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MANY-PARTICLE MANY-HOLE EXCITATIONS AND THE RETARDATION OF MAGNETIC DIPOLE AND GT TRANSITION-STRENGTHS

W. Knüpfer and B.C. Metsch

*Institut für Theoretische Physik der Universität Erlangen-Nürnberg,
8520 Erlangen, F.R.G.*

Résumé - Les effets de structure nucléaire et subnucléaire sur les modes de spin dans les noyaux sont discutés sur trois exemples : la distribution d'intensité Gamow-Teller dans le ^{90}Zr , l'opérateur M1 effectif, et le cas du ^{48}Ca .

Abstract -

Three examples of the role of nuclear and subnuclear structure effects in spin-flip modes in nuclei is discussed viz. the GT strength distribution in ^{90}Zr , an effective M1 operator and a discussion of ^{48}Ca .

INTRODUCTION

Studies of the nuclear response to external fields of the type $\sigma \cdot \nabla e^{i\mathbf{q} \cdot \mathbf{r}}$ provide the possibility to explore the boarder lines between the conventional picture of nuclei consisting of structureless nucleons and its extension to subnuclear degrees of freedom.

The exploration of Gamow Teller (GT) strength distributions in (p,n) reactions /1/ and the investigation of magnetic transitions of low multipolarity (M1, M2) with high-resolution inelastic electron scattering /2/ have revealed the overwhelming evidence that these magnetic transitions are systematically quenched by a factor of two compared to standard RPA or shell model calculations.

In order to find a theoretical interpretation of the quenching effect observed for M1 and GT transitions, two mechanisms are held to be dominant /3/. (i) the retardation through virtual (Δ -h) excitations and (ii) the admixtures via the tensor force of high-lying many-particle many-hole configurations outside the restricted (small) shell-model space.

Both mechanisms certainly play a role. Exploration of the spin-isospin transition strength distribution, therefore provides a valuable tool to study the competition between nuclear and subnuclear degrees of freedom. The interesting question is to study this competition quantitatively.

SPECIFIC EXAMPLES

We begin with a theoretical interpretation of the GT strength distribution of ^{90}Zr with emphasis on the quenching mechanism (ii). Next we will compare the influence of tensor correlations and isobar currents on diagonal- and off diagonal spin-flip matrix elements (magnetic moments and M1-transitions). Finally we will investigate the effects of recently measured proton correlations in the ground state of ^{48}Ca on the M1 strength in this nucleus.

1) TENSOR CORRELATIONS

Bertsch and Hamamoto /4/ have recently investigated the distribution of the strength that is lost in the GT peak of ^{90}Zr due to the mixing with (2p-2h) configurations at large excitation energies. They considered roughly 20000 (2p-2h) states in the 10 - 45 MeV excitation region. For the calculation of the strength function in the continuum region they used a perturbative treatment. They find that roughly half of the GT strength is removed from the resonance into the region of $E_x = 10 - 45$ MeV, thereby explaining the missing strength in the GT peak /1/ without inclusion of isobar currents. However this perturbative calculation does not include the collective energy shift of the GT-peak through the coupling with the tremendous number of (2p-2h) states. This is a crucial point. In the following we will show that the perturbative treatment of /4/ must be extended to a consistent description of both the

excitation energy of the spin-flip resonance and the strength distribution to give a realistic value for the missing strength in the resonance.

The solution to this tremendous eigenvalue problem has been established in the so-called (2p-2h) doorway-model /5,6,7/. Here we will consider only the coupling of the large number (51000) of (2p-2h) states (see fig. 1) with the single RPA-doorway state. With an interaction equivalent to that of the perturbative treatment /4/, the resulting strength distribution is shown in fig.2.

Fig. 1: Level density of (2p-2h) GT excited states of ^{90}Zr . The model space is sketched in the insert.

Fig. 2: Calculated strength distribution $P(E) = \frac{\sum_f \langle f | \sigma \tau | i \rangle \delta(E - E_f)}{\sum_f \langle f | \sigma \tau | i \rangle}$ for the Gamow Teller operator in ^{90}Zr . Upper part: Result with the interaction of /4/ but taking into account the energy shift of the GT resonance (see text). Lower part: Result with the modified interaction (see text).

Roughly 32% (compared to 50% in the perturbative treatment /4/) of the strength is shifted to the 10-80 MeV excitation region, since the calculation places the GT resonance at $E_x = 5.1$ MeV far too low compared to the experimental position $E_x = 8.6$ MeV. Obviously the force is too strong. By reducing the strength of the interaction of /4/ by an overall factor of 0.63 the resonance energy is reproduced. As a result only 26% of the GT strength is now in the 10-80 MeV region with 74% residing in the GT resonance (compared to the experimental value of 50% - 60% /1/). Obviously there is still a need for an explanation of the retardation via mechanism (i).

2) QUENCHING OF THE DIAGONAL AND OFF-DIAGONAL SPIN MATRIX ELEMENTS AND A CONSISTENT DESCRIPTION OF MAGNETIC MOMENTS AND M1-TRANSITIONS

Recently, Towner et al. /8/ and Lawson /9/ pointed out the interesting effect that the inclusion of the quenching mechanisms (i) and (ii) in the calculations leads to large corrections for the resulting off-diagonal magnetic dipole matrix elements and to relatively small corrections for the diagonal M1-matrix elements. This result can be verified by comparing measured M1 spin-flip transitions and magnetic moments with the predictions of RPA or shell model calculations performed in small model spaces ("lowest order" shell model expectations). From Fig. 3a it is evident that the relative deviation between calculated and experimental B(M1) strength increases from almost zero for light to roughly 100 % for heavier nuclei. In contrast the corresponding deviation for magnetic moments illustrated in fig.3a is of the order of 25%

Fig. 3: Relative deviation of calculated and experimental magnetic moments and M1-spin-flip transitions. a) with the free magnetic M1 operator, b) with the effective M1 operator of eq. (2)

only. For this plot full major shell model calculations in the p-shell /10/ and in the (sd)-shell /11/ have been used together with the experimental values quoted there. For $A > 60$, only nuclei near closed shells have been chosen for the analysis and the g-factor $g = \langle j | M1 | j \rangle$ with

$$g = g_l \pm \frac{1}{2l+1} (g_s + \delta g_s^{A.H.} - g_l) \quad \text{for } j = l \pm \frac{1}{2} \quad (1)$$

has been used. In eq. (1) the experimentally derived orbital g-factor $g_l^{\pi} = 1.1$ and $g_l^{\pi} = -0.03$ have been taken, which reflect effects of meson exchange currents and higher order core polarization in agreement with the calculations of /8/ and /12/. The free spin factors g_s with $g_s^{\pi} = 5.58$ and $g_s^{\pi} = -3.82$ are corrected by the so-called Arima-Horie core polarization effect $\delta g_s^{A.H.}$. However, in view of the retardation of the M1 transitions the correction $\delta g_s^{A.H.}$ taken from RPA-calculations in ^{90}Zr /13/ and in ^{208}Pb /14/ have been reduced by a factor of $1/\sqrt{2}$.

The mechanisms (i) and (ii) lead to an effective one-body operator:

$$\underline{M1}_{\text{eff}} = g_l \underline{L} + (g_s + \delta g_s^{A.H.} + \delta g_s) \underline{S} + \delta g_p \sqrt{8\pi} [\underline{Y}_2 \times \underline{S}]^1 \quad (2)$$

where g_s , $\delta g_s^{A.H.}$ and g_l are taken from eq. (1). For diagonal matrix elements of $\underline{M1}_{\text{eff}}$ (magnetic moments) one finds /8/:

$$\langle j | \underline{M1}_{\text{eff}} | j \rangle \propto \delta g_s + f(j) \delta g_p \quad (3)$$

For off diagonal matrix elements of $\underline{M1}_{\text{eff}}$ (M1-transitions) one gets /8/

$$\langle j = l + \frac{1}{2} | \underline{M1}_{\text{eff}} | j' = l - \frac{1}{2} \rangle \propto -\delta g_s + \frac{1}{4} \delta g_p \quad (4)$$

If δg_s and δg_p have different signs, a cancellation occurs in the diagonal matrix elements, whereas they contribute constructively to the non-diagonal (transition) matrix elements. This effect has been pointed out recently by Towner and Khanna /8/ in a calculation where they apply both quenching mechanisms (i) and (ii) to nuclei of the (sd)-shell.

The average values for δg_s and δg_p , separated for proton and neutron,

Fig. 4: Mass dependence of the empirical spin correction δg_s (left) and the tensor correction δg_p (right). The rectangles represent the experimental errors, the triangles are the results of a calculation with the Δ -h mechanism only /9/, the dashed line (KT) is the averaged result of /8/.

obtained from a fit to the magnetic moments and M1 transitions in (sd)-shell nuclei /15/ are shown in fig. 4 together with the average values of ref. /8/ and predictions of Lawson /9/ who took into account the Δ -hole mechanism (i) only.

We extended this analysis to the heavier systems around $A = 90$ and $A = 208$. The resulting curves for δg_s and δg_p show a characteristic mass dependence. The absolute value of δg_s increases and δg_p decreases with the mass number A . Comparison of the adjusted values of δg_s and δg_p with the calculated contributions from the Δ -h mechanism (i) of ref. 9 shows that the Δ -h mechanism accounts for about half of the quenching. The same conclusion was drawn from the large space calculation of the GT strength distribution in ^{90}Zr . To note is that in the (sd)-shell the experimentally derived value for δg_p is substantially smaller than the value obtained by Khanna and Towner. This indicates that in their calculation the tensor correlations are possibly too strong.

With the mass dependent values of δg_s and δg_p in the effective M1 operator of eq. (2), a consistent description of magnetic moments and M1 transitions is obtained (see fig. 3b).

3) CORRELATIONS IN ^{48}Ca

Neutron Correlations: The "small" shell-model space calculations, that include all configurations of 8 neutrons outside a ^{48}Ca core performed by Wildenthal and McGrory /16/ led to a total strength of $\Sigma B(M1\uparrow) = 9\mu_N^2$, about twice the value found experimentally $\Sigma B(M1\uparrow)_{exp} \approx 5.5\mu_N^2$. Essentially the same results can be obtained in a much smaller space that takes into account only the $0p-0h$ and $2p-2h$ configurations for the ground state and the $1p-1h$, $2p-2h$ and $3p-3h$ configurations for the $J^\pi = 1^+$ state. The effect of the neutron correlations, that reduce the IPM value of $12\mu_N^2$ with 30 % is mainly due to destructive interference between $1f_{7/2} \rightarrow 1f_{5/2}$ contributions and the $1f_{5/2} \rightarrow 1f_{7/2}$ contributions between the $2p-2h$ components in the ground state and the $1p-1h$ component of the excited state. This interference reflects a typical

Fig. 5: Dominant graph contributing to the reduction of the M1 strength in the calculation of /16/ (left). The analogous graph involving proton correlations in the ground state cannot contribute (right).

RPA-correlation type diagram (see fig. 5a). Proton Correlations: A recent proton-pick up experiment on ^{48}Ca by Banks et. al. /18/ indicates that the ^{48}Ca ground state contains $\pi(\text{sd})^2\pi(1f_{7/2})^3$ components with an intensity of about 4%. In principle such proton correlations could have a sizeable effect on the magnetic dipole transitions in ^{48}Ca if the admixtures of proton 2p-2h configurations are very different for the ground state and the low-lying 1^+ states. This however is not the case /19/ and the influence of the proton correlations is virtually absent essentially because the RPA correlation diagram (see fig. 5b), that for the neutron correlations produces an appreciable retardation of strength, is forbidden.

Finally, we like to remark that with the effective operator of eq. (2) and the calculation mentioned in the preceding paragraph we obtain a strength for the 1^+ state at 10.2 MeV of $B(M1)^\dagger = 4.5 \mu_N^2$ and a total strength between 9 and 12.5 MeV of $\Sigma B(M1)^\dagger = 5.3 \mu_N^2$, in reasonable agreement with the experimental values $B(M1)^\dagger = 3.9 \pm 0.3$ and $\Sigma B(M1)^\dagger = 5.5 \pm 0.4 \mu_N^2$ /17/.

References

- /1/ C. Gaarde, Nucl. Phys. A 396 (1983) 127c
- /2/ A. Richter, Nucl. Phys. A 374 (1982) 177c
- /3/ I.S. Towner, From soft pions to spin excitations: a treatise on meson-exchange currents, Proc. Erice Intern. School of Nucl. Phys. on "Mesons, isobars, quarks and nuclear excitations", (1983) to be published in Prog. in Part. and Nucl. Phys. Vol. II
- /4/ G.F. Bertsch and I. Hamamoto, Phys. Rev. 26 C (1982) 1323
- /5/ A. Bohr and B. Mottelson, Nuclear structure, Vol. 1 (Benjamin, New York, 1969) p. 302
- /6/ W. Knüpfer, Lecture Notes in Physics 158 (1982) 230
- /7/ J. Wambach and R. Fiebig, Proc. Int. Conf. on Spin Excitations in nuclei, Telluride, Colorado, (1982), Plenum Press (in print).
- /8/ I.S. Towner and F.C. Khanna, Nucl. Phys. A 399 (1983) 334
- /9/ R.D. Lawson, Phys. Lett. 125 B (1983) 255
- /10/ F. van Hees, Thesis, Utrecht (1982)
- /11/ B.H. Wildenthal and W. Chung, in: Mesons in nuclei, eds. M. Rho and P.H. Wilkinson (North Holland, Amsterdam, 1979) Vol. II 721
- /12/ A. Arima, Shell model picture of nuclear magnetic moments, see also /7/
- /13/ A. Arima and H. Hyuga, in: Mesons in nuclei, eds. M. Rho and D.H. Wilkinson (North-Holland, Amsterdam, 1979) Vol. II p. 683
- /14/ J.P. Blaizot and L. Sips, Nucl. Phys. A 337 (1980) 157
- /15/ B.A. Brown and B.H. Wildenthal, preprint MSUCL-413, 1983
- /16/ J.B. McGrory and B.H. Wildenthal, Phys. Lett. 103 B (1981) 173
- /17/ W. Steffen et al., Nucl. Phys. A 404 (1983) 413
- /18/ S.M. Banks et al., Contribution to the Int. Conf. on Nucl. Phys., Florence, 1983
- /19/ W. Knüpfer, B.C. Metsch and A. Richter, Phys. Lett. in press