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THE ROTATION-VIBRATION STRUCTURE OF EVEN-A SAMARIUM AND GADOLINIUM ISOTOPES

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ABSTRACT

The extended rotation-vibration model, which consists of an asymmetric rotor and breathing mode deformation vibrations, has been applied to several even-A samarium and gadolinium isotopes. The comparison between the theoretical and experimental energy levels and the comparison with other model calculations are presented. Also shown are the comparison between the experimental and theoretical B(E2) ratios for the isotopes studied.

The extended rotation-vibration model, which we have previously employed with success to explain the structure of the even-A Pd isotopes[1] and that of ^{196}Pt,[2] has been used to study the structure of several even-A samarium and gadolinium isotopes.

Basically, the model Hamiltonian is that of an asymmetric rotor together with breathing mode deformation vibrations (β-vibration). In addition we assume the existence of an additional degree of freedom, which we regard as quasi-boson in nature, but we do not explicitly treat this degree of freedom. The basic nature of this model has been discussed in detail in Ref. 1 and we shall not repeat the arguments here. It is sufficient to say that the rotation-vibration part of the Hamiltonian results in a sequence of rotor-vibrator energy levels labeled by I, N, and n. The quantum number I labels the state angular momentum, N is an ordinal number labeling the multiple occurrences of a given I value within the same deformation-vibration band. These vibrational bands are labeled by the ordinal number n. We assume that the additional degree of freedom does not couple strongly with the rotation-vibration part of the Hamiltonian and consequently that the spectrum consists of one or more occurrences of very similar rotation-vibration sequences. We label each occurrence by an ordinal number S, S = 1 being the sequence that contains the ground state. A given state is therefore labeled by INnS. For example, 4211 is the second 4^+ level of the first vibrational band in the first sequence, while 4112 would be the first (lowest in energy) 4^+ level of the first vibrational band in the second sequence. The structure of the second sequence will strongly resemble that of the first sequence, which is a consequence of the weak coupling. Regarding the coupling in a perturbative manner, however, we do expect slight differences in the two sequences.

There are three parameters for each sequence: $1/\mu$ is a measure of the vibration stiffness, γ is the asymmetry of the rotor, and an energy scale parameter. To partially account for the effects of the quasi-boson degree of freedom, we allow γ and the energy scale factor but not μ to vary from sequence to sequence.

Insofar as transitions are concerned, we can calculate B(E2) ratios within a sequence, but not from levels in one sequence to those in another sequence. This deficiency is due to our simplistic treatment of the quasi-boson degree of freedom and will have to be removed in future research. For the moment we content ourselves to live with this deficiency.

Tables I and II show a comparison between the theoretical and experimental energy levels for the even-A samarium and gadolinium isotopes we have studied. Also shown are the pairing plus quadrupole (PPQ) model calculations of Kumar et al.[3] where such are available and those of the interacting boson (IBA) model calculation of Scholten et al.[4] Only in ^{156}Gd can we make a comparison of all three models. In that case, it is clear that the extended rotation vibration model accounts for more experimental

levels with considerably better overall agreement between theory and experiment than the other two. Not shown in the boson expansion model calculations of Tamura et al.,[5] which are completely comparable in quality with our results.

Figure 1 shows a part of a comparison between the experimental and theoretical B(E2) ratios for the isotopes studied. In general, the B(E2) ratios for the extended rotation-vibration model are in better agreement with the experiment overall than are those of the models cited in Ref. 3 and 4. Again, our results and those of Ref. 5 are comparable although the models are quite different in character, at least in appearance.

This main difference between our model and the three cited is in the assignment of γ bands. In all other cases the γ-vibration levels were assigned to what we would call the second sequence. Unfortunately, at the moment we cannot calculate transition ratios from sequence to sequence. We are working to rectify that situation so that we may make an even more detailed comparison with these alternative descriptions of such collective nuclei.

Fig. 1. Comparison between the experimental and theoretical B(E2) ratios.
• Theoretical values
△ Samarium isotopes
○ Gadolinium isotopes

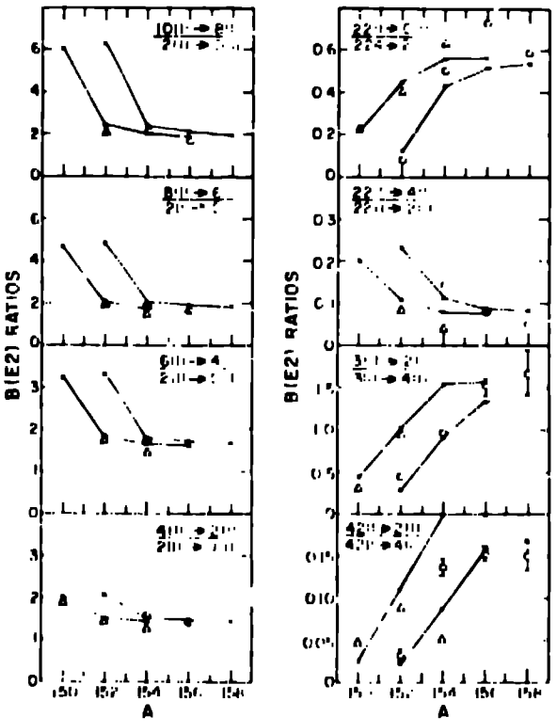

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Table I. Comparison between the experimental and theoretical energy levels of Samarium isotopes.

	^{150}Sm			^{152}Sm			^{154}Sm			^{156}Sm	
	$\mu=1.6^{\circ}, \gamma_1=15.25^{\circ}, \gamma_2=16.97^{\circ}$			$\mu=0.309, \gamma_1=12.04^{\circ}, \gamma_2=23.4^{\circ}$			$\mu=0.246, \gamma_1=8.8^{\circ}, \gamma_2=13.22^{\circ}$			$\mu=0.220, \gamma_1=6.78^{\circ}$	
State	Expt	Theory	PPQ	Expt	Theory	PPQ	Expt	Theory	PPQ	Expt	Theory
0111	0	0	0	0	0	0	0	0	0	0	0
2111	334	325	338	122	120	114	6[illegible]	82	84	76	76
4111	773	823	708	366	377	314	2[illegible]	268	265	250	250
6111	1279	1353	1128	707	738	585	547	544		508	513
0121	1256*	1068		1083	1067		1203	1206			1423
2211	1194*	1346	1179	1086	1103	1397	144[illegible]	1475	1438	1441	144[illegible]
2121	1417*	1347	1508	1293	1208			1303			1504
3111	1573	1476	1673	1234	1193	1559	1543	1539	1543		1504
4211	1642*	1653	1664	1372	1307	1705	1601	1624	1664		1565
4121	1619*	1803			1535			1514			1704
8111	1837	1874		1125	1172		903	859		867	855
5111	2[illegible]	1833	2107		1442			1727			1695
10111	2433	2402		1605	1653			1335			1267
12111	3047	2915		2150	2172			1768			1737
0112	743	743	894	685	685	715	1102	110	105[illegible]	1065	1068
2112	1048	1038		873	872	859	1326	116	119[illegible]		
4112	1444	1452		1023	1064	1045	1373	1394	1437		
0122	176[illegible]	1713			1535			2231			
2122	1855	1749			1075		1256	1743			
3122	2[illegible]*	1943			1175			184[illegible]			
2122	2[illegible]*	1948			1724			2[illegible]			
6122	2357*	1944		1[illegible]	1303	1332		1673			
8122		2413		1644	1833			1940			

* Levels were not used in the fitting.

Table II. Comparison between the experimental and theoretical energy levels of Gadolinium isotopes.

	^{152}Gd			^{154}Gd			^{156}Gd				^{158}Gd	
	$\mu=0.54, \gamma_1=15.28^{\circ}, \gamma_2=19.3^{\circ}$			$\mu=0.26, \gamma_1=13.0^{\circ}, \gamma_2=[illegible]^{\circ}$			$\mu=0.2[illegible], \gamma_1=10.2^{\circ}, \gamma_2=10.2^{\circ}$				$\mu=0.22, \gamma_1=5.9^{\circ}, \gamma_2=[illegible]^{\circ}$	
State	Expt	Theory		Expt	Theory		Expt	Theory	PPQ	IBM	Expt	Theory
0[illegible]	0	0		0	0		0	0	0	0	0	0
2[illegible]	34[illegible]	33[illegible]		12[illegible]	1[illegible]		8[illegible]	8[illegible]	8[illegible]	8[illegible]	8[illegible]	8[illegible]
4[illegible]	7[illegible]	81[illegible]		3[illegible]	3[illegible]		28[illegible]	28[illegible]	28[illegible]	28[illegible]	2[illegible]	26[illegible]
6[illegible]	[illegible]	13[illegible]		71[illegible]	754		5[illegible]	5[illegible]	56[illegible]	5[illegible]	53[illegible]	534
8[illegible]	13[illegible]	18[illegible]		114[illegible]	12[illegible]		9[illegible]	9[illegible]		9[illegible]		8[illegible]
0[illegible]	16[illegible]	106[illegible]		129[illegible]	1211		116[illegible]	116[illegible]			145[illegible]	14[illegible]
	11[illegible]	164[illegible]		99[illegible]	98		1154	117[illegible]	1531	1125	118[illegible]	119[illegible]
	14[illegible]	12[illegible]		11[illegible]	109[illegible]		1249	1258	1600	1210	1[illegible]	12[illegible]
	13[illegible]	1314		1431	1359		1298	12[illegible]			15[illegible]	151[illegible]
[illegible]		14[illegible]		1266	1231		1355	13[illegible]	176[illegible]	1316	1356	135[illegible]
10[illegible]	23[illegible]	23[illegible]		16[illegible]	1704		14[illegible]5	138[illegible]				11[illegible]
9[illegible]		16[illegible]			135[illegible]		15[illegible]	1464	1874		148[illegible]	14[illegible]
4[illegible]	169[illegible]	177[illegible]			16[illegible]		146[illegible]	149[illegible]			16[illegible]	171[illegible]
12[illegible]	2[illegible]	275		218[illegible]	224[illegible]		1916*	1801				17[illegible]
0[illegible]	6[illegible]	615		681	68[illegible]		104[illegible]	1049	1234	1045	119[illegible]	119[illegible]
2[illegible]	9[illegible]	911		81[illegible]	83[illegible]		1125	112[illegible]	14[illegible]	1129	12[illegible]	12[illegible]
4[illegible]	12[illegible]	133[illegible]		106[illegible]	104[illegible]		1298	139[illegible]	161[illegible]	13[illegible]	14[illegible]	14[illegible]
2[illegible]	16[illegible]	149			10[illegible]			21[illegible]				
5[illegible]	14[illegible]*	15[illegible]			17[illegible]			2[illegible]				240
3[illegible]	1[illegible]*	161[illegible]			115[illegible]		218[illegible]	21[illegible]				
6[illegible]	16[illegible]	17[illegible]		136[illegible]	136[illegible]			156[illegible]				162[illegible]
8[illegible]		219[illegible]		175[illegible]	172[illegible]			189[illegible]				19[illegible]

* Levels were not used in the fitting.