Phys. Rev. 112, 1763 (1958).
[10]J. F. Marshall, M. E. Nordberg, and R. L. Burman, Phys. Rev. C 1, 1685 (1970).
[11]G. Dugan, thesis, Columbia University, 1973 (unpublished); G. Dugan, S. Childress, L. M. Lederman, L. Price, and T. Sanford, to be published.
[12]C. Wilkin, Lett. Nuovo Cimento 1, 454 (1970); Lee and McManus, Ref. 2; R. R. Silbar and M. M. Sternheim, Phys. Rev. C 6, 764 (1972); J. Beiner, Nucl. Phys. B53, 349 (1973).
[13]M. M. Sternheim, Phys. Rev. 135, 1364 (1964); C. Schmit, Lett. Nuovo Cimento 1, 454 (1970); Wilkin, Ref. 12.
[14]Wilkin, Ref. 2, p. 300.

Identification of the $\frac{11}{2}^-$ [505] Rotational Band in the "Spherical" Nucleus ^{151}Gd

H. J. Smith, D. G. Burke, M. W. Johns, G. Løvhøiden, and J. C. Waddington
McMaster University, Hamilton, Ontario, Canada
(Received 30 July 1973)

A rotational band in the "spherical" nucleus ^{151}Gd has been populated in the reaction ^{149}Sm$(\alpha,2n)^{151}$Gd. The (d,t) and $(^3\text{He},\alpha)$ cross sections, the value of $|(g_K-g_R)/Q_0|$ for the band, and comparisons with the ^{153,155}Gd isotopes identify the 1209-keV band head with the $\frac{11}{2}^-$ [505] Nilsson state.

In the ^{153}Gd and ^{155}Gd nuclei it has been found[1,2] that the moments of inertia for the $\frac{11}{2}^-$ [505] rotational bands are larger than those for the neighboring even-even nuclei. This indicates that a nucleus is well deformed in this state, and it is therefore of interest to see whether the $\frac{11}{2}^-$ [505] rotational band exists in ^{151}Gd, which is considered to be a "spherical" nucleus with an $f_{7/2}$ ground state.[3]

The experiment ^{149}Sm$(\alpha,2n)^{151}$Gd was performed using 24-MeV α particles from the McMaster University tandem Van de Graaff accelerator. The ^{149}Sm target (~10 mg/cm^2) was prepared from material enriched to >95% in ^{149}Sm. γ rays following the $(\alpha,2n)$ process were recorded by use of Ge(Li) detectors, and angular distributions, excitation functions, and γ-γ coincidence data were obtained.[4]

In the coincidence spectra a cascade of transitions with energies roughly following the $I(I+1)$ rule and with decreasing intensity was found. The excitation functions show that they belong to ^{151}Gd, and the angular distributions display the pattern characteristic of cascade transitions in a rotational band.[4] The coincidence spectra locate the band head at an excitation energy of 1209 keV.[4] A partial decay scheme for ^{151}Gd showing the observed band and its major modes of decay is given in Fig. 1.

Previous (d,t) data[5] and new results[6] from the reaction ^{152}Gd$(^3\text{He},\alpha)^{151}$Gd show that the angular momentum transfer in populating the 1209-keV state is $l=5$, and hence its spin is either $\frac{9}{2}^-$ or $\frac{11}{2}^-$. The existence of a well-developed rotational band based on the 1209-keV state shows that it must be associated with a deformed nucleus. The following arguments show that it is associated with the $\frac{11}{2}^-$ [505] Nilsson state.

The only $\frac{9}{2}^-$ and $\frac{11}{2}^-$ band heads in this mass region predicted by the Nilsson model are the $\frac{9}{2}^-$ [514] and the $\frac{11}{2}^-$ [505] orbitals associated with the $h_{11/2}$ shell, and the $\frac{9}{2}^-$ [505] orbital associated with the $h_{9/2}$ shell. The theoretical C_{jl}^2 coefficients for these band heads are ~0, 1.0, and 1.0, respectively. The measured value of $V^2C_{jl}^2 = 1.14 \pm 0.30$ from the $(^3\text{He},\alpha)$ experiment[6] is in good agreement with the value expected for an $\frac{11}{2}^-$ [505] assignment. Since the $\frac{9}{2}^-$ [505] state is expected to occur at much higher excitation than the $f_{7/2}$ ground state, it should have a very small

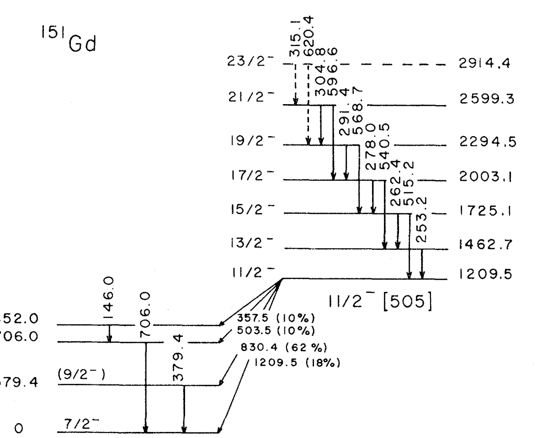

FIG. 1. Partial level scheme for ^{151}Gd showing the $\frac{11}{2}^-$ band and its main modes of decay.

value for V^2 and hence should not be populated appreciably in a neutron-pickup reaction. On the other hand, the $\frac{11}{2}^-$ [505] state should lie below the Fermi surface and appear as a strongly populated hole state in this reaction. The fact that the observed rotational band is not strongly decoupled is evidence that it cannot be based on the low-K Nilsson orbitals originating from the $h_{9/2}$ shell.

Furthermore, assuming $K=\frac{11}{2}$ for the band, it is possible, from the experimental gamma branching ratios, to evaluate the $E2/M1$ mixing ratios δ^2 and the quantities $|(g_K-g_R)/Q_0|$.[7] The deduced values for $|(g_K-g_R)/Q_0|$ agree well with those found for the $\frac{11}{2}^-$ [505] bands in the neighboring ^{153}Gd and ^{155}Gd nuclei (see Table I). Using reasonable values of g_R and Q_0 (e.g., 0.3 ± 0.1 and 6 ± 2 b), the Nilsson model predicts $|(g_K-g_R)/Q_0|$ to be 0.08 ± 0.02 and 0.015 ± 0.015 for the $\frac{11}{2}^-$ [505] and $\frac{9}{2}^-$ [505] states, respectively, again supporting the present assignment.

The rotational parameter for the observed band, expressed as $(E_I-E_{I-1})/2I$, is compared with the same quantities for the $\frac{11}{2}^-$ [505] band in ^{153}Gd and in ^{155}Gd in Fig. 2. The values of the rotational parameters are similar, and there is a systematic decrease with increasing spin and mass number. The decrease with increasing mass number is not as rapid as for the neighboring even-even nuclei.

The $\frac{11}{2}^-$ [505] state exists at quite low excitation energies in ^{153}Gd and ^{155}Gd (171 keV and 121 keV, respectively) and is known to be isomeric because of K forbiddenness.[1,2] In the present experiment the resolving time of the γ-γ coincidence circuit sets an upper limit of 50 nsec for the 1209-keV level in ^{151}Gd. The main mode of decay for the 1209-keV level is via the 830-keV transition to the level at 379 keV. This 379-keV level may be assigned as the $h_{9/2}$ spherical state, which is consistent with shell-model systematics and the (d,t) and (^{3}He, α) data.[5,6] The Weisskopf estimate for the half-life of an 830-keV $M1$ transition is in the picosecond range. Even if this estimate were increased by several orders of magnitude as a result of a shape hindrance of the transition, the lifetime for the 1209-keV level would be too short to have been observed. The large difference in excitation energy for the $\frac{11}{2}^-$ [505] states in ^{153}Gd and ^{151}Gd may be related to a change in deformation, since the single-particle energy for this state varies strongly with this parameter. It could also be due to the difference in energy for spherical and deformed potential surfaces.

The characteristics of the band, the observed cross sections in the neutron-transfer experiments, and the similarity between this and corresponding bands in ^{153}Gd and ^{155}Gd provide convincing arguments for the $\frac{11}{2}^-$ [505] assignment to the 1209-keV state.

Financial support for this project was provided

TABLE I. Mixing ratios and g-factors for the $\frac{11}{2}^-$ [505] band.

Transition $I_i \to I_f$	Energy (keV)	δ^2	$\lvert(g_K-g_R)/Q_0\rvert$
13/2 → 11/2	253.2		
15/2 → 13/2	262.4	0.17 ± 0.04	0.081 ± 0.010
17/2 → 15/2	278.0	0.12 ± 0.03	0.088 ± 0.010
19/2 → 17/2	291.4	0.14 ± 0.03	0.077 ± 0.010
21/2 → 19/2	304.8	0.14 ± 0.03	0.073 ± 0.010

Nuclide	Mean value $\lvert(g_K-g_R)/Q_0\rvert$
^{151}Gd	0.080 ± 0.010
^{153}Gd	0.076 ± 0.011
^{155}Gd	0.076 ± 0.006

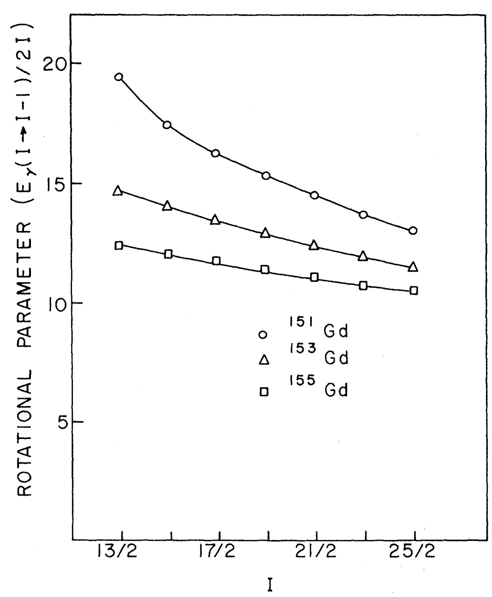

FIG. 2. Rotational parameters for ^{151}Gd, ^{153}Gd, and ^{155}Gd.

by the National Research Council of Canada.

[1]G. Løvhøiden, S. A. Hjorth, H. Ryde, and L. Harms-Ringdahl, Nucl. Phys. A181, 589 (1972).
[2]G. Løvhøiden, J. C. Waddington, K. A. Hagemann, S. A. Hjorth, and H. Ryde, Nucl. Phys. A148, 657 (1970).
[3]M. Gonsior, J. J. Gromova, G. T. Ishkakov, V. V. Kuznetsov, M. Y. Kuznetsova, M. Mikhailov, A. V. Potempa, and V. T. Fominykh, Acta Phys. Pol. B 2, 307 (1971).
[4]H. J. Smith, M. W. Johns, and J. C. Waddington, to be published.
[5]P. O. Tjøm and B. Elbek, Kgl. Dan. Vidensk. Selsk., Mat.-Fys. Medd. 36, No. 8 (1967).
[6]D. G. Burke and G. Løvhøiden, to be published.
[7]P. Alexander, F. Boehm, and E. Kankeleit, Phys. Rev. 133, B284 (1964).

Evidence for Rotational Bands in ^{44}Ti

J. J. Simpson
Department of Physics, University of Guelph, Guelph, Ontario, Canada N1G 2W1

and

W. R. Dixon and R. S. Storey
Division of Physics, National Research Council, Ottawa, Canada K1A 0S1
(Received 16 July 1973)

The results of measurements of γ-ray angular distributions, γ-γ coincidences, and attenuated Doppler shifts for the reaction ^{40}Ca$(\alpha,\gamma)^{44}$Ti are presented, providing strong evidence that twelve of the fourteen excited states below 4.1 MeV can be grouped into four rotational-like bands.

The energy levels of the nucleus ^{44}Ti have been studied recently by a variety of methods, including the reaction ^{40}Ca$(\alpha,\gamma)^{44}$Ti, the (p,t) reaction on ^{46}Ti, and α-transfer reactions such as (^{6}Li, d) and (^{16}O, ^{12}C). One motivation for studying ^{44}Ti was to see if its spectrum exhibited a simplicity similar to that of ^{20}Ne; but the early experiments[1] showed that there are many more levels at low energy in ^{44}Ti than in ^{20}Ne and that the first four excited states in ^{44}Ti could be described in first approximation by the vibrational model. However, because of the strong transition observed between the 2^+ and 0^+ members of the two-phonon state the authors speculated that these levels might alternatively be the first two members of a rotational-like band. There was not sufficient evidence to suggest a particular structure for the more highly excited states. Here we shall present a summary of the results of further α-capture experiments which provide strong evidence that twelve of the fourteen excited states of ^{44}Ti below about 4.1 MeV can be grouped into four rotational-like bands.

The reaction ^{40}Ca$(\alpha,\gamma)^{44}$Ti has been studied using the 4-MV Van de Graaff accelerator of the National Research Council in Ottawa. Experimental details of γ-ray angular-distribution experiments and attenuated Doppler-shift measurements are presented in Ref. 1 and by Dixon, Storey, and Simpson.[2] These experiments have continued and in addition γ-γ coincidence experiments have been carried out to detect weak, low-energy transitions between the bound states, transitions which in some cases are obscured by contaminant lines in singles Ge(Li) spectra. In these experiments an annular NaI(Tl) detector was used to select the high-energy primary γ decays from a resonant state, and a Ge(Li) detector in coincidence recorded the low energy γ-ray spectrum at 0°.

Figure 1 displays the proposed band structure in a plot of E_J versus $J(J+1)$. The evidence for spin assignments in given below. Figure 2 is a decay scheme, separating the levels into the proposed bands, and showing the branching ratios and $E2$ enhancements which are the prime evidence linking certain levels into bands. A summary of the new evidence follows, band by band.

Ground-state band.—States at 1083 keV (2^+), 2454 keV (4^+), and 4015 keV (6^+) form a band based on the ground state. The spin, parity, and lifetime of the first two states are established in Refs. 1 and 2 and in other recent works.[3-5] The 4.02-MeV state is assigned a spin and parity