Octet Baryon Magnetic Moments from an $SU(3)$ Flavor-Symmetric Lattice QCD Calculation†

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The external-field technique and its more recent generalizations are powerful tools with which to compute structural properties of hadrons using lattice QCD (LQCD). Such external magnetic field computations have been performed recently by NPLQCD, in particular: the first computation of the magnetic moments of light nuclei1), the computation of the magnetic transition moment that dominates the $np \to d\gamma$ radiative-capture process2), the determination of magnetic polarizabilities of light nuclei3), and the evidence suggesting the unitary limit of two-nucleon interactions might be achieved in strong magnetic fields4). In this summary, however, we do not focus on few-nucleon physics; instead, we concern ourselves with the single-baryon sector in order to review the computation of magnetic moments within the lowest-lying octet of baryons.

In the limit of $SU(3)$ flavor symmetry, in which $m_u = m_d = m_s$, the octet baryon magnetic moments are determined by just two parameters. These are the Coleman-Glashow moments, μ_D and μ_F, which appear in the Hamiltonian density

$$\mathcal{H} = -\frac{e}{2M_B}\vec{\sigma}\cdot\vec{B}\left[\mu_D\langle\overline{B}\{Q,B\}\rangle + \mu_F\langle\overline{B}[Q,B]\rangle\right], \quad (1)$$

where: $Q = \mathrm{diag}(\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3})$ is the quark electric charge matrix; the octet baryon fields are described by a matrix B, which can be expanded in terms of $SU(3)_F$ generators, $B = \sum_{a=1}^{8} B^a \frac{\lambda^a}{2}$; and, angled brackets are used to denote flavor traces.

The Coleman-Glashow moments are directly calculated by NPLQCD using an $SU(3)_F$-symmetric ensemble of gauge configurations with the octet meson mass $m_\pi \sim 800\,\mathtt{MeV}$, and with the addition of background magnetic fields coupled to the valence quarks. Aside from tiny electrodynamic effects $\lesssim 1\%$, there are no quark-disconnected contributions to the baryon magnetic moments at an $SU(3)_F$-symmetric point due to the condition $\langle Q \rangle = 0$. The determination of μ_D and μ_F at this quark mass is very precise, see Fig. 1.

Away from the limit of $SU(3)_F$ symmetry, the Coleman-Glashow moments can be obtained with additional assumptions. From calculations performed using an $N_f = 2+1$ ensemble of gauge configurations, with a corresponding pion mass of $m_\pi \sim 450\,\mathtt{MeV}$, the octet baryon magnetic moments are also determined. The nucleon moments are utilized to determine μ_D and μ_F, because $SU(3)_F$ breaking only arises from the strange quark in the sea. This effect is proportional to $(m_s - m)/N_c$, where $m = \frac{1}{2}(m_u + m_d)$, and N_c is the number of colors. The effect is estimated to be 6% on this ensemble. The same argument is applied to estimate the Coleman-Glashow moments from the experimental values of the nucleon moments, where the strange sea-quark effect is at the level of 11%.a) The results obtained are depicted in Fig. 1.

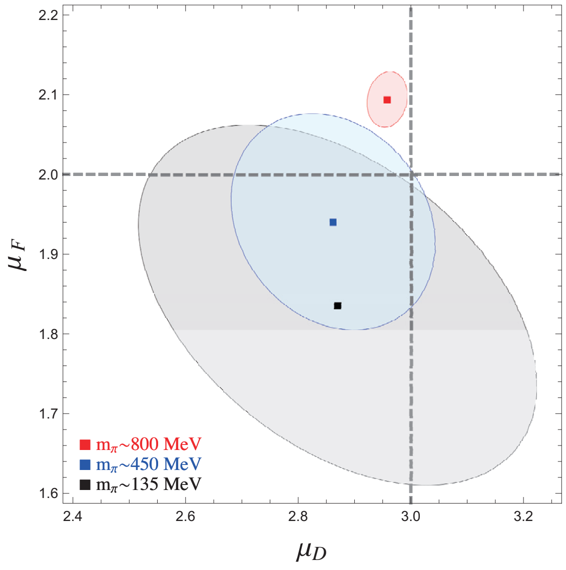

Fig. 1. Determined values of the Coleman-Glashow magnetic moments, μ_D and μ_F, as a function of the pion mass obtained from LQCD and experiment.

The integer values $\mu_D = 3$ and $\mu_F = 2$ arise from the $SU(6)$ symmetry of the nonrelativistic quark model. It is quite surprising how little quark-mass dependence exists in these moments, and how robust the nonrelativistic quark model appears to be as a function of the pion mass. Chiral-limit values of these moments are also estimated, but the large uncertainties from chiral extrapolation currently preclude definite conclusions.

References

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[a] Notice that $SU(3)_F$-breaking quark-disconnected contributions are proportional to $(m_s - m)/N_c^2$, and are hence subleading compared to those estimated above.