The nature of K=0_2 band in ^{158}Gd

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Traditionally, in the Bohr Mottelson collective model, the K=0_2 bands in deformed even-Z– even-N nuclei are regarded as built on the axially symmetric β-vibration. Deviations from the Alaga rules for the B(E2) ratios for the γ-g, β-g inter band transitions are treated in the 2-band or 3-band mixing approximations, wherein the β-γ band mixing is a second order effect.

In the Interacting boson model IBM [1], γ and β bands belong to the same SU(3) (λ=N-4, μ=2) multiplet. Hence β ↔ γ transitions are allowed transitions, and are strong. This also led to a view that some K=0_2 bands may be γγ bands. This should lead to the stronger β-γ transitions than the β-g transitions. However, this is possible even if β-g transitions are weak.

This led to the intense research in the measurement of absolute B(E2) values, to estimate the collectivity of such transitions. This topic is of continuing interest. Here we study a typical deformed nucleus ^{158}Gd.

Table 1. Absolute B(E2) values in ^{158}Gd. Quadrupole strength X=66.0 $A^{-1.4}$, inertial coefficient F_B=2.8, e_n=0.7 in DPPQM. In IBM ε=26.1,QQ= -29.5, ELL=13.0, PAIR=3.1 keV, e_b =0.14, χ=1.3.

I_i I_f	EX	DPPQ	IBM-1
0_1 2_g	4.97 5	4.61	5.00
2_γ	0.085 5	0.097	0.100
$2_{K=02}$	0.008 1	0.063	0.005
0_2 2_g	0.006	0.076	0.0065
2_γ		0.122	0.048
0_2-2_γ/2_g		1.60	7.3
Q(2_1)		-1.93	-2.02

Table 2. Absolute B(E2) values for γ-g transitions.

I_i I_f	EX	DPPQ	IBM−1
2_γ 0_g	0.017 2	0.019	0.013
2_g	0.030 4	0.055	0.020
4_g	0.0013 2	0.0007	0.0013
3_γ 2_g	0.017 1	0.040	0.022
4_g	0.010 1	0.029	0.011
3_γ 2_g/4_g	1.7	1.4	2.0
4_γ 2_g	0.005 1	0.0067	0.0066
4_g	0.037 2	0.064	0.023
2_γ	0.57 4	0.53	0.49

To test these problems for ^{158}Gd, Borner et al. [2], measured the life times of many states in ^{158}Gd and deduced the inter band absolute B(E2) values. This provides a further stringent test of the nuclear theory. The dynamic pairing plus quadrupole model of Kumar-Baranger [3] is well suited to predict absolute B(BE2) values, wherein no experimental data is input. We also cite the results from our IBM-1 calculation, in which we use the level energies to derive the parameters of H_{IBM}. We use the H_{IBM} in MULT mode with 4 terms:

$$H_{IBM=}=\varepsilon n_d+kQ.Q+k'L.L+k''P.P \quad (1)$$

In Table 1, we compare the DPPQM and IBM values for excitations from the ground state to 2_1, 2_2 and 2_3 and the decay of 0_2 to 2_g and 2_γ. Our values are in good agreement with recent data [2]. Also, we get a stronger decay of the state 0_2 to K=2 γ-band, But in DPPQM β-g strength is larger.

For inter band γ-g transitions (Table 2), the DPPQM values are in fair agreement with the measured B(E2) values [2] within a factor of about 2. The relative values agree even better. Both Tables 1 and 2 illustrate the validity of our calculation in IBM-1 and DPPQM

Table 3. The absolute B(E2) (× 100) values for β-g and β-γ transitions.

I_i I_f	EX [2]	DPPQ	IBM-1
2_β 0_g	0.16 1	1.27	0.10
4_g	0.69 4	6.1	0.38
2_g		1.28	0.17
2_γ		0.97	0.93
$0_g/4_g$	0.23	0.20	0.26
4_β 2_g	0.66 4	1.0	0.11
4_g	0.37 6	0.66	0.17
6_g	1.6 1		0.36
2_γ	6.5 10	0.21	0.01
3_γ	24 10	3.37	0.19
2_{02}	230 20	111	108
$2_2/3_1$	0.27	0.06	0.05

β-g and β-γ E2 transitions

Next we study the E2 transitions from the $K=0_2$ band. Since the β-g E2 transitions are very weak, all values in Table 3 are multiplied by a factor of 100. For the 2_β - g the DPPQ values are larger. But the ratio for (2_β-0/4) theory agrees with data. For 2_β, the IBM values agree better with data.

For E2 transitions from 4_β state to ground band, the DPPQ values are in better agreement with data. But the β–γ transitions in theory are weaker. Here, we note that the B(E2, 4_β-2_β) value of 2.30 e^2b^2 exceeds the B(E2, 4_g -2_g) value by a factor of two. The DPPQ value of 1.1 e^2b^2 and of IBM are consistent with the B(E2, 2_g -0_g) known value. Probably the other B(E2) for β=γ transitions also lie on the higher side in [2].

Conclusion

The absolute B(E2) values in theory also depend on the charge parameter. In DPPQM we use e_n=0.7 for the whole region and are not fixing it nucleus to nucleus. In IBM-1the quadrupole operator is,

$$Q= (s^+ d + d^+ d) + \chi d^+d \qquad (2)$$

and $T(E2) = e_b Q$

Here we use $e_{b=}$0.14 and χ=1.3

In the deformed nucleus of ^{158}Gd, the g-g, and γ-g transitions are collective and well given by our calculation in DPPQM and IBM-1. The γ-g and β-g transitions are slightly stronger in DPPQM, but the relative B(E2) ratios are in better agreement. Also some B(E2) values deduced from life time data in [2] are on the higher side than expected. Thus all B(E2) values can be explained by band mixing in the microscopic theory and IBM-1, and there is no indication of the 0_2^+ being a γγ vibration.

From 4_β to γ-band increased mixing is not reproduced in our calculation, but Borner et al. excluded the 0β as γγ vibration, since interband transitions can be explained in band mixing approach.

In an earlier study [4], the γ-g B(E2) ratios were studied in DPPQM

References

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