Light baryon spectrum using improved interpolating field operators

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The theoretical determination of baryon resonances from the fundamental quark and gluon degrees of freedom is an important goal. Lattice QCD is the theoretical method suited to solving this problem. It has provided a reasonably good reproduction of experimental ground state energies for different baryons. However, only a few results for excited state energies have been reported. A complication is that the spectrum of excited states on the lattice contains discrete scattering states that couple strongly to the baryon resonances. In the paper [1], we extract the baryon spectrum of isospin $1/2$ and $3/2$ from the Monte Carlo simulations of lattice QCD.

Special technique employed in this work is the use of improved baryon interpolating fields. Theoretical developments of lattice interpolators is detailed in Ref. [2, 3]. Improved baryon three-quark operators include covariant displacements between quarks to incorporate explicit inter-quark interactions. Such construction is needed in order to gain nonzero orbital angular momenta at source and sink. In these simulations, array of operators are used in each symmetry channel to compute matrices of two-point correlation functions.

Due to the discretization of space, continuum rotational group is broken down to finite point group called the octahedral group. Because the octahedral group contains a finite number of irreducible representations, mapping of spins from energy eigenstates obtained in lattice simulations is difficult even if continuum extrapolation is performed. The only way to identify continuum spin of hadron is to analyze the degeneracy patterns of mass eigenstates over all irreducible representations. The subduction of continuum spins to irreducible representations of the octahedral group is given in Table I. In part, the identification of baryon spin is possible in the preliminary results of the recent work [1]. However, distinction of higher spins such as $7/2$ is still uncertain.

TABLE I: Spinorial irreducible representations of the octahedral group. Dimensions of irreducible representations are listed in the middle column. Spins and parities of continuum irreducible representations of SU(2) that have subductions to each irrep of the octahedral group are listed in the right column.

irrep	dimension			J^P			
$G_{1g/u}$	2	$\frac{1}{2}^{\pm}$			$\frac{7}{2}^{\pm}$	$\frac{9}{2}^{\pm}$	$\frac{11}{2}^{\pm}$
$G_{2g/u}$	2			$\frac{5}{2}^{\pm}$	$\frac{7}{2}^{\pm}$		$\frac{11}{2}^{\pm}$
$H_{g/u}$	4		$\frac{3}{2}^{\pm}$	$\frac{5}{2}^{\pm}$	$\frac{7}{2}^{\pm}$	$\frac{9}{2}^{\pm}$	$\frac{11}{2}^{\pm}$

Figure 1 shows the quenched QCD results of lowest-lying energies that we obtained from the best sets of operators in various spin-parity channel. Pion mass we used is $\simeq 500\,\mathrm{MeV}$. Under this unrealistic conditions, the masses of baryons become heavier than experimental values. Nevertheless, the *pattern* of mass ordering in a given parity by lattice simulations surprizingly agrees with empirical data. In particular, the mass pattern of negative parity states are well explained by the spin-flavor SU(6) quark model with spin-spin contact interaction symmetry breaking term, which makes $1/2^-$ and $3/2^-$ less massive than the unperturbed level. In the future calculations have to be performed with lighter pions so as to extrapolate the spectrum in the chiral limit. Study of decay of heavy particles will be essential. The finite volume analysis on energy levels and spectral densities enables us to identify single-particle state or scattering states.

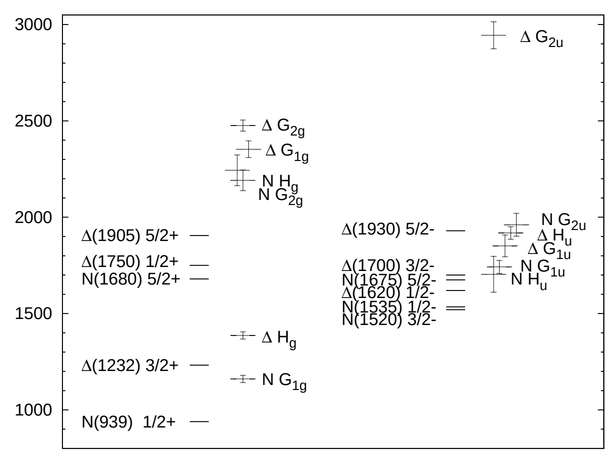

FIG. 1: The lowest energies obtained for each symmetry channel of isospin $\frac{1}{2}$ and $\frac{3}{2}$ baryons

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[2] S. Basak *et al.* [Lattice Hadron Physics Collaboration (LHPC)], Phys. Rev. D **72**, 074501 (2005) [arXiv:hep-lat/0508018].
[3] S. Basak *et al.*, Phys. Rev. D **72**, 094506 (2005) [arXiv:hep-lat/0506029].