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Identification of spherical states at low energy in the deformed nucleus ^{185}Pt

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The nucleus ^{185}Pt, which has a strongly deformed ground state and numerous low-lying rotational bands, is shown to possess low-lying excited states which are nonrotational. This is demonstrated through the absence of rotational excitations associated with two low-spin ($J=\frac{3}{2};\frac{5}{2}$) states at excitations between 500 and 600 keV. The implications of these observations for shape changes and shape coexistence in this region are discussed. [S0556-2813(98)50601-2]

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The nucleus ^{185}Pt is well established to have a strongly deformed ground state and many low-lying rotational bands. This evidence comes from isotope shift data [1,2], together with in-beam γ-ray spectroscopy data [3] and radioactive decay data for ^{185}Au [4,5]. The low-lying states in ^{185}Pt [6], arranged into rotational bands built on Nilsson states, are shown in Fig. 1. The nucleus ^{185}Pt lies at the border of a region of strong ground-state deformation that extends to the very neutron-deficient Pt isotopes (see, e.g., [7–9]). The nucleus ^{187}Pt and heavier Pt isotopes have weakly deformed ground states [1,2]. Thus, the question arises whether weakly deformed states are present or absent in ^{185}Pt. This work shows that weakly deformed states exist in ^{185}Pt at low excitation energy. This establishes shape coexistence in ^{185}Pt.

Shape coexistence has been established in many nuclei (see, e.g., [10,11]). This has usually been in situations where the ground state is weakly deformed and the strongly deformed states appear as rotational bands with their distinctive stretched cascade of γ-ray transitions. This phenomenon is especially dramatic for superdeformed bands (see, e.g., [12]) which are always observed as sequences of states at high excitation. These superdeformed states are easily identified despite being in regions of nuclear excitation where the density of (weakly deformed) states is enormous. Observing weakly deformed states in regions of high density of strongly deformed states is much harder. There are no clear stretched cascades of γ-ray transitions for weakly deformed states and it is difficult to exclude the possibility that they are deformed unless clear proof of the absence of superposed rotational bands can be established. We present data for ^{185}Pt that strongly support the absence of rotational bands for certain excited states.

Excited states in ^{185}Pt were studied using the radioactive decay of ^{185}Au ($T_{1/2}=4.2$ min, $J^\pi=\frac{5}{2}^-$). Gamma-ray and conversion-electron singles and coincidence data were taken using mass-separated sources. The ^{185}Au samples were produced using the Holifield Heavy Ion Research Facility at Oak Ridge National Laboratory and were separated using the UNISOR isotope separator. Levels up to an excitation energy of 960 keV are shown in Figs. 1 and 2. (These levels are based on the very complex unravelling of the decay data, procedures for which are outlined in the thesis of one of the authors [13]. Here, we summarize major features and show examples of detail.) Figure 3 presents selected levels in a plot of excitation energy versus $J(J+1)$, where J is the level spin. This plot clearly shows levels that form a rotational band as a sequence of points on a smooth curve. Two states, shown in Fig. 3, that stand out in contrast to the rotational band sequences are states with $J^\pi=\frac{3}{2}^-$ and $\frac{5}{2}^-$ at 521.3 and 593.4 keV, respectively. The lack of a transition connecting the two states (cf. Fig. 4) typically precludes the existence of a band, however, both the pertinent γ rays and conversion electrons happen to be obscured. A 72 keV γ ray

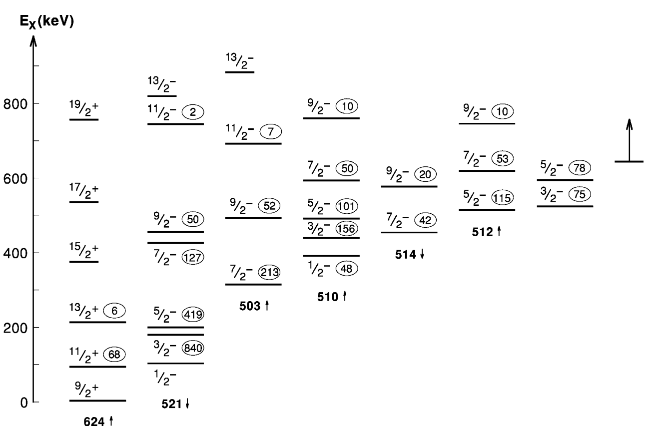

FIG. 1. The low-energy deformed structure in ^{185}Pt arranged by rotational bands built upon Nilsson states. The bandheads are labeled in the asymptotic basis by $Nn_z\Lambda\Sigma$. The circled numbers are a relative measure for the total transition strength out of the level. Two levels on the right at 521.3 keV and 593.4 keV appear to define the beginning of a rotational band with $K^\pi=\frac{3}{2}^-$. The absence of higher band members, which is the central theme discussed in this work, precludes the deformed nature of these states.

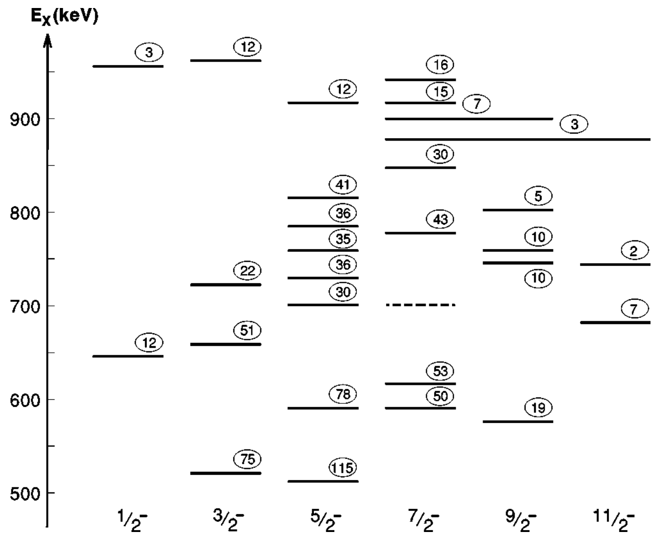

FIG. 2. Systematics of the relative deexcitation strength of levels in ^{185}Pt, as determined by the sum of the total intensities of deexciting transitions, as a function of J^π and energy. The uniform population strength of states with $J^\pi=\frac{3}{2}^-,\frac{5}{2}^-,\frac{7}{2}^-$ at excitation energy between 600 and 800 keV is evident. A $J^\pi=\frac{7}{2}^-$ state at ≈695 keV (dashed line) would be expected to exhibit similar population strength.

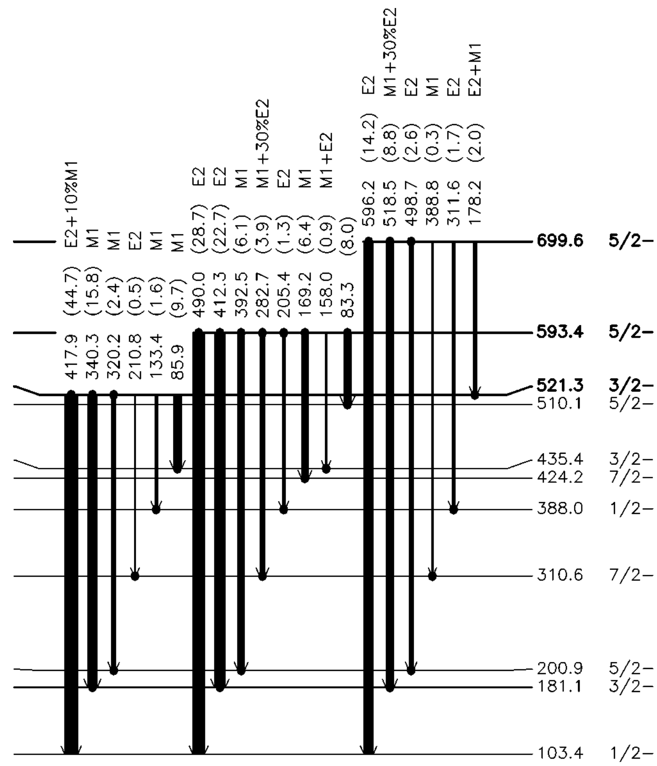

FIG. 4. A portion of the ^{185}Pt level scheme pertaining to the deexcitation of the 521, 593, and 699 keV levels. The pattern of draining transitions mandates the assigned spins and parities.

lies at the edge of the K_β x rays which appear strongly in the coincidence data. Furthermore, the corresponding L-shell conversion electrons that would be observed for a 72 keV transition happen to have the same energy as the K-shell conversion electrons for a strong 138 keV transition that feeds the 521.3 keV level. While the data do not suggest its existence, the possibility of a weak transition cannot be ruled out. In the assumption that, indeed, the two states appear to define the beginning of a rotational band with $K^\pi=\frac{3}{2}^-$, we present arguments that exclude a continuation with band members of $J^\pi=\frac{7}{2}^-,\frac{9}{2}^-,\ldots$.

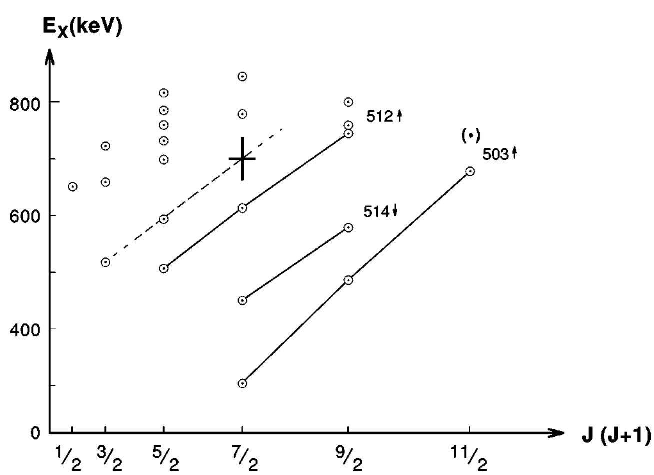

FIG. 3. A plot of excitation energy vs angular momentum eigenstate for the low-lying structure in ^{185}Pt. Rotational bands are revealed by monotonic spin sequences that lie on approximately parallel lines. The 521, $\frac{3}{2}^-$ and 593, $\frac{5}{2}^-$ states, if rotational, would form a band with a $J^\pi=\frac{7}{2}^-$ state at ≈695 keV (cf. mark on dashed line); its absence excludes a deformed structure for these states.

If the states with $J^\pi=\frac{3}{2}^-$ and $\frac{5}{2}^-$ at 521.3 and 593.4 keV, respectively, are rotational then a $\frac{7}{2}^-$ band member should lie at ≈695 keV, according to the rotational patterns evident in Fig. 3. In Fig. 2 we show the population of negative parity states in ^{185}Pt as a function of excitation energy and spin. It is evident that the radioactive decay of ^{185}Au strongly populates all identified $\frac{7}{2}^-$ states up to at least 860 keV excitation. We infer that the scheme is complete, for $J^\pi=\frac{7}{2}^-$, to energies well above the expected rotational band member at ≈695 keV defined above. Figure 1 summarizes the population pattern of the levels from which one can gauge the completeness of the work. In fact, the only excited states that are reasonably near to 695 keV are states at 682.4, 693.0, 699.6, 723.5, and 728.1 keV, none of which have $J^\pi=\frac{7}{2}^-$. Most notably, the state at 699.6 keV is assigned $J^\pi=\frac{5}{2}^-$. This state was previously assigned [6] $J^\pi=(\frac{7}{2}^-)$ and so appeared to fit a rotational sequence with the 521.3 and 593.4 keV states. In Fig. 7 we show coincidence spectra based upon which a $J^\pi=\frac{7}{2}^-$ assignment for the 699.6 keV state is excluded.

It is imperative to the argument that J^π be correctly assigned to the relevant levels. A portion of the level scheme depicting all transitions draining the 521.3, 593.4, and 699.6 keV levels is presented in Fig. 4 to illustrate the J^π assignments of these levels. Coincidence spectra corresponding to gates on transitions feeding these three levels are presented in Figs. 5, 6, and 7; these spectra exclude the possibility of a closely spaced level doublet and are critical in establishing the transitions to the 103.4 keV isomeric state which has $J^\pi=\frac{1}{2}^-$ and so cannot be fed by $J^\pi=\frac{7}{2}^-$ levels.

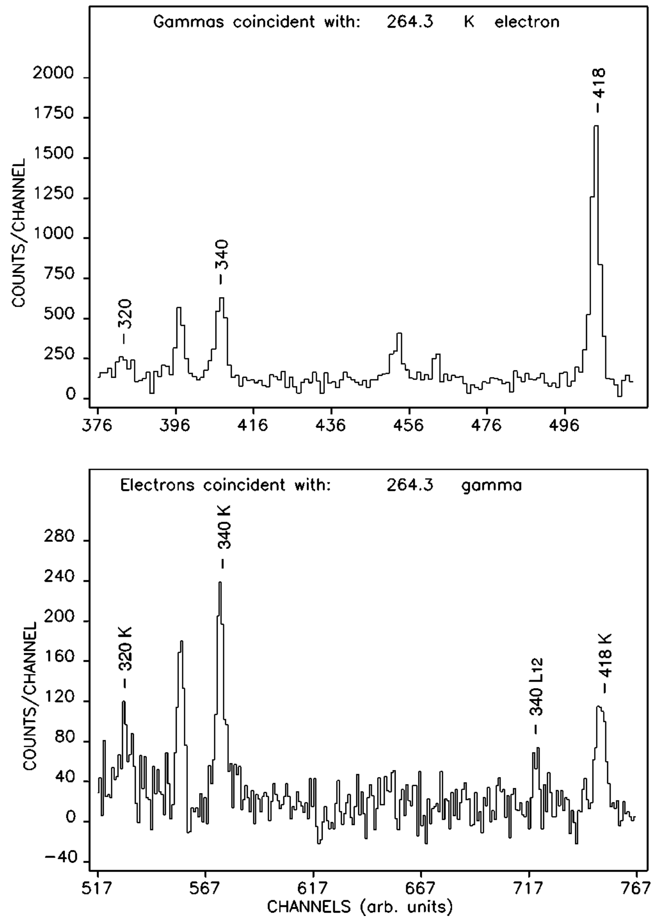

FIG. 5. Gamma rays and corresponding conversion electrons coincident with the 264.3 transition which feeds into the 521.3 keV level. Three main transitions (320, 340, and 418 keV) out of the level appear in the spectrum. Unmarked peaks belong to a different transition at 264 keV energy.

The low-lying states of the odd-mass Pt isotopes with $A \geqslant 189$ do not exhibit rotational patterns. In ^{187}Pt, the ground state and the majority of the low-lying states are apparently nonrotational; however, a rotational band is identified in association with the state at 57 keV. We compare the 521 and 593 keV states in ^{185}Pt with the low-lying states in $^{187-189}$Pt in Fig. 8. We conclude that the nonrotational states in ^{187}Pt and heavier odd-mass Pt isotopes continue into ^{185}Pt, appearing as low-lying excited states with $E_x \geqslant 521$ keV. A comment on the high density of levels at low energy in ^{187}Pt, compared to ^{189,191}Pt, is in order here. Besides the 57 keV state in ^{187}Pt, which is indicated as deformed in Fig. 8 (and as noted above), it is possible that some of the other low-lying states in ^{187}Pt are deformed. The available data for ^{187}Pt (see [14]) are inadequate to address this possibility; although we reiterate that the ground state is not deformed [1,2].

The nucleus ^{185}Pt lies on the border of a region of unexpectedly [15,16] large ground-state deformation. Doubly even nuclei in this region possess well-established shape co-

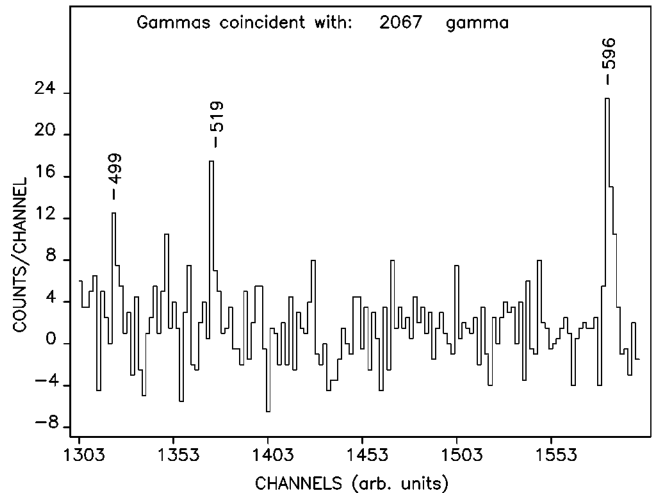

FIG. 7. A portion of a background subtracted coincidence spectrum gated on the 2067 keV transition that feeds the 699.6 keV level. The 596, 519, and 499 keV transitions feeding $J^\pi = \frac{1}{2}^-$, $\frac{3}{2}^-$, and $\frac{5}{2}^-$ levels at 103.4, 181.1, and 200.9 keV, respectively, are depicted. Transitions in prompt gates exhibit $\Delta J \leqslant 2$; thus, due to the 596 keV transition into the 103.4 $\frac{1}{2}^-$ level, a spin-parity assignment of $\frac{7}{2}^-$ is excluded for the 699.6 keV level.

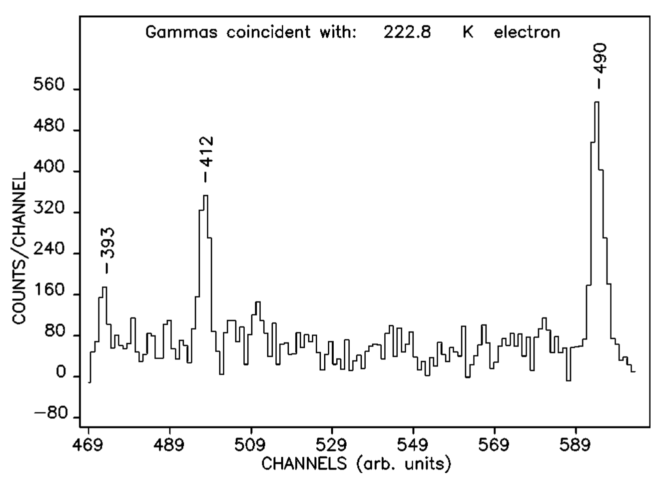

FIG. 6. Background-subtracted $e^- \gamma$ gate on the 222.8 keV transition into the 593.4 keV level showing the three strongest γ rays out of this level.

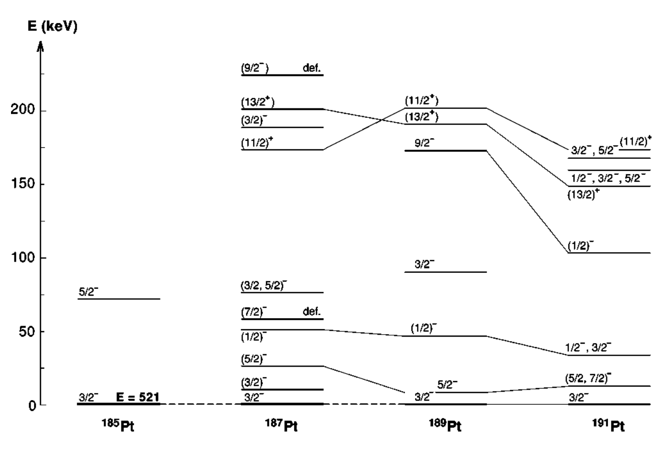

FIG. 8. The low-energy structure of ^{187,189,191}Pt [14,23,24] juxtaposed with the lowest spherical states in ^{185}Pt (see text).

existence [10,11]. In odd-Z nuclei in this region, also, shape coexistence is well established [17]. However, in odd-N nuclei the evidence for shape coexistence has been limited to ^{185}Hg, where it is supported by isomer shift data [18] and in-beam γ-ray spectroscopy data [19], and in ^{183}Hg [20,21] and ^{187}Hg [22] where there is evidence for decoupled and strongly coupled $i_{13/2}$ bands.

The present work provides the first information on shape coexistence of low-spin states in an odd-mass nucleus with a strongly deformed ground state. Further, it demonstrates a direct method for establishing the absence of specific excited states. Finally, it identifies the energy separation between the weakly and strongly deformed states in ^{185}Pt. This separation is very sensitive to parameters of the single-particle average potential. Thus, it will provide strong constraints on single-particle models in this region.

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