Unified quark-quark and quark-antiquark intractions for the meson and baryon sector

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Abstract

An adequate description of heavy dimesons (tetraquarks) requires a unified effective interaction which fits both light and heavy meson as well as light and heavy baryon spectra. Some aspects of the problem have been elucidated in lively discussions.

In the constituent quark model one needs effective quark masses and effective quark-quark interactions. There are two approaches to this input information. In the *first principle* (*ab initio*) calculations one would like to derive effective masses and interactions from QCD, at least approximately. We are, however, involved in the *practical (phenomenological)* approach to the constituent quark model: fit effective quark masses and effective interaction parameters so as to reproduce the known meson and baryon spectra, and then predict new states and explain dynamical processes! The usual restriction is to the two-particle Hilbert space for mesons and the three-particle Hilbert space for baryons. The question arises whether in this restricted space a good fit is possible at all, and whether it contains correct physics.

Since our main interest is in dimesons and dibaryons we need a unified interaction for all sectors. A posssible unified picture of meson and baryon sectors assumes the one-gluon-exchange potential + linear confining potential. This model has had some success [1, 2, 3, 4], but due to flavour independence it sacrifices several states in the baryon sector (for example Roper).

The one-Goldstone-boson-exchange model of Riska, Glozmann, Plessas et al.[5, 6] has a different flavour-spin structure and is more successful for light baryons, but it leaves it as an open question how to extend such a model to describe heavy baryons and mesons. Heavy baryons and mesons certainly need a spin-spin force of the one-gluon-exchange type since they do not feel pions.

The discussions at Bled centered around five issues.

1. It has been suggested in the literature to simply take a combination of the meson-exchange and gluon-exchange effective interactions. The practical difficulty is to

get enough spin-spin splitting for heavy mesons (OGE), enough lowering of Roper (OME), and still not to exceed the $N - \Delta$ splitting (OGE+OME). The conceptual difficulty, strongly advocated by Leonid Glozman, is, however, the coexistence of chirally broken and chirally symmetric phase. According to this doctrine, at the energy scale of light quarks, the chiral symmetry is spontaneously broken and the effective degrees of freedom are constituent quarks and light mesons (Goldstone bosons) – no explicit gluons – therefore OGE would make no sense. At the energy scale of heavy quarks the chiral symmetry plays no role and the effective degrees of freedom are quarks and gluons – perturbative QCD and OGE would make sense. It is then unclear what to use when there are both light and heavy quarks present in the system. The topic remained controversial. A compromise is needed, possible with a modified strength of OGE between a heavy and a light quark.

2. It has been suggested to extend the OME interaction between two quarks (such as has been successfully used by the Graz group) to the light quark-antiquark pair simply by the G-parity transformation. It has to be clarified, however, whether one should invent also relevant annihilation-creation graphs and how should one fit their strength. Such additional interaction would introduce many-quark many-antiquark configurations and the truncation to the one-quark one-antiquark space is questionable. Anyway, also the OGE interaction is not immune against this effect. Moreover, one should avoid double counting. Especially the description of pion using pion-echange between quarks is very delicate.

3. The extended meson-exchange model (with vector meson exchange) offers improvements in dynamical processes of baryons (form factors) but it opens many new problems for the mesonic sector. For example, the G-parity transformed ω-exchange becomes strongly attractive at short distance; we are exploring good and bad consequences.

4. The NJL model is unified for the light meson and baryon sectors (containing u, d and/or s quarks). However, due to lack of confinement, and due to the need of a complicated cutoff, little can be calculated for excited mesons, and is not easy to solve for baryons. Maybe NJL can at least inspire meaningful effective $q - q$ and $q - \bar{q}$ interactions [7].

5. It is of interest to verify as much as possible the "$V_{qq} = \frac{1}{2} V_{q\bar{q}}$" rule. It is implicit in OGE and reasonable fits with lowest experimental levels do not contradict it. A crucial test would be the comparison of charmonium (or botomium) with the QQq baryons as well as $QQ\bar{q}\bar{q}$ dimesons (tetraquarks); $Q = c, b$ and $q = u, d, s$. I would like to emphasise the paramount importance to search for these doubly-heavy baryons and dimesons, possibly at LHC.

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