

THE GOTTFRIED SUM RULE IN AN UNQUENCHED QUARK MODEL

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Abstract

We present an unquenched quark model for baryons in which the effects of quark-antiquark pairs ($u\bar{u}$, $d\bar{d}$ and $s\bar{s}$) are taken into account in an explicit form. The method is illustrated with an application to the flavor asymmetry of the nucleon sea.

1 Introduction

In the constituent quark model (CQM), the proton is described in terms of a uud three-quark configuration. A direct handle on higher Fock components (such as $uud - q\bar{q}$ configurations) is provided by parity-violating electron scattering (PVES) experiments, which have shown evidence for a nonvanishing strange quark contribution, albeit small, to the charge and magnetization distributions of the proton [1]. The contribution of strange quarks to the nucleon is of special interest because it is exclusively part of the quark-antiquark sea $q\bar{q} = s\bar{s}$. Additional evidence for higher Fock components in the proton wave function comes from measurements of the \bar{d}/\bar{u} asymmetry in the nucleon sea [2] and from CQM studies of baryon spectroscopy.

Theoretically, the role of higher Fock components in the CQM has been studied in [3], while the importance of mesonic contributions to the spin and flavor structure of the nucleon is reviewed in [4]. In another, CQM based, approach the effects of $s\bar{s}$ pairs in the proton were included in a flux-tube breaking model [5].

The aim of the present contribution is to discuss the flavor asymmetry of the nucleon sea in an unquenched quark model in which the effects of quark-antiquark pairs are included in a general and systematic way.

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2 Unquenched Quark Model

In the flux-tube model for hadrons, the quark potential model arises from an adiabatic approximation to the gluonic degrees of freedom embodied in a flux tube [6]. The impact of quark-antiquark pairs in meson spectroscopy has been studied in a flux-tube breaking model [7] in which the $q\bar{q}$ pair is created with the 3P_0 quantum numbers of the vacuum. Subsequently, it was shown [8] that a *miraculous* set of cancellations between apparently uncorrelated sets of intermediate states occurs in such a way that they compensate each other and do not destroy the good CQM results for the mesons. In particular, the OZI hierarchy is preserved and there is a near immunity of the long-range confining potential, since the change in the linear potential due to the creation of quark-antiquark pairs in the string can be reabsorbed into a new strength of the linear potential, *i.e.* in a new string tension. As a result, the net effect of the mass shifts due to pair creation is much smaller than the naive expectation of the order of the strong decay widths. However, it is necessary to sum over large towers of intermediate states to see that the spectrum of the mesons, after unquenching and renormalizing, is only weakly perturbed. An important conclusion is that no simple truncation of the set of meson loops is able to reproduce such results [8].

The extension of the flux-tube breaking model to baryons requires a proper treatment of the permutation symmetry between identical quarks. As a first step, Geiger and Isgur investigated the importance of $s\bar{s}$ loops in the proton in an unquenched quark model based on an adiabatic treatment of the flux-tube dynamics to which the $s\bar{s}$ pair creation with vacuum quantum numbers is added as a perturbation [5]. In the conclusions, the authors emphasized: *It also seems very worthwhile to extend this calculation to $u\bar{u}$ and $d\bar{d}$ loops. Such an extension could reveal the origin of the observed violations of the Gottfried sum rule and also complete our understanding of the origin of the spin crisis.* In this contribution, we take up the challenge and present a generalization of the formalism of [5] which now makes it possible to study the effects of $q\bar{q}$ pairs in an unquenched quark model (i) for any initial baryon (ground state or resonance), (ii) for any flavor of the quark-antiquark pair, and (iii) for any model of baryons and mesons, as long as their wave functions are expressed in the basis of the harmonic oscillator.

These extensions were made possible by two developments: the solution of the problem of the permutation symmetry between identical quarks by means of group-theoretical techniques, and the construction of an algorithm to generate a complete set of intermediate states for any model of baryons and mesons.

3 Flavor Asymmetry

The first clear evidence for the flavor asymmetry of the nucleon sea was provided by NMC at CERN [9]. The flavor asymmetry is related to the Gottfried integral for the difference of the proton and neutron electromagnetic structure functions

$$S_G = \int_0^1 dx \frac{F_2^p(x) - F_2^n(x)}{x} = \frac{1}{3} - \frac{2}{3} \int_0^1 dx [\bar{d}(x) - \bar{u}(x)] . \quad (1)$$

Under the assumption of a flavor symmetric sea, one obtains the Gottfried sum rule $S_G = 1/3$. The final NMC value is 0.2281 ± 0.0065 at $Q^2 = 4$ (GeV/c)² for the Gottfried integral over the range $0.004 \leq x \leq 0.8$ [9], which implies a flavor asymmetric sea. The violation of the Gottfried sum rule has been confirmed by other experimental collaborations [10, 11]. Theoretically, it was shown [12], that the coupling of the nucleon to the pion cloud provides a natural mechanism to produce a flavor asymmetry.

In the present model, the flavor asymmetry can be calculated from the difference of the number of d and u sea quarks in the proton

$$N_{\bar{d}} - N_{\bar{u}} = \int_0^1 dx [\bar{d}(x) - \bar{u}(x)] . \quad (2)$$

Note that, even in absence of explicit information on the (anti)quark distribution functions, the integrated value can be obtained directly from the left-hand side of Eq. (2). The corresponding value for the Gottfried integral is 0.185, in qualitative agreement with the NMC result. It is important to note that in this calculation the parameters were taken from the literature [5, 13], and that no attempt was made to optimize their values. Since the dependence of the Gottfried integral on the value of these parameters and/or different models of baryons and mesons has not yet been investigated in detail, the numerical value quoted here is to be regarded as preliminary.

4 Summary, conclusions and outlook

We discussed an unquenched quark model for baryons which includes, in addition to $s\bar{s}$ loops, the contributions of $u\bar{u}$ and $d\bar{d}$ loops. In an application to the flavor asymmetry of the nucleon sea, it was shown that the $q\bar{q}$ pairs immediately lead to an excess of \bar{d} over \bar{u} quarks in the proton, in agreement with the experimental data.

In our opinion, the result for the flavor asymmetry is very promising and encouraging. We believe that the inclusion of the effects of quark-antiquark

pairs in a general and consistent way, as suggested in [14] and in this contribution, may provide a major improvement to the constituent quark model, increasing considerably its range of applicability.

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