound states of valence (anti)quarks, but should also contain higher Fock components. We propose to model the additional quark-antiquark pairs by means of mesons which can couple directly to the valence (anti)quarks.

A natural starting point for this kind of description is the chiral constituent quark model [2]. Within this model it is assumed that the effective degrees of freedom emerging from the spontaneous breaking of chiral symmetry are (confined) constituent (anti)quarks and Goldstone bosons, i.e. the lightest pseudoscalar mesons. We use the point form of relativistic quantum mechanics in connection with the Bakamjian-Thomas construction to calculate mass spectra and decay widths. This kind of approach is Poincaré invariant and one only has to deal with an eigenvalue problem for an appropriately defined mass operator [3].

In order to allow for the decay of hadron excitations into a lower lying state by emission of a Goldstone boson we adopt a 2-channel mass operator. A general mass eigenstate has then a valence-(anti)quark component $|\psi_{\text{val}}\rangle$ and a valence-(anti)quark + Goldstone-boson component $|\psi_{\text{val+GB}}\rangle$. These components are coupled via vertex operators \hat{K} and \hat{K}^\dagger that describe the emission and absorption of the Goldstone boson by the (anti)quark, respectively. If $|\psi_{\text{val+GB}}\rangle$ is eliminated by means of a Feshbach reduction one ends up with a mass-eigenvalue equation for $|\psi_{\text{val}}\rangle$ which takes on the form:

$$(1) \quad (\hat{M}_{\text{val}} + \underbrace{\hat{K}^\dagger (m - \hat{M}_{\text{val+GB}} + i0)^{-1} \hat{K}}_{\hat{V}_{\text{opt}}(m)}) |\psi_{\text{val}}\rangle = m |\psi_{\text{val}}\rangle.$$

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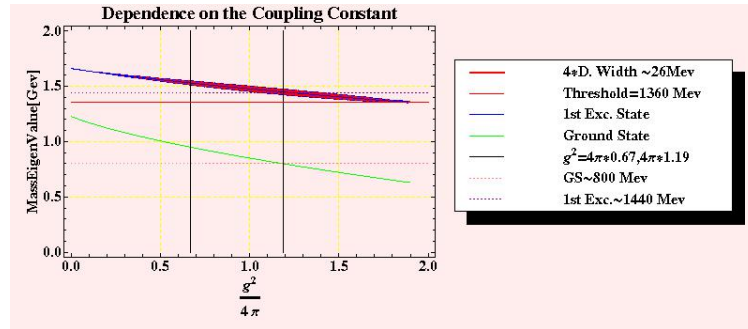


Figure 1: Predictions of our toy model. The mass of the ground state (green line) and the first excited state (blue line) as functions of the Goldstone-boson-quark coupling. The red band between the dashed blue lines indicates the decay width of the first excited state (multiplied by a factor 4 for better visibility). The range of couplings allowed by the Goldberger-Treiman relation is indicated by the black vertical lines.

The channel mass operators \hat{M}_{val} and $\hat{M}_{\text{val}+GB}$ consist of a kinetic-energy term and an instantaneous confining potential. By expanding $|\psi_{\text{val}}\rangle$ in terms of eigenstates of \hat{M}_{val} (which we call “bare hadrons”) Eq. (1) can be converted into a system of algebraic equations for the expansion coefficients. Physically speaking, this system represents again a (non-linear) mass-eigenvalue problem, but on the hadronic level rather than on the quark level. It describes the coupling of bare hadrons via Goldstone-boson loops and has to be solved self-consistently (for details, see Ref. [4]).

As a first test we have applied these ideas to a simple toy model in which spin and isospin are completely neglected and the bare hadrons are just quark-antiquark pairs confined by a harmonic oscillator potential. In order to give the model some physical meaning we have adjusted the parameters such that the masses of the ground state and the first excited state of the ω are approximately reproduced. As can be seen in Fig. 1 the decay width of the first excited state exhibits a maximum of about 26 MeV as a function of the Goldstone-boson-(anti)quark coupling strength and vanishes as soon as the real part of the mass eigenvalue approaches the lowest threshold. We observe a considerable increase of the decay width as compared to perturbative calculations. This gives some hope that typical decay widths of 0.1 GeV or even more can be achieved for baryon resonances within the full chiral constituent-quark model.

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