BLED WORKSHOPS
IN PHYSICS
VOL. 14, NO. 1
p. 1

Proceedings of the Mini-Workshop
Looking into Hadrons
Bled, Slovenia, July 7 - 14, 2013

The role of valence and sea quarks in light baryons[*]

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Abstract. In this contribution, we discuss the spin and flavor content of the proton in two extensions of the quark model, the unquenched quark model and the chiral quark model, and address the role of valence and sea quarks in light baryons.

1 Introduction

The constituent quark model (CQM) describes the nucleon as a system of three constituent, or valence, quarks. Despite the successes of the CQM (e.g. masses, electromagnetic coupling, magnetic moments), there is compelling evidence for the presence of sea quarks from the measurement of the flavor asymmetry of the proton and the so-called proton spin crisis. The role of the pion cloud in the nucleon has been the subject of many studies [1–3], and was shown to hold the key to understand the flavor asymmetry and the spin-crisis of the proton. Recently, it was pointed out these two properties are closely related: angular momentum conservation of the pionic fluctuations of the nucleon leads to a relation between the flavor asymmetry and the contribution of orbital angular momentum to the spin of the proton $\mathcal{A}(p) = \Delta L$ [4]. This identity can be understood from the fact that the flavor asymmetry is a matrix element in isospin space, and the orbital angular momentum in spin space with the same values of the quantum numbers.

The aim of this contribution is to study two different extensions of the quark model, the unquenched quark model and the chiral quark model, at the level of toy models which may provide important insight into the properties of the nucleon.[1]

2 Flavor and spin content

The first model is the unquenched quark model (UQM) in which the effect of the quark-antiquark pairs is taken into account via a ${}^3P_0$ creation mechanism. The

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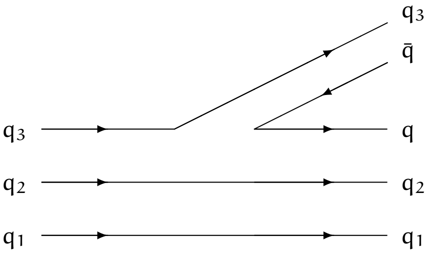
[*] Talk delivered by R. Bijker

[1] Aage Bohr once remarked that describing the properties of a many-body system like the atomic nucleus in terms of symmetry arguments provides important insight into the properties of the system. On the other hand, when one is able to describe the same system in terms of the detailed motion of the particles (nucleons), and of the couplings to the fields which act upon them (vibration, rotations) one obtains, as a rule, a true understanding of the system under consideration [5].

resulting wave function is given by [6]

$$\mid \psi_A \rangle = \mathcal{N} \left\{ \mid A \rangle + \gamma \sum_{BClJ} \int d\mathbf{K} k^2 dk \mid BC, l, J; \mathbf{K}, k \rangle \frac{\langle BC, l, J; \mathbf{K}, k \mid T^\dagger \mid A \rangle}{M_A - E_B(k) - E_C(k)} \right\} , \quad (1)$$

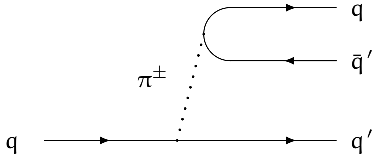
where γ is the coupling strength of the ${}^3P_0$ whose value is determined from the flavor asymmetry of the proton. In the calculations presented in this section only the contribution from the pions is taken into account.



The second model is the chiral quark model (χQM) [7, 8] in which the pion is emitted from the individual constituent (up and down) quarks

$$|\psi_{u_\pm}\rangle = \frac{1}{\sqrt{1+g^2}} \left[|u_\pm\rangle \pm \frac{1}{3}\, g \left(|u_\pm \pi^0\rangle - \sqrt{2} |d_\pm \pi^+\rangle \right)_{l,m=1,0} \right.$$
$$\left. \mp \frac{\sqrt{2}}{3}\, g \left(|u_\mp \pi^0\rangle - \sqrt{2} |d_\mp \pi^+\rangle \right)_{l,m=1,\pm 1} \right] , \quad (2)$$

and a similar expression for d quarks. Here l, m denote the relative orbital angular momentum between the quark and the pion. In the present version, both the helicity changing and conserving contributions are taken into account. The final quark wave function has the full spin and isospin structure [9].



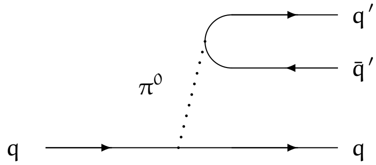


Table 1 shows the results for the flavor and spin content of the proton. The last column for UQM also holds for the meson-cloud model in which the coefficients a and b multiply the $N\pi$ and $\Delta\pi$ components of the nucleon wave function.

The ab term in Table 1 denotes the contribution from the cross terms between the $N\pi$ and $\Delta\pi$ components. In the UQM, the three coefficients a^2, b^2 and ab all depend on the ${}^3P_0$ coupling strength γ, and are expressed in terms of an integral over the relative momentum k. In this case the value of the cross term ab is not the product of a and b, although the numerical value is close. It is interesting to note that in the absence of the contribution of the $\Delta\pi$ component in the UQM, *i.e.* $b^2 = ab = 0$, the two models give the same results for these observables. The same observation was made by Rosina in a comparison of pion couplings to the nucleon and to the quarks [10].

Table 1. Spin and flavor content of the proton in he constituyent quark model (CQM), the chiral quark model (χQM) and the unquenched quark model (UQM).

	CQM	χQM	UQM
$\mathcal{A}(p) = \Delta L$	0	$\frac{2g^2}{3(1+g^2)}$	$\frac{2a^2-b^2}{3(1+a^2+b^2)}$
Δu	$\frac{4}{3}$	$\frac{4}{3} - \frac{38g^2}{27(1+g^2)}$	$\frac{4}{3} - \frac{38a^2+b^2-16ab\sqrt{2}}{27(1+a^2+b^2)}$
Δd	$-\frac{1}{3}$	$-\frac{1}{3} + \frac{2g^2}{27(1+g^2)}$	$-\frac{1}{3} + \frac{2a^2+19b^2-16ab\sqrt{2}}{27(1+a^2+b^2)}$
Δs	0	0	0
$\Delta\Sigma = \Delta u + \Delta d + \Delta s$	1	$1 - \frac{4g^2}{3(1+g^2)}$	$1 - \frac{4a^2-2b^2}{3(1+a^2+b^2)}$
$g_A = \Delta u - \Delta d$	$\frac{5}{3}$	$\frac{5}{3} - \frac{40g^2}{27(1+g^2)}$	$\frac{5}{3} - \frac{40a^2+20b^2-32ab\sqrt{2}}{27(1+a^2+b^2)}$

Since both models, UQM and χQM, contain the full spin and isospin structure, both satisfy the relation between the flavor asymmetry and the contribution of the orbital angular momentum to the spin of the proton $\mathcal{A}(p) = \Delta L$ [4], and therefore $\Delta\Sigma = 1 - 2\Delta L$. This relation does not hold for the chiral quark model of [7, 8] in which the orbital angular momentum is enhanced with respect to the flavor asymmetry $\Delta L = 3\mathcal{A}(p)/2$ as a consequence of the requirement of a helicity flip of the quark.

Table 2 shows the results for the spin and flavor content of the proton normalized to the proton flavor asymmetry, The second and third column are normalized to the E866/NuSea value [11], and the last two to the somewhat higher NMC value [12].

The probability that a proton fluctuates in $n\pi^+$

$$|\langle n\pi^+|p\rangle|^2 = \frac{2a^2}{3(1+a^2+b^2)} = 0.180 \, , \tag{3}$$

(UQM1 value) is in close agreement with the experimental value 0.17 ± 0.01 determined in an analysis of forward neutron production in electron-proton collisions at 300 GeV by the H1 and ZEUS Collaborations at DESY [13,14]. The total probability for a pion fluctuation of the proton is given by

$$|\langle N\pi|p\rangle|^2 + |\langle \Delta\pi|p\rangle|^2 = \frac{a^2+b^2}{1+a^2+b^2} = 0.455 , \tag{4}$$

(UQM1 value), in good agreement with the value of 0.470 as determined in an analysis of the quark distribution functions measured in Drell-Yan experiments and semi-inclusive DIS experiments [15].

Finally, Table 3 shows the flavor asymmetry for octet baryons. In the χQM the flavor asymmetries are given by $\mathcal{A}(\Sigma^+) = 2\mathcal{A}(p) = 2\mathcal{A}(\Xi^0)$ no matter whether one includes only pions or also kaons and eta mesons. In the UQCM, one has $\mathcal{A}(\Sigma^+) > \mathcal{A}(p) > \mathcal{A}(\Xi^0)$. In order to distinguish between the predictions of the different models (see also [6]) and to obtain a better understanding of the non-perturbative structure of QCD, new experiments are needed to measure the flavor asymmetry of hyperons. In particular, the flavor asymmetry of charged Σ hyperons can obtained from Drell-Yan experiments using charged hyperon beams on the proton [16] or by means of backward $K^\pm$ electroproduction [17].

3 Summary and conclusions

In this contribution, we studied the predictions of two extensions of the quark model, the unquenched quark model and the chiral quark model. In both cases,

Table 2. Spin and flavor content of the proton normalized to the flavor asymmetry, χQM1 and UQM1 using the E866/NuSea value [11] and χQM2 and UQM2 using the NMC value [12].

	CQM	χQM1	UQM1	χQM2	UQM2
$\mathcal{A}(p) = \Delta L$	0	$*0.118$	$*0.118$	$*0.158$	$*0.158$
Δu	4/3	1.084	1.132	1.000	1.064
Δd	$-1/3$	-0.320	-0.368	-0.316	-0.380
$\Delta\Sigma$	1	0.764	0.764	0.684	0.684
g_A	5/3	1.404	1.500	1.316	1.444

Table 3. Flavor asymmetry of octet baryons relative to that of the proton, $\mathcal{A}/\mathcal{A}(p)$.

Baryon	χQM	UQM1	UQM2
Σ^+	2	1.45	1.62
Ξ^0	1	0.64	0.81

only pion fluctuations were taken into account. The results were normalized to the observed value of the proton flavor asymmetry. It was shown that the pion fluctuations in both schemes lead to a reduction of quark model value of Δu and g_A, and give rise to a sizeable contribution (25 - 30 %) of orbital angular momentum to the spin of the proton. In addition, it was found that the probabilities for pion fluctuations in the UQM are in good agreement with the values determined in analyses of the available experimental data.

In another contribution to these proceedings, Rosina addresses many of the same questions, and suggests to use two-pion probabilities to distinguish between pion couplings to the nucleon versus couplings to quarks [10]. The two contributions give complementary information.

Acknowledgements

It is a pleasure to thank Mitja Rosina for stimulating discussions on the properties of the pion cloud and his kind invitation to participate in the 2013 Bled Workshop. This work was supported in part by research grants from CONACyT and PAPIIT-UNAM.

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