Excited superdeformed band in ^{131}Ce

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An excited superdeformed band has been observed in ^{131}Ce consisting of 13 γ rays and extending to spin $\sim 50\hbar$. Possible configurations are discussed in terms of particle-hole excitations in a deformed Woods-Saxon potential. [S0556-2813(96)01007-2]

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The existence of rotational bands in nuclei at large deformations is now firmly established. In particular, superdeformed (SD) structures have been observed in nuclei in the $A \approx 80$ [1], 130 [2], 150 [3], and 190 [4] mass regions with quadrupole deformation parameters $\beta_2 \approx$ 0.5, 0.4, 0.6, and 0.45, respectively. The current generation of γ-ray spectrometers such as Eurogam [5,6] and Gammasphere [6,7] take advantage of the increase in sensitivity that can be achieved with the use of higher-fold coincidences for the detection of γ rays. This has helped facilitate the discovery of excited superdeformed bands which are typically populated with an intensity below the 1% level of that in the reaction channel. The two isotopes ^{131}Ce and ^{132}Ce have been known to exhibit rotational bands indicative of superdeformation for many years [8], and [9], respectively. In both cases these yrast SD bands are relatively strongly populated with an intensity $\sim$5% of the respective reaction channel. No excited SD bands had been observed in either nucleus until the existence of two excited SD bands in ^{132}Ce were reported [10]. ^{131}Ce has one neutron less than the doubly magic superdeformed ^{132}Ce core, and so the observation of excited SD bands in this nucleus provides valuable information on neutron orbitals close to the Fermi surface at large deformation. This Brief Report documents the observation of an excited SD band in ^{131}Ce and discusses the proposed configuration for the band.

High-spin states in ^{131}Ce were populated using the ^{100}Mo(^{36}S,5n)^{131}Ce reaction at a beam energy of 155 MeV. This reaction populated states in ^{131}Ce with approximately 40% of the total yield and states in ^{132}Ce with approximately 50% . The beam was provided by the tandem Van de Graaff accelerator at the Nuclear Structure Facility, Daresbury, and was incident on a self-supporting ^{100}Mo target of thickness 625 μg/cm^2. Coincident γ rays were detected using the Eurogam (phase I) spectrometer [5,6] equipped with 41 escape-suppressed germanium detectors. Events were recorded for an unsuppressed fold condition $\geqslant$7, from which a total of 3.5 $\times$ 10^9 suppressed triple and 2.0 $\times$ 10^9 suppressed quadruple coincidence events were unpacked during offline analysis.

Figure 1 shows a spectrum of the excited SD band in ^{131}Ce (^{131}Ce band 2). It was found that triple γ-ray coincidence analysis provided the best combination of low con-

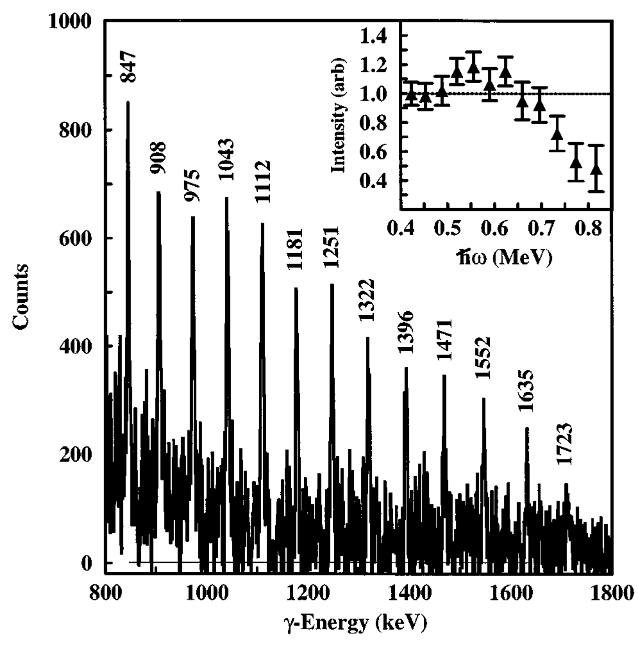

FIG. 1. Spectrum showing ^{131}Ce band 2, produced from the sum of double-gated triple γ-ray coincidences on all transitions below 1552 keV. Accurate energies are 846.80(10), 908.07(10), 975.52(10), 1043.13(10), 1112.24(11), 1181.28(12), 1250.71(12), 1322.04(12), 1396.22(15), 1470.66(15), 1551.81(19), 1634.80(20), 1723.02(25). The inset shows the normalized relative intensity for the band.

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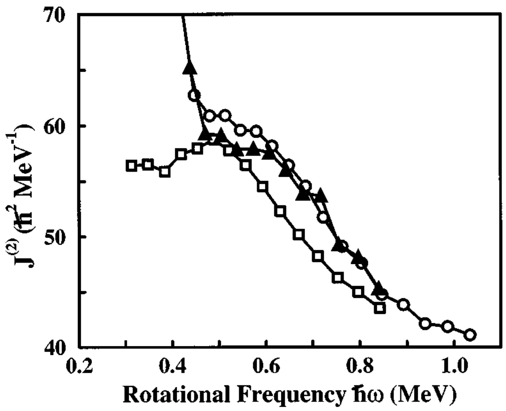

FIG. 2. The $\Im^{(2)}$ dynamic moment of inertia as a function of rotational frequency for ^{131}Ce band 2 (solid triangles), ^{131}Ce band 1 (open squares), and ^{132}Ce band 1 (open circles).

tamination and high statistics. The band consists of 13 γ rays and has a population intensity of $\approx$1% the ^{131}Ce reaction channel. It has been observed to feed into the normal-deformed decay sequence at spin $\sim 39/2\hbar$. Although no linking transitions have been observed, it is assumed that they carry $\sim 4\hbar$, which implies that the bandhead has spin $\sim 47/2\hbar$ and the band is thus observed to $\sim 99/2\hbar$. The inset of Fig. 1 shows the normalized relative intensity distribution for the band. Although it is difficult to conclude too much from the distribution due to the errors, it appears that the band may be populated over only the last three or four transitions. This is in contrast to ^{131}Ce band 1 (the yrast SD band in ^{131}Ce) which is populated over most of the band. Figure 2 shows the experimental $\Im^{(2)}$ dynamic moment of inertia ($\Im^{(2)} \approx dI/d\omega$) for the new band. Also shown in the diagram are the experimental $\Im^{(2)}$ for ^{131}Ce band 1 and ^{132}Ce band 1 (the yrast SD band in ^{132}Ce). The sharp rise in the $\Im^{(2)}$ for ^{132}Ce band 1 at $\hbar\omega \approx 0.4$ MeV has been attributed to the combined effect of $i_{13/2}$ neutron and $h_{11/2}$ proton alignments, indicating that ^{132}Ce band 1 has a high-N particle configuration of $\pi 5^4$ $\nu 6^2$ (N=74). This feature is not observed for ^{131}Ce band 1, which has a high-N particle configuration of $\pi 5^4$ $\nu 6^1$ (N=73). The sharp rise in $\Im^{(2)}$ in ^{131}Ce band 2 near this alignment frequency and the similarity of the bands over a range of frequency suggest an identical high-N intruder configuration, and ^{131}Ce band 2 is therefore assumed to possess a $\pi 5^4$ $\nu 6^2$ configuration.

The occupation of both $i_{13/2}$ neutron orbitals would suggest that the deformation of ^{131}Ce band 2 may be similar to that of ^{132}Ce band 1 (measured to be $Q_0 = 8.8 \pm 0.8$ e b [11], $Q_0 = 8.0 \pm 0.8$ e b [12], $Q_0 = 7.5 \pm 0.6$ e b [13]) rather than ^{131}Ce band 1 (measured to be $Q_0 = 6.0 \pm 0.6$ e b [14], $Q_0 = 6.4 \pm 0.6$ e b [15]). However, recent work [16] in which the deformations could be measured in the same experiment (and therefore relative to each other) indicates that both ^{131}Ce band 1 and ^{132}Ce band 1 have the same deformation of $Q_0 = 7.4 \pm 0.3$ e b, and that ^{131}Ce band 2 has a considerably larger deformation of $Q_0 = 8.5 \pm 0.4$ eb. The same quadrupole moment for both yrast SD bands would imply that the occupation of $i_{13/2}$ intruder orbitals does not have as large an effect on deformation as previously thought. Theoretical cranked Woods-Saxon calculations with a representative deformation of $\beta_2 = 0.4$ are shown in Fig. 3. At this deformation, the $i_{13/2}$ neutron orbitals are present in the immediate vicinity of the Fermi surface so that neutron excitations are likely to be more favorable than proton excitations, for which a large energy gap occurs at Z=58 up to high frequency. It is therefore expected that all bands discussed in this paper will have all proton orbitals unoccupied above Z=58 in Fig. 3, and the excited bands will involve neutron

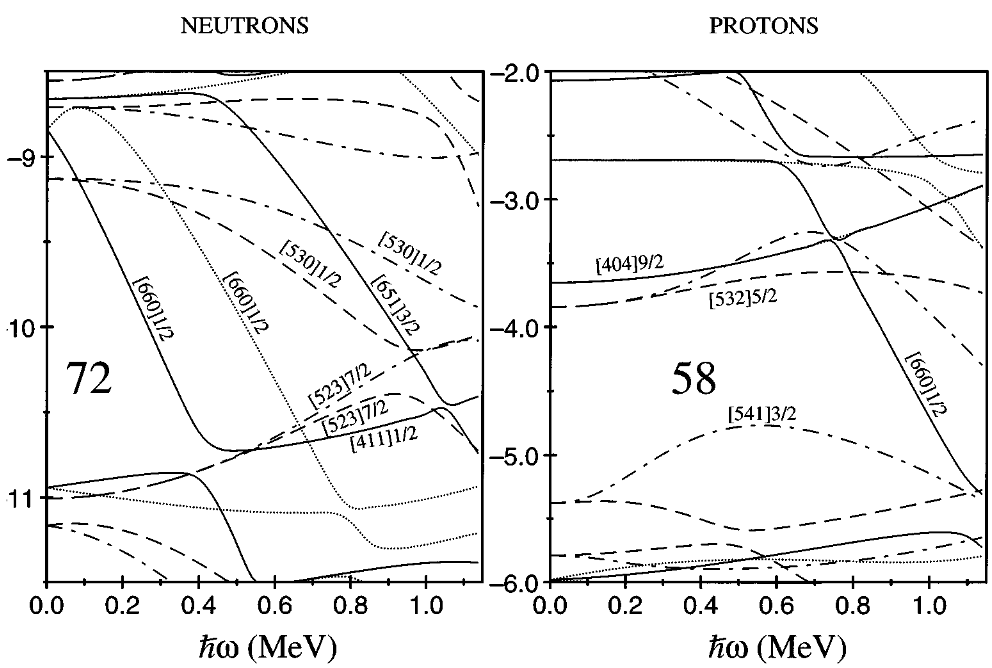

FIG. 3. Single-particle calculations for $\beta_2 = 0.4$, $\beta_4 = 0$, $\gamma = 0°$. The N=6 $i_{13/2}$ intruder orbitals ([660]$1/2^+$) are close to the Fermi surface at this deformation. Each orbital is referred to by its parity and signature (π,α): Solid lines = (+,+1/2), dotted lines = (+,–1/2), dot-dashed lines = (–,+1/2), dashed lines = (–,–1/2).

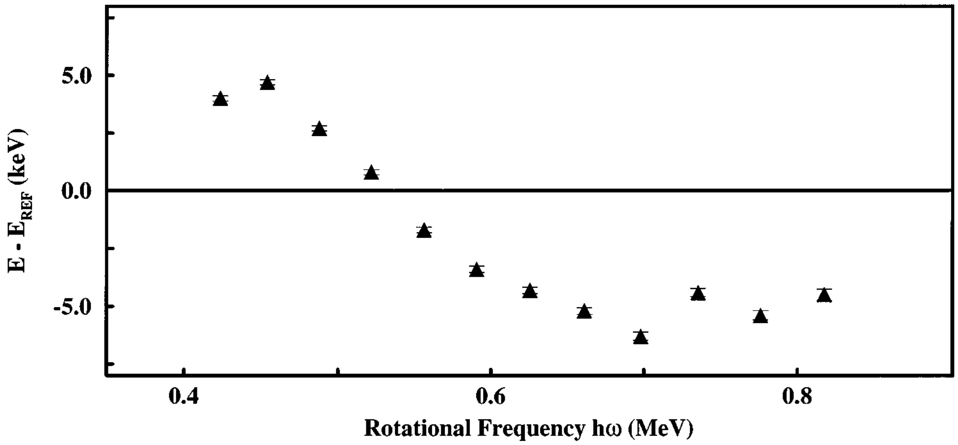

FIG. 4. Calculated energy differences between the transition energies in ^{131}Ce band 2 (E) and the quarter points of the transition energies in ^{132}Ce band 1 (E_{REF}). The rms value of the differences is $\sim$4.3 keV.

particle-hole excitations. The most probable excitations are from the $[523]7/2^-$ ($\alpha=\pm 1/2$) and the $[411]1/2^+$ ($\alpha=+1/2$) neutron orbitals into the $[660]1/2^+$ ($\alpha=-1/2$) neutron orbital. However, it would be expected that any excitation involving one of the $[523]7/2^-$ orbitals would be accompanied by a signature-partner band of similar population intensity (the signature splitting is small at low rotational frequencies). Since only one excited band is observed in this nucleus, the most likely excitation is considered to be from the $[411]1/2^+$ ($\alpha=+1/2$) orbital into the $[660]1/2^+$ ($\alpha=-1/2$) neutron orbital. The new excited band in ^{131}Ce is therefore produced by coupling a $[411]1/2^+$ hole to the yrast SD band in ^{132}Ce.

The absence of a pair of signature-partner bands corresponding to excitations from the $[523]7/2^-$ ($\alpha=\pm 1/2$) should be addressed, as it is difficult to resolve this matter within the confines of the cranked shell model at this deformation. Similar calculations to those shown in Fig. 3 for a larger deformation of $\beta_2\approx 0.45$ predict that the two $[523]7/2^-$ orbitals would be lowered in energy relative to the $[411]1/2^+$ ($\alpha=+1/2$) neutron orbital and thus placing a hole in the $[411]1/2^+$ orbital becomes energetically favorable. Furthermore, since this orbital has a negative quadrupole moment, a hole in this orbital would favor increased quadrupole deformation.

An identical $\mathfrak{J}^{(2)}$ moment of inertia between two bands is often taken as an indication of a very similar deformation. The identical nature of the $\mathfrak{J}^{(2)}$'s for ^{132}Ce band 1 and ^{131}Ce band 2 (Fig. 2) is therefore remarkable when it is considered that these two bands have such largely different measured quadrupole moments ($Q_0=7.4\pm 0.3$ e b and $Q_0=8.5\pm 0.4$ e b, respectively [16]). It is interesting to note that the $[411]1/2^+$ orbital is playing a similar role in these bands as it plays in SD bands in the mass $A\approx 150$ region. In both cases, the orbital has a slightly negative quadrupole moment and lies just below the SD magic gap. It has been proposed that ^{151}Dy SD band 4 [17] is built upon an excitation from the $[411]1/2^+$ neutron orbital into the $[770]1/2^-$ ($\alpha=+1/2$) neutron orbital which lies just above it. In both cases therefore, the bands in ^{131}Ce and ^{151}Dy are produced by coupling a $[411]1/2^+$ hole to the doubly magic core of the yrast SD band in the $A+1$ nucleus. The decoupling parameter of the $[411]1/2^+$ state is equal to $a=-1$ in the pseudoasymptotic limit [18], and so any SD band built upon this configuration should have transition energies which lie halfway between those of its identical partner. In agreement with this, ^{151}Dy SD band 4 is observed to have transition energies which lie near the midpoints of those of ^{152}Dy SD band 1. However, ^{131}Ce SD band 2 has transition energies which lie at the quarter points of those in ^{132}Ce SD band 1, and not at the midpoints as predicted by the pseudo-SU(3) symmetry.

It is possible, however, that the identicality between ^{131}Ce SD band 2 and ^{132}Ce SD band 1 is purely accidental. The lower mass of ^{131}Ce relative to ^{132}Ce would produce a lower $\mathfrak{J}^{(2)}$ for ^{131}Ce band 2 than for ^{132}Ce band 1, whereas the prolate driving effect of the $[411]1/2^+$ hole in ^{131}Ce band 2 would generally produce a higher $\mathfrak{J}^{(2)}$ in ^{131}Ce band 2 than for ^{132}Ce band 1. A cancellation between these two effects could therefore produce an identical $\mathfrak{J}^{(2)}$ moment of inertia relationship between the two bands. Figure 4 shows the calculated energy differences between the transition energies in ^{131}Ce band 2 and the quarter points of the transition energies in ^{132}Ce band 1. The rms value of these differences is $\approx$4.3 keV so that the degree of identicality of these bands is

$$\frac{E-E_{\mathrm{ref}}}{E_\gamma}\approx\frac{4.3}{1200}\approx 0.35\%, \tag{1}$$

and it is difficult to imagine that this could arise completely by accident.

In summary, an excited SD band has been observed in ^{131}Ce. Cranked-shell model calculations indicate that a number of excitations are favorable in producing this band, but the most likely is from the $[411]1/2^+$ ($\alpha=+1/2$) orbital into the $[660]1/2^+$ ($\alpha=-1/2$) neutron orbital. It is not clear why the $i_{13/2}$ neutron occupation does not effect the deformation as much as could be expected or why ^{131}Ce band 2 should have such a relatively large deformation for this mass region. The identical nature of the band with ^{132}Ce band 1 is also not understood in the context of the pseudo-SU(3) symmetry.

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