Magnetic moments of baryons

C. P. Singh
Department of Physics, Panjab University, Chandigarh-160014, India
(Received 19 May 1980; revised manuscript received 15 August 1980)

A new quark-mass-ratio parameter $y = (M_\Delta - M_\omega)/(M_\Omega - M_\phi)$ is suggested and magnetic moments of ordinary baryons are evaluated. With the mass correction $(M_p/M_B)^{1/2}$, a much better fit is obtained.

The baryon magnetic moments have attracted a lot of attention during the last few years. Many authors,[1-6] employing different techniques, have calculated these, and on the experimental front, except for $\mu(\Sigma^0)$, the magnetic moments of all the uncharmed octet baryons are known to a reasonable degree of accuracy. But none of the theoretical approaches used so far has been able to give an overall satisfactory fit. The experimental values though consistent with $\mu(p)/\mu(n) = -\frac{3}{2}$ do not satisfy the relation $\mu(\Lambda) = \mu(n)/2$, which are SU(6) and additive-quark-model results.[7] This led to the consideration of symmetry breaking arising due to the differences in quark masses and, as such, many attempts have been made, incorporating various mass corrections to include and account for the symmetry-breaking effects. De Rújula *et al.*,[1] assigning pointlike Dirac magnetic moments to the quarks and determining the quark-mass-ratio parameter y from the known baryon masses as

$$y = \frac{m_u}{m_s} = \frac{2(M_\Sigma^* - M_\Sigma)}{2M_\Sigma^* + M_\Sigma - 3M_\Lambda} = 0.62\ , \tag{1}$$

successfully predicted $\mu(\Lambda) = -0.61$. But, with the same quark parameters, the prediction for $\mu(\Xi^0)$ [which was measured in the same experiment as $\mu(\Lambda)$] is found to be very different from the experimental result. Furthermore, recently observed values of $\mu(\Sigma^+)$ (Ref. 8) and $\mu(\Xi^-)$ (Ref. 9) are at variance with the predicted values, which seems to demand some rethinking.

In this context Tomozawa[4] and other authors[6,10] have suggested certain different and somewhat modified approaches of including the mass breaking effects. Tomozawa, modifying relation (1), considers the mass-ratio parameter as

$$y = \frac{M_\omega}{M_\Phi} = 0.77\ , \tag{2}$$

where the physical masses of the particles are used and the interaction between the quarks is allowed and implicitly taken into consideration. Relation (2) will be a good approximation for the parameter y if the quark binding energies are neglected in comparison to quark masses as subsequently argued by the author[4]—which we think is not justified for the following reasons. If one takes the mass of a hadron as the sum of the masses of the quarks it contains plus the two-body quark-quark (antiquark) interaction energies[11] and makes use of the Lipkin relation[2]

$$m_s - m_u = M_\Lambda - M_p\ , \tag{3}$$

which yields a good value for the magnetic moment $\mu(\Lambda) = -0.61$, then it can be shown that

$$V^1_{u\bar{u}} - V^1_{s\bar{s}} \simeq 120\ \text{MeV}. \tag{4}$$

Therefore, if the interaction energies $V_{u\bar{u}}$ and V_{ss} are both of the same sign then, at least one of them has to be larger than 120 MeV, and hence its effect cannot be completely ignored.

In this note we suggest another version which gives an improved fit with available data. We take the parameter y to be given by

$$y = \frac{M_\Delta - M_\omega}{M_\Omega - M_\Phi} = 0.69\ , \tag{5}$$

where by taking the mass differences the effect of binding energies will be minimized because of the quantum-chromodynamic consideration of quark-quark (q-q) and quark-antiquark (q-$\bar{q}$) interaction.[12] Using this new value of parameter y, we calculate the octet baryon magnetic moments which are given in Table I. It is seen that $\mu(\Lambda)$ is not very much disturbed whereas $\mu(\Sigma^-)$, $\mu(\Xi^-)$, and transition moment $\mu(\Lambda\Sigma^0)$ are reasonably improved.

Recently, Teese and Settles[6] argued that the formula

$$\mu(B) = \left\langle B, S_z = \frac{1}{2} \middle| \sum_q \mu_q \sigma_z^q \middle| B, S_z = \tfrac{1}{2} \right\rangle, \tag{6}$$

where

$$\mu_q = \frac{e_q \hbar}{2m_q c}$$

used in calculating the magnetic moments predicts moments in intrinsic magnetons rather than nuclear magnetons. In practice that can be obtained by multiplying each formula by a factor (M_p/M_B) or $(M_p/M_B)^{1/2}$. They obtained a better fit with the

TABLE I. Magnetic moments of baryons.

Particles	Matrix elements	Tomozawa (Ref. 4)	Present analysis	Teese and Settles (Ref. 6) with mass correction $(M_p/M_B)^{1/2}$	Present analysis with mass correction $(M_p/M_B)^{1/2}$	Experimental value
p	$\frac{1}{9}(8+x)$	2.79	2.79	2.79	2.79	2.79
h	$-\frac{2}{9}(1+2x)$	−1.91	−1.91	−1.91	−1.91	−1.91
Λ	$-\frac{1}{3}y$	−0.61	−0.64	−0.612	−0.608	−0.61 ± 0.034 (Ref. 13)
Σ^+	$\frac{1}{9}(8+y)$	2.14	2.69	2.39	2.37	2.33 ± 0.13 (Ref. 8)
Σ^-	$-\frac{1}{9}(4x-y)$	−0.83	−1.12	−0.95	−0.99	−1.40 ± 0.37 (Ref. 14)
Σ^0	$\frac{1}{9}(4-2x+y)$	0.65	0.78	0.61	0.69	
Ξ^0	$-\frac{2}{9}(2y+1)$	−1.13	−1.44	−1.27	−1.22	−1.20 ± 0.06 (Ref. 15)
Ξ^-	$-\frac{1}{9}(4y-x)$	−0.46	−0.56	−0.48	−0.48	−0.75 ± 0.07 (Ref. 9)
$\Lambda\Sigma^0$	$\frac{1}{3\sqrt{3}}(x+2)$	1.21	1.67	1.45	1.50	$1.82^{+0.25}_{-0.18}$ (Ref. 16)

mass correction $(M_p/M_B)^{1/2}$. Now if we apply the same mass correction to our values then the fit improves to a reasonable degree. The values $\mu(\Lambda)$, $\mu(\Sigma^+)$, and $\mu(\Xi^0)$ are best fitted. Other values also compare favorably (Table I). From our results one can conclude that the quark-quark (quark-antiquark) interaction which is neglected by Tomozawa has certain deeper influence on the magnetic moments. The discrepancies still present between theory and experiment may possibly be due to relativistic effects, quark-quark interactions, and the effects of the $q\bar{q}$ sea (meson current), which have to be examined thoroughly.

The author would like to thank Dr. M. P. Khanna for stimulating discussions and P. N. Pandit for critically reading the manuscript. This work was supported by the University Grants Commission, New Dehli under Faculty Improvement Program.

[1]A. De Rújula, H. Georgi, and S. L. Glashow, Phys. Rev. D 12, 147 (1975).
[2]H. J. Lipkin, Phys. Rev. Lett. 41, 1629 (1978).
[3]J. Franklin, Phys. Rev. D 20, 1742 (1979).
[4]Y. Tomozawa, Phys. Rev. D 19, 1626 (1979).
[5]C. P. Singh, R. C. Verma, and M. P. Khanna, Pramana 13, 261 (1979).
[6]R. B. Teese and R. Settles, Phys. Lett. 87B, 111 (1979).
[7]J. J. Kokkedee, *The Quark Model* (Benjamin, New York, 1969).
[8]R. Settles *et al.*, Phys. Rev. D 20, 2154 (1979).
[9]T. Devlin, Bull. Am. Phys. Soc. 25, 572 (1980).
[10]N. Isgur and G. Karl, Toronto report, 1979 (unpublished).
[11]H. R. Rubinstein, Phys. Rev. Lett. 17, 41 (1966); Phys. Lett. 22, 210 (1966). A. W. Hendry and D. B. Lichtenberg, Phys. Rev. D 12, 2756 (1975).
[12]F. E. Close, *An Introduction to Quarks and Partons* (Academic, New York, 1979).
[13]L. Schachingar *et al.*, Phys. Rev. Lett. 41, 1348 (1978).
[14]G. Dugan *et al.*, Nucl. Phys. A254, 396 (1975).
[15]G. Bunce *et al.*, Phys. Lett. 86B, 386 (1979).
[16]F. Dydak *et al.*, Nucl. Phys. B118, 1 (1977).