energy distribution which describes the low energy. The result of this experiment indicates that compound-nucleus formation applies to at least 80% of the nonelastic interactions.

Recently Weisskopf[16] proposed a more general scheme for the description of nuclear reactions. Instead of the two-stage Bohr description, he divided the nuclear reaction in three successive stages, the independent stage, the compound-system stage, and the final stage. He also pointed out that we face a varied range of phenomena in the second stage of his model, which can be grouped in the two extremes, direct interaction and formation of real compound nucleus.

Table III shows the elastic differential cross sections at several angles. The angular resolution for each point is ±8°.

[16] V. F. Weisskopf, Revs. Modern Phys. **29**, 174 (1957).

TABLE III. Elastic differential cross sections in barns per steradian at several angles in the center-of-mass system.

θ	20°	30°	50°
$\sigma(\theta)$	1.25±0.09	0.35±0.04	0.025±0.008
θ	70°	90°	120°
$\sigma(\theta)$	0.018±0.007	0.014±0.006	0.010±0.006

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Rotational Spectrum of Tm^{171}†

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The gamma rays emitted from Tm^{171} following the Er^{171} beta decay have been measured with the two-meter curved-crystal spectrometer and a semicircular beta-ray spectrometer, enabling a comparison of the nuclear levels and rotational parameters for the Tm^{171} ground-state band with the corresponding levels and parameters of Tm^{169}. The measured gamma rays have the following energies in kev: 5.06±0.05, 12.40 ±0.05, 111.63±0.02, 116.69±0.03, 124.03±0.03, 210.62±0.15, 284.9±0.7, 295.97±0.15, 308.37±0.15. In comparing the rotational parameters, a slight increase in the deformation of Tm^{171} over that of Tm^{169} is noted. The relatively large change in the decoupling parameter ($a=-0.8563$) for Tm^{171} compared with that of Tm^{169} cannot be accounted for entirely by the small change in nuclear deformation.

RECENT experimental studies[1] of the gamma-ray spectrum of Tm^{171} following the 7.8-hour Er^{171} beta decay have shown that the Tm^{171} nuclear level structure has striking similarity to that of Tm^{169}. From the curves of odd-proton orbitals in a deformed nuclear potential given by Mottelson and Nilsson,[2] both Tm^{169} and Tm^{171} could be expected to have $K=\frac{1}{2}$ ground states since both of these odd-A nuclei contain 69 protons. The anomalous rotational spectrum, characteristic of a $K=\frac{1}{2}$ ground state, has indeed been observed in the studies of nuclear levels in both isotopes.[1,3]

Since a precise determination of the energy levels in Tm^{169} had been carried out with the two-meter curved-crystal spectrometer at Caltech,[4] it was of interest to determine the energies of the corresponding levels in Tm^{171} with the same instrument. In addition, two low-energy transitions of 5 and 12 kev were implied from the proposed Tm^{171} level scheme[1] but had not been observed so that a study of the low-energy internal conversion spectrum was also desirable.

Approximately 10 mg of high-purity Er_2O_3 (supplied by Johnson, Matthey and Company, Ltd., London), enclosed in a 0.015 in.×1 in. quartz capillary, was irradiated for 24 hours in the Materials Testing Reactor at Arco, Idaho,[5] to serve as the gamma-ray source for the curved-crystal spectrometer. A thin layer of the radioactive Er_2O_3 was evaporated in vacuum on an aluminized mica backing and represented the source for the low-energy beta-ray spectrometer. The semicircular

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[1] S. D. Koički and A. M. Koički, Bull. Inst. Nuclear Sci. Boris Kidrich **6**, 1 (1956); Cranston, Bunker, Mize, and Starner, Bull. Am. Phys. Soc. Ser. II, **1**, 389 (1956); S. A. E. Johansson, Phys. Rev. **105**, 189 (1957).
[2] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).
[3] *Nuclear Data Cards*, edited by C. L. McGinnis (National Research Council, Washington, D. C.).
[4] Hatch, Boehm, Marmier, and DuMond, Phys. Rev. **104**, 745 (1956).
[5] We are grateful to the staff of the MTR at Arco for their efficient cooperation in connection with the irradiation.

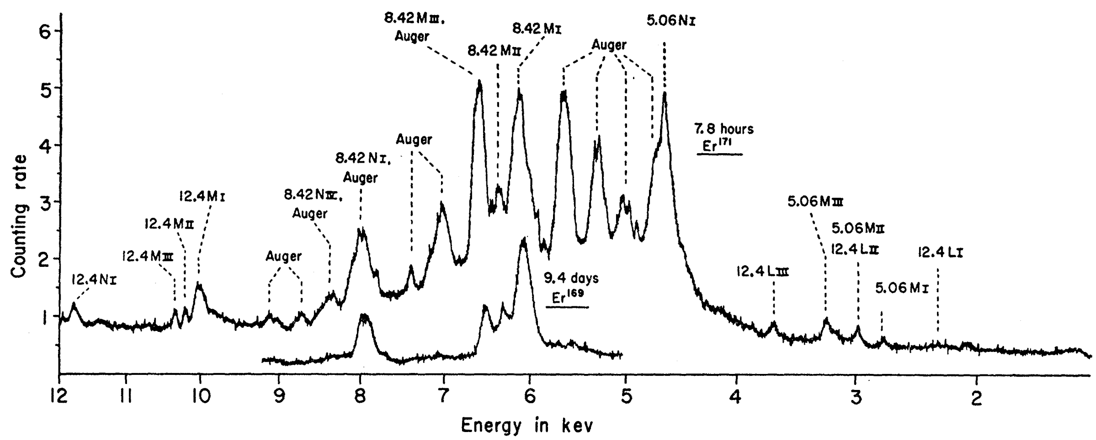

FIG. 1. The upper curve represents the internal conversion spectrum of the erbium source from 2 to 12 kev observed with the semicircular spectrometer. The lower curve is obtained with the same source at a time when the 7.8-hr Er^{171} activity was decayed and brings to evidence the M and N conversion lines due to the 8.42-kev transition in Tm^{169}.

beta-ray spectrometer[6] was operated with 0.8% resolution and was provided with a Geiger counter with a 15-μg/cm^2 Formvar window.

The internal conversion spectrum from 2 to 12 kev observed with the semicircular spectrometer is shown in Fig. 1. In this spectrum the M and N lines of the 5.06- and 12.40-kev transitions are clearly seen. The M and N lines of the 8.42-kev transition[7] in Tm^{169} following the nine-day beta decay from Er^{169} are also present. A later run (lower curve) with the same source at a time when the 7.8-hour Er^{171} activity had decayed brings these conversion lines into evidence.

The energies and relative intensities of the gamma rays measured with the curved-crystal spectrometer are given in Table I.[8] The relative intensities of the 111.63-, 116.69-, and 124.03-kev gamma rays agree within experimental errors with those of the corresponding transitions in Tm^{169}.[4] The energies of the Tm^{171} levels resulting from the present measurements, compared with the corresponding levels in Tm^{169}, are presented in Fig. 2.

According to the collective model of the nucleus, the energy spacings of the levels in a $K=\frac{1}{2}$ rotational

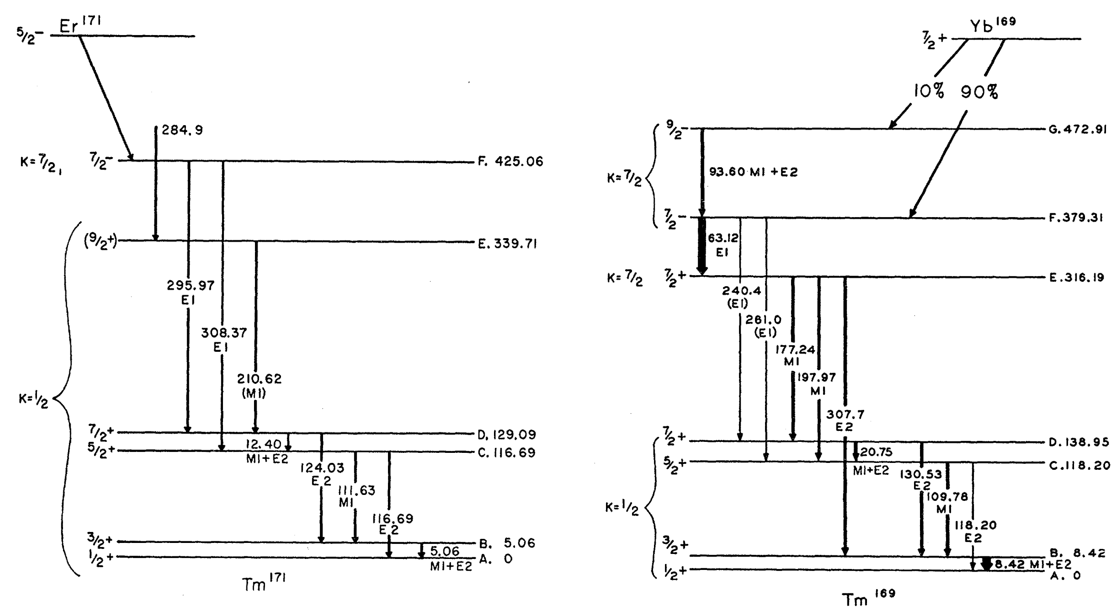

FIG. 2. Energy level scheme of Tm^{171} as compared with the level scheme of Tm^{169}. Energies are given in kev.

[6] H. Henrikson, Special Technical Report No. 24, California Institute of Technology (unpublished).
[7] E. N. Hatch and F. Boehm, Bull. Am. Phys. Soc. Ser. II, 1, 390 (1956).
[8] Preliminary results were reported previously by E. N. Hatch and F. Boehm, Bull. Am. Phys. Soc. Ser. II, 2, 212 (1957).

band are given by[9]

$$E(I)=E^{(0)}+E^{(1)}\{I(I+1)+a(-1)^{I+\frac{1}{2}}(I+\tfrac{1}{2})\}+E^{(2)}\{I(I+1)+a(-1)^{I+\frac{1}{2}}(I+\tfrac{1}{2})\}^2, \quad (1)$$

where $E(I)$ is the energy above ground state of the rotational level with spin I, $E^{(0)}$ is a constant, $E^{(1)}$ is the rotational splitting term $\hbar^2/2\mathcal{J}$, a is the decoupling parameter, and $E^{(2)}$ is the coefficient of the second-order term.

When the measured energies for levels A, B, C, and D (Fig. 2) are substituted in Eq. (1), the parameters a, $E^{(1)}$, and $E^{(2)}$ can be determined for the Tm^{171} $K=\frac{1}{2}$ band. These parameters are compared with the corresponding ones obtained[4] for Tm^{169} in Table II. Level

TABLE I. Tm^{171} gamma-ray energies and relative intensities.

γ-ray energy (kev)	γ-ray relative intensity	Internal conversion data
5.06±0.05[a]	···	
12.40±0.05[a]	···	$L_I:L_{II}:L_{III}\simeq 1:1:2$ $M_I:M_{II}:M_{III}=3:1.2:1$
111.63±0.02	27	$K/L=7$
116.69±0.03	∼3	$K/L=0.8$
124.03±0.03	12	$K/L=1.0$
210.62±0.15	∼1	
284.9 ±0.7	···	
295.97±0.15	42	
308.37±0.15	100	
8.42±0.05[b]		$M_I:M_{II}:M_{III}:M_{IV,V}=3:1:1:\leq 0.05$

[a] These transitions were measured with the semicircular β-ray spectrometer only.
[b] Line in Tm^{169}.

TABLE II. Rotational parameters of the $K=\frac{1}{2}$ band in Tm^{169} and Tm^{171}.

	Tm^{169}	Tm^{171}
$E^{(1)}$	11.969 kev	11.631 kev
$E^{(2)}$	+0.03389 kev	+0.02965 kev
a	−0.7680	−0.8563

E is tentatively assigned spin and parity 9/2+ because of the close agreement of its measured energy (339.7 kev) with the value (343.9 kev) obtained from Eq. (1) using the parameters of Table II for the 9/2 rotational level in the Tm^{171} $K=\frac{1}{2}$ band. The tentative $M1$

[9] A. Bohr and B. R. Mottelson, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), Chap. 17.

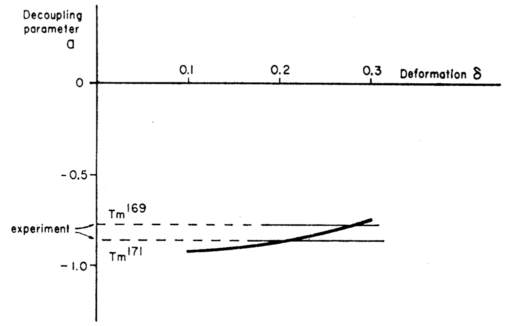

FIG. 3. Theoretical and experimental values of the decoupling parameter a as a function of deformation for Tm^{169} and Tm^{171}. The solid curve represents the theoretical values for a obtained by Mottelson and Nilsson.[10]

assignment to the 210.62-kev transition is made for the same reason. The 5.06- and 12.40-kev transitions were identified as $M1+E2$ on the basis of their conversion subshell ratios. The other multipole assignments indicated in Fig. 2 are those obtained by Cranston *et al.*[1] An 85.35-kev transition FE, which has been reported as an 88-kev gamma ray by Johansson[1] was searched for at the outset of the measurements, but was not observed.

As can be noted in Table II, the parameters $E^{(1)}$ and $E^{(2)}$ for Tm^{171} show close agreement to those of Tm^{169}. The slightly lower values for Tm^{171}, which has two more neutrons than Tm^{169}, probably indicate a slight increase in the deformation of Tm^{171} accompanied by a slightly increased moment of inertia for the $K=\frac{1}{2}$ band. In Fig. 3 is shown the theoretical values of the decoupling parameter a as a function of deformation as computed by Mottelson and Nilsson[10] and compared with the experimental values from Table II. The decoupling parameter for Tm^{169} is in agreement with the calculation, while that for Tm^{171} appears to be more negative than can be accounted for by the apparent slight increase in the deformation.

ACKNOWLEDGMENTS

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[10] B. R. Mottelson and S. G. Nilsson, Z. Physik **141**, 217 (1955).