Behavior of the Excited Deformed Band and Search for Shape Isomerism in ^{184}Hg

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The new isotope ^{184}Tl has been identified with $T_{1/2} = 11 \pm 1$ sec and the levels in ^{184}Hg investigated from its decay. The 0^+ band head of a deformed band was found to drop to 375 keV in agreement with theoretical predictions. The mean life of the 375-keV 0^+ level was measured to be 0.9 ± 0.3 nsec which is a factor of 10 faster than theoretically predicted for a shape-isomeric $E2$ transition.

In a recent Letter,[1] we reported the coexistence and crossing of two bands of states, one built on a near spherical and one on a deformed shape in both ^{186,188}Hg. The 0^+ head of the deformed band dropped from 825 keV in ^{188}Hg to 522 keV in ^{186}Hg. Recent theoretical calculations[2-4] predict that the deformed band will continue to drop in ^{184}Hg. The large change in the radii of ^{183,185}Hg as compared to ^{187}Hg seen in optical pumping experiments[5] is presently explained by these calculations[2-4] which indicate that ^{183,185}Hg are deformed in their ground states from the coupling of the odd neutron to the even-even core. The continued drop in energy of the deformed band predicted for ^{184}Hg must occur if this explanation is correct.

Equally important, Kolb and Wong[4] have pointed out that the ground-state properties in this transitional region depend sensitively on the single-particle spectra, and this is why earlier calculations[6,7] have predicted incorrectly permanent large deformations in ^{184}Hg and ^{186}Hg. Turning it around, they[4] emphasize that these mercury nuclei provide a good probe of the single-particle spectrum in the deformed region. In their calculations, the prolate minimum lies only 350 keV above the oblate minimum and only a few keV above the first 2^+ level in ^{184}Hg. The establishment of the 0^+ and 2^+ members of the deformed band and the energies of these states in ^{184}Hg are crucial tests of the calculations and provide important insights into the single-particle spectra. Finally, Dickmann and Dietrich[2] predict that the 0^+ deformed band heads in $^{184,186}Hg$ should be shape isomers. They predict that the $E2$ decay of 0^+ deformed band heads to the first excited 2^+ states, considered to be a mixture of near spherical and deformed states, will be hindered so that these 0^+ states will be shape isomers with roughly 10–20 nsec mean lives in $^{186,184}Hg$.

To test these theoretical ideas, we have identified for the first time the new isotope ^{184}Tl and studied its decay. As predicted,[2-4] the 0^+ band head in ^{184}Hg does drop to where it is only 8 keV above the first 2^+ state. The lifetime of the 0^+ state in ^{184}Hg was measured by delayed-coincidence techniques and this state was found to be isomeric but with a much shorter mean life than predicted.[2]

The new isotope ^{184}Tl was produced by bombarding an isotopically enriched target of ^{180}W with ^{14}N ions of 177 MeV at the Oak Ridge isochronous cyclotron. Multiscale α, γ, and conversion electron singles and e-γ and γ-γ coincidences were carried out on line for the 184 mass chain at the UNISOR mass separator. The new isotope ^{184}Tl was identified from the coincidences of the known[8] yrast transitions in ^{184}Hg with annihilation radiation. There is β decay to the 8^+ yrast level but the dominant decay is to the first 2^+ level. The $8\to 6$, $6\to 4$, $4\to 2$, and $2\to 0$ transitions, α, and electron spectra all have a 11± 1 sec half-life within limits of error. Thus, either the high and low spin isomers of ^{184}Tl have similar half-lives or there is unobserved isomeric feeding between them.

Above 200 keV, the strongest line in the electron spectrum is at 292 keV, 8 keV above the K line of the first excited $2^+\to 0^+$, 367-keV transition (see Fig. 1). The e-γ coincidence data show that this transition is in coincidence with Hg x rays and annihilation radiation but not with the 367-keV transition. These data and the absence of a 375 keV γ ray establish it as $E0$. Thus a 0^+ level is established at 375 keV in good agreement with the energy predicted from fitting the energies[8] of the 10^+, 8^+, and 6^+ energies to a rotational energy formula, $E_0 + AI(I+1) + BI^2(I+1)^2$.

From the γ-γ coincidence data, a 535-keV level is established and is a 2^+ level based on the conversion coefficient of the 535-keV transition.

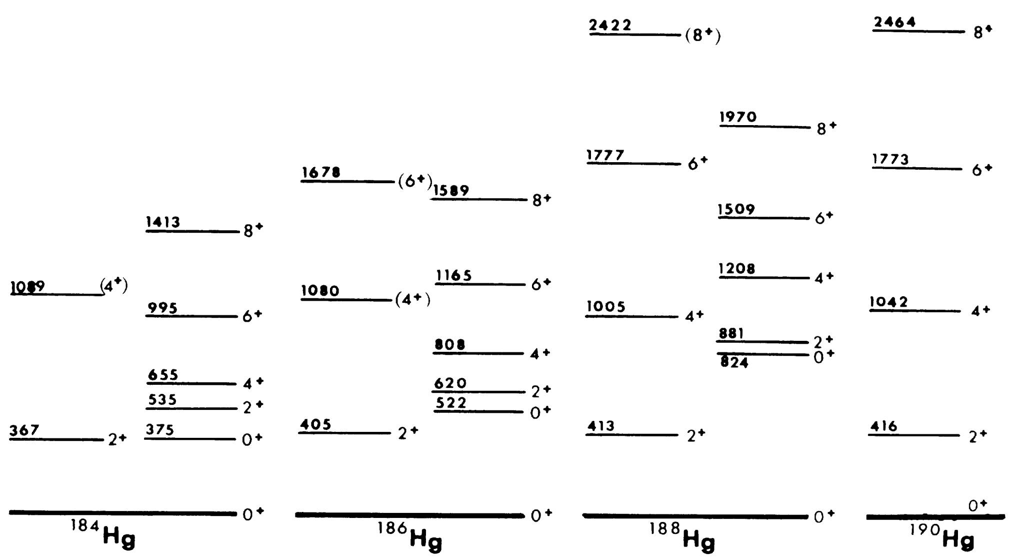

FIG. 1. Systematics of the deformed and near spherical bands in light mass Hg isotopes.

The α_K of the 168-keV $2^{+\prime} \to 2^+$ transition placed from coincidence data is greater than the theoretical $M1$ value. Thus it has a strong $E0$ contribution as found[1] for the analogous $2^{+\prime} \to 2^+$ transitions in ^{186,188}Hg. Unfortunately a possible $M1$ admixture has not been measured so the total $E0$ strength cannot be extracted. The e-γ data also suggest a weak 159-keV transition in coincidence with the K line of the 375-keV transition. These data support the 535-keV level as the 2^+ member of the deformed band. The energy extracted for the deformed 2^+ state from the rotational formula on the basis of other band members is very near the nearly constant energy of the 2^+ spherical states in $^{186-198}$Hg (Fig. 1). These two 2^+ states are strongly mixed in the theoretical calculations[2,4] so that one could be pushed up and the other down. Such mixing[2,4] explains why the 0^+ and 2^+ members of the deformed band are not seen in the in-beam work and why the transition from the deformed 4^+ yrast state to the first 2^+ state is not strongly retarded The predicted γ-ray branching of the 4^+ yrast state to the upper and lower mixed 2^+ states in the coexistence model is ~0.003 (Ref. 2) and ~0.01 (Ref. 4) based on overlap integrals which are related to the transition probability, in general agreement with our value $\lesssim$ 0 03. More interesting, the second 4^+ state is so highly mixed in the calculations of Kolb and Wong[4] that the unexpected results of nearly equal branching is predicted to the two 2^+ states. This agrees with the experimental results of equal branching within limits of error for a 1089-keV level which is presumably the more near-spherical 4^+ level. In summary, the energies of these new 0^+ and 2^+ members of the deformed band are in very good agreement with the theoretical calculations[3,4] and substantiate the predicted drop in deformed-band-head energy in ^{184}Hg. The systematic behavior of the near-spherical and deformed bands shown in Fig. 1 confirm very nicely the more recent theoretical calculations,[2-4] including the details of the energy spacings and branching ratios.[4]

Other than the yrast cascade and the 0^+, 2^+, and tentative 4^+ levels discussed above, only one other level is established by coincidence data at 983 keV. The 983-keV level decays predominantly to the 0^+ 375-keV level, with the $(2\to 0)/(2\to 2)$ γ-ray branching ratio ≈ 1.3. (An impurity line prevents a precise determination.) The 608.3-keV transition is the strongest line in the gate on the K line of the 375.2-keV transition and no such high-energy decays to the 0^+ band heads were observed in the ^{186,188}Tl decays.[1] The 983-keV level is in the energy range expected for a two-phonon-type 2^+ state. However, since it strongly decays to the excited 0^+ state, it is interesting to speculate that this could be a 2^+ β- or γ-type vibrational state built on the deformed band. Since both lower 2^+ states have strong deformed components, decays to these levels would be expected too.

Now look at the predicted shape isomerism[2] of the 0^+ band heads. Figure 2 is a plot of the delayed coincidences between the K electrons of the 375-keV $E0$ transitions and γ rays (primarily 511 annihilation radiation and 608-keV γ rays with x rays excluded). A prompt shape was obtained by gating on the K lines of the 366.7- and 286.8-keV transitions and their coincidence γ rays. The centroid of this gate agreed with the one obtained from a gate on electrons and positrons above 420 keV in coincidence with γ rays above 511 keV. The centroid-shift method yielded a mean life of 0.9± 0.3 nsec which is an order of magnitude shorter than predicted.[2] The prediction, however, was based on the $E2$ strength which is probably negligible for the 8-keV transition in ^{184}Hg. Our data show the importance of the neglected $E0$ mode in ^{184}Hg, where the deformed and near-spherical states are weakly mixed according to Kolb and Wong.[4] In any prediction of lifetimes of

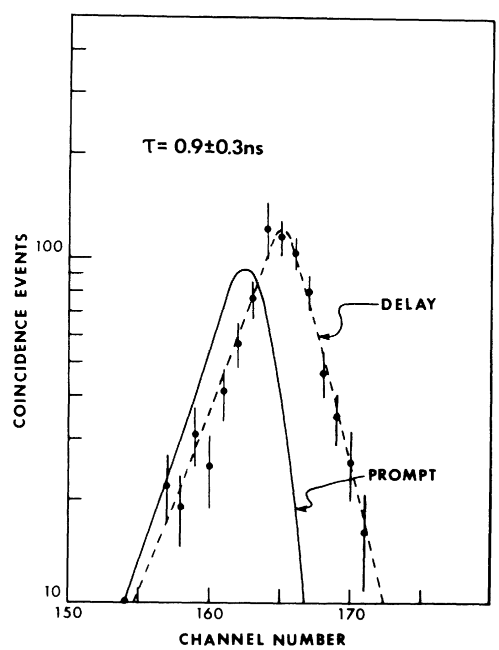

FIG. 2. Delayed coincidences of K electrons of the 375-keV $E0$ transition with γ rays. The prompt curve is also shown.

shape isomers this mode must be considered. There is still the question of hindrance of the $E0$ mode. Unfortunately, there are no accurate measurements of 0^+ state lifetimes in this region. For essentially no decay via an 8-keV transition, we extract from τ a monopole matrix element $\rho = 0.07^{+0.02}_{-0.01}$. This ρ is a factor of 5 smaller than those observed from 0^+ β-type vibrational states in deformed rare-earth nuclei. While these β-vibrational states are in a different region, the differences in ρ are suggestive that retardation has occurred as expected for a shape isomer. It is necessary to calculate the monopole strength in a coexistence model before predictions of shape isomerism really can be tested. Indeed, these 0^+ states provide sensitive tests of future calculations.

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Observation of Giant Resonances in ^{24,25,26}Mg and ^{27}Al by Inelastic α Scattering

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The $E2$ giant-resonance region in *sd*-shell nuclei was studied by inelastic scattering of 106-, 120-, 145-, and 172.5-MeV α particles. Strong excitation in this region was observed for all investigated nuclei (^{24,25,26}Mg and ^{27}Al) at the higher incident energies. At lower incident energies, the tail of the giant resonance tends to be obscured by another broad distribution. In the $E2$ giant-resonance region, there is more fine structure in the Mg isotopes than in ^{27}Al.

This Letter is written in view of very recent work[1] concerning the excitation of giant quadrupole resonances in various nuclei by inelastic α scattering at 96 and 115 MeV. The authors of Ref. 1 claim that in going from heavy nuclei to lighter ones ($A < 32$) a qualitative change occurs in the isoscalar giant quadrupole resonance (GQR). From their experiments no GQR peaks were apparent for nuclei with $A < 32$. Therefore, they conclude that for these light nuclei the $E2$ strength is no longer clustered in a single broad peak but must be fragmented among many levels over a wide energy range. Moreover, investigations of $E2$ strength distributions in light nuclei[2] with radiative capture experiments indicate a fragmented distribution of $E2$ strength which is spread out over about 15 MeV, with very little strength in the region of the expected position of the GQR ($63A^{-1/3}$ MeV). On the other hand, there are experimental indications that quadrupole strength in light nuclei is concentrated (^{12}C,[3] ^{16}O,[4,5] ^{24}Mg,[6] ^{20,22}Ne, ^{28}Si,[7] and ^{27}Al[8]), exhausting a considerable amount of the energy-weighted sum rule (EWSR).

In order to investigate in more detail the question of strength concentration in the GQR region in light *sd*-shell nuclei, inelastic scattering experiments were performed on ^{24,25,26}Mg and ^{27}Al nuclei by use of 106-, 120-, 145-, and 172.5-MeV α beams of the Jülich isochronous cyclotron JULIC. The idea was that possibly there is an energy dependence in the yield of the GQR in (α, α') experiments which may explain part of the controversial results mentioned above. Great efforts were made to optimize the beam properties and to avoid slit scattering.[9] The targets were self-supporting foils of highly enriched ^{24}Mg, ^{25}Mg, and ^{26}Mg and a foil of natural ^{27}Al.