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

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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}) excitations¹⁻⁷⁾. Namely, due to the quark structure of hadrons an external field F applied 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 ($M_\Delta - M_N \approx 300$ 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

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

only flips the isospin it will excite only the members of the $\{20, 1^-\}$ multiplet of $SU_4 \times O(3)$ with intrinsic spin $S = \frac{1}{2}$, i.e. the states

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

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

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

$$\begin{aligned} \vec{R} &= \frac{1}{\sqrt{3}} (\vec{r}_1 + \vec{r}_2 + \vec{r}_3), \\ \vec{\lambda} &= \frac{1}{\sqrt{6}} (\vec{r}_1 - \vec{r}_2 - 2\vec{r}_3), \\ \vec{\rho} &= \frac{1}{\sqrt{2}} (\vec{r}_1 - \vec{r}_2) \end{aligned} \quad (2)$$

one finds⁶⁾

$$F_{\mu, \mu_\tau} = \left(\frac{3}{4\pi}\right)^{1/2} \left(F_{\mu, \mu_\tau}^N + F_{\mu, \mu_\tau}^B \right) \quad (3)$$

where

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

and

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

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)}

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

and

$$\begin{aligned} |N^*\rangle &= \frac{1}{2} \left[|\psi_1^\delta; 0, \frac{1}{2}; 1, \frac{1}{2}\rangle - |\psi_1^\delta; 1, \frac{1}{2}; 0, \frac{1}{2}\rangle \right. \\ &\quad \left. + |\psi_1^\lambda; 0, \frac{1}{2}; 0, \frac{1}{2}\rangle - |\psi_1^\lambda; 1, \frac{1}{2}; 1, \frac{1}{2}\rangle \right], \end{aligned} \quad (7a)$$

.5.

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

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 $|\psi_0\rangle$ and the orbital $L=1$ excited states are $|\psi_{1\mu}^\lambda\rangle \propto \lambda_\mu |\psi_0\rangle$ and $|\psi_{1\mu}^\delta\rangle \propto \rho_\mu |\psi_0\rangle$. 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

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

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

and one obtains

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

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

.6.

The values of the transition strengths

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

are

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

Similarly

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

It is worth noting that the following sum rules are valid

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

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

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

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)}

$$\gamma_V \equiv 1 - \kappa_V \chi_V^{(0)}, \quad (15)$$

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

is the isovector dipole coupling constant and

$$\chi_V^{(0)} \equiv \frac{2S(\mu_T=0)}{\Delta M} = \frac{2A b_B^2}{\pi \Delta M}, \quad (17)$$

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

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

we obtain

$$\gamma_V \equiv 1 - 0.18 A^{-2/3} \quad (18)$$

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 $F_{A_2, H_T} / g_A$, where $g_A = 5/3$ is the axial-vector coupling constant,

$$\kappa_A \equiv 0.72 \kappa_V \quad (19)$$

as estimated by Nakayama et al.⁴⁾, and

$$\chi_A^{(0)} = \frac{3}{25} \chi_V^{(0)}, \quad (20)$$

for the negative parity baryons. Therefore

$$\kappa_A \chi_A^{(0)} \equiv 0.09 \kappa_V \chi_V^{(0)}, \quad (21)$$

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 theory¹¹⁾. 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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