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Constituent-Quark Masses and Baryon Spectroscopy

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Abstract. We discuss the hierarchy of constituent quark masses prevailing in effective models of quantum chromodynamics, specifically in the relativistic constituent-quark model. We observe that the dynamical mass gain over current-quark masses is more or less independent of the quark flavor and amounts to about $\Delta m \approx 370 \pm 30$ MeV. Similar values are also supported by alternative effective descriptions of baryon spectroscopy such as the Dyson-Schwinger approach.

The modern constituent-quark model has turned out to be quite successful as an effective tool to describe a variety of baryon properties and reactions [1]. It considers baryons as relativistic bound states of three constituent quarks Q interacting mutually. The Q-Q forces rely on a confinement and a hyperfine interaction. In such a framework constituent quarks are to be considered as quasi-particles whose masses are generated dynamically. The spontaneous breaking of chiral symmetry (SBχS) of low-energy quantum chromodynamics (QCD) is generally assumed to be responsible for attributing mass to constituent quarks.

We have set up a relativistic constituent-quark model (RCQM) covering all known baryons with flavors u, d, s, c, and b in a universal framework [2–4]. It relies on a relativistically invariant mass operator containing a linear confinement interaction, according to the string tension of QCD, and a hyperfine interaction, representing the exchange of pseudoscalar Goldstone bosons in the regime of SBχS of low-energy QCD. The model contains a total of 13 input parameters, of which 10 are assumed as predetermined or taken as educated guesses and only three are considered as really open fit parameters; the latter are determined by a best fit of the baryon spectra (for details see Refs. [2] or [5]).

Among the input parameters we also find the masses of the constituent quarks of flavors u, d, s, c, and b. While the masses of the light-flavored constituent quarks are set to the traditional values of $m_u = m_d \approx 300$ MeV, the magnitudes of the constituent-quark masses of the other flavors s, c, and b are determined such as to best reproduce the lowest lying baryons containing one of these flavors, i.e. Λ, Λ_c, and Λ_b. This leads to the hierarchy of constituent quark masses given in the third column of the Table.

It is immediately evident that the dynamical mass gains of constituent quarks over current quarks scatter around a value of ~370 MeV for all flavors in the RCQM. This is to some extent surprising, since for heavier flavors the transition from current to constituent quarks has usually been considered as insignificant. We emphasize, however, that the values of the constituent-quark masses

Quark flavor	PDG [6] m_q	RCQM [2,5] m_Q	RCQM [2,5] Δm	DSE [7] Δm
$\frac{1}{2}(u+d)$	$3.3-4.2$	340	~ 336	~ 276
s	95 ± 5	480	~ 385	~ 278
c	1275 ± 25	1675	~ 400	~ 330
b	4660 ± 30	5055	~ 395	~ 400

Table 1. Masses of current quarks q and constituent quarks Q as well as their differences $\Delta m = m_Q - m_q$ for the flavors u, d, s, c, and b, as found in the RCQM and DSE approaches.

as quoted in the Table are essential for the RCQM to reproduce the phenomenological spectra of all known baryons in good quality. Furthermore, the magnitudes Δm occurring in the RCQM compare reasonably well with the quark-mass gains towards low momenta obtained in the relativistic framework of Dyson-Schwinger equations (DSE), as followed, e.g., in Ref. [7]. Only, the latter fall a bit lower and stretch over a wider range, namely, $\Delta m \approx 340 \pm 60$ MeV.

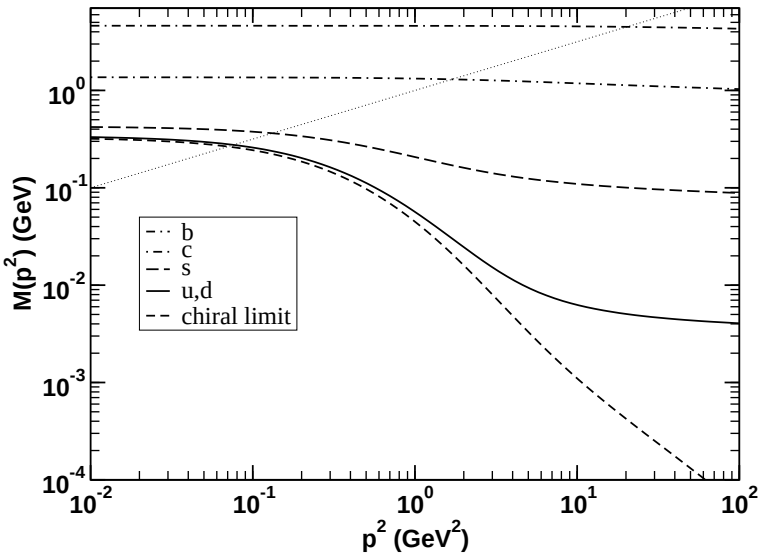

Fig. 1. Momentum dependence of quark masses from the DSE approach [7]. Figure by courtesy from A. Krassnigg.

The generation of constituent-quark masses can nicely be followed in the DSE approach. From the Figure it is seen, how the dynamical mass is acquired, when going from higher momenta (current quarks) to lower momenta (constituent quarks). For the various flavors mass gains are obtained as quoted in the last column of the Table. The phenomenon is even observed with approximately the same result, when starting from the chiral limit of $m_q = 0$. One may thus expect

a common reason for all flavors to develop a similar mass gain in the transition from current to constituent quarks.

We note that a similar investigation of the pattern of constituent-quark masses has been done by M. Rosina, including evidences from even other effective approaches to low-energy QCD, employing the notion of constituent quarks. The evidences he found are basically in line with the ones presented here [8].

While the hierarchy of constituent-quark masses has been discussed here by evidences from baryon spectroscopy, it should be mentioned that the same RCQM, with the Q−Q hyperfine interaction based on Goldstone-boson exchange is also capable of describing the baryon electroweak structures (see, e.g., Refs. [1] or [9]), gravitational form factors [5], and a series of other baryon observables [10, 11] in good agreement with phenomenology and in cases, where experimental data are missing, in concordance with results from lattice QCD.

In summary it remains as a challenge to determine the very dynamical ingredients for generating constituent-quark masses. Several possibilities are offered in the literature for producing quasi-particles. None has hitherto been carried out to such an extent or is conclusive insofar as to provide an explanation of the constituent-quark masses of all flavors u, d, s, c, and b in QCD.

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Kvarkovski propagator v coulombski umeritvi kvantne kromodinamike

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Proučujemo kvarkovski propagator na konfiguracijah gašenega umeritvenega polja v coulombski umeritvi. Pri tem uporabimo kiralno simetrične "prekrivalne fermione". V tej umeritvi lahko povežemo "funkcijo oblačenja" kvarkovskega propagatorja s priporom in kiralno simetrijo kromodinamike. Pripor lahko pripišemo infrardeče divergentni vektorski "funkciji oblačenja". Izvrednotimo "funkcije oblačenja" kvarkovskega propagatorja, razberemo dinamično maso kvarka in ekstrapoliramo vse te količine proti kiralni limiti. Končno razpravljamo, kako se odstranijo nizke Diracove ekscitacije.

Mase oblečenih kvarkov in barionska spektroskopija

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Prikažemo hierarhijo mas oblečenih kvarkov, ki prevladujejo v efektivnih modelih kvantne kromodinamike, zlasti v relativističnem modelu z oblečenimi kvarki. Opazimo, da je presežek dinamično generirane mase nad golo maso bolj ali manj neodvisen od okusa kvarkov in znaša $\Delta m \approx (370 \pm 30)$ MeV. Podobne vrednosti dajo tudi alternativni efektivni opisi barionske spektroskopije, na primer Dyson-Schwingerjev pristop.

Primerjava jedrskih potencialov za hiperon Lambda in za nukleon

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Raziskujeva verjetni mehanizem, zakaj čuti hiperon Λ dvakrat šibkejše jedrsko polje (okrog -27 MeV) kot nukleon (okrog -50 MeV).