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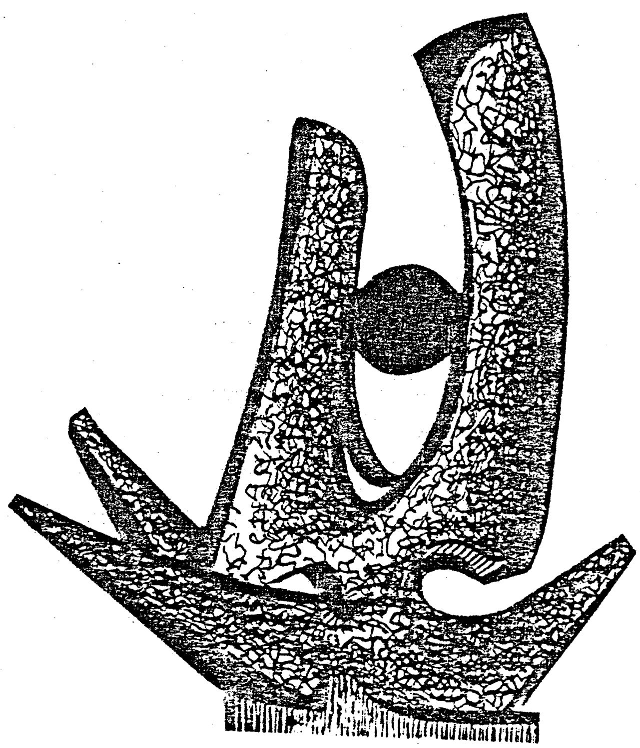

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Effects of 2-Particle 2-Hole Ground-State Correlations on Spin-Dipole Transitions in ^{12}N

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Abstracts

We have studied the effect of 2-particle 2-hole ground-state correlations on the spin-dipole transitions in ^{12}N. We found that the transition strengths in the energy range E_x=(2-12) MeV are quenched 25% by the ground state correlations. The tensor correlation is important for 1^- and 2^- states, while the spin-orbit force has an appreciable effect on 1^- states only.

The (p,n) reaction at intermediate energy is an extremely useful probe for the study of $\sigma.\tau$ correlations in nuclei.[1] The cross section at zero degrees has been studied in detail and the Gamow-Teller (G-T) strength for $\ell=0$ transition has been extracted systematically in many nuclei throughout the periodic table.[1,2] Moreover, the neutron spectra at larger angles (θ=5-15°) show strong transitions characterized by $\ell=1$ angular distributions with a large width of around 10 MeV for nuclei $A \geq 40$.[1] These broad resonances are interpreted by an envelope of collective states with spin parities $2^-, 1^-$ and 0^- excited through the transition operators,[3]

$$T_{\lambda\mu} = \sum_i r_i [Y_{\ell=1}(\hat{r}_i) \times \vec{\sigma}_i]_{\lambda\mu} \, \tau_{-1}, \quad \lambda = 2^-, 1^-, 0^- . \tag{1}$$

We refer to them as spin-dipole transition operators. The particle-hole matrix elements for these operators are given by

$$\langle (j_h^{-1} j_p)\lambda || r^{\ell} [Y_{\ell} \times \vec{\sigma}]_{\lambda} || 0 \rangle$$

$$= [(2j_h+1)/4\pi]^{1/2} \langle j_h \tfrac{1}{2}\, \lambda 0 | j_p \tfrac{1}{2} \rangle \langle \ell_p | r^{\ell} | \ell_h \rangle$$

$$\times \begin{cases} 1, & \lambda = 0^- \\ -[(2\lambda+1)/(\lambda\cdot(\lambda+1))]^{1/2} \{(-)^{\ell p+1/2-jp}(j_p+\tfrac{1}{2}) - (-)^{\ell h+1/2-jh}(j_h+\tfrac{1}{2})\}, & \lambda = 1^- \\ [\lambda]^{1/2} \{1+(-)^{\ell p+1/2-jp}(j_p+\tfrac{1}{2}) + (-)^{\ell h+1/2-jh}(j_h+\tfrac{1}{2})\}, & \lambda = 2^- \end{cases} \tag{2}$$

It has not been possible to resolve the broad peaks at angles (θ=5-15°) in heavy nuclei into their components and comfirm each transition strength partly due to the poor energy resolution of neutron spectra. Recently, in the light nucleus ^{12}N, the spin-dipole states with $\lambda^{\pi}=1^-,2^-$ have been observed separately in the energy region E_x=(2-12) MeV.[4] From the experimental neutron spectrum for the $^{12}C(p,n)^{12}N$ reaction at E_p=160 MeV and θ=8°, the extracted cross section obtained by adding the total yield (corrected for cosmic ray background) is given by

$$\sum_{E_x} \frac{d\sigma}{d\Omega}(E_x=2\text{-}12\ \mathrm{MeV})_{exp} = (12.0 \pm 1.8)\mathrm{mb/sr} \tag{3}$$

while a shell-model calculation[4] gives the summed cross section,

$$\sum_{E_x} \frac{d\sigma}{d\Omega}(E_x=2\text{-}12\ \mathrm{MeV})_{theory} = 20\ \mathrm{mb/sr} \tag{4}$$

The model prediction in ref. (4) took into account 1-particle 1-hole (1p-1h) states built on the lowest six odd-parity states of A=11 system and the excitations from $os_{1/2}$-orbit were not allowed.

We show in Table (1) the results of a full 1 $\hbar\omega$ 1p-1h configuration space calculation based on the Cohen-Kurath wave function for the A=11 system in comparison with the result of ref. (4). A Yukawa-type potential with central, spin-orbit and tensor components is used for the present calculation;

$$V(r) = V_c(r)+V_{LS}(r)+V_T(r)$$

$$V_c(r) = V_c(a_c^{11}P^{11} + a_c^{31}P^{31} + a_c^{13}P^{13} + a_c^{33}P^{33}) \frac{\mu_c}{r} \exp(-\frac{r}{\mu_c})$$

$$V_{LS}(r) = V_{LS}(a_{LS}^{13}P^{13} + a_{LS}^{33}P^{33})\vec{L}.\vec{S} \frac{\mu_{LS}}{r} \exp(-\frac{r}{\mu_{LS}}) \quad (5)$$

$$V_T(r) = V_T(a_T^{13}P^{13} + a_T^{33}P^{33})S_{12} \frac{\mu_T}{r} \exp(-\frac{r}{\mu_T})$$

where $P^{2T+1,2S+1}$ is the projection operator of (T,S) channel and S_{12} is the tensor operator. We adopted the parameter set of Millener-Kurath[5] which is listed in Table (2). The summed cross section $d\sigma/d\Omega$ (E_x=2-12 MeV) for the present calculation is 19 mb/sr compared to the 20 mb/sr obtained in the restricted space calculation.[4] Both calculations show about 10% of the total transition strengths in the energy region E_x=12-18 MeV. However, the full space calculation shows 15% of the total strength above E_x= 18 MeV, while there is no transition strength in this region in the calculation of ref.(4).

We study in this letter the effect of 2p-2h ground-state correlations on the spin-dipole transitions in ^{12}N using perturbation theory. The 2p-2h correlation is claimed as an important effect for the quenching of magnetic dipole and Gamow-Teller transition strengths in recent microscopic calculations.[6,7] The ground-state correlation is shown diagrammatically in Fig. 1. The first-order perturbation theory gives the following wave function;

$$|\tilde{0}\rangle = |0\rangle + \sum_{\substack{ph,p'h' \\ J}} \frac{\langle (ph^{-1})J,(p'h'^{-1})J;0^+|V|0^+\rangle}{E_0-E_J(ph,p'h')} |(ph^{-1})J,(p'h'^{-1})J;0^+\rangle \quad (6)$$

Using this perturbed wave function (6), we obtain the modified transition strength,

$$\langle (ph^{-1})\lambda || T_\lambda || \tilde{0} \rangle = \langle (ph^{-1})\lambda || T_\lambda || 0 \rangle (1-\alpha) \qquad (7)$$

where

$$\alpha = \sum_{p'h'} \frac{\langle (ph^{-1})\lambda | V | (p'h'^{-1})\lambda \rangle}{E_\lambda(ph,p'h')-E_0} \langle (p'h'^{-1})\lambda || T_\lambda || 0 \rangle \qquad (8)$$

We calculate the particle-hole (p-h) matrix elements with the Yukawa-type potential with central, spin-orbit and tensor components as given in Eq. (5). The p-h energy difference is taken to be 15.4 MeV. The oscillator length is determined as b=1.64 fm in order to reproduce the mean charge radius of ^{12}C.

The calculated values of α are given in Table (2). The central interaction gives α=0.13 which decreases the spin-dipole transition strength by about 25%. This positive value of α is due to the fact that the spin-isospin p-h interaction is repulsive. We also calculated α by using the parameter set for the central interaction given by Ferrell-Visher.[8] This gave a slightly larger value of α = 0.15.

The tensor correlation increases the value of α for the state with $\lambda^\pi=1^-$ by (10-20)%, while decreasing the value of α for $\lambda^\pi=0^-$ by about the same amount. The transition strength of 2^- state is not changed much by the tensor correlation. This result can be understood intuitively by the following argument given by Mottelson.[9]

The tensor interaction can be given in the form,

$$V_T(r) = F(r)\{[\vec{\sigma}_1\times\vec{\sigma}_2]^{(2)}\times[r^2Y_2(\hat{r})]^{(2)}\}^{(0)} \tag{9}$$

Since the solid spherical harmonics $r^2Y_{2m}(\hat{r})$ can be expanded by the formula,

$$r^2Y_{2m}(\hat{r}) = \sum_{\lambda'\mu'} \sqrt{4\pi}\,(-)^{\lambda'}[5!/(2\lambda'+1)!(5-2\lambda'+1)!]^{1/2}\langle 2-\lambda'\lambda' m-\mu'\mu'|2m\rangle$$

$$* r_1^{2-\lambda'} r_2^{\lambda'} Y_{2-\lambda',m-\mu'}(\hat{r}_1)Y_{\lambda'\mu'}(\hat{r}_2) \tag{10}$$

the tensor interaction (9) can be expressed in terms of the spin-dipole operators,

$$V_T(r) = F(r)\sum_{\lambda}(-)\frac{\sqrt{4\pi}}{6}\left[\frac{10}{3}\right]^{1/2}\begin{Bmatrix} 2\sqrt{5} \\ -\sqrt{15} \\ 1 \end{Bmatrix} \tag{11}$$

$$*\{r_1[\vec{\sigma}_1\times Y_1(\hat{r}_1)]^{(\lambda)}\times r_2[\vec{\sigma}_2\times Y_1(\hat{r}_2)]^{(\lambda)}\}^{(0)},\quad \lambda^{\pi}=\begin{Bmatrix} 0^- \\ 1^- \\ 2^- \end{Bmatrix}$$

where we choose $\lambda'=1$ only in the expansion (10). Since the coupling strength $F(r)$ is repulsive for the tensor interaction, the tensor correlation for 1^- state is additive to that of the central interaction. On the other hand, the two contributions tend to cancel each other in the case of the 0^- state. A smaller tensor correlation for the 2^- state is also quite reasonable since the coefficient for 2^- in Eq.(11) is several times smaller than those for 0^- and 1^-. The results given in Table 3 are slightly different from that expected from Eq. (11) because of the exchange term contribution.

As can be seen in the last column of Table 3, the spin-orbit two-body force has an appreciable effect only on 1^- states. The spin-orbit two-body operator is given by

$$\vec{L}\cdot\vec{S} = \frac{1}{2}(\vec{r}_1-\vec{r}_2)\times(\vec{p}_1-\vec{p}_2)\cdot(\vec{\sigma}_1+\vec{\sigma}_2) \quad (12)$$

When Eq. (12) is expanded in terms of the spin-dipole operators, the important terms for the direct two-body matrix elements in Eq. (8) are

$$\vec{L}\cdot\vec{S} \propto r_1\{[\vec{\sigma}_1\times Y_1(\hat{r}_1)]^{(1)}\times\vec{p}_2\}^{(0)}+r_2\{[\vec{\sigma}_2\times Y_1(\hat{r}_2)]\times\vec{p}_1\}^{(0)} \quad (13)$$

where the spin-dipole operator can couple to $\lambda^\pi=1^-$ only. This is the reason why the spin-orbit force contributes appreciably to the value of α for the states with $\lambda^\pi=1^-$, but not for the states with $\lambda^\pi=0^-$ and 2^-.

In summary, we have studied the effect of 2p-2h ground state correlation on the spin-dipole transition in ^{12}N. We found that the net effect of the central, tensor and spin-orbit forces, averaging over the transition matrix elements, gives the values α = 0.089, 0.139 and 0.122 for $\lambda^\pi=0^-,1^-$ and 2^-, respectively. Because the experimental data in the region E_x =(2-12) MeV is dominated by 1^- and 2^- resonances, the value α substantially decreases the spin-dipole transition strength by about 25%. The tensor correlation contributes (10-20)% to the renormalization factors α for 0^- and 1^- states, while the 2^- state is insensitive to the tensor force. The effect of the two-body spin-orbit correlation is appreciable only in the transition strength of 1^- state. The experimental cross section in the energy region E_x = (2-12) MeV is 40% less than the 1p-1h shell-model prediction in the full configuration space and the present study suggests that the 2p-2h ground-state correlations explain the major part (60%) of this missing strength. The transition strengths might be decreased further by meson-exchange currents[7] and Δ-hole couplings[10] together with higher 2p-2h excitations above $1\hbar\omega$ configuration space.[5]

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Figure caption

Fig.(1) Diagrammatical representation of the 2p-2h ground-state correlation.

Table 1. Sum rule values for the spin-dipole transitions in ^{12}N. The values in row (1) are obtained by the 1p-1h excitations from $op_{3/2}$- and $os_{1/2}$-states assuming a $op_{3/2}$-closed shell. The shell-model calculation of ref. (4) in row (2) took into account only 1p-1h excitations from the lowest six odd-parity states of the A=11 system , while the present calculation in row (3) includes all configurations from op- and os-orbits. For details, see the text.

	B (ℓ=1 ; λ^{π})		
	0^-	1^-	2^-
(1) 1p-1h	5.56	14.11	14.97
(2) ref.(4)	3.79	10.76	16.03
(3) present	4.56	12.61	17.48
(4) ref.(4) (Ex≦ 12 MeV)	3.34	9.70	15.00
(5) present (Ex≦ 12 MeV)	2.69	8.60	14.67
(6) ref.(4) (Ex≦ 18 MeV)	3.79	10.76	16.03
(7) present (Ex≦ 18 MeV)	3.63	9.97	15.80

Table (2)

Interaction parameters

	a^{11}	a^{31}	a^{13}	a^{33}	b/μ	V(MeV)
central	-.714	0.6	1	-.286	1.18	-44.8
tensor	0	0	1	-.38	1.18	-16.25
spin-orbit	0	0	1	3.5	2.36	-26.

Table (3)

Normalization factors α for spin-dipole transitions

λ^{π}	(p-h)	$<(h^{-1}p)\lambda\|\|T\|\|0>$	$\alpha(V_C)$	$\alpha(V_C+V_T)$	$\alpha(V_C+V_T+V_{LS})$
0^-	$(2s1/2,1p1/2^{-1})$	-0.654	0.093	0.077	0.077
	$(1d3/2,1p3/2^{-1})$	1.463	0.135	0.095	0.095
	$(1d3/2,1p1/2^{-1})$	1.035	0.135	0.158	0.133
	$(2s1/2,1p1/2^{-1})$	0.925	0.093	0.101	0.116
1^-	$(1d3/2,1p3/2^{-1})$	1.851	0.135	0.154	0.147
	$(1d5/2,1p3/2^{-1})$	-1.388	0.135	0.156	0.180
	$(2s1/2,1p3/2^{-1})$	0.654	0.093	0.101	0.072
	$(1d3/2,1p1/2^{-1})$	-0.463	0.135	0.085	0.089
	$(1d5/2,1p1/2^{-1})$	2.266	0.135	0.133	0.133
2^-	$(1d3/2,1p3/2^{-1})$	-0.925	0.135	0.145	0.147
	$(1d5/2,1p3/2^{-1})$	2.120	0.135	0.129	0.127
	$(2s1/2,1p3/2^{-1})$	1.463	0.093	0.091	0.091

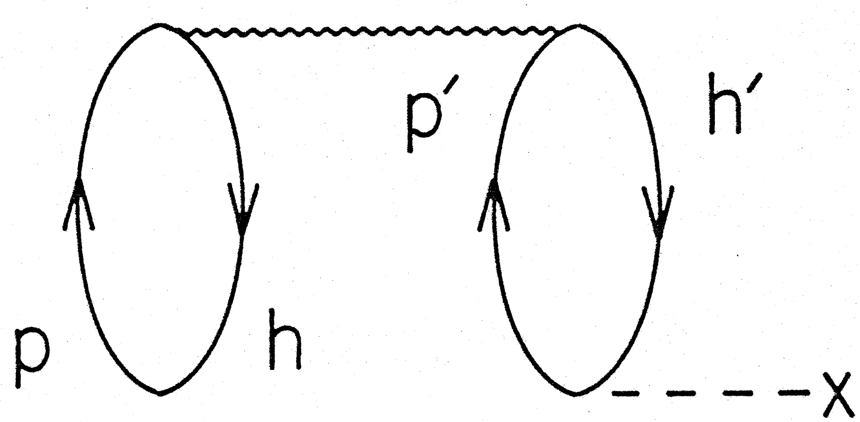

Figure 1