OCTUPOLE DEFORMATION IN THE ODD-ODD NUCLEUS ^{224}Ac

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In recent years, it has been shown that many nuclei around thorium have large octupole-octupole correlations. These correlations give rise to low-lying (below 300 keV) $K^{\pi}=0^{-}$ rotational bands with spin sequence 1, 3, 5 ... in even-even nuclei. These bands, known as "octupole bands", have large B(E3) values (~30 single particle units) for transitions to the ground bands. The fact that the 1^{-} level does not lie below the 2^{+} rotational level indicates that the even-even nuclei do not have octupole deformation. The $K^{\pi}=0^{-}$ bands are interpreted as octupole vibrations. The addition of an unpaired nucleon to the system (i.e., odd mass nuclei) increases the octupole correlations, and several theoretical calculations[1,2] predict that some odd-mass Ra, Ac, Th, Pa nuclei develop stable octupole (pear like) shapes. Experimental data on ^{223}Ac, ^{225}Ac, ^{229}Pa, ^{223}Ra and ^{225}Ra are consistent with calculations that use octupole deformation $\beta_3=0.1$, but not with calculations with $\beta_3=0$. The most pronounced effects occur in ^{223}Ac and ^{225}Ac,[3,4] where several matrix elements have been deduced which support the occurrence of an octupole shape.

Since the presence of one unpaired nucleon increases the octupole correlations over that observed in the even-even core, it has been anticipated that the presence of two unpaired nucleons (i.e., odd-odd nuclei) will make the nucleus more octupole stable. Study of the structure of the odd-odd nuclei is difficult because of the high level density near the ground state. The situation is worse for a nucleus with octupole deformation where one expects roughly twice as many levels as for a nucleus with a reflection symmetric shape. For this reason, the structure of octupole deformed odd-odd nuclei near ground have not been studied. We have now initiated a study of levels in ^{224}Ac, which is expected to have large octupole deformation, by measuring radiations associated with the alpha decay of ^{228}Pa.

The isotope ^{228}Pa, which has a half-life of 22 h and decays by alpha particle emission with ~2% branching, was produced by irradiating a 1 cm × 1 cm × 0.012 cm thorium metal foil with 45-MeV protons at the Indiana University Cyclotron. The beam current was ~ 300 nA, and the irradiation time ranged from 12 to 24 h. After a 6 h cooling period, the irradiated Th foil was transported to Argonne, where chemical separation of Pa was carried out. The Th was first dissolved in acid and the Pa fraction was isolated by using three ion-exchange resin columns. The purified sample was used to prepare thin sources on quartz discs with tetraethylene glycol as a spreading agent. Four separate irradiations were performed from July 1990 to March 1991.

^{228}Pa decays predominantly (98%) by electron capture and the only way to observe radiations associated with alpha decay is to measure them in coincidence with alpha particles. Since the expected gamma-ray energies in the alpha decay range from ~5 keV to ~400 keV, three different types of detectors sensitive to different energy ranges were used. These detectors were a Si(Li), a 21 cm^2 × 1 cm planar Ge (LEPS), and a 25% coaxial Ge. The measurements involved Alpha-LEPS, Alpha-Ge, and Alpha-LEPS-Ge coincidences. The alpha singles spectrum measured with a 1 cm^2 ion-implanted passivated Si detector is shown in Fig. 1. The resolution (FWHM) of alpha peaks in the spectrum is ~14 keV. In addition to ^{228}Pa, the sample also contains ^{229}Pa and ^{230}Pa produced in the irradiation, and their decay products. The energies of alpha groups in the figure are in excellent agreement with the more precise values measured by Hill[5,6] with a magnetic spectrograph.

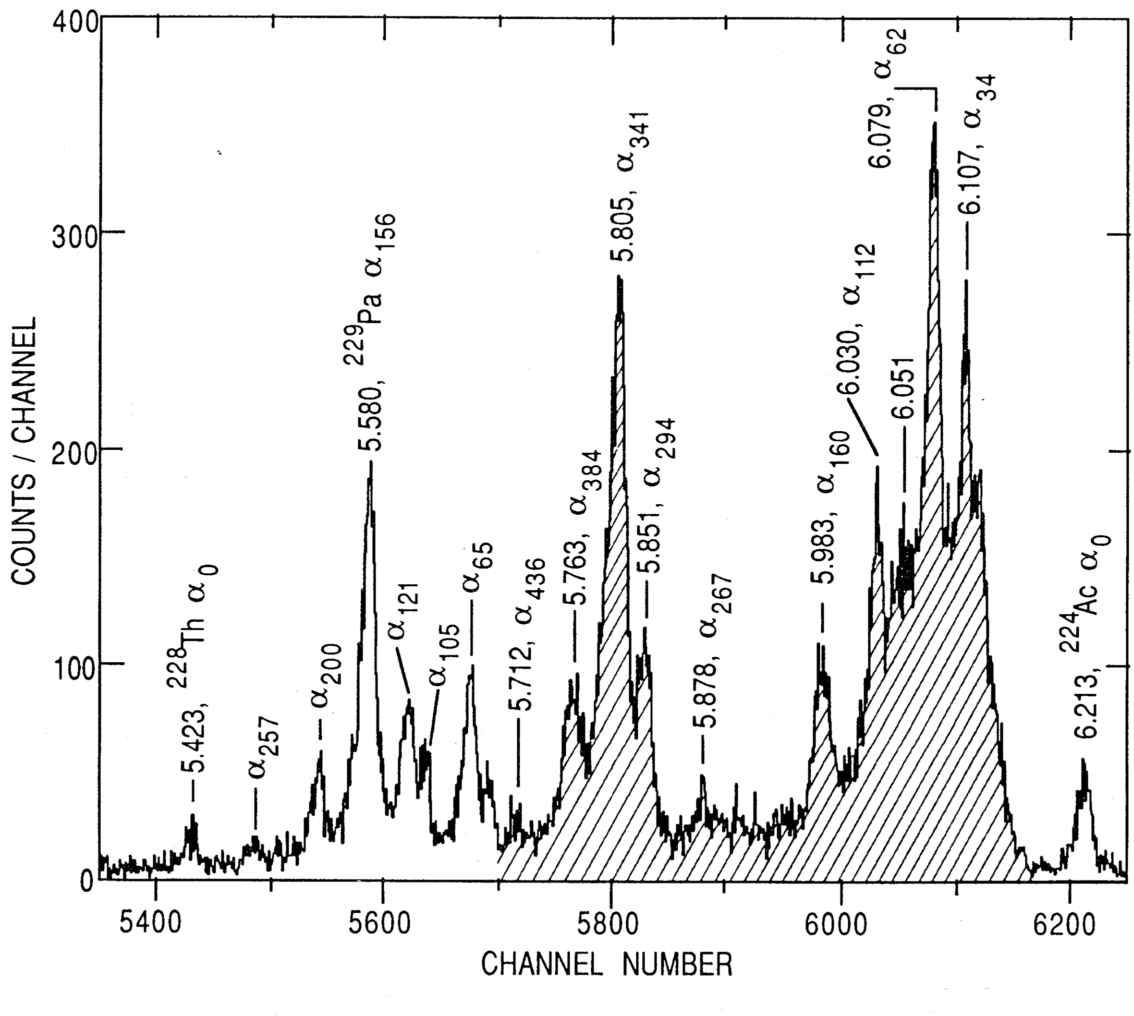

Figure 1. Alpha spectrum of a ^{228}Pa sample measured with a 1 cm^2 ion-implanted passivated Si detector. The counting time was 30 min with a detector detector solid angle of ~3%. The energy scale is ~1.0 keV per channel. The shaded region shows α groups from ^{228}Pa decay. The numbers near the peaks denote their energies in MeV. The Th K X-rays are due to chance coincidences.

The gamma-ray spectrum measured with the LEPS detector and in coincidence with ^{228}Pa alpha particles is shown in Fig. 2. In the alpha-Ge coincidence, strong gamma rays with energies 230.0, 308.1, and 316.9, and 330.3 keV were observed in coincidence with the 5.805-MeV alpha group. All gamma rays reported here have been observed for the first time.

Since the energies of the ^{228}Pa alpha groups overlap with the energies of alpha groups associated with the decay of the daughter ^{224}Ac (2.9 h), it is important to measure the spectra of ^{228}Pa and ^{224}Ac separately. For this reason, a sample from which Pa was chemically removed was prepared, and the spectra of this sample were measured. From a comparison of these spectra and those of the Pa source, we were able to identify ^{228}Pa transitions.

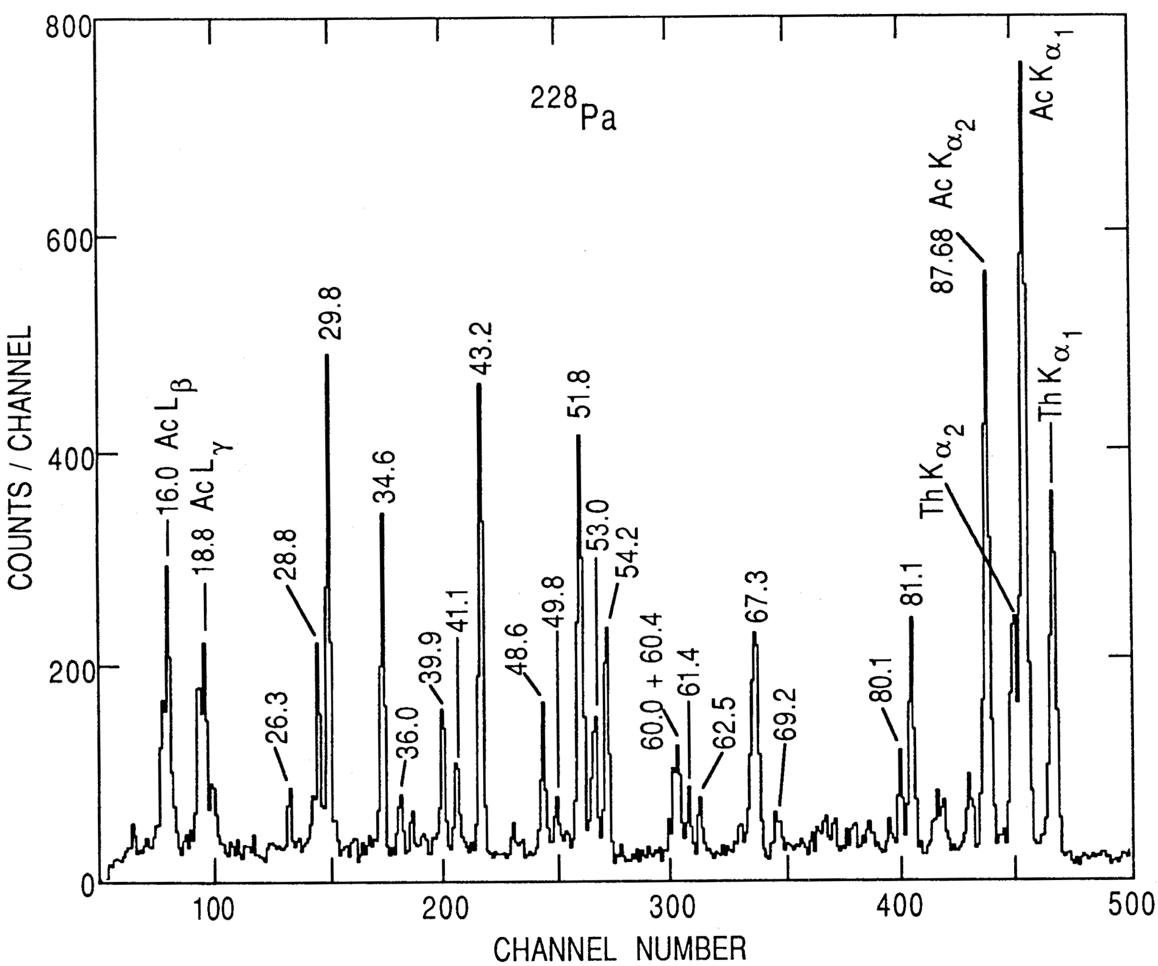

Figure 2. Gamma-ray spectrum of a ^{228}Pa source measured with a 2 cm^2 $\times$ 1 cm LEPS detector in coincidence with ^{228}Pa alpha particles (5.7-6.2 MeV). The numbers near the peaks denote their energies in keV. The energy scale is $\sim$0.20 keV per channel.

A conversion electron spectrum of a Pa source was measured in coincidence with alpha particles using a room temperature silicon PIN diode.[7] The resolution [FWHM] of the electron peaks was 3.0 keV. The K conversion lines of the 230.0, 308.1, 316.9, and 330.9 keV transitions were observed and their intensities indicate that all of them have M1 multipolarity.

From these measurements, a partial level scheme for ^{224}Ac involving 20 levels has been constructed. The level scheme is complex and spin-parity assignments have not been made to all levels. One more irradiation is scheduled in July to measure very low energy (5-30 keV) gamma rays. However, the data do suggest a large octupole deformation for ^{224}Ac. We have measured the decay pattern of the 337 and 343 keV levels which deexcite to different levels near ground suggesting that they have opposite parities. These states have large alpha intensities (low hindrance factors) indicating that the wave functions of the two states are similar. Thus, the small energy difference and almost equal alpha decay rates provide evidence of large octupole deformation in the nucleus ^{224}Ac. We anticipate that the detailed analysis of the data and the experiment in July will enable us to make assignments to most of the levels in ^{224}Ac and deduce the extent of octupole correlations in this nucleus.

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1. R. R. Chasman, Phys. Lett. **96B**, 7 (1980).
2. G. A. Leander and R. K. Sheline, Nucl. Phys. **A413**, 375 (1984).
3. I. Ahmad, R. R. Chasman, J. E. Gindler, and A. M. Friedman, Phys. Rev. Lett. **52**, 503 (1984).
4. I. Ahmad, R. Holzmann, R. V. F. Janssens, P. Dendooven, M. Huyse, G. Reusen, J. Wauters, P. Van Duppen, Nucl. Phys. **A505**, 257 (1989).
5. M. W. Hill, University of California Report UCRL-8423 (1958) unpublished.
6. C. M. Lederer and V. S. Shirley, "Table of Isotopes" (John Wiley, New York, 1978).
7. I. Ahmad, R. R. Betts, T. Happ, D. J. Henderson, F. L. H. Wolfs, and A. H. Wuosmaa, Nucl. Instr. and Meth. **A229**, 201 (1990).