The Pion-Nucleon Sigma Term
and the
SU(3) Cloudy Bag Model

by

Iain Jameson

A thesis submitted in fulfillment of the
requirements for the degree of
Doctor of Philosophy
at the
University of Adelaide

February 1991
Contents

1 Introduction .......................................................... 1
    1.1 The Eight-Fold Way .............................................. 2
    1.2 Chiral Symmetry ................................................ 3
    1.2.1 Chiral Algebra .............................................. 5
    1.2.2 Chiral Symmetry Breaking ............................... 6
    1.3 The Quark Model ............................................... 13
    1.4 QCD .................................................................. 15
    1.5 Bag Models .......................................................... 19
    1.5.1 The CBM ...................................................... 22
    1.6 The Sigma Term .................................................. 23

2 The Pion-Nucleon Sigma Term .................................... 25
    2.1 Experimental Estimates of the Sigma Term .............. 27
    2.2 The Sigma Term in QCD ....................................... 38
    2.2.1 Hybrid Bag Calculation .................................... 49
    2.2.2 Latest Experimental Results ............................. 51

3 The SU(3) CBM ......................................................... 55
    3.1 The CBM Lagrangian ............................................ 55
    3.2 The SU(3) Hamiltonian ...................................... 60
Abstract

QCD is approximately invariant under chiral $SU(3)_L \times SU(3)_R$ transformations. Experimental evidence (i.e., no parity doublets) tells us that the symmetry must be broken spontaneously. The term in the Hamiltonian which breaks chiral symmetry belongs to the $(3, \overline{3}) + (\overline{3}, 3)$ representation of $SU(3)_L \times SU(3)_R$. In the quark model, this term is $\bar{q}m_q q$ with the quark fields written as left and right handed fields.

We can construct, from matrix elements which depend only on the symmetry breaking part of the Hamiltonian, the sigma term, and this can be (indirectly) determined from experiment. As such, it is a powerful tool in that it can be used to test symmetry breaking mechanisms. Experimentally, the sigma term is $\Sigma_{\pi N}(t = 2M_\pi^2) = 60 \pm 12$ MeV ($t$ is the square of the momentum transfer). Given this value, it has been found that $\Sigma_{\pi N}(t = 0) = 45 \pm 12$ MeV.

The theoretical value (calculated at $t = 0$ and denoted $\sigma_{\pi N}(0)$), using the $(3, \overline{3}) + (\overline{3}, 3)$ model, is approximately 26 MeV. Using chiral perturbation theory and dispersion relations, this value can be increased to 45 MeV. This value includes a contribution from the leading nonanalytic term and an estimate of higher order corrections to the sigma term (amounting to 10 MeV) and assumes the nucleon has a small strange quark component.

We have made an explicit calculation of the quark and meson contributions to the sigma term within the Cloudy Bag Model. Assuming a current quark mass of $12 \pm 3$ MeV, at the bag scale of 0.5 GeV, we find that the
valence quarks contribute 17.5 ± 4.5 MeV. Our expression for the meson contribution includes contributions from pion, kaon and eta loops. We find that the kaon and eta contribute less than 1 MeV. The pion contribution is due to πNN and πNΔ loops. If we consider only the first loop, representing contributions from the leading nonanalytic term, then for 0.8 ≤ R ≤ 1.1 fm, the pion contributes 12 ≤ σ_{πN}(0) ≤ 16 MeV to the sigma term. Adding contributions from the second loop (representing higher order corrections) increases the pion contribution to 20 ≤ σ_{πN}(0) ≤ 26 MeV. Adding valence quark contributions, we find 37 ≤ σ_{πN}(0) ≤ 44 MeV ±4.5 MeV (c.f. Σ_{πN}(t = 0) given above). We argue that there is no strange quark component in the nucleon, and that chiral perturbation theory omits contributions from the second loop and, thus, underestimates the contribution from higher order corrections by approximately 7 to 10 MeV.