Bled Workshops in Physics
Vol. 10, No. 1
p. 28

Proceedings of the Mini-Workshop
Problems in Multi-Quark States
Bled, Slovenia, June 29 - July 6, 2009

Axial charges of nucleon resonances⋆

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Recently, first results have become available from lattice quantum chromodynamics (QCD) for two of the nucleon excitations, namely, the negative-parity $N^*(1535)$ and $N^*(1650)$ resonances [1]. The axial charge of the nucleon ground state had been studied before by different lattice-QCD groups in quenched calculations and with dynamical quarks [2–7]. In some of these works one has used chiral extrapolations (for a recent discussion of the associated problems see Ref. [8]), and the bulk of results obtained for g_A of the nucleon varies between about $1.10 \sim 1.40$.

Lately, the issue of axial constants of N^* resonances has become debated a lot due to the suggestion of chiral-symmetry restoration in the higher hadron spectra [9,10]. According to this scenario there should appear chiral doublets of positive- and negative-parity states and as a further consequence their axial charges should became small or almost vanishing. The first parity partners above the nucleon ground state are supposed to be the $N^*(1440){-}N^*(1535)$, the next ones the $N^*(1710){-}N^*(1650)$. The axial charges of the negative-parity partners in these pairs have been calculated in lattice QCD to be ~0.00 and ~0.55, respectively [1]; for the positive-parity states no results are yet available.

We have performed a study of the axial charges of N^* resonances in the framework of the relativistic constituent quark model (RCQM). Specifically we have extended a previous investigation of the nucleon axial form factors [11,12] to the first $J^P = \frac{1}{2}^{\pm}$ nucleon excitations. Our approach relies on solving the eigenvalue problem of the Poincaré-invariant mass operator in the framework of relativistic quantum mechanics. The axial current operator is chosen according to the spectator model (SM) [13]. For the RCQM we employed in the first instance the extended Goldstone-boson exchange (EGBE) RCQM [14], as it produces the most elaborate nucleon and N^* wave functions.

In Table 1 we present a selection of results for the axial charges g_A of the nucleon and the $N^*(1440)$, $N^*(1710)$, $N^*(1535)$, as well as $N^*(1650)$ resonances in case of the EGBE RCQM. It is immediately evident that the EGBE RCQM produces reasonable values for the axial charges in all instances without any further fittings. In the cases where a comparison is possible it produces the same pattern as lattice QCD. The g_A of the nucleon and of $N^*(1440)$ are practically of the same size, with the theoretical result for the nucleon being quite close to the experi-

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mental value of g_A=1.2695±0.0029 [15]. The nonrelativistic calculations cannot produce this value, neither in the simplistic $SU(6) \times O(3)$ quark model nor in the nonrelativistic limit of the RCQM. For the negative-parity $N^*(1535)$ resonance the g_A is predicted to be compatible with 0, while for the negative-parity $N^*(1650)$ resonance it is 0.51; both cases agree with the lattice-QCD results of Ref. [1]. Accidentally, the g_A value of the nonrelativistic $SU(6) \times O(3)$ quark model is similar in the $N^*(1650)$ case but the nonrelativistic limit of the EGBE RCQM shows deviations for both of the $\frac{1}{2}^-$ resonances. At this time nothing is known from lattice QCD for the $\frac{1}{2}^+$ resonances. For the latter, it would also be most interesting to check our results against lattice QCD, and we look forward to corresponding calculations.

Table 1. Predictions for axial charges g_A of the EGBE in comparison to available lattice QCD results [1-7], the values calculated by Glozman and Nefediev [9] within the $SU(6) \times O(3)$ nonrelativistic quark model, and the nonrelativistic limit from the EGBE RCQM.

State	J^P	EGBE	Lattice QCD	$SU(6) \times O(3)$ QM	EGBE nonrel
N(939)	$\frac{1}{2}^+$	1.15	1.10~1.40	1.66	1.65
N(1440)	$\frac{1}{2}^+$	1.16	–	1.66	1.61
N(1535)	$\frac{1}{2}^-$	0.02	~0.00	-0.11	-0.20
N(1710)	$\frac{1}{2}^+$	0.35	–	0.33	0.42
N(1650)	$\frac{1}{2}^-$	0.51	~0.55	0.55	0.64

It is particularly satisfying to find the RCQM predictions for the axial charges of the $N^*(1535)$ and $N^*(1650)$ resonances in agreement with the lattice-QCD results. We may thus be confident that at least for zero momentum-transfer processes the mass eigenstates of these nucleon excitations as produced especially with EGBE RCQM are quite reasonable. The latter is supposed to model the SBχS property of low-energy QCD. This type of hyperfine interaction, which also introduces an explicit flavor dependence, has been remarkably successful in describing a number of phenomena in low-energy baryon physics. Most prominently, it produces the correct level orderings of the positive- and negative-parity N^* resonances and simultaneously the ones in the other hyperon spectra, notably the Λ spectrum. The RCQM with GBE dynamics does not have any mechanism for chiral-symmetry restoration built in. As such it cannot be expected to produce parity doublets due to this reason. Nevertheless the EGBE RCQM describes the N^* resonance masses with good accuracy (mostly within the experimental error bars or at most exceeding them by 4%).

Acknowledgments K-S. C. is grateful to the organizers of the Mini-Workshop for the invitation and for creating such a lively working atmosphere. This work was supported by the Austrian Science Fund (through the Doctoral Program on *Hadrons in Vacuum, Nuclei, and Stars*; FWF DK W1203-N08).

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