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SHAPE COEXISTENCE IN ^{185}Au*

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Abstract

The β-decay of ^{185}Hg → ^{185}Au has been studied following on-line mass separation at UNISOR/HHIRF. Transitions with strong E0 components were observed feeding the $h_{9/2}$ and $h_{11/2}$ bands and are interpreted as resulting from the coupling of the $h_{9/2}$ and $h_{11/2}$ single-proton configurations in the ^{184}Pt and ^{186}Hg cores, respectively.

The first indication of shape coexistence near Z=82, N=104 came from the observation [BON72] of a large increase in the mean-square charge radius in going from ^{187}Hg to ^{185}Hg. This result was obtained [BON76] by optical pumping of on-line separated Hg isotopes at the ISOLDE facility. Later measurements [KUH77, BON79] included many isomeric states as well as the ground states of ^{184,183,181}Hg. Interestingly, while the 55 sec $1/2^-$ ground state of ^{185}Hg shows a large increase in the mean-square charge radius, the 28 sec $13/2^+$ isomer does not.

Early in-beam γ-spectroscopy on ^{184}Hg and ^{186}Hg showed that their yrast bands become deformed above the 2^+ state [PRO73, RUD76]. Studies of the ^{188}Tℓ → ^{188}Hg, ^{186}Tℓ → ^{186}Hg and ^{184}Tℓ → ^{184}Hg decays at UNISOR and ISOCELE clearly revealed two coexisting bands which approach each other with decreasing mass [HAM75, BON76, COL76, COL77, BER77, COL84]. Recent in-beam work [MA 84] on ^{182}Hg indicates that the deformed band continues to drop in energy relative to the ground state band, although the rate of approach appears to have greatly diminished. These data [HAM85] are shown in fig. 1,

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which is presented here as the classic example of a coexistence of levels built on different shapes. Shape coexistence appears to be a general feature of nuclei in the neutron deficient region near Z=82. Concurrently, but

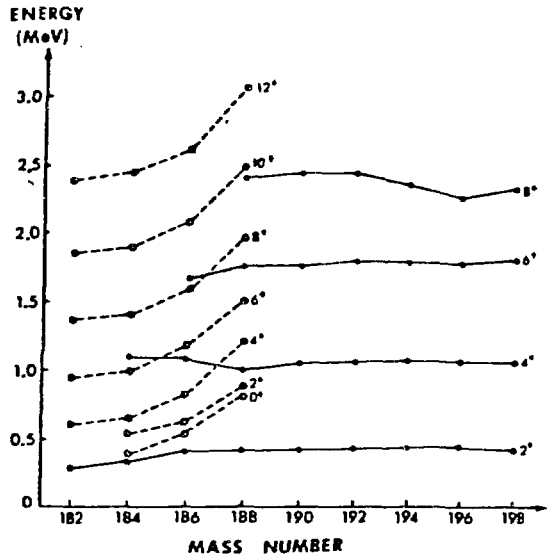

Fig. 1. The energies of the spherical and deformed states in even-even $^{182-198}$Hg. Deformed states for A > 188 have not been observed [MA 84, HAM85].

independent of these developments, coexisting bands in the odd-proton Tℓ and Au isotopes were established by radioactive decay and in-beam reaction studies [HEY83].

For the even-even nuclei in the region, one has the possibility that a pair of particles or holes can couple to quite different cores. This has been shown [DUP84] to occur even in proton magic Pb isotopes, where excited 0_2^+ deformed states are observed in $^{192-198}$Pb with a continuous drop in energy such that the 0_2^+ level become the first excited state in ^{192}Pb and ^{194}Pb. Most theoretical calculations indicate [HAM85] that the near-spherical shape is oblate and the well-deformed shape is prolate, although this is not firmly established experimentally. For odd-A nuclei in the region, it then becomes possible to form multiple shape coexisting configurations. For example, in the odd-mass Au isotopes the odd proton particle can couple to the two configurations with different deformation in the Pt cores, and the odd-proton hole to the two structures with different deformation in the Hg cores.

The energy level spacings of the 0^+-2^+-4^+ members of the shape coexisting structures observed in the even-even Pt isotopes do not provide as clear an indication of which band is the more spherical as do the corresponding levels in the even-even Hg isotopes. Evidence from

systematics indicates [WOO81] that for neutron deficient isotopes of Pt with A < 186, a deformed configuration is present in the ground state. Additionally, a staggering of rotational band parameters has been found [HAG78] for $^{176-182}$Pt, where the odd-mass Pt isotopes appear more deformed than the even-mass ones.

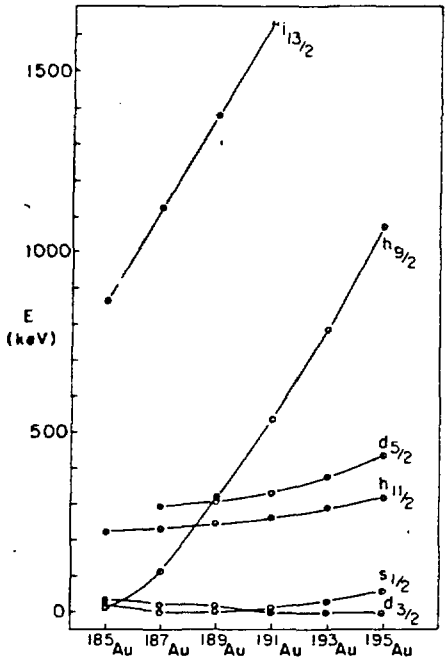

Fig. 2. Shell model states in $^{185-195}$ Au.

A consistent picture of the details presented above, based on the idea that nuclear deformation is due to the residual force between valence neutrons and valence protons, has been proposed [WOO82, HEY83]. In this picture, the excitation of nucleons into shell-model intruder states leads to the coexistence of states with different deformations. Shell-model intruder states for the odd-mass Au isotopes, for example, are presented in fig. 2. Note that the $h_{9/2}$ and $i_{13/2}$ intruders drop rapidly as one goes more neutron deficient [ZGA80]. In ^{185}Au the $5/2^-$ member of the $h_{9/2}$ intruder band actually becomes the ground state [EKS76]. The corresponding data for the odd-mass Tℓ isotopes also show the $h_{9/2}$ and $i_{13/2}$ intruders, but in that case the $h_{9/2}$ reaches a minimum near ^{189}Tℓ and then rises again as the system becomes more neutron deficient [HEY83, HAM85]. That the intruder energy should increase as one moves away from mid-shell (N ≈ 104 in this case) is consistent with the above picture [WOO82, HEY83]. Also shown in fig. 2 are the proton hole states. Note particularly the unique parity $h_{11/2}$ state. The coexistence observed in the odd-mass Au isotopes can be understood as arising from the coupling of the proton particle ($h_{9/2}$) and the proton hole ($h_{11/2}$) to the different core shapes in the even-even Pt and Hg isotopes, respectively. This is shown schematically for the Pt ⊕ $\pi h^{+1}_{9/2}$ coupling in fig. 3. These ideas were stimulated by the study [ZGA81] of the low-energy structure of ^{187}Au at UNISOR following the decay of ^{187g,m}Hg. In that case the $h_{9/2}$ particle couples to the ^{186}Pt core to form two bands with states of the same spin connected in many cases by transitions of E0+M1+... multipolarity [ZGA81].

These two bands can be interpreted (see fig. 3) as arising from the couplings $^{186}Pt\ [0_1^+\ \pi(2p\text{-}6h)] \oplus \pi h_{9/2}^{+1}$ and $^{186}Pt\ [0_2^+\ \pi(4h)] \oplus \pi h_{9/2}^{+1}$. When the odd proton is in the $h_{9/2}$ intruder orbital, the formation of the (2p-6h)

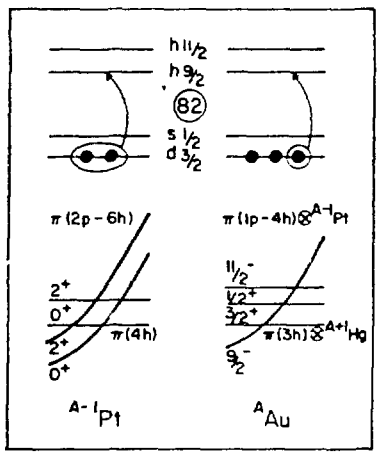

Fig. 3. A schematic view of intruder states near Z=82. The normal proton configurations for Au and Pt are $\pi(3h)$ and $\pi(4h)$ respectively. The proton intruder configurations are $\pi(1p\text{-}4h)$ and $\pi(2p\text{-}6h)$ respectively, where p=particle and h=hole.

configuration in the ^{186}Pt core is blocked due to the Pauli principle and the core configuration for ^{187}Au will then be correspondingly affected. The data indicate that it is the ground state of ^{186}Pt which is blocked and, consequently, that the ground state of ^{186}Pt consists largely of the (2p-6h) configuration resulting from the promotion of a pair of protons into the intruding $h_{9/2}$ orbital [WOO81, ZGA81].

We initiated a careful and detailed study of the $^{185g,m}Hg$ decay at UNISOR for the following reasons: To explore further the coexistence picture described above; to resolve the disagreement between our earlier data on this decay and that of the Orsay group [BOU82]; and to provide complementary information for an in-beam study [LAR85] of ^{185}Au. The decay of ^{185m}Hg (28s, $13/2^+$) and ^{185g}Hg (55s, $1/2^-$) to excited states in ^{185}Au were studied by γ-ray and conversion-electron singles, time-sequence spectroscopy and coincidence measurements. The ^{185}Hg sources were produced by the $^{176}Hf(^{16}O,7n)$ reaction using 140 MeV beams of $^{16}O^{+7}$ and were mass separated with the UNISOR on-line isotope separator. As previously observed in the study on ^{187}Au [ZGA81], this coexistence of particle and hole states, for the odd proton as well as the ^{184}Pt core, leads to a large level density and, consequently, to a very high spectral line density. It is only with data of great statistical quality coupled with an extremely careful analysis procedure (e.g. running coincidence gates, [ZGA81]) that one can obtain

reliable and consistent results. For example, an important feature of the two $h_{9/2}$ bands are the E0+M1+... transitions. Preliminary analysis of our results on ^{185}Au supports our earlier [ZGA81] interpretation of such transitions as E0+M1+E2 in ^{187}Au and contradicts the interpretation [BOU82] that these transitions in ^{185}Au have anomalous M1 components. The Orsay group [BOU82] were forced to conclude that anomalous M1 components were involved since they obtained conversion coefficients larger than M1 or E2 for a number of transitions between levels of different spin. Our coincidence data were of sufficient statistical quality that we could quantitatively distinguish unresolved doublets. In essentially all cases, we were able to account for the anomalous internal conversion [BOU82] by locating another transition of nearly the same energy which connected states of the same spin and could thus contain an E0 component.

As in the ^{187}Au study, transitions in ^{185}Au with strong E0 components were observed to feed the $h_{9/2}$ and $h_{11/2}$ bands. One example for each is presented in figs. 4 and 5, respectively. These transitions are therefore interpreted as decays out of the $h'_{9/2}$ and $h'_{11/2}$ bands to the $h_{9/2}$ and $h_{11/2}$ bands respectively. The $h'_{9/2}$ and $h'_{11/2}$ bands, of course, result from the coupling of the $h_{9/2}$ and $h_{11/2}$ single proton configurations to the excited 0^+ configurations in the ^{184}Pt and ^{186}Hg cores, respectively. These results are shown in fig. 6.

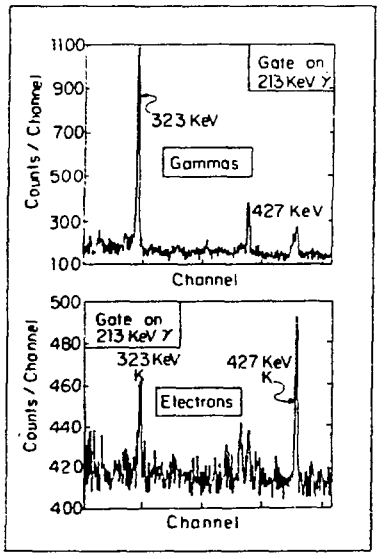

Fig. 4. Portions of the electron and γ-spectra gated on the 213 keV γ which is in cascade with both the 323 and 427 keV transitions. With E2 multipolarity for the 323, the 427 α(K) is determined to be 0.33 ± 0.03. The α(K) for M1 is 0.25.

In summary, ^{185}Au lies in a most interesting region of shape coexistence where many different shapes are observed at low energies. Recent in-beam work [LAR85] on ^{185}Au suggests that these various shapes are made up of both oblate and prolate structures which can be understood as arising from the competition between close lying K=1/2 (oblate) and K=11/2 (prolate) states for $h_{11/2}$; and K=1/2 (prolate) and K=9/2 (oblate) for $h_{9/2}$. While the results of these

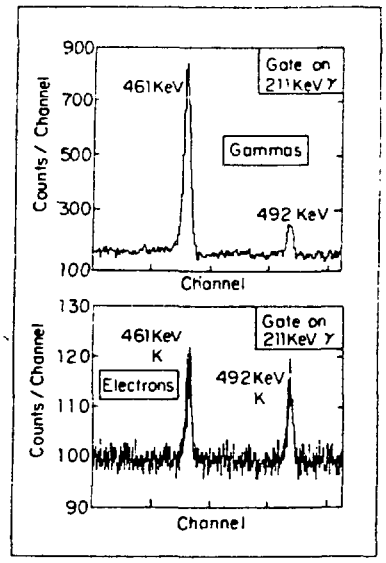

Fig. 5. Portions of the electron and γ-spectra gated on the 211 keV γ which is in cascade with both the 461 and 492 keV transitions. With E2 multipolarity for the 461, the 492 α(K) is determined to be 0.14 ± 0.02. The α(K) for M1 is 0.072.

studies are consistent with the explanation [WOOS2, HEY83] of shape coexistence based on the promotion of a pair of particles into an intruder orbital, additional experimental and theoretical work is needed to fully determine which mechanism gives rise to shape coexistence in the Z=82 region.

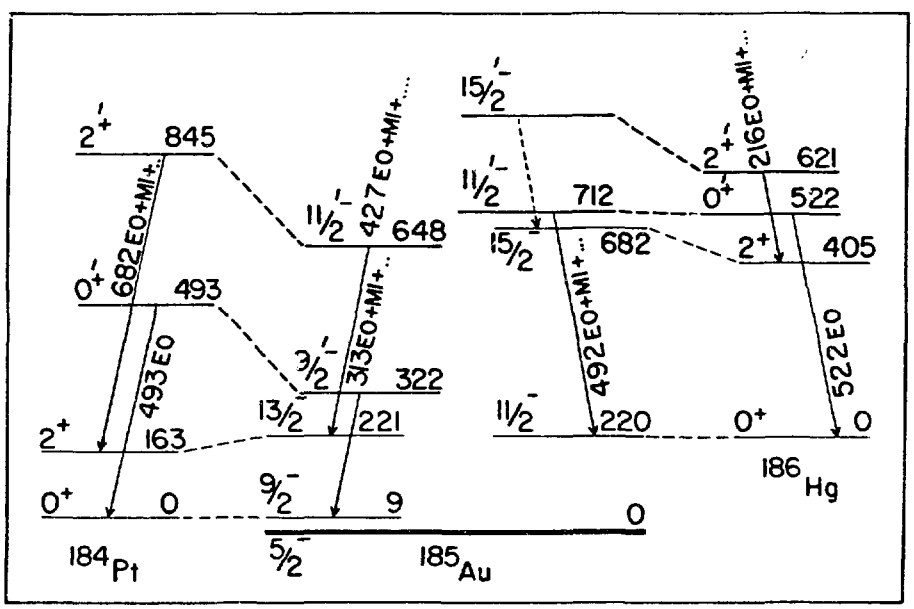

Fig. 6. Portions of the $h_{9/2}$, $h_{11/2}$, $h'_{9/2}$ and $h'_{11/2}$ bands in ^{185}Au compared to the 0^+, 2^+ and $0^{+\prime}$, $2^{+\prime}$ levels in ^{184}Pt and ^{186}Hg. The corresponding core-particle couplings are noted with dashed lines. Only transitions with E0 components are shown.

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