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THE NATURE OF THE GAMMA BAND IN ERBIUM AND DYSPROSIUM*

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The angular distribution of 50 MeV alpha particles corresponding to the gamma band levels of ^{166}Er has been calculated in terms of a phenomenological model including a hexadecapole vibration.

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We have found it impossible¹⁾, using the usual phenomenological model of gamma vibrations together with the coupled channel technique, to fit the angular distribution of alpha particles corresponding to the $4+$ level in the gamma band of ^{166}Er . The experimental cross section is very high and strongly enough peaked in the forward direction to suggest that a considerable part of the excitation takes place directly from the ground state. Previous work²⁾ involving (d,d') reactions at lower energies suggested the existence of direct Y_4 excitations from the ground state; we believe that our detailed fit to the much more structured diffraction pattern of 50 MeV α particles confirms this phenomenon and that the method we use to excite these levels is suggestive, in phenomenological terms, of their physical nature. The coupled channel calculations¹⁾ are extended to include a surface expansion about a mean deformation β_2 of the following form:

*This work performed under the auspices of the U. S. Atomic Energy Commission.

$$\frac{\delta R}{R_0} = \beta_2 Y_{20} + \bar{a}_2' (\cos\theta (Y_{22} + Y_{2-2}) + \sin\theta (Y_{42} + Y_{4-2})) \quad (1)$$

using the notation of refs. 3) and 4). Our collective variable is $\bar{a}_2'$; that of ref. 4), (FGS) is a_2' , the total Y_{22} deformation ($\bar{a}_2' \cos\theta$); we shall refer below to the Y_{42} deformation ($\bar{a}_2' \sin\theta$) as a_{42} . For each power of n , the expansion is carried to second order in a_2' ; the second order terms are found to make a slight difference to the γ_{4+} level, as is shown in Fig. 1, where the results of calculations using expansion (1) with $\theta = 30^\circ$ are shown together with the data of B. G. Harvey, K. L. Hendrie, and Jeannette Mahoney⁵⁾. We find that a complex optical potential is needed to fit the gamma band and that with matrix elements of $\bar{a}_2'$ between the bands that which would be obtained for a_2' (with $\theta = 0$) using wave functions of FGS, then the optical potential coupling to the γ band must be reduced by a factor of about 0.63. This compares with the factor of 0.7 found with $\theta = 0$ as described⁴⁾ in spite of the further $\cos\theta$ factor. A significant part of the γ_{2+} excitation is second order through the Y_{42} term and the data cannot be fitted with a Y_{42} term coupling the ground band to the γ_{4+} alone thereby ignoring higher order transitions. The reduction factor, 0.63 conceals an ignorance of both the wave functions and the correct optical potential for coupling to states less collective than rotational. Separate reduction factors for the real and imaginary parts of the optical potential were allowed but did not lead to better fits.

The γ_{4+} level is now fit quite well and the γ_{2+} fit is improved except perhaps at the most forward angles (where, indeed, the data seems most uncertain). To fit the data, we need θ about 30° .

To fit the gamma band of ^{166}Er , then, the wave functions derived from harmonic potentials fail both as to transition amplitude and in the Y_4 excitation property. The former seems reasonable in view of the calculations of Preston

and Das Gupta⁶⁾ who, in establishing axial symmetry for this nucleus, find a dependence of the energy on a_2' which is extremely shallow near the origin. If we suppose that the energy minimum as a function of a_2' is no longer at $a_2' = 0$ for $a_4' \neq 0$, then we can picture a mode of vibration with a_4' and a_2' oscillating together. The additional assumption of simultaneous harmonicity in a_2' and a_4' leads to the picture implied by (1), that is a vibration involving a collective coordinate $\bar{a}_2'$ corresponding to harmonic vibration along a line in the a_2', a_4' plane at an angle θ from the a_2' axis. The gamma band in ^{166}Er is well defined up to the 7+ state, and obeys the $I(I+1)$ energy rule very well; in fact the 4+ state departs from the value predicted on this basis from the known 2+ and 3+ energies by 0.1%, which is a smaller departure than would be induced by the rotation-vibration interaction. We note that this deviation is an order of magnitude less than for all other γ -bands except those in precisely the cases, ^{162}Dy , ^{164}Dy , ^{166}Er , ^{168}Er where Elbek et al. find evidence of Y_{44} excitation. Thus we are sure that this phenomenon is not due to an admixture of some foreign state to the $\gamma 4+$ state, and must be a property of the intrinsic state.

An immediate consequence of the simple picture we have suggested would be the existence of $K = 2$ bands in these nuclei, defined in terms of a normal mode orthogonal to that involved here. A well defined $K = 2$ band exists in ^{164}Dy with 2+ at 1.987 MeV. The 4+ of this band is seen by Grottdal et al. but the 2+ is apparently not seen. On this model, clearly, the 4+ should be more strongly excited than the 2+. Certainly, this band could be a 2 quasiparticle band as suggested by Shelton and Sheline⁷⁾; the band cannot consist of a gamma plus a beta phonon, as there is no low energy beta phonon.

The importance of the Y_4 multipole of residual interaction is suggested by inelastic scattering experiments on spherical nuclei⁸⁾; in terms of the Kumar and Baranger⁹⁾ picture where a self consistent field links a nuclear deformation to an interaction of the same multipolarity, the present phenomenon is a manifestation of the Y_4 interaction. A comparison of the energies of β and γ bands shows why there is no reason to expect Y_{40} and Y_{44} vibrations to occur in the same region as Y_{42} vibrations.

We comment apropos the custom of assigning the spin of a level from a diffraction pattern, that the γ band 2+ level diffraction pattern excited by a Y_{22} shape, is exactly "out of phase" with the 2+ level of the ground band, and of somewhat different slope.

A calculation in which static Y_{22} and Y_{42} deformations are included is also illustrated in the figure. The fit to the 4+ level seems poorer. The Y_{22} deformation needed, $a_2' = 0.035$ and $a_2'/\beta_2 = 0.136$ and $\gamma = 0.193$, is somewhat less than that implied by a fit to the energies on a Davydov¹⁰⁾ model, where the spectrum can be fitted with $a_2'/\beta_2 = 0.154$ or $\gamma = 0.220$, but the possibility of simultaneous Y_{42} and Y_{22} deformations remains; it is not excluded by the work of Das Gupta and Preston. Hybrid theories of vibrational gamma bands with fixed Y_{42} seem unappealing. Finally we note that our results depend critically on the sign of θ in (1); a negative θ completely spoils both the 2+ and 4+ angular distributions.

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Figure Captions

Fig. 1. Angular distribution of 50 MeV alpha particles inelastically scattered from the ground band and gamma band of ^{166}Er . The data for the gamma band differs from that shown in (1) in that a second set of data was included and the points simply joined where the sets disagreed. For the curves labelled Davydov model, the static deformation is $\beta_2 = 0.253$, $a_2' = 0.035$, $a_{42} = 0.024$ corresponding to $\gamma = 0.193$.

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Fig. 1

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