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Coriolis effects and the microscopic structure of gamma-vibrational levels

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Examination of experimental data for γ-vibrational states reveals strong correlations between the nonadiabatic effect deviations of the $4_\gamma \rightarrow 2_\gamma$ to $3_\gamma \rightarrow 2_\gamma$ energy ratio from the adiabatic limit with $\Sigma_i \alpha_i{}^2$, where α_i are the coefficients for the $N = 6$, $i_{13/2}$ neutron configuration in the expansion $|2^+_\gamma\rangle = \Sigma_i \alpha_i |2^+_{q\,p}\rangle_i$. This correlation and other evidence presented indicate that in contrast to the usual exclusion of Coriolis effects in the structure of γ-vibrational states, Coriolis effects are the primary source of the nonadiabaticity.

[NUCLEAR STRUCTURE Nonadiabatic effects in γ-vibrational levels correlated to microscopic structure.]

An understanding of the properties of β- and γ-vibrational levels in deformed nuclei has been a problem of long standing as reviewed earlier.[1] In terms of the collective model,[2,3] the energies of the β, γ, and ground bands are given by

$$E_{\rm rot} = AI(I+1) + BI^2(I+1)^2 + D(-1)^I f(I),$$

where the B and D coefficients reflect deviations from the adiabatic theoretical limit. The strength of the nonadiabatic effects can be described by $\Delta S = S_{\rm exp} - S_{\rm adiab}$, where $S = h\nu(4^+_\gamma - 2^+_\gamma)/h\nu(3^+_\gamma - 2^+_\gamma)$ and $S_{\rm adiab} = 2.333$. In seeking to understand the origin of the nonadiabatic effects, it is interesting to note the marked difference between the behavior of ΔS for the $K=2$ octupole and γ-vibrational bands. For γ bands $\Delta S < 0$ always and varies rather smoothly with A (and so smoothly with deformation), but for the analogous spin states of octupole bands generally $\Delta S > 0$, but not always. Neergård and Vogel[4] have shown that the nonadiabatic effects for octupole bands (at least for $I \leq 5$) can arise from a strong Coriolis interaction between the four octupole bands with $K^\pi = 0^-$, 1^-, 2^-, and 3^-.

The splitting of the quadrupole vibration into $K^\pi = 0^+$ and 2^+ bands, however, does not yield a Coriolis interaction since they cannot be connected by such an interaction. Thus attempts (for example see Ref. 1) to understand the nonadiabatic effects in these bands have been through the mixing of β, γ, and ground bands and perhaps couplings to other $K^\pi = 0^+$ and 2^+ levels but not through Coriolis interactions. We will present in this paper evidence that indeed Coriolis effects from the $i_{13/2}$ neutron configuration are present in the low-spin states of the γ-vibrational states and that the strengths of these configurations are strongly correlated to the variation in ΔS with deformation.

In Fig. 1 are shown the two possible cases for the relative position of the β- and γ- vibrational bands; one where the 2^+_β energy is below and the other above the 2^+_γ energy. The interaction of the two bands would shift the 2^+ and 4^+ bands as shown so that on the left the $4^+_\gamma, 6^+_\gamma$ states are pushed down near the $3^+_\gamma, 5^+_\gamma$ states, respectively, and therefore $D<0$, while on the right the $2^+_\gamma, 4^+_\gamma$ states are pushed up near the $3^+_\gamma, 5^+_\gamma$ states, respectively (and $D>0$). In $^{150}_{60}$Nd, $^{150,152,154}_{62}$Sm, $^{152,154,156}_{64}$Gd, and $^{156}_{66}$Dy (Ref. 5), the experimental levels are as shown on the right in Fig. 1 and we can expect $D>0$: but in fact $D = -225$ eV (^{150}Sm); -235 eV (^{152}Gd); -22 eV (^{154}Gd); -16 eV (^{156}Gd); and -11 eV (^{156}Dy), i.e., $D<0$ (Refs. 5 and 6). These deviations from the expected positive D values indicate that other effects are present.

A second anomaly observed for γ-vibrational bands concerns variations in ΔS in Er, Yb, and Hf nuclei. In Sm, Gd, and Dy nuclei, ΔS decreases smoothly toward the adiabatic limit with an increase in neutron number and corresponding in-

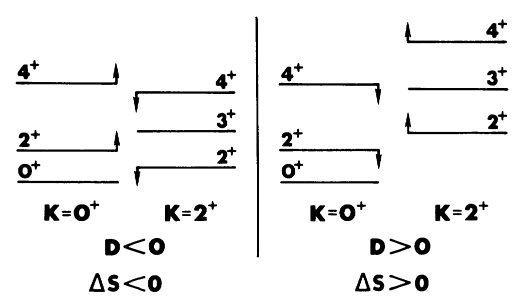

FIG. 1. The expected signs of D (and ΔS) caused by $\Delta K=2$ coupling for different relative positions of the γ-vibrational band and the closest $K=0^+$ band (β-vibrational band).

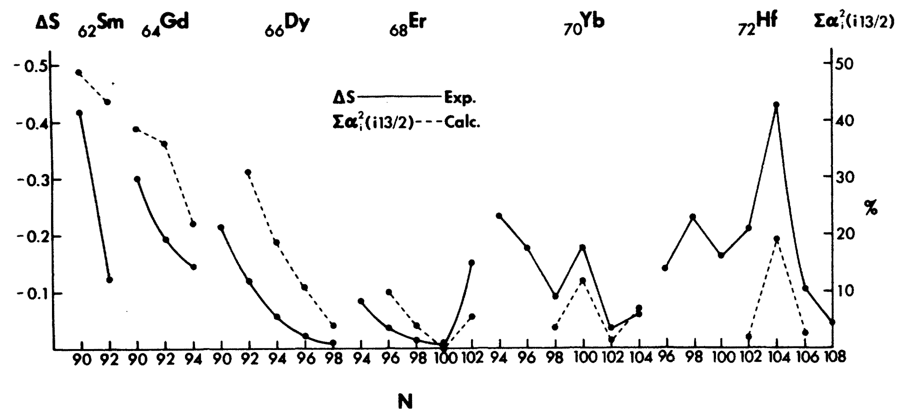

FIG. 2. The correlation between the strength of the nonadiabaticity ΔS and $\sum_i \alpha_i^2$ where α_i are the coefficients for the $i_{13/2}$-neutron configuration in the expansion $|2_\gamma^+\rangle = \sum_i \alpha_i |2_{qp}^+\rangle_i$.

creases in deformation, as shown in Fig. 2, whereas in Er, Yb, and Hf nuclei, sudden increases and decreases in ΔS are seen that cannot be connected with the change of β (deformation parameter).

These variations from the behavior expected from simple mixing of $K^\pi = 0^+$ and 2^+ bands led us to look for other explanations. We conclude that in spite of the usual opinion to the contrary, Coriolis coupling is one of the most important factors producing the nonadiabatic effects (at least at $I < 6$) in γ bands. To see this it is necessary to consider the microscopic structure of the γ-vibrational states.

Among various components that could be involved in the γ-vibrational state, let us look at two particle configurations that include nuclear states with large N, for example $N = 6$, $i_{13/2}$ neutrons. It is well known that this neutron is responsible for a very strong nonadiabatic Coriolis effect in the neighboring odd-neutron nuclei (see for example Refs. 7 and 8). The same must be true for two particle levels which include such a neutron (of course, these considerations are valid not only for $N = 6$, $i_{13/2}$ levels, but also for other high j, low Ω levels). Now look at the γ bands. If the Coriolis coupling is of great importance in the properties of γ-vibrational levels in nuclei with $A = 150-180$ where the $i_{13/2}$, low Ω levels are important, we must find a strong correlation between the summed (common) weight of the two neutron configurations including neutrons with $N = 6$, $i_{13/2}$ and the strength of the nonadiabaticity ΔS.

Grigorev and Soloviev[6] have calculated the microscopic structure of the γ-vibrational levels. In Fig. 2, ΔS is compared with $\sum_i \alpha_i^2$ where α_i are coefficients in the expansion $\psi(K=2^+) = \sum_i \alpha_i \psi_i$ for $\psi_i(N=6)$. There is a striking correlation seen in Fig. 2 between these two, with excellent agreement with the sudden changes seen in ^{170}Er, ^{170}Yb, and ^{176}Hf. Also the Coriolis coupling can account for the increasing ΔS with decreasing deformation in the Sm, Gd, and Dy nuclei. (The Coriolis coupling can also account for the anomalous negative sign of D discussed above.) Because the same $i_{13/2}$ neutrons are responsible for the nonadiabatic (Coriolis) effect, the sign of the nonadiabaticity ΔS and D must be the same in all nuclei considered. It means that in nuclei $A = 150-156$ the sign of ΔS or D must be < 0 but not $D > 0$ as expected from the usual $\Delta K = 2$ coupling.

As a further test of this idea let us look at the $K^\pi = 2^+$ ($E_{2^+} = 1341$ keV) and $K^\pi = 3^+$ ($E_{3^+} = 1577$ keV) bands in ^{176}Hf. Khoo *et al.*[9] found a strong nonadiabatic effect (odd-even shift) in the $K^\pi = 2^+$ band but not in the $K^\pi = 3^+$ band which is nearly adiabatic without any odd-even shift. This is understandable for the assignment $K = 3^+\{\frac{7}{2}^-[514]_n, \frac{1}{2}[521]_n\}$ does not include the $N = 6$, $i_{13/2}$ low Ω neutron which we suggest is responsible for the strong nonadiabaticity.

It should also be mentioned that the data[10] on backbending in even and odd isotopes of Re and Os show that in nuclei with $A \gtrsim 180$ the $h_{9/2}$ proton is primarily responsible for the observed effects and not the $i_{13/2}$ neutron. This means that in W, Os, and Pt nuclei, a correlation should not exist between ΔS and α_i^2 $(N = 6, i_{13/2})$. Only in W nuclei are data available and no correlation is observed there. In ^{180,182,184}W, $\Delta S(\alpha_i^2)$ are 0.32(<1%), 0.088(<1%), and −0.03, respectively. There is even a sign change in ΔS.

Thus we conclude that there is considerable diversified evidence to support our conclusion that the Coriolis interaction is the important factor in the nonadiabatic effects observed in the γ-vibrational states in the rare earth region.

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[1]J. H. Hamilton, Izv. Akad. Nauk, SSSR, Fiz. Ser. 36, 17 (1972) [Bull. Acad. Sci. USSR. Ser. Phys. 36, 17 (1972)].

[2]A. Bohr and B. R. Mottelson, K. Dan. Vidensk. Selsk., Mat.-Fys. Medd. 27, No. 16 (1953).

[3]A. Bohr and B. R. Mottelson, Lectures on Nuclear Structure and Energy Spectra, Copenhagen, 1962 (unpublished). Also see O. Nathan and S. G. Nielson, *Alpha-, Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland, Amsterdam, 1965), p. 601.

[4]K. Neergård and P. Vogel, Phys. Lett. 30B, 75 (1969); Nucl. Phys. A145, 33 (1970); A149, 217 (1970).

[5]M. Sakai, At. Data Nucl. Data Tables 15, 531 (1975); Institute for Nuclear Studies, Tokyo, Report No. 231, 1975 (unpublished).

[6]E. P. Grigorev and V. G. Soloviev, *The Structure of Even Deformed Nuclei* (Nauka, Moskow, 1976).

[7]E. Grosse, F. S. Stephens, and R. M. Diamond, Phys. Rev. Lett. 31, 840 (1973); 32, 74 (1974).

[8]L. L. Riedinger, G. J. Smith, P. H. Stelson, E. Eichler, G. B. Hagemann, D. C. Hensley, N. R. Johnson, R. L. Robinson, and R. O. Sayer, Phys. Rev. Lett. 33, 1346 (1974).

[9]T. L. Khoo, J. C. Waddington, Z. Preibisz, and M. W. Johns, Nucl. Phys. A202, 289 (1973).

[10]A. Neskakis, R. M. Lieder, M. Müllerveggian, H. Beuschen, W. F. Davidson, and C. Mayer-Böricke, Nucl. Phys. A261, 189 (1976).