Intra-band transitions of positive parity baryons in a deformed oscillator quark model

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More than eighty baryons have been observed in experiment, and their masses, spins, flavors, and parities are known [1]. Among them, it is known that the Gell-Mann-Okubo (GO) mass formula works well to describe the pattern of the flavor octet and decuplet baryons in the ground states; the difference of masses among different flavor baryons can be explained by that of the constituent quarks.

Recently, we have applied the GO mass formula to all observed baryons not only ground states but also excited states, and found that there is a flavor independent systematics in spectra [2, 3]. The mass difference between grounds states and the first excited states is 500 MeV, and the next excited states 700 MeV, etc. Remarkably, we have found that these patterns of mass spectra have a behavior quite similar to the *rotational band* in the deformed nuclei, which seems to imply spatial deformation of excited states of baryons. We have then investigated these spectra in terms of an effective non-relativistic quark model with a deformed harmonic oscillator potential, which we call the deformed oscillator quark (DOQ) model, and shown that almost all data can be reproduced with only one parameter by the DOQ model.

In the deformed nuclei, typical transitions are observed among rotational bands, which are classified as *inter*-band or *intra*-band transitions. In baryon spectrum, we can also identify three bands as shown in Fig. 1 and define inter-band and intra-band transitions. We expect that we can also observe similar transitions in the excited baryons if the pattern of their spectra is nothing but a rotational band [4]. In this brief report, we study intra-band transitions of excited baryons through an emission of a pion in the framework of the DOQ model.

We calculate transition amplitudes $\mathcal{M} = \langle P_f; J_f\, M_f | H_{\pi qq} | P_i; J_i\, M_i \rangle$ in the DOQ model, where $|P_{i(f)}; J_{i(f)}, M_{i(f)}\rangle$ denotes the initial (final) N^* state with momentum $P_{i(f)}$, total spin $J_{i(f)}$ and its z component $M_{i(f)}$. $E_{P_{i(f)}}$ is the energy of the initial (final) N^* and ω_k is the energy of the emitted pion.

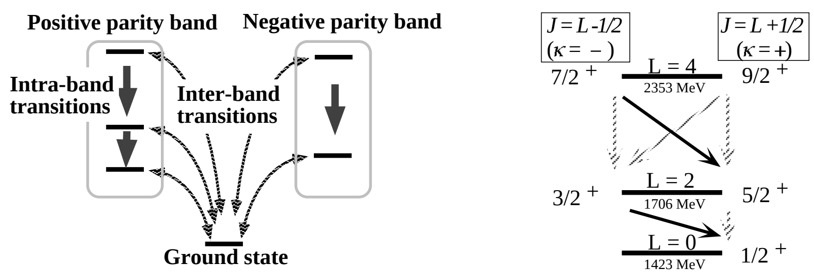

Figure 1: Definition of intra- and inter- band transitions (left) and selection rule for intra-band transitions among positive parity baryons (right)

Table 1: Selection rule for strong intra-band decays $N^* \to N^*\pi$ and decay widths in units of MeV are shown. L, $J(J')$, Δl are angular momentum of initial state, total spin of initial (final) state and allowed angular momentum of emitted pion, respectively. κ (κ') is a relative orientation of spin and orbital angular momentum, which is denoted by either + (parallel) or − (anti-parallel)

L	(J^P)	(J'^P)	$(\Delta l\ )$	$\kappa \to \kappa'$	Γ(MeV)
	$9/2^+ \to$	$5/2^+$	3^+	$+ \to +$	5.8
$L = 4$	$9/2^+ \to$	$3/2^+$	3^+	$+ \to -$	10.9
	$7/2^+ \to$	$5/2^+$	1^+, 3^+	$- \to +$	35.5
	$7/2^+ \to$	$3/2^+$	3^+	$- \to -$	0.2
$L = 2$	$5/2^+ \to$	$1/2^+$	3^+	$+ \to +$	0.1
	$3/2^+ \to$	$1/2^+$	1^+, 3^+	$- \to +$	0.2

The non-relativistic interaction Hamiltonian in the coordinate representation is given by $H_{\pi qq}(\vec{X}) = -\frac{g}{2m}\frac{1}{\sqrt{2\omega_k}}\left(\vec{\sigma}\cdot\vec{\nabla}\exp(i\vec{k}\cdot\vec{X})\right)\tau_a$, where g is πqq coupling constant, m constituent quark mass and τ_a Pauli matrices for isospin. The wave function is written as a product of orbital, spin χ, isospin ϕ and color wave function and anti-symmetrized as in conventional quark model,

$$|P; JM\rangle = \mathcal{A}\Big(\Big[\Big(Y_{LL_z}(\Theta)\Psi^{(int)}(\vec{x})\Big)\otimes\chi\Big]_{JM}\otimes\phi\otimes(\text{color})\Big). \tag{1}$$

Here we use a semi-classical (cranking) picture for the orbital wave function by introducing collective coordinate Θ and collective motion of a deformed intrinsic state, which is expressed by spherical harmonics in collective coordinate.

By virtue of the cranking picture, transition amplitude has the form

$$\mathcal{M} = \int d\Theta\langle[L_f, 1/2]^{J_f}_{M_f}|3\mathcal{O}^{int}_N(\Theta)|[L_i, 1/2]^{J_i}_{M_i}\rangle\,, \tag{2}$$

where $\mathcal{O}$ contains integration over body-fixed coordinate and can be considered as a operator in the collective coordinate. An overall factor 3 represent number of quarks in a baryon. The operator $\mathcal{O}$ has rather complicated form, however, it is essentially given by a geometrical factor composed of Clebsch-Gordan coefficients and the l-moment, $Q^{(l)}_N(k) \equiv \langle N^{(int)}|j_l(kx)Y_{l0}(\hat{x})|N^{(int)}\rangle$, which includes all the information of deformed intrinsic states. Resulting transition amplitude is written as a product of moment Q and geometrical factor.

Numerical results of the decay width $W_{fi} = 6\pi\int\frac{d^3q}{(2\pi)^3}\delta(E_f + \omega_q - E_i)\frac{1}{2J_i+1}\sum_{M_iM_f}|\mathcal{M}|^2$ are tabulated in Table 1. Transitions from $L = 2$ to $L = 0$ are almost forbidden due to the phase space factor, while a transition $7/2^+ \to 3/2^+$ is also forbidden due to the geometrical factor. Transition $7/2^+ \to 5/2^+$ has rather large decay width since $\Delta l = 1$ pion can contribute to this process. Calculations including negative parity baryons are remained as a future work.

References

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