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Rapid Communications

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Observation of parity doublets in ^{219}Ac

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The level structure of ^{219}Ac up to a spin of $J=\frac{31}{2}$ and $E_x=2.2$ MeV has been studied via the ^{209}Bi(^{13}C,3nγ) reaction. The dominant γ-ray deexcitation sequence consists of two parallel cascades, each containing alternating positive and negative parity states. In addition, there is a sideband probably built on the $\pi i_{13/2}$ single particle state. The most striking feature of this level scheme is the appearance of parity doublets similar to those seen in the heavier actinides.

The actinide nuclei with $A\sim 220$ have been of special interest recently, following the identification of parity doublets[1,2] with enhanced $E1$ transitions in ^{229}Pa and ^{225}Ac, and the observation of yrast bands in even-even nuclei characterized by spin states of alternating parity connected by enhanced $E1$ transitions[3-5] in ^{218}Ra and ^{220,222}Th. That this region is also characterized by relatively small α-hindrance factors to excited states and large ground state α-decay probabilities[6] led to the development, by Iachello and coworkers, of a molecular alpha-particle cluster or Vibron model[7] to describe the observed structure of light actinide nuclei. There has also been reported the application of a quadrupole-octupole deformed model[8-10] to these same nuclei; this has been particularly successful[9] in the description of the single particle properties of $A\sim 225$ odd mass nuclei. We present in this Rapid Communication the first study of the levels of ^{219}Ac, the odd-Z isotone of ^{218}Ra and ^{220}Th. The hope was to provide spectroscopic information on an odd-A, relatively spherical, nucleus in this mass region and, therefore, to provide a further test for the competing theoretical descriptions.

The nucleus was populated via the ^{209}Bi(^{13}C,3n) reaction and studied using standard γ-ray spectroscopic techniques and ^{13}C beams from the MP Tandem Van de Graaff Accelerator in this laboratory. The energies were in the range of 61–73 MeV. The ^{209}Bi targets used ranged in areal density from 0.2 to 24 mg/cm^2. The experiments included in this study are γ-ray and α-particle excitation function, α-γ coincidence, γ-γ coincidence, and γ-ray angular distribution measurements. The optimum beam energy for the 3n channel was determined to be 67 MeV from observation of the yield of the 8.67 MeV α-decay line from the ^{219}Ac ground state and of the competition from the 4n ^{218}Ac reaction channel observed in the 70 MeV data. The initial identification of transitions arising from ^{219}Ac was made through α-γ-coincidence measurements, gating on the ^{219}Ac α-decay peak. Our experimental details are described in Ref. 11.

After the identification based on the angular distribution measurements of several stretched dipole transitions, a three Ge crystal Compton polarimeter was used in an attempt to establish the electric or magnetic character of these transitions. Unfortunately, these transitions were too low in energy (< 250 keV) and too low in intensity for significantly nonzero asymmetries to be observed. Because of this inability to determine unambiguously the multipolarity of the interband transitions, we have been forced to rely on total intensity arguments in order to assign the character of transitions and, hence, to make parity assignments to levels. Because of the large difference in the magnitude of the internal conversion coefficients[12] for $M1$ and $E1$ transitions for $Z=89$ (e.g., for a 133-keV $M1$ transition, $\alpha_K\sim 7$, while for a 133-keV $E1$ transition, $\alpha_K\sim 0.2$), the stretched dipole transitions must be electric in character for their total intensity to be less than that of the first excited to ground state transition.

The level scheme of ^{219}Ac as deduced from our data is presented in Fig. 1 and has several interesting features. (For the subsequent discussion, we shall assume definite parity assignments for the levels in this figure, although we emphasize that both our spin and parity assignments are based on internal consistency arguments and cannot be considered as absolute.) Starting with the $\frac{9}{2}^-$ ground state, the level scheme separates into two distinct structures with alternating negative and positive parity states. The highest spin measured in each structure is $\frac{31}{2}\hbar$. The level scheme also contains a great many parity doublets. The first doublet consists of the $\frac{17}{2}^-$, $\frac{17}{2}^{(+)}$ levels at 714 and 867 keV, respectively. The doublets continue up to the $\frac{31}{2}^{(+)}$, $\frac{31}{2}^{(-)}$ levels at 2149 and 2245 keV, respectively. In addition to these two structures, there appears to be a sideband, the structure of which appears to be different from that observed in the two main sequences, and which may consist of a rotational band built on the $\pi i_{13/2}$ particle state. Because of the low intensity of the 535- and 668-keV transitions, we cannot make spin assignments for the levels at 1461 and

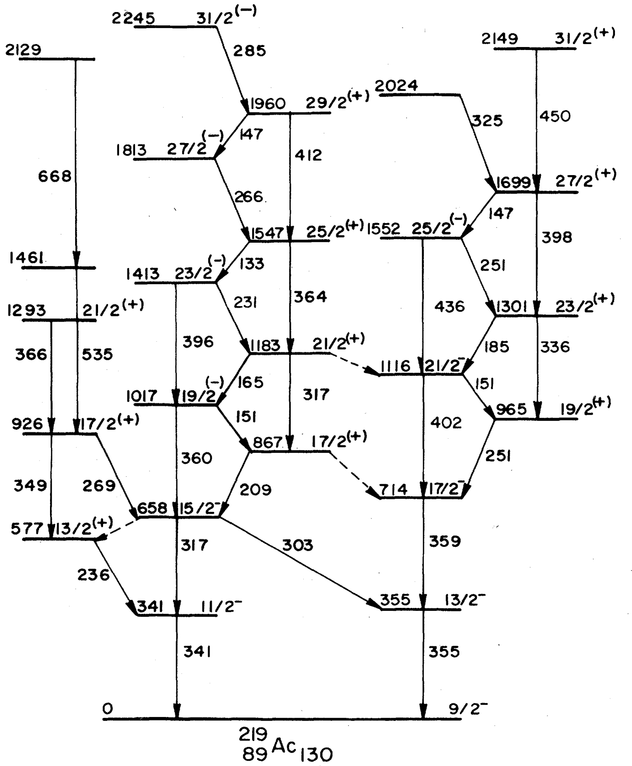

FIG. 1. The level spectrum of ^{219}Ac obtained from the $^{209}Bi(^{13}C,3n\gamma)$ reaction.

2129 keV and, therefore, cannot test this hypothesis further.

The level spectrum responsible for the dominant cascades in ^{219}Ac is compared in Fig. 2 with those of the $N=130$ isotones[3,4] ^{218}Ra and ^{220}Th. The structure of ^{219}Ac appears to correspond to a coupling of an $h_{9/2}$ proton to the even-even

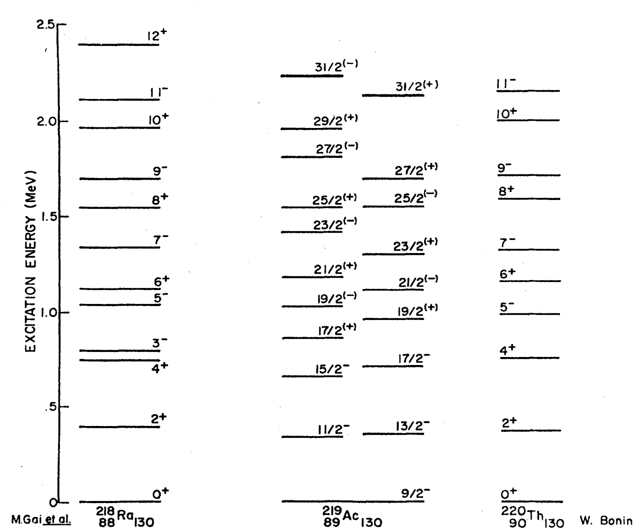

FIG. 2. A comparison of the systematics of the $N=130$ isotones ^{218}Ra (Ref. 3), ^{219}Ac, and ^{220}Th (Ref. 4).

core shapes. The similarities between the three level spectra extend to the corresponding reduced transition probabilities. The $B_W(E1)/B_W(E2)$ ratios for several states in ^{219}Ac range from $6.5\pm1.5\times10^{-5}$ to $1.1\pm0.2\times10^{-4}$, compared with the $B_W(E1)/B_W(E2)$ ratios published[3] for ^{218}Ra which range from 3.7×10^{-5} to 1.2×10^{-4}. Given $B(E2)$ values in the even core[3] ~ 40 W.u., the $B(E1)$ values are thus $\sim 10^{-2}$ W.u., corresponding to a large $E1$ enhancement.

As mentioned in the beginning of this paper, parity doublets have been observed previously in the heavier actinides. Observation of such parity doublets is predicted by the stable octupole deformation model[9] and is, in fact, a necessary condition, but not sufficient, for stable octupole deformation. The systematics of the parity doublet energies in ^{219}Ac can be elucidated further by reclassifying the states in terms of the "simplex" quantum number suggested[13] by Nazarewicz *et al.* Using this quantum number, the sequence starting with the $\frac{13}{2}^-$ level has $s=-i$, while that starting with the $\frac{11}{2}^-$ state has $s=i$.

Labeling the states by the simplex and parity (s,π), in the doublets with $(i,-)$ and $(-i,+)$ the negative parity states are all higher in energy, and the doublet energy splitting ranges from 52 to 114 keV. The situation is different for the $(i,+)$ and $(-i,-)$ doublets where the positive parity members initially are higher in energy, with a splitting of 153 keV for the $\frac{17}{2}$ doublet. Moving up the sequences,

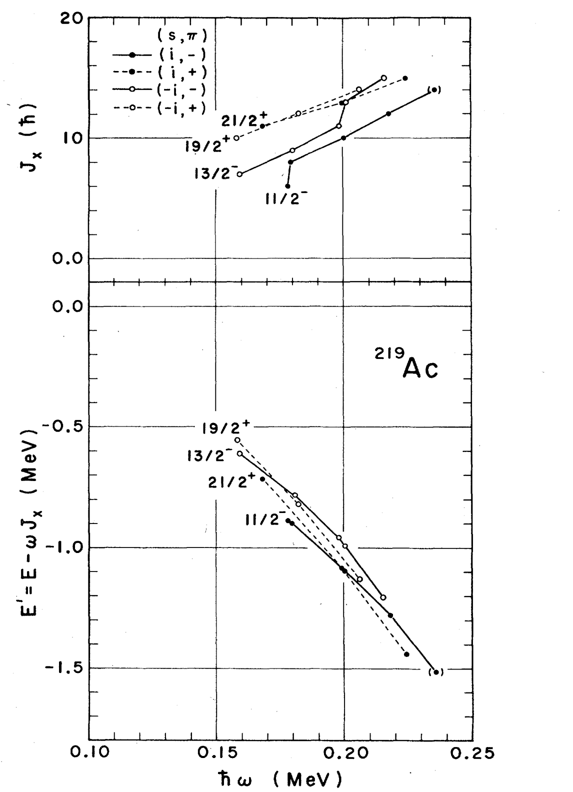

FIG. 3. The levels in ^{219}Ac are plotted in terms of (a) the projections J_x of the angular momentum along the x axis as a function of frequency, and (b) in terms of the quasiparticle energies in the rotating frame as a function of frequency (with no reference taken into account). The levels are labeled in terms of the simplex and parity, (s,π), quantum numbers.

the splitting decreases to 5 keV for the $\frac{25}{2}$ doublets and may even change sign should the spin and parity of the 2024 keV level be $\frac{29}{2}^-$.

Another way to examine the change in structure as a function of angular momentum is shown in Fig. 3 where the angular momentum along the rotation axis, J_x, and the quasiparticle energies in the rotating frame, E', are plotted as functions of rotational frequency $\hbar\omega$, for the different (s, π) bands. The quantities J_x and E' were extracted in the usual manner;[14] because the yrast levels do not follow a rotational pattern, but are indicative of a quasiparticle decoupled from the deformation, a value of $K=0$ was chosen. No reference configuration was subtracted because of the ambiguities[5] found in extracting it in ^{222}Th, which is even more deformed than ^{218}Ra or ^{220}Th, the cores in the present case.

There is considerable simplex splitting observed for both the negative and positive parity bands, with the $s=i$ configuration occurring lower in energy than the $s=-i$. For the negative parity sequences, this splitting changes from ~ 120 keV at $\hbar\omega=0.18$ MeV to ~ 50 keV at $\hbar\omega=0.215$ MeV, while for the positive parity ones the splitting is constant at ~ 60 keV. This pattern of simplex splitting is insensitive to our choice of $K=0$ used in determining J_x. To reproduce the magnitude of the simplex splitting and the differences in this splitting as a function of rotational frequency for the positive and negative parity sequences will provide another sensitive test for theoretical models.

In summary, ^{219}Ac, a nucleus far from the line of stability, shows structure which is neither shell model like nor prolate rotational. The structure appears to be related to the structure of its $N=130$ isotones,[3,4] ^{218}Ra and ^{220}Th, which have been described in terms of the α-clustering model.[7] There are also parity doublets similar to those seen in the heavier actinide nuclei for which the stable octupole model[9,10] has been applied. That the dominant structure of ^{219}Ac is a weak coupling of an $h_{9/2}$ proton to the even-even cores supports a collective description of the $N=130$ nuclei although it is not clear which model would provide the best description of the structure of ^{219}Ac. Any further attempt at interpretation will have to wait for the extension of the vibron model to odd-A nuclei and the extension of the quadrupole-octupole model to more spherical nuclei.

Note added. A similar level scheme for ^{219}Ac was obtained in a concurrent study.[15]

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