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Superdeformation in ^{198}Po

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The ^{174}Yb(^{29}Si,5n) reaction at 148 MeV with thin targets was used to populate high-angular momentum states in ^{198}Po. Resulting γ rays were observed with Gammasphere. A weakly populated superdeformed band of 10 γ-ray transitions was found and has been assigned to ^{198}Po. This is the first observation of an SD band in the $A \approx 190$ region in a nucleus with $Z > 83$. The $\mathscr{J}^{(2)}$ of the new band is very similar to those of the yrast SD bands in ^{194}Hg and ^{196}Pb. The intensity profile suggests that this band is populated through states close to where the SD band crosses the yrast line and the angular momentum at which the fission process dominates.

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More than 40 superdeformed (SD) bands have been identified to date in the $A \approx 190$ region. They have in common characteristics which include (1) a γ-ray energy spacing which results in an upsloping dynamic moment of inertia, $\mathscr{J}^{(2)}$, with respect to rotational frequency, and (2) an intensity pattern that suggests SD bands are populated over several of the highest-spin states and are sharply depopulated over 1–3 of the lowest energy states. The population is thought to occur in the region at which the SD band becomes yrast [1,2].

Mapping the existence of SD bands in the $A \approx 190$ region and their properties as a function of neutron and proton number is important for understanding the nuclear structure effects that lead to the development of the second well. Three SD bands have recently been observed in bismuth ($Z = 83$) nuclei [3]. Theoretical calculations of Po nuclei (e.g. [4,5]) suggest that the second well in ^{198}Po exists at an excitation energy of about 4 MeV and a well depth of about 2 MeV at $I = 0$. However, a simple comparison of the fissility parameter, Z^2/A, indicates that ^{198}Po is much more prone to fission than other nuclei studied in this region. Studies of superdeformation in polonium are therefore difficult because fission contributes to a larger spectroscopic background and reduces the population of high angular momentum states that populate SD bands. The measurement reported here shows evidence for an SD band in ^{198}Po ($Z = 84$), the largest proton number for which an SD band in the $A \approx 190$ region has been found.

In our initial experiment [6] with Gammasphere Early Implementation, a candidate for an SD band was found. At that time, the data did not have sufficient statistics to determine whether the transitions were actually part of an SD cascade. Here we report the results from the second experiment which confirm the existence of the band.

We observed ^{198}Po with the ^{174}Yb(^{29}Si,5n) reaction at a beam energy of 148 MeV. The beam was provided by the 88-Inch Cyclotron Facility at the Lawrence Berkeley National Laboratory. The target consisted of three, self-supporting enriched ^{174}Yb ($\approx 98\%$) foils each with a thickness of 600 μg cm^{-2}. The ℓ_{max} for this reaction in the middle of the target is $\sim 38\hbar$ [7]. The γ-ray spectroscopy was done with the Gammasphere array which, at the time of the experiment, consisted of 56 Compton-suppressed Ge detectors with Ta-Cu absorbers placed in front to reduce x rays. A total of 1.4×10^9 three- and higher-fold coincidence events was collected. The two most intensely populated evaporation residue channels were ^{198}Po and ^{199}Po ($\approx 50\%$ and $\approx 40\%$, respectively). Unfolded triples were sorted into a symmetrized γ-γ-γ cube with γ-ray energies ranging from 100 to 767 keV. The sum spectrum produced by all combinations of uncontaminated double gates on the band transitions is shown in Fig. 1(a). As is evident from the figure, this cascade is rather weak, and therefore, analysis is prone to background problems. To minimize background effects we used higher-fold data in sorting a γ-γ matrix which was double gated on all combinations of γ-ray energies in the cascade. The spectrum of the SD band shown in Fig. 1(b) was generated by gating on the band transitions in this matrix and subtracting a background spectrum obtained from selected background gates.

The analysis of these data produced a spectrum with a γ-ray sequence that has properties characteristic of SD bands in this mass region. Limited statistics prevented a directional correlations of oriented nuclei (DCO) analysis to establish transition multipolarity. In this paper we assume that this is an SD structure of $E2$ transitions. The search algorithm developed by Hughes *et al.* [8] was used to aid in the process of looking for additional SD bands. No other cascade with energy spacings characteristic of an SD band was found in the data set.

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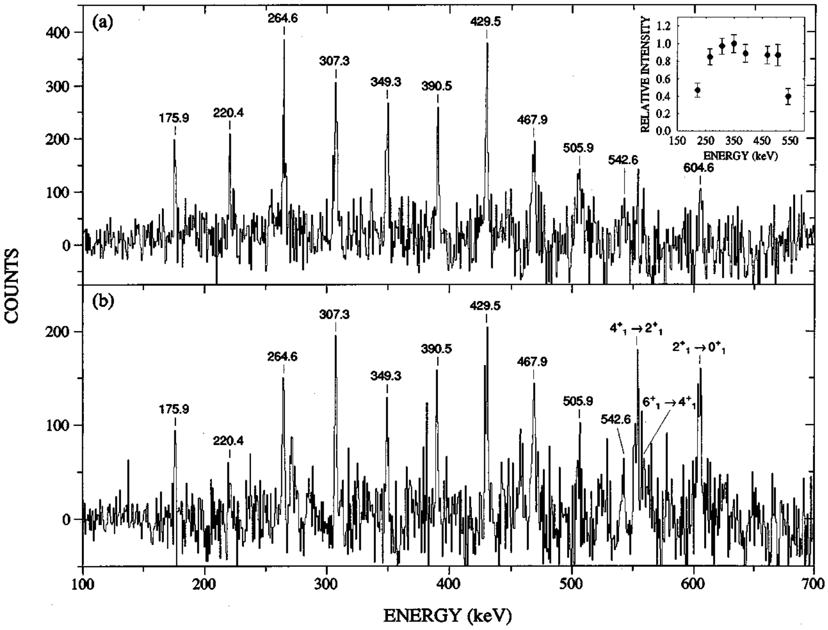

FIG. 1. Spectra of the ^{198}Po SD band with different sorting conditions. (a) Generated by summing all combinations of clean double gates on the SD transitions listed in Table I. The inset shows the intensity distribution of these SD transitions. (b) Generated by summing all combinations of triple gates on the SD transitions listed in Table I.

We have assigned the SD band to ^{198}Po because the spectrum in Fig. 1(b) clearly indicates that this cascade is in coincidence with low excitation energy transitions in ^{198}Po, including the 559.2-keV $[6_1^+ \to 4_1^+]$, 553.2-keV $[4_1^+ \to 2_1^+]$, and 604.6-keV $[2_1^+ \to 0_1^+]$ transitions [9]. It should be noted, however, that the gates on the 307.3- and 429.5-keV band members are possibly contaminated by the 305.8-keV $[7^- \to 5^-]$ and the 428.4-keV $[6_3^+ \to 5^-]$ transitions in ^{198}Po. However, when these possible contaminants are removed from the gating conditions, the 604.6- and 553.2-keV lines persist. Thus, the low-lying lines are due to the decay of the SD band to the first well states of ^{198}Po. In addition, we see no evidence of proton emission channels, which would form Bi nuclei. There are some α-channel events, mainly to $^{194-196}$Pb. However, there is no evidence for the SD bands previously observed [10–16] in these nuclei, which provides further support of the ^{198}Po assignment.

The transition energies and relative intensities, given in Table I, were obtained from a sum of all combinations of double gates of the SD γ-ray energies in the sorted cube. A generalized background subtraction [17] was employed for these spectra. We estimate the upper limit of the relative intensity of the SD band compared with the normal states to be 0.3%. This was obtained by dividing the intensity of the 307.3-keV SD transition, as seen in the spectrum double gated on 349.3- and 390.5-keV transitions, by the summed intensity of transitions feeding the 0_1^+ ground state level and the known 750-ns 12^+ isomer in ^{198}Po.

The ^{198}Po SD band has properties characteristic of most SD bands found in the $A \approx 190$ region. The average spacing of the γ-ray energies is $\overline{\Delta E_\gamma} = 40.7(5)$ keV for frequencies between $\hbar\omega = 0.088$ and 0.271 MeV. The dynamic moment of inertia for this band is displayed in Fig. 2, where it is compared with selected SD bands in $A \approx 190$ even-even nuclei. It is interesting to note that the $\mathscr{J}^{(2)}$ of the ^{198}Po band is most similar to the SD yrast bands in ^{194}Hg [18,19] and ^{196}Pb [14–16]. The rise in the $\mathscr{J}^{(2)}$ for these three isotones is understood as the gradual alignment of pairs of $j_{15/2}$ neutrons and $i_{13/2}$ protons under the influence of weak pairing correlations [18]. The small differences of magnitude for the $\mathscr{J}^{(2)}$ can possibly be attributed to differences in pairing and/or deformation, but the calculations are not sufficiently sensitive to predict such small effects.

Using the method described by Becker *et al.* [20], the fitted spin of the level populated by the 175.9-keV transition is $6.1(1)\hbar$. This near integer value for the spin lends further credence to assigning the band to the even-even ^{198}Po. This spin assignment is also consistent with the average spin $\approx 4\hbar$ of the low-excitation energy states populated by the SD band decay.

An interesting feature of this SD band is that the highest observed SD transition has an energy below 550 keV, which corresponds to a relatively low spin transition, $26\hbar \to 24\hbar$. Most yrast SD bands in $A \approx 190$ nuclei extend to transition energies above 650 keV. Our analysis of the population of

TABLE I. Energies and relative intensities of ^{198}Po SD transitions.

Energy (keV)	Intensity[a]
175.91(27)	b
220.37(20)	0.47(8)
264.59(15)	0.85(9)
307.29(15)	0.97(9)
349.29(16)	1.00(10)
390.46(20)	0.89(10)
429.54(19)	b
467.90(38)	0.87(10)
505.85(42)	0.87(12)
542.57(42)	0.40(9)

[a] Intensities have been corrected for detector efficiency and electron conversion.

[b] The intensities of these transitions have not been extracted. The contaminants are a 176-keV line from the Coulomb excitation of the target and a low-lying 429-keV transition in ^{198}Po [6].

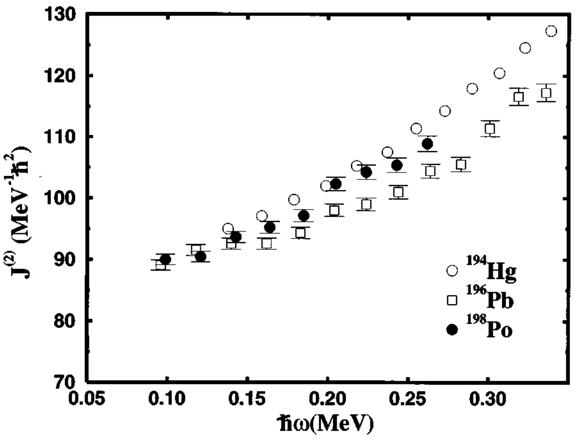

FIG. 2. Comparison of $\mathscr{J}^{(2)}$ of the ^{198}Po SD band with SD bands in ^{196}Pb and ^{194}Hg. Data are taken from Refs. [16,19] and the present work.

the normal states in ^{198}Po [6] determined that fission dominates compound nucleus decay above about $22\hbar$. A reasonable explanation for not observing any γ-ray transition in the SD band above 550 keV in ^{198}Po is that the fission process strongly dominates above $\approx 26\hbar$—population of even highly deformed configurations in the evaporation residue cannot compete with fission at higher angular momentum.

The intensity profile, shown in Fig. 1(a), indicates that the SD band is sharply fed over few transitions. The fission process is limiting the maximum angular momentum of the ^{198}Po residue, thereby reducing the entry region over which the SD band is populated. Since the population of SD bands is thought to occur in the region where the SD band crosses the yrast line [1,2], the intensity analysis suggests that the SD band is crossing the yrast line at roughly the same spin at which fission begins to dominate the ^{198}Po channel. The rather low intensity of the band relative to the total intensity in the $5n$ channel supports the conclusion that we are close to the limit where the fission process cuts off the entry region, which is dependent upon the spin at which the SD band becomes yrast.

To summarize, we have observed a new SD band which has been assigned to ^{198}Po. Our results represent the first observation of a superdeformed band in the $A \approx 190$ region with $Z > 83$. The upsloping $\mathscr{J}^{(2)}$ is very similar to that observed in other $N = 114$ isotones, most likely reflecting the role of aligning $j_{15/2}$ neutrons. The population of this band and its intensity profile suggests that ^{198}Po is close to the limit where the fission process cuts off the entry region to the SD band. Observation of an SD configuration in ^{198}Po, in spite of intense competition from fission, suggests that this region of superdeformed shapes can be extended to heavier nuclei where SD minima are predicted to exist. However, a successful search for SD excitations in $Z > 84$ systems will require high statistics data, such as will be available with full implementation Gammasphere.

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