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ON THE ROLE OF THE L=1 BARYON EXCITATION IN THE GIANT ELECTRIC DIPOLE RESONANCES

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ABSTRACT

A simple estimate, based on the quark model, is made of the effect of the odd parity baryon resonances N^* and Δ^* on the vector dipole excitations in the nucleus. Although the coupling between the nuclear and baryon L=1 degrees of freedom seems to be quite more relevant for the vector dipole fields than for the corresponding axial-vector ones, it still represents a minor effect.

Excited states of the nucleon can be described in the same way as excited state of the nucleus:

a) The first excited state is the Δ-resonance (of intrinsic spin $S=\frac{3}{2}$, isospin $T=\frac{3}{2}$ and positive parity) at about 1230 MeV. It is constructed simply by flipping the spin and isospin of a single quark constituent just as in the nucleus one excites an isovector M1 or a Gamow-Teller state by the action of a spin-isospin field.

b) The odd parity baryon resonances N^* and Δ^* with $T=\frac{1}{2}$ and $\frac{3}{2}$, respectively and $S=\frac{1}{2}$ and $\frac{3}{2}$, in the energy region of 1520-1710 MeV are thought to be formed by raising one of the quark of the nucleon to an orbital $L=1$ state. Thus they are directly analogous to the giant E1 and M2 resonances, as well as to the giant first-forbidden resonances, in the nucleus(*).

In recent years a large amount of effort has been devoted to explain a large quenching (30-50%) of the observed strength in M1, Gamow-Teller and first-forbidden axial-vector resonances. The motive commonly invoked for this effect is the coupling of the Δ-isobar-nucleon-hole ($N\Delta^{-1}$) excitations with the nucleon-particle-nucleon-hole (NN^{-1}) excitations[1-7]. Namely, due to the quark structure of hadrons an external field F apllied to the nucleus excites both the nuclear and hadron degrees of freedom and couples them with each other. When the excitation is coherent a large effect can be build up despite the large mass difference between the nucleon mass M_N and

(*) *The positive parity N^* resonance with $S=\frac{1}{2}$ and $T=\frac{1}{2}$ at 1470 MeV is interpreted to be formed by the radial excitation (breathing mode) of the quarks within the nucleon, directly analogous to the E0 resonances in nuclei.*

the mass of the Δ-resonance M_Δ ($M_\Delta - M_N \cong 300$ MeV).

Suzuki et al.[6] have also studied the role of the odd parity baryon excitations in the first-forbidden axial-vector collective states. They have found that the quenching effect induced by these resonance is smaller by a factor $10^{-2} - 10^{-3}$ than that of the Δ-isobar.

In the present paper we discuss the influence of the baryon intrinsic excitations on the dipole vector resonances, or more specifically on the giant E1 resonances. As the field operator

$$F^V_{\mu,\mu_\tau} = \sum_{i=1}^{3} r_i \, Y_{1\mu}(\Omega_i) \tau_{\mu_\tau}(i) \quad , \tag{1}$$

only flips the isospin it will excite only the members of the $\{20,1^-\}$ multiplet of $SU4 \times O(3)$ with intrinsic spin $S = \frac{1}{2}$, i.e. the states

$$|N^*\rangle \equiv |L=1 \; , \; S = \tfrac{1}{2} \; , \; I = \tfrac{1}{2}\rangle \quad ,$$

$$|\Delta^*\rangle \equiv |L=1 \; , \; S = \tfrac{1}{2} \; , \; I = \tfrac{3}{2}\rangle \quad .$$

Introducing Jacobi's coordinates $\vec{R}$, $\vec{\lambda}$ and $\vec{\rho}$ through the relations[8,9]

$$\vec{R} = \frac{1}{\sqrt{3}} (\vec{r}_1 + \vec{r}_2 + \vec{r}_3) \quad ,$$

$$\vec{\lambda} = \frac{1}{\sqrt{6}} (\vec{r}_1 - \vec{r}_2 - 2\vec{r}_3) \quad , \tag{2}$$

$$\vec{\rho} = \frac{1}{\sqrt{2}} (\vec{r}_1 - \vec{r}_2) \quad ,$$

one finds[6]

$$F_{\mu,\mu_\tau} = \left(\frac{3}{4\pi}\right)^{1/2} \left(F^N_{\mu,\mu_\tau} + F^B_{\mu,\mu_\tau}\right) \tag{3}$$

where

$$F^N_{\mu,\mu_\tau} = R_\mu \sum_{i=1}^{3} \tau_{\mu_\tau}(i) \quad , \tag{4}$$

and

$$F^B_{\mu,\mu_\tau} = \frac{\rho_\mu}{\sqrt{2}} \left[\tau_{\mu_\tau}(1) - \tau_{\mu_\tau}(2)\right] + \frac{\lambda_\mu}{\sqrt{6}} \left[\tau_{\mu_\tau}(1) - \tau_{\mu_\tau}(2) - 2\tau_{\mu_\tau}(3)\right] \tag{5}$$

separating of the center-of-mass motion of the three quarks connected with the variable $\vec{R}$, which describes the orbital motion of the nucleon is the nucleus. The integral motion of the quarks depends on the variables $\vec{\lambda}$ and $\vec{\rho}$. In other words, while the operator F^N produces an excited state by changing the orbital angular momentum of the nucleonic motion, the operator F^B increases the orbital angular momentum of a quark exciting the negative parity states of the baryon.

The matrix elements of the operator F^B have to be evaluated between the totally symmetric wave functions of the three quarks[8,9]

$$|N\rangle = \frac{1}{\sqrt{2}} \left[|\psi_0 \, ; 1,\tfrac{1}{2} \, ; 1,\tfrac{1}{2}\rangle + |\psi_0 \, ; 0,\tfrac{1}{2} \, ; 0,\tfrac{1}{2}\rangle\right] \quad , \tag{6}$$

and

$$|N^*\rangle = \frac{1}{2} \Big[|\psi_1^\delta \, ; 0,\tfrac{1}{2} \, ; 1,\tfrac{1}{2}\rangle - |\psi_1^\delta \, ; 1,\tfrac{1}{2} \, ; 0,\tfrac{1}{2}\rangle$$

$$+ |\psi_1^\lambda \, ; 0,\tfrac{1}{2} \, ; 0,\tfrac{1}{2}\rangle - |\psi_1^\lambda \, ; 1,\tfrac{1}{2} \, ; 1,\tfrac{1}{2}\rangle\Big] \quad , \tag{7a}$$

$$|\Delta^*\rangle = \frac{1}{\sqrt{2}}\left[|\psi_1^\lambda ; 1,\tfrac{1}{2} ; 1,\tfrac{3}{2}\rangle + |\psi_1^\delta ; 0,\tfrac{1}{2} ; 1,\tfrac{3}{2}\rangle\right] \quad . \qquad (7b)$$

Here $|\psi_L ; S_{12},S ; I_{12},I\rangle \equiv |\psi_L\rangle|S_{12},S\rangle|I_{12},I\rangle$ stands for the orbital wavefunction $|\psi_L\rangle$, the spin wavefunction $|S_{12},S\rangle$ and the isospin wavefunction $|I_{12},I\rangle$ of the three quarks inside the baryon. The orbital ground state is $|\psi_o\rangle$ and the orbital $L=1$ excited states are $|\psi^\lambda_{1\mu}\rangle \propto \lambda_\mu|\psi_o\rangle$ and $|\psi^\delta_{1\mu}\rangle \propto \rho_\mu|\psi_o\rangle$. The symbol $S_{12}(I_{12})$ denotes the two-body spin (isospin) value of particle 1 and 2 and $S(I)$ is the total spin (isospin) of the three quarks.

The calculation of the matrix elements can be easily done by means of relations

$$\langle I'_{12}I'||\tau(1)||I_{12},I\rangle = (-)^{I_{12}+I'_{12}}\langle I'_{12},I||\tau(2)||I_{12},I\rangle$$

$$= (-1)^{I_{12}+I'_{12}+I-\frac{1}{2}}\left[6(2I+1)(2I'+1)(2I_{12}+1)(2I'+1)\right]^{1/2}\begin{Bmatrix} I_{12} & \frac{1}{2} & I \\ I' & 1 & I'_{12}\end{Bmatrix}\begin{Bmatrix} \frac{1}{2} & \frac{1}{2} & I_{12} \\ I'_{12} & 1 & \frac{1}{2}\end{Bmatrix}, \qquad (8)$$

$$\langle I'_{12},I'||\tau(3)||I_{12},I\rangle = \delta_{I_{12},I'_{12}}(-1)^{I_{12}+I'-\frac{1}{2}}\left[6(2I+1)(2I'+1)\right]^{1/2}\begin{Bmatrix} I_{12} & \frac{1}{2} & I \\ 1 & I' & \frac{1}{2}\end{Bmatrix}, \qquad (9)$$

and one obtains

$$\langle N^*|||F|||N\rangle = -\langle\Delta^*|||F|||N\rangle = -\frac{6}{\sqrt{4\pi}}\,b_B \quad , \qquad (10)$$

where the triple bar matrix elements are reduced both in space and isospace and b_B is the baryon harmonic oscillator length parameter.

The values of the transition strengths

$$S_{N^*}(\mu_\tau) = \sum_N |\langle(N^*N^{-1})J=1,\mu|F_{\mu,\mu_\tau}|0\rangle|^2 \quad , \qquad (10)$$

are

$$S_{N^*}(\mu_\tau) = \frac{b_B^2}{4\pi}\begin{cases} 4N & \mu_\tau = -1 \\ 2A & \mu_\tau = 0 \\ 4Z & \mu_\tau = 1 \quad . \end{cases} \qquad (11)$$

Similarly

$$S_{\Delta^*}(\mu_\tau) = \frac{b_B^2}{4\pi}\begin{cases} 3Z+N & \mu_\tau = -1 \\ 2A & \mu_\tau = 0 \\ 3N+Z & \mu_\tau = 1 \quad . \end{cases} \qquad (12)$$

It is worth nothing that the following sum rules are valid

$$S(\mu_\tau=1) + S(\mu_\tau=-1) = 2S(\mu_\tau=0) \quad ,$$
$$S(\mu_\tau=1) - S(\mu_\tau=-1) = \frac{b_B^2}{4\pi}\,2(N-Z) \quad , \qquad (13)$$

where $S(\mu_\tau) = S_{N^*}(\mu_\tau) + S_{\Delta^*}(\mu_\tau)$. The same sum rules are also fullfilled by the axial vector fields

$$F_{\lambda_\mu,\mu_\tau} = \sum_{i=1}^{3} r_i(Y_i(\Omega_i)\otimes\sigma(i))_{\lambda_\mu}\,\tau_\mu(i) \qquad (14)$$

studied by Suzuki et al.[6].

Let us now estimate the renormalization of the vector-dipole giant transition amplitudes (both the E1 and charge exchange) by the baryon L=1 excitations. In the context of the approximation used here the quenching factor reads[4,7)]

$$\gamma_V \cong 1 - \kappa_V \chi_V^{(o)} \quad , \tag{15}$$

where $\kappa_V = \dfrac{\pi V_1}{A\langle r^2\rangle}$ and $V_1 = 130$ MeV , (16)

is the isovector dipole coupling constant and

$$\chi_V^{(o)} \cong \frac{2S(\mu_\tau=0)}{\Delta M} = \frac{2A\, b_B^2}{\pi \Delta M} \quad , \tag{17}$$

where $\Delta M = M_{N*} - M_n \cong 700$ MeV is the unperturbed isobar-hole response function ($M_{\Delta *} \cong M_{N*}$) .

Taking $b_B = 0.65$ fm and $\langle r^2\rangle = 0.6\ (1.2)^2 A^{2/3}\,\mathrm{fm}^2$ we obtain

$$\gamma_V \cong 1 - 0.18\ A^{-2/3} \tag{18}$$

which yields $\gamma_V^2 = 0.84$ for $A = 16$, 0.97 for $A = 48$ and 0.99 for $A = 208$.

It should be noticed that for the axial-vector fields $F_{\lambda_\mu,\mu_\tau}/g_A$, where $g_A = 5/3$ is the axial-vector coupling constant,

$$\kappa_A \cong 0.72\ \kappa_V \tag{19}$$

as estimated by Nakayama et al.[4)], and

$$\chi_A^{(o)} = \frac{3}{25}\chi_V^{(o)} \quad , \tag{20}$$

for the negative parity baryons. Therefore

$$\kappa_A\, \chi_A^{(o)} \cong 0.09\ \kappa_V\, \chi_V^{(o)} \quad , \tag{21}$$

which means that the retardation factor which comes from the L=1 excitations is one order of magnitude smaller in the axial-vector case.

We can summarize our considerations by saying that:

i) the coupling of the NN^{-1} nuclear excitations to the N^*N^{-1} and Δ^*N^{-1} baryon excitations is more pronounced for the vector-dipole resonances than for the axial-vector resonances;

ii) the virtual excitations of the isobaric internal degrees of freedom do not have a remarkable effect on the E1 giant resonances; the effect is particularly small for medium and heavy nuclei.

Finally it should be stressed that the fields (1) and (14) do not come out in a natural way from bag models or any other QCD theory[11)]. They are just simple generalizations of the corresponding nuclear fields which were performed in order to include quark degrees of freedom. The only justification for such a description of intrinsic baryon excitations is its simplicity.

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