Spin of the ^{219}Ra ground state

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(Received 20 April 1989)

The ^{208}Pb(^{18}O,3n)^{223}Th reaction at 83 MeV bombarding energy was used to populate the alpha-radioactive nucleus ^{223}Th. Out-of-beam alpha-gamma coincidences were recorded at correlation angles of 90° and 180°. The a_2 angular correlation coefficient was extracted for an alpha-gamma cascade to the ^{215}Rn ground state via the 0.316 MeV excited state. This limited the assignment of the ground-state spin of ^{219}Ra to $(\frac{7}{2},\frac{11}{2})^+$.

I. INTRODUCTION

Interest has grown recently in stable octupole-quadrupole deformation in the $A=218-230$ region. A recent paper by Sheline[1] attempts to define the boundaries of octupole-deformed nuclei by comparing measured ground-state state spins and parities to those predicted by various theories. In particular, ^{219}Ra lies close to the predicted boundary but no firm assignment of spin and parity has been made to its ground state.

A recent study by El-Lawindy *et al.*[2] used an 83 MeV pulsed oxygen beam to produce thorium via the ^{208}Pb(^{18}O,3n)^{223}Th reaction. The thorium α decays through the chain $^{223}\text{Th}\rightarrow{}^{219}\text{Ra}\rightarrow{}^{215}\text{Rn}\rightarrow{}^{211}\text{Po}\rightarrow{}^{207}\text{Pb}$. Beam pulsing made it possible to collect α-γ coincidences during the 0.75 s beam-off periods without the background of direct products. Their data revealed many excited states which were populated by the various α decays. In particular the α decay of the ^{219}Ra ground state with a half-life of 10 ms populates a 0.316 MeV excited state of ^{215}Rn which decays through an $M1$ γ transition to the $J^\pi=\frac{9}{2}^+$ ^{215}Rn ground state. The γ-ray multipolarity was assigned on the strength of conversion electron measurements. This limits the possible spins of the 0.316 MeV state to $(\frac{7}{2},\frac{9}{2},\frac{11}{2})^+$. One can extend the corresponding assignment to the ^{219}Ra ground state since an unhindered α decay (hindrance factor$=3.4\pm0.5$)[2] connects the two. El-Lawindy *et al.*[2] favored $J^\pi=\frac{7}{2}^+$ for both of these states.

This paper reports a measurement of the α-γ angular correlation of the cascade, in an attempt to obtain a firm spin assignment. Provided the α decay is not dominated by the S-wave component the value of the a_2 angular correlation coefficient is quite sensitive to the specific spin change $\Delta J=+1, 0, -1$, involved in the γ transition.

II. EXPERIMENTAL PROCEDURE

An 83 MeV ^{18}O beam from the McMaster University tandem accelerator was pulsed at 1 ms intervals on a 1.3 mg/cm^2 self-supporting foil of 97.8% enriched ^{208}Pb. The 316 keV γ ray of interest was easily identified following the work of El-Lawindy *et al.*[2]

Two silicon surface-barrier detectors and a 26% Ortec model GMX germanium detector were positioned as in Fig. 1. This configuration allowed us to collect coincident gamma rays at both 90° and 180° to the detected alpha particles. The dominant $M1$ nature of the γ-ray transition necessitated measurements for only two angles in order to determine the a_2 coefficient in the angular distribution. The γ detector was subsequently moved to position B of Fig. 1 and more coincidences collected with the roles of the α detectors reversed. In this way detector efficiencies canceled when the $W(180°)/W(90°)$ ratios for positions A and B were combined.

A standard fast-slow coincidence circuit selected events within a 400 ns coincidence window. All α-γ

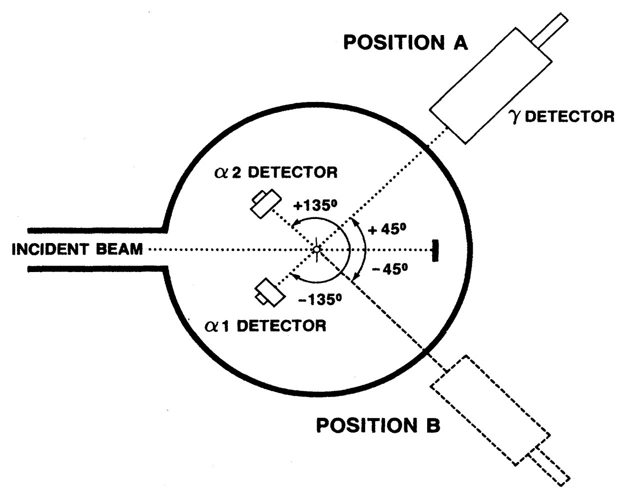

FIG. 1. The target chamber and detector layout. In position A the α-γ coincidence yield $W(180°)$ is measured by the $\alpha1$ detector while $W(90°)$ is measured by the $\alpha2$ detector. Moving the γ detector to position B reverses the angles and allows us to eliminate detector efficiencies and geometrical factors when computing the ratio $R=W(180°)/W(90°)$.

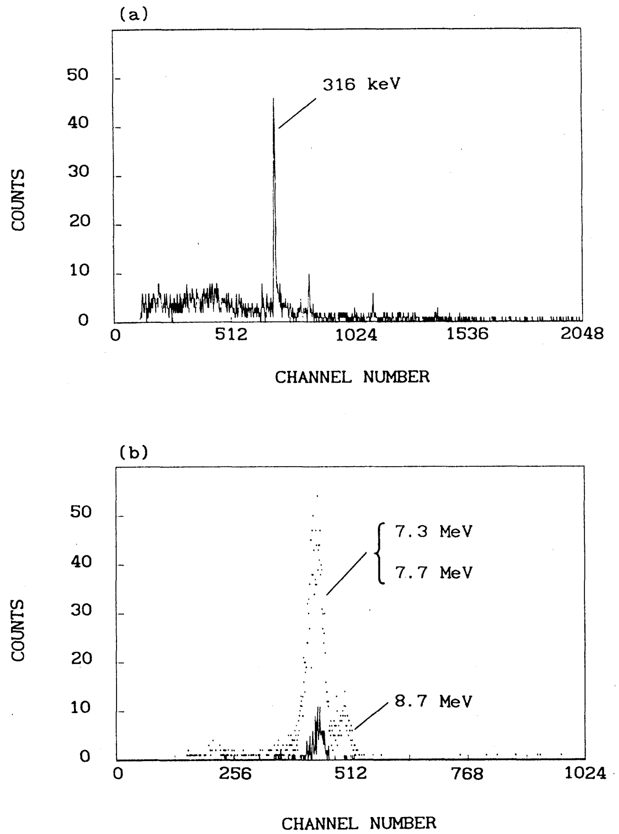

FIG. 2. (a) shows a gamma spectrum detected in coincidence with α particles in the decay of ^{223}Th. (b) shows a spectrum of α particles coincident with γ rays of any energy (dotted line) and coincident with the 316 keV γ ray (solid line).

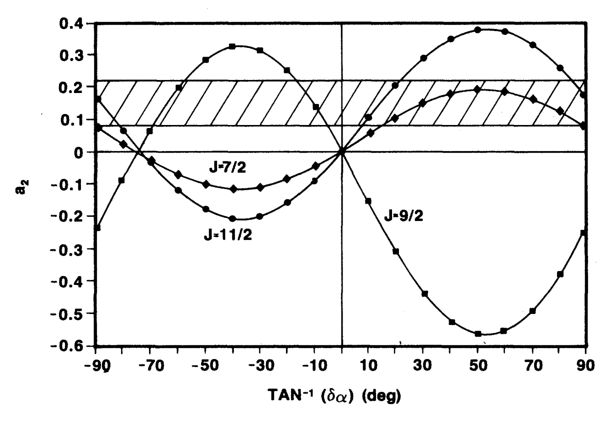

FIG. 3. The experimental result $a_2=0.15\pm0.07$ (dashed box), assuming a pure $M1$ transition, is compared with theoretical predictions. The theoretical values of the a_2 coefficient are plotted as a function of δ_α with $\delta_\gamma=0$ for the three possible spins ($\frac{7}{2}$, $\frac{9}{2}$, $\frac{11}{2}$) of the intermediate state. Only positive values of δ_α have physical significance.

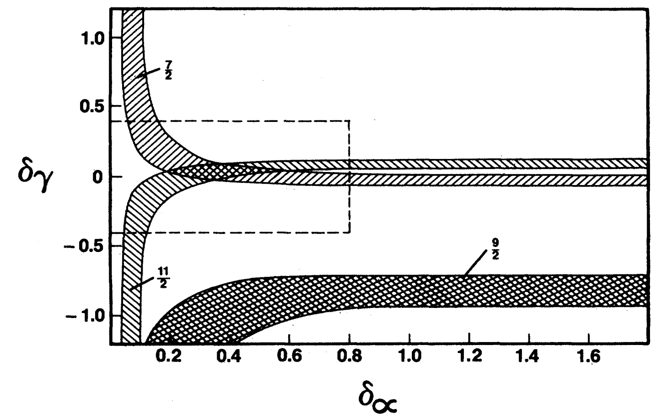

FIG. 4. Plots of a limited range of δ_γ vs δ_α for the three possible spins ($\frac{7}{2}$, $\frac{9}{2}$, $\frac{11}{2}$) of the initial (and identically the intermediate) state are given. The crosshatched regions mark a combination of δ_γ and δ_α with a theoretically predicted asymmetry ratio, $R=W(180°)/W90°)$, lying within the experimentally obtained range of 1.24 ± 0.12. The dashed boundary encloses the physically acceptable region as discussed in the text.

coincidence events were stored on tape and later replayed with various gates set on the α or γ peaks. Figure 2(a) shows a typical coincidence γ spectrum. Figure 2(b) shows the corresponding α spectrum with no gate on the γ energy (dotted outline) and with a gate set on the 316 keV γ peak (solid line). A gate set on the α peak [solid line of Fig. 2(b)] produced the final γ spectra for analysis. The resulting γ peaks were then summed and the background was subtracted. In computing the ratio $R=W(180°)/W(90°)$ the count rate errors were added in quadrature. The final result of the experiment, which is described in more detail elsewhere,[3] was

$$R=1.24\pm0.12 \ .$$

Finally, the a_2 was calculated from

$$a_2=\frac{R-1}{1+\frac{1}{2}R} \ .$$

The above analysis yielded a result $a_2=0.15\pm0.07$.

III. DISCUSSION

In calculating theoretical a_2 values, we are left with two adjustable parameters, δ_α and δ_γ, the mixing ratios of the α and γ transitions. Normally one would expect an $l=2$ contribution in the α decay with a probability of about 60% ($\delta_\alpha \simeq 0.8$) of the $l=0$ contribution based on penetrability considerations.[4] This is consistent with the nonzero measured value of a_2. Figure 3 shows the theoretical predictions (using the phase convention of Rose and Brink[5]) for a_2 as a function of δ_α, assuming $\delta_\gamma=0$. Although the figure shows the entire range for $\delta_\alpha=-\infty$ to $+\infty$, δ_α is restricted to positive values only.

Values of δ_α significantly larger than 0.8 would be inconsistent with the hindrance factor of 3.4 ± 0.5 measured by El-Lawindy *et al.*[2] For this case we can definitely rule out $J^\pi = \frac{9}{2}^+$ for the ^{219}Ra ground state. We must, however consider the effect of a nonzero δ_γ. The $M1$ character of the γ transition is based on conversion electron measurements.[2] An uncertainty of two standard deviations on the conversion coefficient would imply an upper limit of $|\delta_\gamma| \le 0.4$. Figure 4 shows the combinations of δ_γ and δ_α for the three spin hypotheses which allow theoretical asymmetry coefficients R within the experimentally measured range 1.24 ± 0.12. It is clear that the $J^\pi = \frac{9}{2}^+$ hypothesis is ruled out even for very relaxed values of the γ-ray mixing ratio and α-particle mixing ratio.

We are left with a spin assignment of $J^\pi = (\frac{7}{2}, \frac{11}{2})^+$ for the ^{215}Rn excited state, and hence for the ^{219}Ra ground state. This is an interesting deviation from the $\frac{9}{2}^+$ ground state of the isotone ^{217}Rn.[6] As El-Lawindy *et al.*[2] have pointed out, a similar cascade from the $(\frac{5}{2}^+)$ ^{223}Th ground state makes $J^\pi = \frac{7}{2}^+$ the more likely of the two possibilities, however, we cannot rule out $J^\pi = \frac{11}{2}^+$ on the basis of the experimental data alone.

It is noteworthy to mention that a recent set of model calculations[7] based on a reflection asymmetric rotor model for odd $A \simeq 219-229$ nuclei is able to predict $J^\pi = \frac{7}{2}^+$ for the ground state of ^{219}Ra, based on the premise that this nucleus does indeed have an octupole deformation.

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