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Comment on the question of reflection asymmetry in ^{229}Pa

Raymond K. Sheline
Chemistry and Physics Departments, Florida State University Tallahassee, Florida 32306
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The alpha decay hindrance factors from the ^{229}Pa $5/2^+$ ground state to the $5/2^{\pm}$ parity doublet bands in ^{225}Ac suggest strong reflection asymmetry in ^{229}Pa and the expectation that a $5/2^{\pm}$ parity doublet will be found in this nucleus.

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In 1980 Chasman [1] predicted reflection asymmetry in the ground state of ^{229}Pa characterized by a $5/2^{\pm}$ parity doublet (PD) ground state. Two years later Ahmad *et al.* [2] presented evidence for this $5/2^{\pm}$ PD in which the $5/2^-$ member of the doublet was observed just 0.22 ± 0.05 keV above the $5/2^+$ ground state. This nearly degenerate PD, together with the very fast $E1$ between the $5/2^-$ and $5/2^+$ states [2] had been the experimental basis for assuming that the ^{229}Pa ground state was reflection asymmetric. Recently, however, Grafen *et al.* [3], noting that ^{229}Pa lies on the border of the accepted region of reflection asymmetry, undertook ^{230}Th$(p,2n)^{229}$Pa and ^{231}Pa$(p,t)^{229}$Pa studies of the level structure of ^{229}Pa. The results of the studies were not consistent with the level structure of ^{229}Pa observed by Ahmad *et al.* [2] and in particular with the $5/2^+$-$5/2^-$ ground state PD. As a result Grafen *et al.* [3] suggest that the octupole correlations in ^{229}Pa might be less important than previously believed.

In this paper I wish to present evidence based on the alpha decay of ^{229}Pa which suggests that reflection asymmetry is indeed important in the ^{229}Pa ground state.

The crucial factor is that, in alpha decay of highly reflection asymmetric nuclei, the parity mixed reflection asymmetric orbital describing the ground state of the parent will overlap equally with both parity doublet bands arising from the same parity mixed orbital in the daughter nucleus. Consider for example the ground state of the odd-A parent nucleus arising from the parity mixed reflection asymmetric orbital, Ω $(\langle\hat{s}\rangle, \langle\hat{\pi}\rangle)$ [4]. The ground state will of course have definite parity, either Ω^+ or Ω^-. When it alpha decays to the parity doublet bands with Ω^+ and Ω^-, the allowed unhindered alpha transitions to both bands will have the same low hindrance factors (HFs) in the limiting case when the barrier between the mirror minima in the octupole potential function is very high. In practice the HFs between states of the same parity are somewhat smaller. However, the ratio between the HFs connecting states of opposite parity to those with the same parity is clearly related to the ratio of the overlaps. As this ratio approaches 1 we approach the limiting case of rigid reflection asymmetry.

In Fig. 1 the ratios of HFs for three daughter odd-A isotopic chains of nuclei (Fr, Ra, and Ac) are presented. The data are from Ref. [5]. The HF ratios for the Fr, Ra and Ac daughters are connected by long dashed, short dashed, and solid lines, respectively. It is immediately obvious that the HF ratios approach a limiting value of 2.5 to 4.2 from 136 neutrons down to 132 neutrons. The only exception is ^{221}Ra. This exception however may

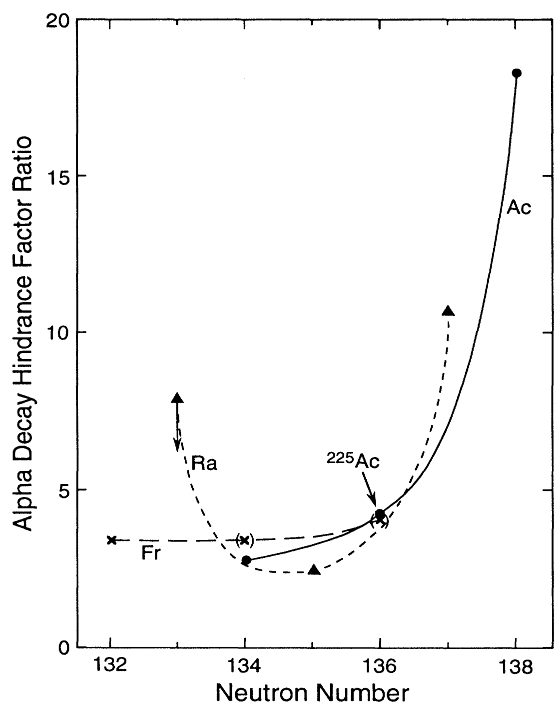

FIG. 1. The ratio of the alpha decay transition probability between states of the same parity to those of opposite parity in odd-A nuclei is plotted against neutron number. Ratios for odd-A Fr nuclei are shown as $\times$'s connected by long dashed lines; odd-A Ra, as triangles connected by short dashed lines; and odd-A Ac, as dots connected by solid lines. Since all alpha transitions in this figure are between states with the same parity mixed orbitals, all alpha transitions are of the most favored type. All references in the plot are to daughter nuclei. Thus the point corresponding to ^{225}Ac represents the alpha decay hindrance factor ratio for ^{229}Pa$(5/2^+$ g.s.$)$ $\overset{\alpha}{\to}$ ^{225}Ac$(5/2^+)/^{229}$Pa$(5/2^+$ g.s.$)$ $\overset{\alpha}{\to}$ ^{225}Ac$(5/2^-)$. The ratio for ^{221}Ra is anomalous (see text). Where there is uncertainty in the spin-parity assignments in ^{221}Fr and ^{223}Fr, the points are given in parentheses.

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be understood. The experimentally observed anomalous structure of the $\Omega = 3/2^{\pm}$ PD bands in ^{221}Ra clearly implies [6] extensive mixing with the near-lying $\Omega = 1/2^{\pm}$ PD bands. This dilution in the purity of these bands should cause an anomaly in the HF ratio. This is emphasized by the arrow on the point for ^{221}Ra in Fig. 1. However, above 136 neutrons the HF ratios increase dramatically, implying decreasing reflection asymmetry in either the parent or the daughter or both.

Now consider ^{225}Ac specifically noted in Fig. 1. The HF ratio is 4.2 which implies that the alpha decay of the $5/2^{+}$ g.s. of ^{229}Pa is 4.2 times more allowed to the $5/2^{+}$ bandhead than to the $5/2^{-}$ bandhead in ^{225}Ac. Note that both bands result from the 5/2(0.2,0.4) orbital. Significantly, this ratio (4.2) is in the group of the lowest HF ratios in Fig. 1, and implies that reflection asymmetry is important in *both* ^{229}Pa and ^{225}Ac.

The experiments of Grafen *et al.* [3] show that the nearly degenerate $\Omega = 5/2^{\pm}$ PD bands in ^{229}Pa proposed by Ahmad *et al.* [2] are in error. However, the alpha decay hindrance ratios between the ^{229}Pa ground state and the $\Omega = 5/2^{\pm}$ bandheads in ^{225}Ac strongly suggest that we should yet expect to find $\Omega = 5/2^{\pm}$ PD bands in a more complete level structure of ^{229}Pa. However, the $K^{\pi} = 5/2^{-}$ band will undoubtedly lie higher than suggested by Ahmed *et al.* [2]. Thus the answer to the question raised in the title of Ref. [3] "Does a $5/2^{-}$-$5/2^{+}$ ground state parity doublet exist in ^{229}Pa?" is most probably "yes."

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