Quark and gluon contributions to the low energy properties of nucleons

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Introduction

The statistical approach advocated in Ref.[1,2] was successful in describing the large asymmetry between $\bar{u}$ and $\bar{d}$ quark distributions of the proton. We have extended that approach by decomposing various quark-gluon Fock states into states in which the three quark core and the rest of the stuff (called sea) have definite spin and color quantum numbers, using the assumption of equal probability for each substate of such a state of the nucleon. We have further used the approximation in which a quark in the core is not antisymmetrized with an identical quark in the sea, and have treated quarks and gluons as nonrelativistic particles moving in S-wave (except for a single $q\bar{q}$ sea) motion. Also, we have not taken into account any contribution of the s-quark and other heavy quarks, and we have covered only ≈ 86% of the total Fock state. With these approximations we have calculated the quarks contribution to the spin of the nucleons, the ratio of the magnetic moments of the nucleons , their weak decay constant , and the ratio of SU(3) reduced matrix elements for the axial current. All of these quantities give integrated result of Bjorken variable. We have also considered two modifications of the above statistical approach with a view to reduce the contributions of the sea components with higher multiplicities, and have done the above calculations for those two cases as well.

The effect of Melosh rotation is to increase the values of the physical quantities related to the nucleon spin, which are measured in the rest frame of the nucleon while keeping the quark contribution to the nucleon spin, measured in the light–cone frame, unchanged. If we treat the Melosh rotation as free parameter, we can reproduce the experimental value of g_A/g_V along with μ_p/μ_n =1.415, and F/D =0.610 with the Melosh rotation parameters, ($\langle M_u\rangle$,$\langle M_d\rangle$) = (0.699, 0.719), (0.797, 0.827) and (0.825, 0.692) for three different cases.

Sea and its Structure

In Ref.[1,2], treating the proton as an ensemble of quark-gluon Fock states, the proton state has been expanded in a complete set of such states as

$$|p\rangle = \sum_{ijk} C_{ijk} |uud, i, j, k\rangle$$

where i is the number of $u\bar{u}$ pairs, j is the number of $d\bar{d}$ pairs, and k is the number of gluons. The probability to find a proton in the Fock state $|uud,i,j,k\rangle$ is

$\rho_{ijk} = |C_{ijk}|^2$,

where ρ_{ijk} satisfies the normalization condition,

$$\sum_{ijk} \rho_{ijk} = 1$$

Then, using the detailed balance principle or balance principle, and with sub processes $q \Leftrightarrow q\, g$, $g \Leftrightarrow q\bar{q}$ and $g \Leftrightarrow gg$ considered, all ρ_{ijk} have been calculated explicitly. Interestingly, the model predicts an asymmetry in the sea flavor of $\bar{u}$ and $\bar{d}$ as $\bar{d}$ - $\bar{u}$ ~0.124 in surprising agreement with the experimental data 0.118±0.012. These quarks and gluons have to be understood as "intrinsic" partons of the proton as opposed to the "extrinsic" partons generated from the QCD hard bremsstrahlung and gluon splitting as a part of the lepton nucleon scattering interaction [3]. The $q\bar{q}$ pairs and gluons, which are multiconnected non-perturbatively to the valence quarks, will collectively be referred to as the sea. Since the proton should be colorless and a q^3 state can be in color state 1_c , 8_c and 10_c, the sea should also be in the corresponding color state to form a color singlet proton. Furthermore, if the sea is in an S-wave state relative to the q^3 core, conservation of angular momentum restricts that the spin of the sea can only be 0,1or 2 to give a spin-1/2 proton.

The case of the sea with one $q\bar{q}$ pair, where the sea or at least one of the quarks is needed to be in a relative P-wave to meet the positive parity requirement of the proton, will be treated separately. We take the probabilities of finding various quark-gluon Fock states in a proton from Ref.[2], and assume that the quarks and the gluons can be treated nonrelativistically for our problem, and also that, in general, these are in S-wave motion. The effect of the relativistic motion of the constituents will be discussed later. The case of a neutron will be treated in an analogous way using isospin symmetry.

We assume that the rest of the quark-gluon sea spanning ~14% of the Fock space of the nucleon also decomposes in color and spin subspaces in approximately the same proportion as the one which we have worked out explicitly above. The number of strange quark-antiquark pairs in the statistical model is 0.05 in the nucleon as compared to the average number of particles which is 5.57.

Result and conclusion

Our results of calculation holds good for a typical hadronic energy scale~1 GeV^2[2]. Experimental results for I_1^p and I_1^n apply for $Q^2 \approx 10$ GeV^2, and their values will increase when evolved to a lower energy scale. Hence, our calculated results for I_1^p and I_1^n may well be consistent with the data. Our result for the ratio of magnetic moments of nucleons is within few percent of the data. Weak decay constant has been calculated using Bjorken sum rule, written up to $O(\alpha_s^3/\pi^3)$. There is some controversy in the value of α_s at the low energy~1GeV we are working at, and we have chosen three typical values taken from recent literature. The significance of the Melosh rotation connecting the spin states in the light-front dynamics and the conventional instant form dynamics has been widely recognized. We have tried to construct a spin wave function of a nucleon with a non trivial sea in the nucleon rest frame from a statistical model of a nucleon. Such a wave function, along with a Melosh rotation, is capable of giving a reasonable result for several physical quantities related to the nucleon spin.

We will calculate the self-masses of nucleons within the framework of baryon chiral perturbation theory including the η'. One-loop diagrams of the η and η' with vertices generated from gluonic (Q-fields) interactions will be accounted for .It will be further evaluated in the chiral limit and compared with gluon contribution to the nucleon mass obtained in other approaches.

References

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