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Nuclear Spin of Samarium-153*

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The atomic-beam magnetic-resonance method has been used to measure the nuclear angular momentum of 47-hour Sm^{153}. It is found that $I=\frac{3}{2}$.

INTRODUCTION

THIS paper presents the results of measurements performed to determine the nuclear spin of Sm^{153}. These measurements are part of a program to determine the properties of the nuclear ground states and of the low-lying electronic states of the radioactive rare earth isotopes.

BEAM PRODUCTION

Samarium-153 is produced by neutron irradiation of 50 mg of stable Sm^{152} at a flux of 2×10^{13} neutrons/cm^2 sec for 16 hours. The irradiated material is placed directly into the tantalum oven which contains a small inner crucible with a sharp lip designed to control creep (Fig. 1). The oven is then heated in the atomic beam apparatus to about 1300°C at which temperature an adequate samarium beam is found. This procedure was successful on the first attempt and no subsequent difficulties were experienced.

EXPERIMENTAL TECHNIQUE AND OBSERVATIONS

The apparatus used in this experiment has been described elsewhere, and employs the flop-in type of magnet arrangement first proposed by Zacharias.[1] Radioactive detection of the samarium beam is used. Platinum foils in the detector position are exposed to the samarium beam at a particular frequency setting of the rf oscillator used to power the hairpin. After a 5-minute exposure the foil is placed in a gas-flow proportional β counter (background about 2 to 5 counts/min), and its counting rate is measured. Typical resonance counting rates are about 15 counts/min.

Optical spectroscopic measurements[2] on samarium had established the ground-state configuration of this

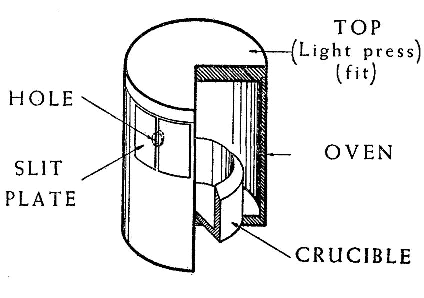

FIG. 1. Cutaway view of oven used to produce samarium beams.

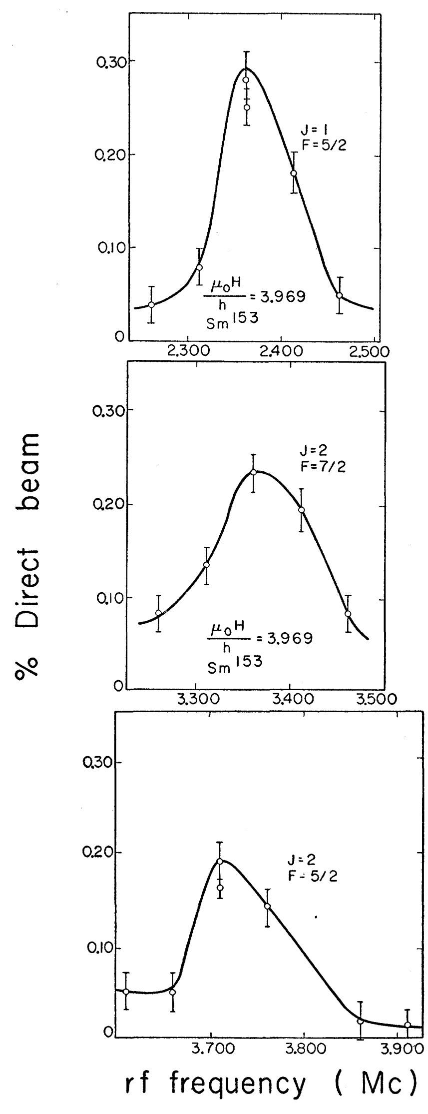

FIG. 2. Resonances observed in the $J=1$ and $J=2$ states of Sm^{153}. The direct beam is the beam reaching the detector with the magnetic fields switched on and the stopwire removed.

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[1] J. R. Zacharias, Phys. Rev. **61**, 270 (1942).

[2] W. Albertson, Phys. Rev. **47**, 370 (1935).

TABLE I. All observed g_F values.

$\mu_0 H/h$ (Mc/sec)	$J=1, F=\frac{5}{2}$	$J=2, F=\frac{7}{2}$	$J=2, F=\frac{5}{2}$
1.000	0.61 ±0.05	0.91 ±0.05	1.01 ±0.05
1.985	0.60 ±0.03	0.86 ±0.02	0.94 ±0.02
3.945	0.598±0.010	0.855±0.011	0.941±0.013
Mean g_F	0.598±0.010	0.856±0.011	0.941±0.010
Predicted g_F ($I=\frac{3}{2}$; $g_J=1.5$)	0.600	0.857	0.943

element to be $(4f)^6(6s)^2$, coupling to the ground-state term ^7F. In this experiment, measurements were made on the states $J=1$ and $J=2$ that arise from this term. That these states are both present in the beam in sufficient quantities to enable measurements to be made is consistent with the optically measured fine structure.[2] Three resonances were observed in a low-field search at 1.0 gauss. These were ascribed to the multiple-quantum transitions

$$I=\tfrac{3}{2},\ J=1;\ F=\tfrac{5}{2}\ \left.\begin{array}{l} m_f=\frac{5}{2} \\ m_f=\frac{3}{2} \\ m_f=\frac{1}{2} \\ m_f=-\frac{1}{2} \end{array}\right\} \leftrightarrow F=\tfrac{5}{2},\ m_f=-\tfrac{5}{2},$$

$$I=\tfrac{3}{2},\ J=2;\ F=\tfrac{7}{2}\ \left.\begin{array}{l} m_f=\frac{7}{2} \\ m_f=\frac{5}{2} \\ m_f=\frac{3}{2} \\ m_f=\frac{1}{2} \end{array}\right\} \leftrightarrow F=\tfrac{7}{2},\ m_f=-\tfrac{7}{2},$$

$$m_f=-\tfrac{1}{2} \leftrightarrow F=\tfrac{7}{2},\ m_f=-\tfrac{5}{2},$$

and

$$I=\tfrac{3}{2},\ J=2;\ F=\tfrac{5}{2}\ \left.\begin{array}{l} m_f=\frac{5}{2} \\ m_f=\frac{3}{2} \\ m_f=\frac{1}{2} \end{array}\right\} \leftrightarrow F=\tfrac{5}{2},\ m_f=-\tfrac{3}{2}.$$

All the transitions corresponding to a given I, J, and F occur at the same frequency in the Zeeman region and contribute to the resonance intensity.

Each of these sets of transitions was observed at three fields, and resonance curves were traced out (Fig. 2). These resonances are characterized by three g_F values tabulated with the observations in Table I.

INTERPRETATION AND CONCLUSIONS

In the Zeeman region, the g_F value is given by

$$g_F \approx g_J \frac{F(F+1)+J(J+1)-I(I+1)}{2F(F+1)},$$

where g_J is the electronic g value. A term of the order of the nuclear moment has been neglected.

The observed g_F values are fitted to well within the experimental error on the assumption that $I=\frac{3}{2}$, that the states $J=1$ and $J=2$ are both present in the beam, and that the g_J value of both J states is 1.5, the value obtained from pure L-S coupling among the six $4f$ electrons. It is of interest to note that the g_J value of the $J=1$ state in plutonium, the transuranic homolog of samarium, is 1.4975±0.0010.[3] This is very nearly identical to the samarium value and implies that similar considerations hold for the coupling of electrons in the ground-state multiplets of these elements.

The observed spin of $\frac{3}{2}$ is consistent with the beta decay from the ground state of Sm^{153}.[4] Interpretation of spin $\frac{3}{2}$ is difficult on the shell model. However, by use of the energy-level diagram of Nilsson,[5] $I=\frac{3}{2}$ can be explained by assuming large deformations and that the state of the 91st neutron is either $\frac{3}{2}-[521]$ or $\frac{3}{2}+[651]$, where the notation is that of Mottelson.[6]

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[4] V. S. Dubey, C. E. Mandeville, and M. A. Rothman, Phys. Rev. **103**, 1430 (1956).
[5] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 16 (1955).
[6] B. R. Mottelson and S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Skrifter **1**, No. 8 (1958).