PHYSICAL REVIEW C VOLUME 32, NUMBER 1 JULY 1985

Magnetic quadrupole strength in ^{12}C

B. Castel*
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

I. P. Johnstone
Physics Department, Queen's University, Kingston, Ontario K7L 3N6 Canada

A. G. M. van Hees
Physics Laboratory, University of Utrecht, The Netherlands

(Received 20 March 1985)

The question of the origin of the missing $M2$ strength in ^{12}C is examined. A large scale shell model calculation of 2^- states and their decay is presented. It indicates that the role of 2p-2h correlations is probably the most important in explaining the $M2$ quenching and that the two-body spin-orbit force is instrumental in inducing such a quenching. The role of the tensor force as well as of the Δ-N excitations remains fairly modest.

One of the persistent problems in current nuclear structure calculations concerns the nature of the quenching of magnetic excitations. Three reactions, (p,n), electron, and pion scattering, generally offer complementary pictures of the quenching of spin-isospin transitions. In the ^{12}C case, which is of interest here, the three reactions have located a large concentration of $M2$ strength at about 19 MeV with *cross sections reduced by over a factor of 2 compared with theory.*[1] The theoretical estimates are based, however, on simplified 1p-1h calculations and we feel that the question of the missing strength cannot be truly answered without considering other important mechanisms like the role of 2p-2h and Δ-hole excitations. This is what we present in the following two sections of our paper. We then devote our conclusion to a survey of the theoretical efforts at understanding the mechanisms invoked in spin-isopsin excitations in light nuclei.

In a recent (p,n) experiment at the Indiana Cyclotron Facility, using a ^{12}C target, Gaarde *et al.*[2] have detected the presence of a strong "collective" 2^- state at 18.6 MeV exhausting 65% of the spin-dipole sum rule. The same state is also observed in the (π^-,γ) reaction as well as in several inelastic electron scattering experiments.[1,4–6] A simplified 1p-1h, Cohen-Kurath type, shell model estimate indeed yields the correct energy for this strong 2^- state but *overestimates the cross section by over a factor of 2.*[1] This last result is also obtained in the analysis of (e,e') data,[3] where an effective $g_s^{\mathrm{eff}}=0.65$ [or $(0.65)^2$ in strength] is used for the spin part of the $M2$ operator in order to achieve agreement between calculated and experimental $B(M2)$ values.[1,4,5]

The influence of 2p-2h correlations have often been invoked, at least in heavy nuclei, as a spreading and quenching mechanism. We examine here its effect on the $M2$ strength distribution by isolating first the effects due to central and spin-orbit plus tensor components using a Sussex interaction. Although the extension to a 2p-2h space involves 143 states, most of the isovector $M2$ strength remains concentrated in one single peak when only the central part of the interaction is used. This is clearly demonstrated in Fig. 1, where the $B(M2\uparrow)$ strength distribution is presented as a function of energy. Introducing the noncentral components in Fig. 2 splits the main strength into

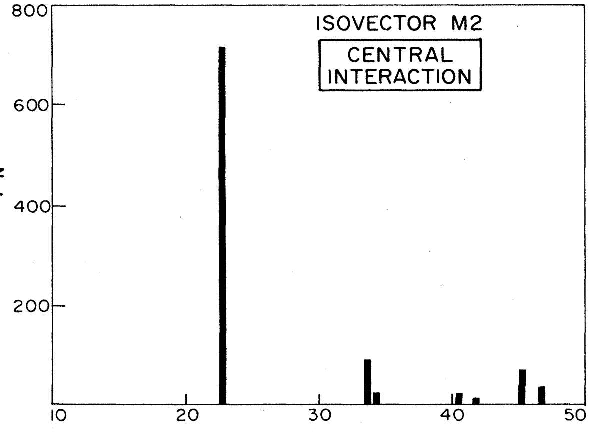

FIG. 1. Distribution of isovector $M2$ strength, calculated with the central part of the Sussex interaction. Additional details on the interaction are given in Ref. 19.

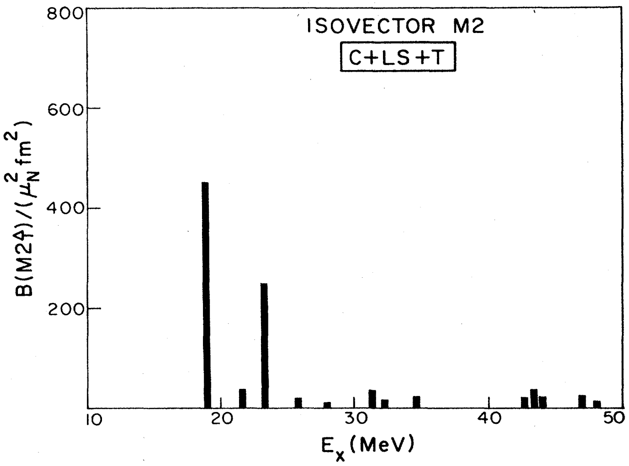

FIG. 2. Distribution of isovector $M2$ strength, calculated with the complete Sussex interaction.

two unequal peaks, with the lower one corresponding to the state strongly excited in the (p,n) reaction, and the higher one to the peak seen at about 22.7 MeV in the (e,e') experiments.[1,7] The overall quenching resulting from 2p-2h correlations reduces the $B(M2\uparrow)$ transition rate to the 2_1^- state by 71% compared with its 1p-1h prediction. We should mention that most of the quenching is due to the influence of the spin-orbit force and that the effect of the tensor component is rather modest. This can be understood by writing the tensor interaction[8,9]

$$V_T(r)=F(r)\{[\boldsymbol{\sigma}_1\boldsymbol{\sigma}_2]^{(2)}[r^2Y_2(\hat{r})]^{(2)}\}^{(0)}\ , \tag{1}$$

in terms of the spin-dipole operators

$$V_T(r)=F(r)\sum_{\lambda}(-)\frac{\sqrt{4\pi}}{6}\left(\frac{10}{3}\right)^{1/2}*\{r_1[\boldsymbol{\sigma}_1Y_1(\hat{r}_1)]^{(\lambda)}r_2[\boldsymbol{\sigma}_2Y_1(\hat{r}_2)]^{(\lambda)}\}^{(0)}\times\begin{cases}2\sqrt{5}\\ -\sqrt{15}, & \text{for } \lambda^{\pi}=\\ 1\end{cases}\begin{cases}0^-\\ 1^-\\ 2^-\end{cases}. \tag{2}$$

Since the coupling strength $F(r)$ is repulsive for the tensor force, the tensor correlation *is additive to that of the central interaction for $J=1^-$ states but of opposite sign for $J=2^-$ states.* This explains the rather modest effect obtained at least in the $J=2^-$ channel in tensor quenching. Recently Sagawa and Brown have used perturbation theory to examine the influence of 2p-2h correlations on (p,n) cross sections.[10] They found that although the tensor force contributes 10%–20% of the magnetic quenching to the 0^- and 1^- states, its effect on the $B(M2;0^+\rightarrow 2^-)$ value is minimal, in agreement with our own conclusion.

In Figs. 3 and 4, we present the results for the isoscalar $M2$ calculations, of course, much weaker than their $T=1$ analog, showing that most of the strength is concentrated in two peaks between 15 and 20 MeV in general agreement with experiment.[1,4,7]

Recently several authors have emphasized the importance of the nucleon internal excitation in quenching isovector magnetic transitions.[11,12] These effects should become important, however, in heavier nuclei, where the nuclear core contributions are not blocked by the Pauli principle. In the $A=12$ system, the renormalization due to Δ-hole excitation effects should be very limited as we will see.

Our calculation follows closely the dimesic function method developed earlier by Toki and Weise[11,12] in the context of pion condensation, where the renormalization of spin-isospin operators arise from intermediate nucleon-hole and isobar-hole excitations. The method is also described in detail in our previous study of $M4$ and beta decay in $A=40$ nuclei (Ref. 13).

Both the nucleon-hole and Δ-hole are described by the exchange of π and ρ mesons. An additional short range repulsive interaction is introduced whose strength is given by a Migdal parameter g' set here at 0.7. Here g' incorporates the effect of vortex screening, short range correlations, and the exchange of heavier mesons. In order to distinguish the effect of the isobar from that of the nucleons we have computed the renormalizations separately. The renormalization of g_s due to Δ-hole polarization amounts to -0.08 (i.e., $\delta g_s/g_s=8\%$) but $(\Delta+\text{N})$ together reduces the effect by half [i.e., $(\delta g_s/g_s)(\Delta+\text{N})=4\%$]. This rather modest result is consistent with our previous study of angular momentum dependence of Δ excitations,[14] where we concluded that $(\Delta+\text{N})$ renormalizations actually *decrease* with angular momentum, being largest for $M1$ transitions. We also found that, for all angular momenta, the quenching *increased with mass number,* thus the small nucleon space available in ^{12}C is consistent with the modest scale of the $(\Delta\text{-N}^{-1})$ renormalizations. Recently Grecksch *et al.*[15] have investigated the importance of Δ excitations on the renormalization of $M\lambda$ operators and their calculation, although using a different potential, substantially agrees with the scale of our results.

We have examined in detail two of the mechanisms gen-

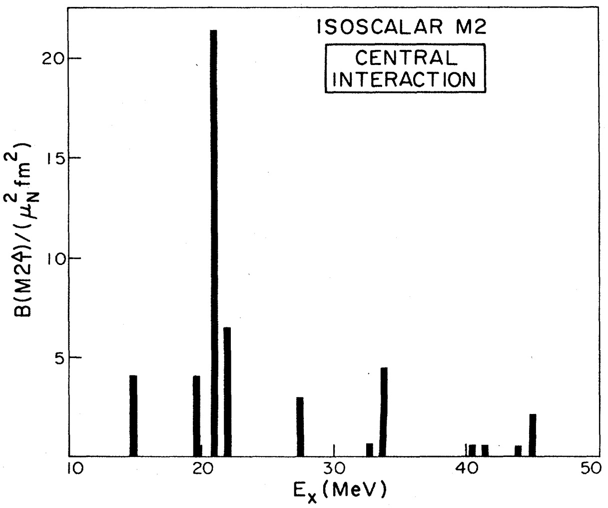

FIG. 3. Distribution of isoscalar $M2$ strength, calculated with the central part of the Sussex interaction.

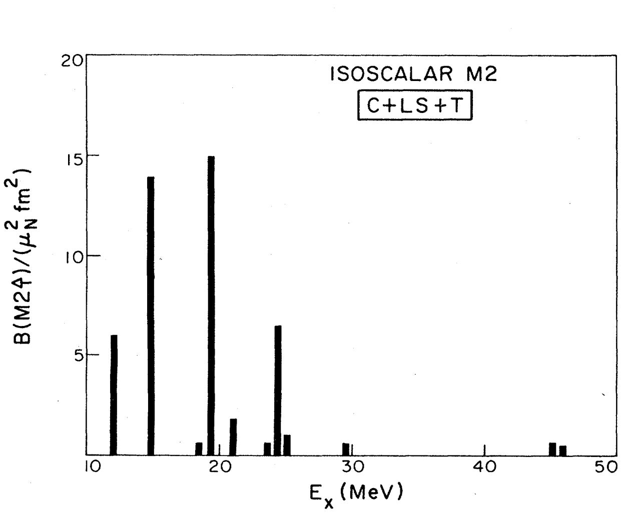

FIG. 4. Distribution of isoscalar $M2$ strength, calculated with the complete Sussex interaction.

erally invoked in explaining the quenching of magnetic transitions. Our results indicate that in ^{12}C the role of 2p-2h correlations is probably the most important in explaining the $M2$ quenching and that the two-body spin-orbit force is instrumental in inducing such a quenching. The role of the tensor force as well as of the other degrees of freedom like Δ-N^{-1} excitations remains fairly modest.

Another suggestion concerning the missing magnetic strength has been linked to background subtraction. Recently Osterfeld[16] has questioned the way the background is subtracted under "giant" $M\lambda$ and GT resonances by calculating particle-hole RPA strength with $L=1$ and $L=2$, in addition to $L=0$. This is an interesting possibility which should be examined further both by theory and by careful comparisons of the data emanating from different probes. Preliminary estimates of background subtraction effects indicate them to yield a 60% reduction of shell model strength.

Finally Ericson[17] and Orlandini *et al.*[18] have pointed out the importance of Jastrow type tensor correlation in increasing the $M1$ sum rule in heavy nuclei. If this phenomenon was of a general nature in all spin-isospin excitations, it would seem as if the conjured effects of 2p-2h, Δ-N^{-1} excitations and tensor correlation could, at least in heavy nuclei, bring theory and experiment to a substantial degree of agreement.[19]

The authors thank L. Zamick, H. Toki, and H. Sagawa for helpful comments. This work was supported in part by the Natural Sciences and Engineering Research Council of Canada and the U.S. Department of Energy.

---

[*] Present address: Physics Department, Queen's University at Kingston, Kingston, Ontario K7L 3N6 Canada.

[1] R. S. Hicks *et al.*, Phys. Rev. C **30**, 1 (1984).

[2] C. Gaarde *et al.*, Nucl. Phys. **A422**, 189 (1984).

[3] P. Truol, Nucl. Phys. **A335**, 55 (1980).

[4] T. E. Drake *et al.*, Nucl. Phys. **A118**, 138 (1968).

[5] A. Yamaguchi *et al.*, Phys. Rev. C **3**, 1750 (1971).

[6] K. W. Jones *et al.*, Phys. Lett. **128B**, 281 (1983).

[7] G. Kuchler *et al.*, Nucl. Phys. **A406**, 473 (1983).

[8] B Mottelson (private communication).

[9] H. Sagawa and B. Castel, Nucl. Phys. **A435**, 1 (1985).

[10] H. Sagawa and B. A. Brown, Phys. Lett. (unpublished).

[11] H. Toki and W. Weise, Phys. Lett. **97B**, 12 (1980).

[12] H. Toki, in *Proceedings of the International Symposium on Nuclear Spectroscopy and Nuclear Interactions, Osaka, Japan, 1984*, edited by H. Ejiri and T. Fukuda (World Scientific, Singapore, 1984).

[13] B. Castel and P. Blunden, Phys. Rev. C **25**, 2148 (1982).

[14] P. Blunden and B. Castel, Nucl. Phys. (unpublished).

[15] E. Grecksch *et al.*, Z. Phys. A **302**, 253 (1981).

[16] F. Osterfeld, in Proceedings of the International Conference on Spin Excitations in Nuclei, Telluride, 1982.

[17] M. Ericson, Phys. Lett. **120B**, 285 (1983).

[18] G. Orlandini *et al.*, Phys. Lett. **134B**, 143 (1984).

[19] B. Castel, A. G. M. Van Hees, and L. Zamick, Nucl. Phys. **A415**, 30 (1984).