Superdeformed band in ^{130}Ce

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An ''identical'' superdeformed (SD) band has been discovered in the nucleus ^{130}Ce. This band has transition energies which are identical to the half-way points between the energies in the yrast SD band of ^{131}Ce to a mean degeneracy of 0.4%. The discovery of this band completes the chain of SD Ce isotopes from ^{129}Ce to ^{133}Ce. However, at 0.5% of the reaction channel, it is populated with an intensity which is an order of magnitude smaller than neighboring SD bands. The valence neutron configuration is assigned as $\nu 6^1$ with a hole in either the [523]7/2$^-$ or [411]1/2$^+$ Nilsson orbitals. [S0556-2813(96)05312-5]

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Superdeformation in the mass $A \approx 130$ region was first observed in the nucleus ^{132}Ce [1,2]. Since then, superdeformed bands have been discovered in Ce [3], Pr [4], and Nd [5,6] isotopes. These bands have the similar characteristics of large quadrupole moments of $Q_0 = 5-8$ e b, and high dynamical moments of inertia. These SD states exist in a second minimum of the nuclear potential energy, which is stabilized by the large shell correction energy at the $Z=58$ and $N=72$ shell gaps, with a deformation of $\beta_2 \approx 0.4$.

Until recently, it was thought unlikely that the phenomenon of superdeformation would be observed in nuclei with neutron numbers at or below $N=72$ due to the possible absence of intruder orbitals near the Fermi surface for these nuclei [7]. With the discovery of superdeformation in ^{131}Pr [8], it has been shown that bare shell gaps alone are sufficient to stabilize the superdeformed shape below $N=72$. Very recently, a superdeformed band has been discovered in the nucleus ^{129}Ce [9], demonstrating that the superdeformed minimum persists in lighter Ce isotopes. However, in this particular nucleus it is unclear whether an $\nu i_{13/2}$ intruder orbital is occupied or not. In this experiment we have concentrated on the nucleus ^{130}Ce, at the $Z=58$ and $N=72$ shell gaps.

The experiment was performed with the 8π γ-ray spectrometer at the TASSC facility, Chalk River. The 8π spectrometer consists of 20 Compton suppressed, high resolution Germanium detectors and a 71-element Bismuth Germanate (BGO) inner ball. The inner ball allows measurement of the event γ-ray multiplicity (K) and sum-energy (H). High-spin states in ^{130}Ce were populated with the ^{100}Mo(^{34}S,4n) reaction at a bombarding energy of 145 MeV. In total, 600 million γ-γ coincidence events, with a BGO ball multiplicity of $K>6$, were collected and recorded on magnetic tape.

A scan of the data for regularly spaced structures revealed a single SD band of very weak intensity (its strongest transition was measured to have 0.5% of the intensity of the 2^+-0^+ transition in ^{130}Ce). This band extends from transition energies of 840 keV to 1416 keV with an energy spacing of $\approx$70 keV, which corresponds to a high dynamical moment of inertia of $\mathcal{I}^{(2)} \approx 60\hbar^2$ MeV^{-1}, similar to other SD bands in the region (see Fig. 1).

As the band is so weakly populated, it is unreliable to assign it to the nucleus ^{130}Ce based soley on observed coincidences with γ rays between normal deformed states in ^{130}Ce, due to the uncertainty in the background subtraction. Nevertheless, it has been possible to confirm the assignment of the band to ^{130}Ce by placing the same gates on three γ-γ coincidence matrices gated on BGO multiplicity (i) $K<15$, (ii) $15>K>23$, (iii) $K>23$ in order to preferentially select 3, 4, and 5 particle exit channels. The new band was present in matrix (ii), but not matrices (i) and (iii), indicating that four particles were evaporated. We have, therefore, assigned the band to the ^{130}Ce nucleus, as other four particle exit channels, producing the nuclei ^{130}La ($p3n$) and ^{127}Ba ($\alpha 3n$), were not populated with any significant strength.

The discovery of this band completes the chain of SD Ce isotopes from ^{129}Ce to ^{133}Ce. This chain is analogous to the chain of superdeformed Gd isotopes from ^{144}Gd to ^{150}Gd in the $A \approx 150$ mass region, where the shell gap of $Z=64$ stabilizes the SD shape at $\beta_2 \approx 0.5-0.6$.

As the yrast SD band in ^{131}Ce also was populated in this experiment, it was possible to obtain an accurate measure of

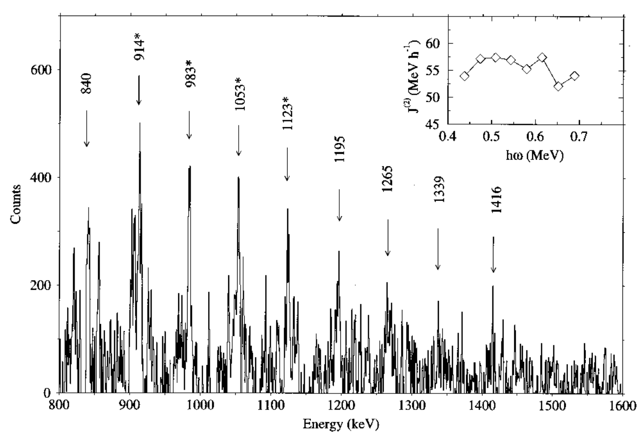

FIG. 1. Spectrum of the superdeformed band in ^{130}Ce created from a sum of gates set on the transitions marked with an asterisk. The dynamical moment of inertia extracted from the transition energies is inset.

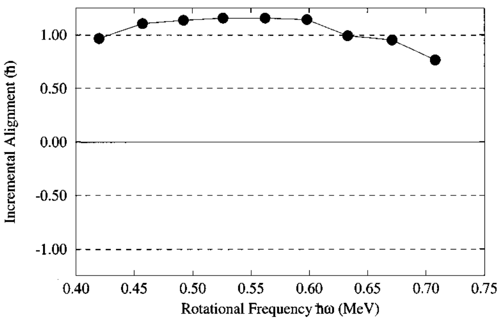

FIG. 2. Incremental alignment for the superdeformed band in ^{130}Ce with the measured transition energies of the yrast SD band in ^{131}Ce as a reference.

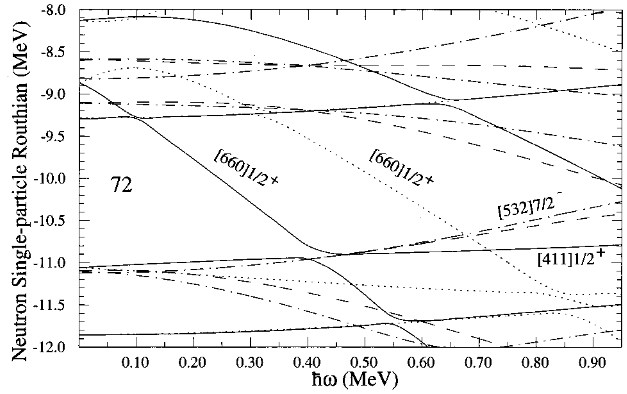

FIG. 3. Neutron single-particle Routhians around the $N=70$ shell gap, calculated with the universal Woods-Saxon potential with deformation parameters taken from the calculated Total Routhian Surface minimum at $\hbar\omega=0.4$. The Routhians are labeled with the asymptotic Nilsson quantum numbers $[N,\ n_z,\ \Lambda]\Omega$.

the experimental incremental alignment [10] of the new band with respect to the yrast band in ^{131}Ce. The incremental alignment was extracted from the transition energies of both bands (see Fig. 2). Over the entire length of the band, the incremental alignment is very close to unity since the transition energies lie at the half-way points between the energies in the yrast SD band of ^{131}Ce. The measured mean degeneracy for all nine transitions with the half-way points is 0.4%, making this one of the best examples of identical bands in the mass $A\approx 130$ region [11,12].

Unpaired, cranked shell model calculations based on the universal Woods-Saxon potential [7], have been used to produce the single-particle Routhians for neutrons near the Fermi surface (see Fig. 3). The deformation parameters of $\beta_2=0.371$, $\beta_4=0.015$, and $\gamma=2.9°$ defining this potential have been taken from total Routhian surface calculations.

The fact that the band in ^{130}Ce is identical to that of the band in ^{131}Ce suggests that the intruder orbital configuration is the same (i.e., one neutron in the $[660]1/2^+$ orbital). Examination of the calculated Routhians shows that in the frequency range over which the band is populated, the $[660]1/2^+$ orbital is below the Fermi surface and should therefore be occupied. The difference between the configurations of the bands in ^{131}Ce and ^{130}Ce is a hole in the positive signature of the $[411]1/2^+$ Nilsson orbital or either signature of the $[523]7/2^-$ Nilsson orbital.

The scenario of a hole in either signature of the $[523]7/2^-$ orbital is the most energetically favorable. However, the calculations predict that there is very little signature splitting and, hence, two bands of similar intensity would be expected. Nevertheless, the observation of only one band does not rule out this possibility, since its partner would have transition energies lying very close to those of the yrast band in ^{131}Ce, the intensity of which is an order of magnitude higher (5% of the ^{131}Ce reaction channel). This would make a weak signature partner difficult to observe.

The other scenario involves a hole in the $[411]1/2^+$ orbital. This orbital is implicated in generating identical bands in the $A\approx 150$ mass region. However, the theoretical aligned spin of $0.2\hbar$ for this orbital is too low to account for the identity relationship making the first scenario more plausible.

To summarize, an ‘‘identical’’ superdeformed band has been discovered in the nucleus ^{130}Ce. This band has transition energies which are identical to the half-way points between the energies in the yrast SD band of ^{131}Ce, to a mean degeneracy of 0.4%. The most likely single particle configuration is one neutron in the $[660]1/2^+$ orbital, with a hole in the positive signature of the $[523]7/2^-$ orbital. It is now possible to perform systematic studies of the SD isotopes in the Ce chain, investigating the evolution in valence neutron configurations, deformations, and population intensities.

[1] P. J. Nolan *et al.*, J. Phys. G **11**, 17 (1985).
[2] A. J. Kirwan *et al.*, Phys. Rev. Lett. **58**, 467 (1987).
[3] Y.-X. Luo *et al.*, Z. Phys. A **329**, 125 (1988).
[4] J. N. Wilson *et al.*, Phys. Rev. Lett. **74**, 1950 (1995).
[5] E. M. Beck *et al.*, Phys. Rev. Lett. **58**, 2182 (1987).
[6] R. Wadsworth *et al.*, J. Phys. G **13**, 207 (1987).
[7] R. Wyss, A. Johnson, W. Nazarewicz, and J. Nyberg, Phys. Lett. B **215**, 211 (1988).
[8] A. Galindo-Uribarri *et al.*, Phys. Rev. C **50**, 2655 (1994).
[9] A. Galindo-Uribarri *et al.*, Phys. Rev. C **54**, 454 (1996).
[10] F. S. Stephens, *et al.*, Phys. Rev. Lett. **65**, 301 (1990).
[11] P. J. Nolan *et al.*, Proceedings of the Conference on Physics from Large γ-ray Detector Arrays, Berkeley, California, 1994.
[12] C. Baktash *et al.*, Annu. Rev. Nucl. Part. Sci. (1995), p. 485.