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Berkeley, California

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Recently several publications[1,2,3] have appeared which attempt to justify theoretically the validity of the empirical coupling rules of Gallagher and Moszkowski[4] for deformed odd-odd nuclei. These rules state that the lower energy band of the two possible rotational bands formed from a given proton-neutron configuration will be the one which maximizes the parallel coupling of the intrinsic spins of the odd neutron and proton. The recent theoretical studies cited have considered only the first order contributions of the neutron-proton interaction and in one case were confined to a delta-function potential. DePinho and Picard[1] have shown that in first order perturbation theory an effective interaction of the form

$$V(|\underset{\sim}{r}|) = V(|\underset{\sim}{r}_p - \underset{\sim}{r}_n|) \quad [1 - \alpha + \alpha \underset{\sim}{\sigma}_p \cdot \underset{\sim}{\sigma}_n] \quad ,$$

can give good agreement with many of the known splittings provided α is positive and is determined for each case. With such a simplified force only the spin dependent term will contribute to the relative splitting in first order.

Then two questions arise. Can such a simple force or, for that matter, any neutron-proton central interaction which reproduces experimental spectra for spherical nuclei be used to compute all non-collective spectroscopic properties of deformed nuclei? Also, to what extent do configuration

interaction and so-called Coriolis terms affect the energies and wavefunctions in odd-odd deformed nuclei?

Recently a paper[5] has been published in which the level structure in Ho^{166} has been studied by (d,p) reaction spectroscopy. Six different rotational bands have been assigned in the first 426 keV of excitation. Especially interesting is the order of the two lowest bands {7/2(523), 7/2(633), K = 0-, 7-} which violates the Gallagher and Moszkowski coupling rules. These data make it possible to make stringent tests of the effective neutron-proton residual force through a shell model calculation using Nilsson[6] wavefunctions for the deformed rare-earth region.

A calculation is now in progress in which BCS-type superfluid solutions for odd neutron and odd proton systems are found and then the neutron-proton interaction is diagonalized with basis vectors which consist of these solutions. However, as a first approximation to this somewhat involved scheme, the proton and neutron single-particle energies can be chosen from experimental data on the adjacent odd mass nuclei Ho^{165} [7] and Dy^{165} [8] Although some of the effects of the neutron-neutron and proton-proton interactions as well as the neutron-proton self-energy terms have been accounted for, a sharp Fermi surface has been assumed. An important consequence is that certain matrix elements connecting "particle-excited" states and "hole-excited" states vanish, while with a diffuse surface they are not zero but depend on the occupation probabilities of the states involved. Other consequences may at least in part be compensated by the choice of force parameters. There are also two other considerations which may affect the renormalization of the force parameters from those which reproduce experimental spectra for spherical nuclei near closed shells. Unlike the spherical shell model there is no natural energy cut-off for the single particle states

used in the calculation. This may make it necessary to use a stronger potential to compensate for the neglect of important configuration interactions. Also it is often assumed a central force can be mocked up to represent a general proton-neutron interaction. But as Nilsson states approach their asymptotic limit, this in principle no longer becomes possible for matrix elements connecting singlet and triplet configurations and a non-central force must be used to describe such scatterings. This neglect of non-central forces may require in some cases additional renormalizations of the central force parameters.

The present calculation consists of diagonalizing the energy matrix in the basis of properly symmetrized Nilsson[6] single-particle states deduced from the experimental data on Ho^{165} and Dy^{165} for each value of spin and parity from spin 0 to 7. Because of the numerical complexity involved in computing two body matrix elements with Nilsson[6] wavefunctions, a finite range central force with Gaussian radial dependence was assumed. The strength of the Coriolis terms is determined by the inertial parameter ($\hbar^2/2\mathcal{J}$), and this was chosen to be 9 keV, the value for the ground state rotational band. Initially a neutron-proton residual interaction was chosen which is compatible with singlet and triplet effective ranges and scattering lengths deduced from low energy nucleon-nucleon data. Such data fix the even components of the n-p residual force, and we restricted ourselves to small variations in the even force parameters. However, the odd force components are undetermined by lowest energy scattering, and we allowed ourselves a large degree of freedom in varying strengths of odd force components. Only those forces having little space exchange (i.e., strong attractive odd as well as even components) reproduce the many experimental energy levels in Ho^{166}. The final best effective force mix is not only similar to DePinho and Picard[1] but also very similar

to a central force mix (without tensor) recently used by Kim for shell model calculations of the spherical odd-odd nucleus Y^{90} [9].

In fig. 1 a comparison between the states which have been characterized experimentally and their theoretical analogues is given. The force parameters used are V_{TE} = -43.00 MeV, V_{TO} = -43.00 MeV, V_{SE} = -17.20 MeV, V_{SO} = -27.95 MeV, Range = 1.9f and $\nu = 0.179f^{-2}$. In all cases the maximum prolate deformation ($\eta = 6$) was used for the Nilsson wavefunctions. The relative positions of the {0-, 7-},{3+, 6+} and {1+, 4+} pairs of states are very sensitive to the space exchange character, range, ν and singlet to triplet ratios in the force. Thus for the restricted number of configurations used in this calculation, the above force gave the best fit of approximately fifty different forces examined. The fit is satisfactory, but the most important point is that the violation of Gallagher and Moszkowski's rule for the ground state configuration does not occur in first order but only after configuration interaction is taken into account. To appreciate the extent of this configuration mixing, in Table 1 the state vectors for the 0- and 1- states which are predominantly from the configuration {7/2(523), 7/2(633), K = 0-} are listed, along with the single-particle states used in the calculations. The mixing is appreciable, but also interesting is the fact that these two members of a rotational band have different intrinsic wavefunctions. This is attributable not only to Coriolis mixing, but also to the neutron-proton interaction which has different expectation values for the even and odd members of a K = 0 rotational band[10]. The mathematical details and a more complete discussion of the physical meaning of this calculation are being published separately[11].

With the rapid increase of experimental information on odd-odd deformed nuclei, it should be emphasized that the effects of the neutron-proton residual interaction do not appear to be small. Although the order of the lowest two bands of Ho^{166} is currently the only known violation of the Gallagher and Moszkowski coupling rules in the rare-earth region, such violations may be common with higher energy configurations. The general presence of appreciable configuration mixing in deformed odd-odd nuclei certainly has important consequences for other properties, such as magnetic moments, moments of inertia, and transition rates.

Table 1

A listing of the single nucleon levels which have been observed experimentally, the basis vectors used in the calculation, and the state vectors for the lowest energy 0- and 1- states.

Code	Single particle or basic states even parity	odd parity	State Vectors 0-	1-
p1		7/2 - [523]		
p2	3/2 + [411]			
p3	1/2 + [411]			
n1	7/2 + [633]			
n2		1/2 - [521]		
n3		5/2 - [512]		
n4		5/2 - [523]		
n5		3/2 - [521]		
a1	$\|IM1\ p1\ n3\rangle$	$\|IM0\ p1\ n1\rangle$	0.9713	0.9947
a2	$\|IM1\ p1\ n4\rangle$	$\|IM0\ p2\ n5\rangle$	-0.1375	-0.0871
a3	$\|IM2\ p1\ n5\rangle$	$\|IM0\ p3\ n2\rangle$	0.1742	-0.0554
a4	$\|IM2\ p2\ n1\rangle$	$\|IM1\ p2\ n2\rangle$		
a5	$\|IM3\ p1\ n2\rangle$	$\|IM1\ p2\ n3\rangle$		
a6	$\|IM3\ p3\ n1\rangle$	$\|IM1\ p2\ n4\rangle$		0.0017
a7	$\|IM4\ p1\ n2\rangle$	$\|IM1\ p3\ n2\rangle$		0.0003
a8	$\|IM4\ p3\ n1\rangle$	$\|IM1\ p3\ n5\rangle$		
a9	$\|IM5\ p1\ n5\rangle$	$\|IM2\ p2\ n2\rangle$		
a10	$\|IM5\ p2\ n1\rangle$	$\|IM2\ p3\ n3\rangle$		
a11	$\|IM6\ p1\ n3\rangle$	$\|IM2\ p3\ n4\rangle$		
a12	$\|IM6\ p1\ n4\rangle$	$\|IM2\ p3\ n5\rangle$		
a13		$\|IM3\ p2\ n5\rangle$		
a14		$\|IM3\ p3\ n3\rangle$		
a15		$\|IM3\ p3\ n4\rangle$		
a16		$\|IM4\ p2\ n3\rangle$		
a17		$\|IM4\ p2\ n4\rangle$		
a18		$\|IM7\ p1\ n1\rangle$		

Figure Captions

Figure 1. A comparison of the experimentally observed single-particle excitations and their theoretically predicted energies. Column one gives the predictions of the zeroth order model. Column two displays the results when the first order effects of H_{INT} are included. Column three displays the results when configuration interactions and the Coriolis effects are included. The quantity B is one-half of the energy shift between the even and odd members of a K = 0 rotational band.

References

1. A. G. DePinho and J. Picard, Phys. Letters 15 (1965) 250
2. N. I. Pyatov, Bull. Acad. Sci. USSR. Ser. Phys. 27 (1963) 1409
3. V. M. Mikhailov, Bull. Acad. Sci. USSR. Ser. Phys. 27 (1964) 23
4. C. J. Gallagher, Jr. and S. A. Moszkowski, Phys. Rev. 111 (1958) 1282
5. G. L. Struble, J. Kern and R. K. Sheline, Phys. Rev. 137 (1965) B772
6. S. G. Nilsson, Dan. Mat. Fys. Medd., 29, No. 16 (1955)
7. Nuclear Data Sheets, National Research Council Committee on Nuclear Science
8. R. K. Sheline, W. N. Shelton, H. T. Motz and R. E. Carter, Phys. Rev. 136 (1964) B351
9. Y. E. Kim, UCRL-10865
10. N. D. Newby, Jr., Phys. Rev. 125 (1962) 2063
11. H. Motz, R. K. Sheline, J. Kern, O. W. B. Schult, R. Koch, U. Gruber, B. P. Maier, T. V. Egidy, E. Bieber, Th. Elze, and G. L. Struble, to be published

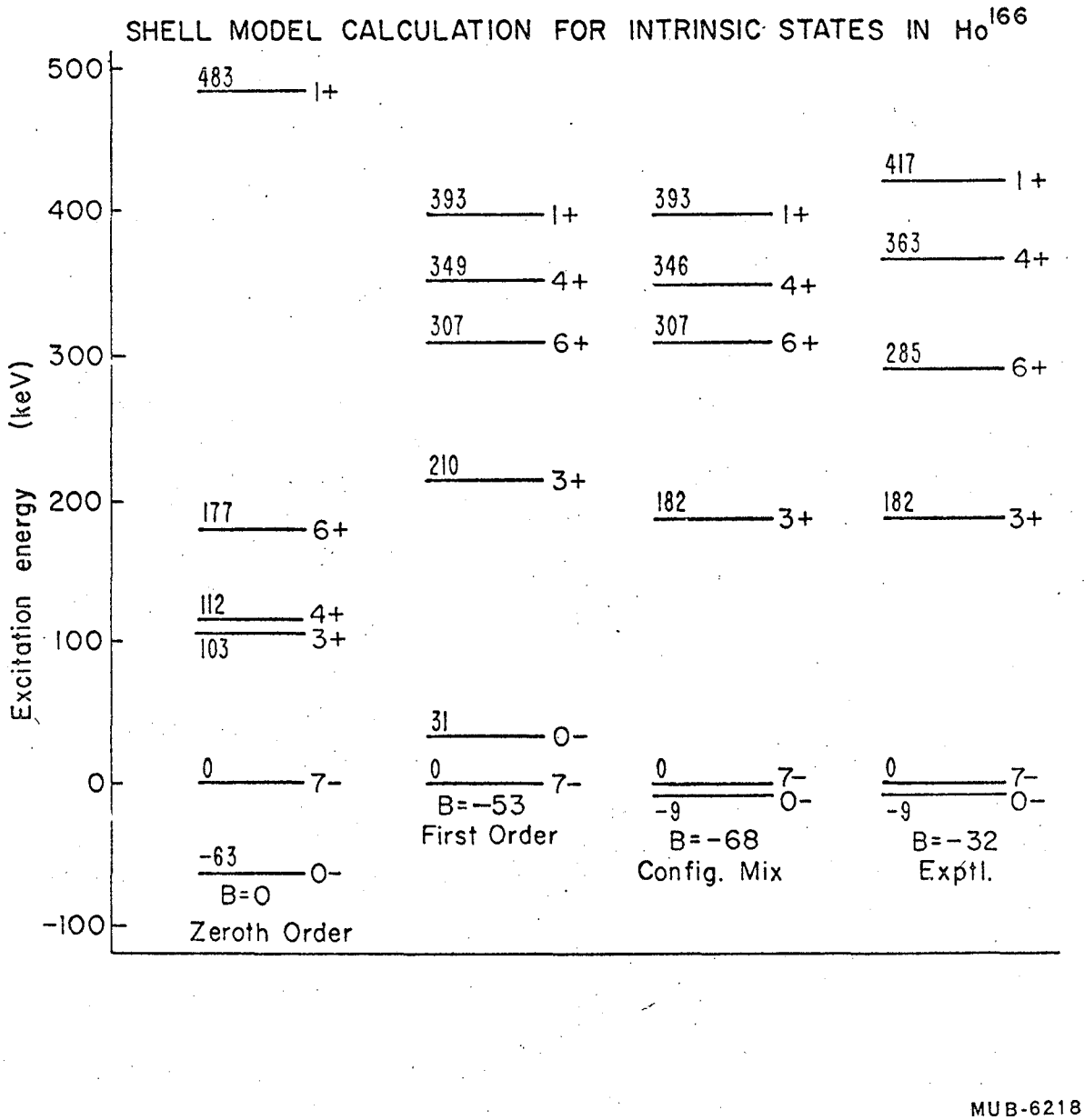

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Fig. 1

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