EXCITED ROTATIONAL BAND IN "SPHERICAL" ^{150}Sm †

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Evidence is presented from the reaction $^{152}\mathrm{Sm}(p,t)^{150}\mathrm{Sm}$ for the existence of an excited rotational band based on the 1.256-MeV 0^+ state of ^{150}Sm, with 2^+ and 4^+ members at 1.417 and 1.819 MeV.

The low-lying states of nuclei around $N=88$ undergo a transition in character from harmonic vibrational ($N<88$) to rotational ($N>88$). This can be interpreted as indicating a shape change from spherical to deformed. However, these nuclei, especially those close to $N=88$, are quite soft to shape variation and probably have zero-point vibrations whose amplitude is comparable with their average deformation.[1] In the following we will refer to "spherical" and "deformed" states, realizing that this describes only in some average way the nuclear shape.

^{150}Sm ($N=88$) and ^{152}Sm ($N=90$) are spherical and deformed, respectively, in their ground states, but have excited 0^+ states which are believed to have shapes quite unlike the ground states. The 1.091-MeV 0^+ state of ^{152}Sm is strongly populated by the (t,p) reaction from the spherical ground state of ^{150}Sm,[2,3] in contrast to the usual weak population of excited 0^+ states by the (t,p) and (p,t) reactions. Hinds et al.[2] interpret this as indicating a spherical character for the state. Further support for this picture comes from a recent (p,t) experiment[4] in which this state is not seen in pickup from deformed ^{154}Sm.

Likewise, the unusual strength with which the (p,t) reaction connects the deformed ground state of ^{152}Sm with the 1.256-MeV 0^+ state of ^{150}Sm[5] indicates that the latter is a deformed state of a nucleus whose ground state is spherical. If the 1.256-MeV state is indeed deformed, it must serve as the basis for a rotational band. The resolution of the earlier (p,t) experiment left unanswered the question of whether such a rotational band exists.

We are currently studying the (p,t) reaction at 19 MeV for a range of rare-earth nuclei. Targets of ^{152}Sm on C backing have been bombarded with 19-MeV protons from the John H. Williams Laboratory MP tandem. The resultant tritons were analyzed with a split-pole magnetic spectrometer and were recorded on nuclear emulsion. The overall energy resolution was approximately 10 keV. The spectrum of tritons recorded at $\theta=25°$ is displayed in Fig. 1. Table I gives the excitation energies, angular momenta, and relative cross sections for the states observed in ^{150}Sm.

The 1.256-MeV 0^+ state is strongly excited, as in the earlier experiment,[5] and candidates for the 2^+ and 4^+ members of its rotational band appear at 1.417 and 1.819 MeV, respectively. The 1.417-MeV state has been assigned $J^\pi=2^+$ by Lure, Peker, and Prokofév[6] and by Smither and Buss.[7] Lure, Peker, and Prokofév suggested that the state is a rotation of the 1.256-MeV 0^+ state. The 1.819-MeV state has recently been assigned $J^\pi=4^+$ by Smither and Buss[7] from resonance capture in the reaction $^{149}\mathrm{Sm}(n,\gamma)^{150}\mathrm{Sm}$. Thus, the angular momenta of these states are proper for a $K=0$ rotational band.

Angular distributions of $^{152}\mathrm{Sm}(p,t)^{150}\mathrm{Sm}$ with $L=0$ leading to 0^+ final states are shown in Fig. 2. They have nearly identical shapes, while the various $L=2$ angular distributions shown in Fig. 3 have dissimilar shapes. This dissimilarity of $L=2$ angular distributions is reminiscent of that noticed by McLatchie et al. in the reaction $^{154}\mathrm{Sm}(p,t)^{152}\mathrm{Sm}$.[4] We have demonstrated that it is not a Q-value effect by raising the proton energy to 20 MeV and observing no change in the relative shapes of the $L=2$ angular distributions. The $L=2$ angular distributions are not sufficiently characteristic to serve as a basis for assigning angular momenta to the final states. Nevertheless,

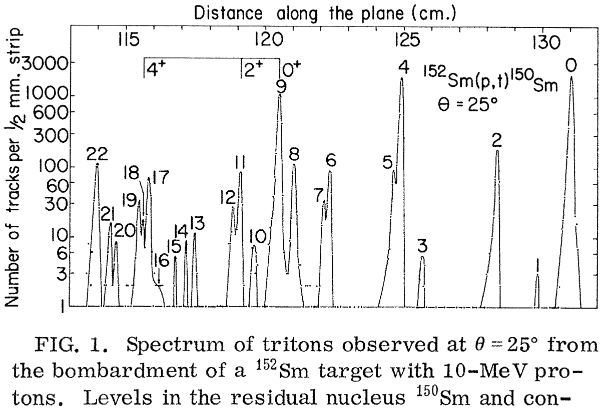

FIG. 1. Spectrum of tritons observed at $\theta=25°$ from the bombardment of a ^{152}Sm target with 10-MeV protons. Levels in the residual nucleus ^{150}Sm and contaminants are identified in Table I. The 0^+, 2^+, and 4^+ members of the excited ^{150}Sm rotational band are indicated.

Table I. Excitation energies, J^π values, and relative cross sections of the levels numbered in Fig. 1. States in ^{150}Sm which have been observed previously are assigned the previously measured energies (without errors) and J^π values.[a-e] States not previously observed have been assigned excitation energies (with errors) by interpolation from known excitation energies.

Level no.	E_x (MeV)	J^π	$\sigma_{\text{lab.}}$ (25°) (arbitrary units)
0	0.0	0^+	5537±250
	^{152}Sm g.s.	0^+	< 66
	^{148}Sm g.s.	0^+	< 31
1	^{147}Sm g.s.	$7/2^-$	7
2	.334	2^+	527±23
3	^{152}Sm (.685 MeV)	0^+	17
4	.741	0^+	4718±200
5	.774	4^+	185±25
6	1.046	2^+	241±18
7	1.072	3^-	78±15
8	1.165	2^+	15±8
	1.194	2^+	346±20
9	1.256	0^+	3172±100
	1.279	3^+, (6^+)	< 50
10	1.357	3^-	30±10
11	1.417	2^+	231±25
12	1.449	4^+	89±20
13	1.604±.010	-	22±7
14	1.642	4^+	16±6
15	1.684	3^-	8±4
16	1.759	2^- or 3^-	7±4
	^{152}Sm (1.775 MeV)	3^- or 4^-	< 7
17	1.794	2^+	192±18
18	1.819	4^+	41±9
19	1.833	2^+ or 5^+	91±12
20	1.925±.010	-	23±7
21	1.949	-	46±8
22	2.006±.010	-	352±20

[a] See Ref. 3.

[b] See Ref. 6.

[c] See Ref. 7

[d] R. K. Smither, Phys. Rev. 150, 964 (1966).

[e] C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes* (Wiley, New York, 1967), 6th ed.

the angular distribution for the 1.417-MeV rotational state is at least compatible with the assignment of $J^\pi = 2^+$ to the state. Thus, the (p, t) angular distributions for the excited rotational states support the angular momentum assignment for the 0^+ member and are consistent with the assignment for the 2^+ member. The angular distribution of the 1.819-MeV state shown in Fig. 3 cannot be used to confirm the 4^+ assignment.

Further evidence for the rotational nature of these states comes from their excitation energies. Figure 4 shows the energy spacings of the ground-state rotational bands in deformed even-even samarium nuclides and of the proposed ex-

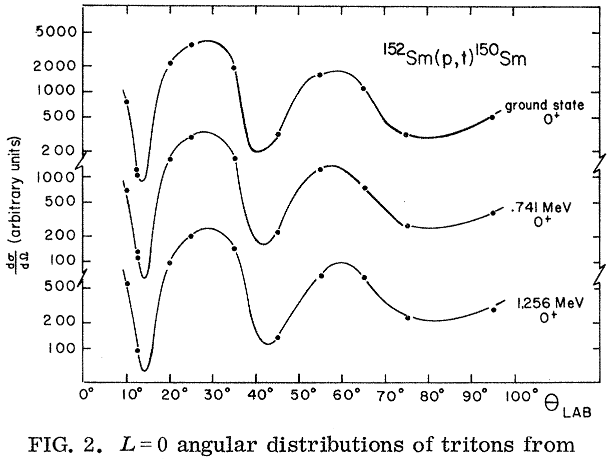

FIG. 2. $L = 0$ angular distributions of tritons from the reaction ^{152}Sm(p, t). The cross sections for three different 0^+ final states in ^{150}Sm are given in the same arbitrary units.

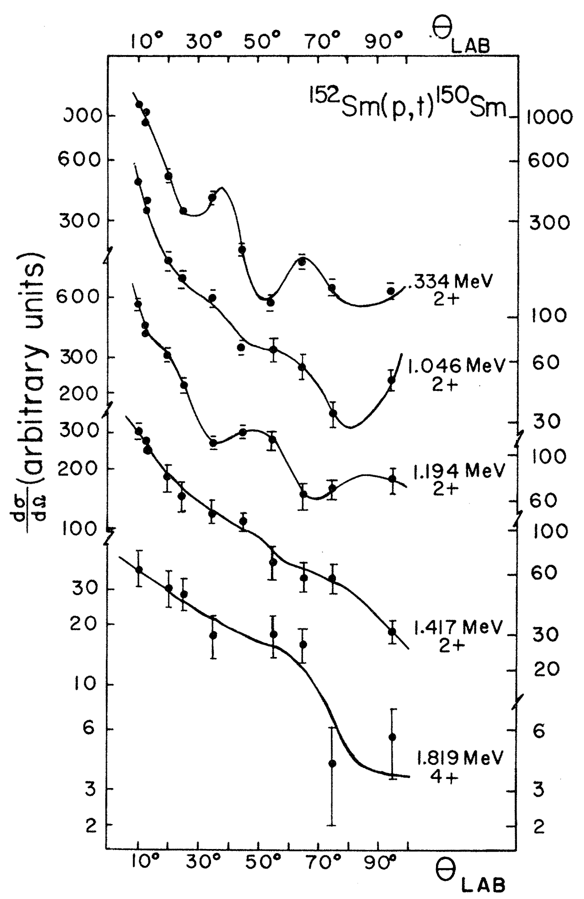

FIG. 3. Triton angular distributions from ^{152}Sm(p,t) leading to some final states in ^{150}Sm with $J^\pi = 2^+$ $(L = 2)$ and $J^\pi = 4^+$ $(L = 4)$. The $L = 4$ angular distributions are all poorly defined due to the proximity of the 4^+ states to strong neighboring states. The angular distribution shown for the 1.819-MeV 4^+ state is typical in this regard.

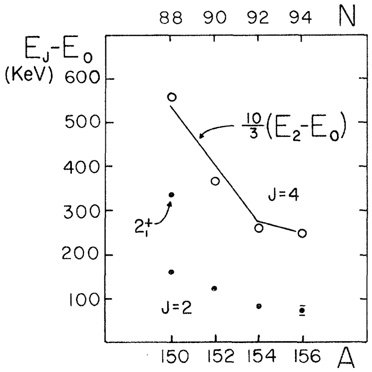

FIG. 4. Energy spacings of $K=0$ rotational bands in even-even samarium nuclides. The energy of the state J relative to the 0^+ band head is shown for $J=2$ (closed circles) and for $J=4$ (open circles). The solid line connects the energies which are predicted from a $J(J+1)$ formula. The spacings shown are for the ground-state bands of ^{152,154,156}Sm ($E_0=0$) and the excited band of ^{150}Sm ($E_0=1.256$ MeV). For ^{150}Sm, the energy of the first-excited 2^+ state (2_1^+) relative to the ground state is shown for comparison.

cited rotational band in ^{150}Sm. The adherence of these spacings to a $J(J+1)$ dependence supports the rotational picture. The systematic increase in the rotational energies with decreasing neutron number reflects a decrease in the moments of inertia. This systematic N dependence of the moment of inertia indicates that the intrinsic shape of the excited ^{150}Sm rotational band is smoothly related to the ground-state shapes of the deformed samarium nuclides.

The strengths with which the (p,t) reaction populates the 2^+ and 4^+ members of the excited ^{150}Sm rotational band, relative to the 0^+ member, are 0.20 ± 0.04 and 0.03 ± 0.01, respectively. The numbers are the relative differential cross sections summed over a distance set of reaction angles. We have measured the corresponding strengths for the ground-state rotational band of ^{152}Sm in the reaction ^{154}Sm$(p,t)^{152}$Sm, $E_p=19$ MeV. They are 0.272 ± 0.015 and 0.045 ± 0.005. Broglia, Riedel, and Udagawa[8] have shown that the relative strength to the state J observed in two-neutron-transfer reactions on deformed nuclei measures the Jth multipole component of the deformation carried by the transferred pair. Thus, the similarity of the relative strengths points to a similarity in intrinsic shape for the ground-state ^{152}Sm and excited ^{150}Sm rotational bands.

In summary, the levels at 1.256, 1.417, and 1.819 MeV in ^{150}Sm have angular momenta, energy spacings, and two-neutron pickup intensities which identify them as members of a rotational band with properties similar to the ground bands of the neighboring samarium nuclides.

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