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Baryon axial charges*

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In the Standard Model of elementary-particle physics the axial charges g_A of baryons are decisive quantities for the comprehension of both the electroweak and strong interactions. In the first instance they govern weak processes, such as the β decay. Furthermore, they also relate to the strong interaction, what is most clearly seen through the Goldberger-Treiman relation. In case of the nucleon N, for example, it reads $g_A = f_\pi g_{\pi NN}/M_N$. Therefore, given the π decay constant f_π and the nucleon mass M_N, the πNN coupling constant $g_{\pi NN}$ just turns out to be proportional to g_A. By this relation one can thus estimate the role of π degrees of freedom in low-energy hadronic physics: Whenever g_A becomes sizable, the π coupling should also become appreciably strong and vice versa. In other words, g_A can also be viewed as an indicator for the phenomenon of spontaneous breaking of chiral symmetry of low-energy quantum chromodynamics (QCD). Consequently, any reasonable model for hadronic physics should yield the g_A of correct sizes.

More recently, the axial charges not only of the baryon ground states but also of the N resonances have come into the focus of interest. In particular, it has been suggested that the sizes of g_A should become small for almost degenerate parity-partner N resonances; these can be interpreted as chiral doublets, indicating the onset of chiral-symmetry restoration with higher excitation energies [1,2]. Unfortunately, the g_A values of the N resonances are unknown from phenomenology and will be hard to measure in experiment. However, the problem can be explored with the use of lattice QCD. Corresponding first results have already become available, but only for two of the N resonances, namely, N(1535) and N(1650) [3]. Both of these resonances have the same spin $J = \frac{1}{2}$ and parity $P = -1$. Since there is not yet any lattice-QCD result for positive-parity states, the above issue relating to parity-doubling remains unresolved from this side.

In addition, the axial charges of octet and decuplet ground states N, Σ, Ξ, Δ, Σ^*, and Ξ^* are also important to learn about the role of $SU(3)_F$ flavor-symmetry breaking. Under the assumption of $SU(3)_F$ symmetry, the axial charges of the N, Σ, and Ξ ground states are connected by the following simple relations:

$$g_A^N = F + D\,, \quad g_A^\Sigma = \sqrt{2}F\,, \quad g_A^\Xi = F - D\,. \tag{1}$$

* Talk delivered by Ki-Seok Choi

Violation of these relations indicates the amount of $SU(3)_F$ symmetry breaking.

Recently, we have performed a comprehensive study of the axial charges of octet and decuplet ground states N, Σ, Ξ, Δ, Σ*, and Ξ* as well as their resonances along RCQMs [4,5]. Specifically, we have employed the RCQMs whose quark-quark hyperfine interactions derive from one-gluon-exchange and Goldstone-boson-exchange dynamics; for the latter we have considered both the version with only the spin-spin interaction from pseudoscalar exchange as well as the extended version (EGBE) that includes all force components (i.e. central, tensor, spin-spin, and spin-orbit) from pseudoscalar, scalar, and vector exchanges [6]. In this contribution we refer only to results of this version. The calculations have been performed in the framework of Poincaré-invariant quantum mechanics. In order to keep the numerical computations manageable, we had to restrict the axial current operator to the so-called spectator model (SM) [7]. It means that the weak-interaction gauge boson couples only to one of the constituent quarks in the baryon. This approximation has turned out to be very reasonable already in previous studies of the axial and induced pseudoscalar as well as electromagnetic form factors of the nucleon.

Table 1. Axial charges g_A^B of octet and decuplet ground states as predicted by the EGBE RCQM [5] in comparison to experiment [8] and lattice-QCD results from Lin and Orginos (LO) [9] and Erkol, Oka, and Takahashi (EOT) [10] as well as results from chiral perturbation theory by Jiang and Tiburzi (JT) [11,12]; also given is the nonrelativistic limit (NR) from the EGBE RCQM.

	Exp	EGBE	LO	EOT	JT	NR
N	1.2695±0.0029	1.15	1.18±0.10	1.314±0.024	1.18	1.65
Σ	···	0.65	0.636±0.068†	0.686±0.021†	0.73	0.93
Ξ	···	-0.21	-0.277±0.034	-0.299±0.014‡	-0.23‡	-0.32
Δ	···	-4.48	···	···	∼-4.5	-6.00
Σ*	···	-1.06	···	···	···	-1.41
Ξ*	···	-0.75	···	···	···	-1.00

† Because of another definition of g_A^Σ this numerical value is different by a $\sqrt{2}$ from the one quoted in the original paper.

‡ Because of another definition of g_A^Ξ this value has a sign opposite to the one in the original paper.

In Table 1 we present the predictions of the EGBE RCQM for the axial charges g_A^B of the octet and decuplet ground states $B = N, \Sigma, \Xi, \Delta, \Sigma^*$, and Ξ^*. Except for the N there are no direct experimental data for g_A^B. The EGBE RCQM prediction for g_A^N come close to the experimental value, with only slightly falling below it. This is also the trend of most modern lattice-QCD calculations; only the result by Erkol et al. seems to represent a notable exception. In addition, our result compares well with the g_A^N prediction obtained from chiral perturbation theory by Jiang and Tiburzi. In the last column of Table 1 we quote also the nonrelativistic limit of the prediction by the EGBE RCQM. It deviates grossly from the relativistic result, indicating that a nonrelativistic treatment of axial charges is unreliable.

For the g_A^B of the other octet and decuplet ground states, the EGBE RCQM again yields results very similar to the other approaches. For the octet states Σ and Ξ the figures compare well with the lattice-QCD as well as chiral-perturbation-theory results. For the decuplet states we can only compare the result for g_A^Δ to the one by Jiang and Tiburzi, what shows again a striking similarity. Evidently, all the results from the nonrelativistic limit of the EGBE RCQM fall short; as in the case of the N, the corresponding values are always bigger (in absolute value) than all of the other results.

In Table 2 we have collected the predictions of the EGBE RCQM for g_A of all ground and resonance states of N, Σ, Ξ, Δ, Σ^*, and Ξ^*. They are classified as belonging to the flavor octets and decuplets specified by total angular momentum and parity, J^P, where in addition their total orbital angular momenta L and total spins S (in the rest frame) are given. Except for N(1535) and N(1650), which are known from a lattice-QCD calculation [3] to be of the same sizes as our results, these are first relativistic predictions for axial charges of baryon resonances.

Table 2. Axial charges of octet (upper part) as well as decuplet (lower part) baryon ground states and resonances as predicted by the EGBE RCQM. The flavor-multiplet assignments follow ref. [13].

$(LS)\,J^P$	State	g_A	State	g_A	State	g_A
$(0\frac{1}{2})\,\frac{1}{2}^+$	$N(939)$	1.15	$\Sigma(1193)$	0.65	$\Xi(1318)$	-0.21
$(0\frac{1}{2})\,\frac{1}{2}^+$	$N(1440)$	1.16	$\Sigma(1660)$	0.69	$\Xi(1690)$	-0.23
$(0\frac{1}{2})\,\frac{1}{2}^+$	$N(1710)$	0.35	$\Sigma(1880)$	0.38		
$(1\frac{1}{2})\,\frac{1}{2}^-$	$N(1535)$	0.02	$\Sigma(1560)$	-0.15		
$(1\frac{3}{2})\,\frac{1}{2}^-$	$N(1650)$	0.51	$\Sigma(1620)$	0.62		
$(2\frac{1}{2})\,\frac{3}{2}^+$	$N(1720)$	0.35				
$(1\frac{1}{2})\,\frac{3}{2}^-$	$N(1520)$	-0.64	$\Sigma(1670)$	-0.92	$\Xi(1820)$	-0.38
$(1\frac{3}{2})\,\frac{3}{2}^-$	$N(1700)$	-0.10	$\Sigma(1940)$	-0.45		
$(2\frac{1}{2})\,\frac{5}{2}^+$	$N(1680)$	0.84				
$(1\frac{3}{2})\,\frac{5}{2}^-$	$N(1675)$	0.89	$\Sigma(1775)$	1.06		
$(0\frac{3}{2})\,\frac{3}{2}^+$	$\Delta(1232)$	-4.48	$\Sigma^*(1385)$	-1.06	$\Xi^*(1535)$	-0.75
$(0\frac{3}{2})\,\frac{3}{2}^+$	$\Delta(1600)$	-4.41	$\Sigma^*(1690)$	-1.05		
$(1\frac{1}{2})\,\frac{1}{2}^-$	$\Delta(1620)$	-0.76	$\Sigma^*(1750)$	-0.08		
$(1\frac{1}{2})\,\frac{3}{2}^-$	$\Delta(1700)$	-1.68				

We find it noticeable that the axial charges of members of two particular flavor multiplets are all relatively small, namely the ones of the $J^P = \frac{1}{2}^-$ octet with N(1535) and decuplet with Δ(1620). Interestingly, they are both the first $\frac{1}{2}^-$ excitations above the corresponding positive-parity ground states, the N(939) and the Δ(1232).

Our results in Table 2 cannot tell anything regarding the issue of chiral-symmetry restoration higher in the baryon excitation spectra. The more it will be interesting to have in the near future calculations of resonance axial charges from lattice QCD and other approaches. They will hopefully confirm or disprove the pattern of results as produced by the RCQMs.

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