inserting a delay between one counter and the coincidence circuit.

The pair spectrum shows the strong 6.05-Mev electric monopole pair line from O^{16}. Internal pair peaks are seen corresponding to 3.86, 6.92, and 7.12 (unresolved), and 8.87-Mev gamma rays from O^{16}, and a 4.43-Mev gamma-ray grom C^{12}. The counts near 11 Mev are due to background from cosmic rays and electronic noise. The vertical lines indicate standard deviations. Because of the few counts, some of the fluctuations may be due to effects other than statistics. No peak is observed corresponding to a 10.98-Mev pair transition This spectrum was corrected for accidental coincidences and decomposed into its individual line shapes, giving

$$\frac{\text{number of 10.98-Mev pair counts}}{\text{number of 3.86-Mev pair counts}} < 2\times10^{-2}.$$

The internal pair formation coefficient[9] for a 3.86-Mev $M1$ gamma ray is 10^{-3}. This gives

$$\frac{\text{number of 10.98-Mev pair transitions}}{\text{number of 3.86-Mev gamma-ray transitions}} < 2\times10^{-5}.$$

If the single-particle estimate[10] of 6×10^{-16} sec is taken for the mean life of the 3.86-Mev $M1$ transition, a lower limit of $\tau > 3\times10^{-11}$ sec is obtained for the partial lifetime of the 10.98-Mev $0^- \rightarrow 0^+$ pair transition. Surveys of radiative transitions in light nuclei by Wilkinson[11] together with recent theoretical arguments by Morpurgo[12] indicate that the mean life of the 3.86-Mev $M1$ transition in O^{16} should be about 700 times greater than the single-particle estimate given above. If this is the case, then a lower limit of $\tau > 2\times10^{-8}$ sec is obtained for the partial lifetime of the 10.98-Mev $0^- \rightarrow 0^+$ pair transition.

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Isomers in Tb^{158} and Ho^{163}†*

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The isomeric transition in Tb^{158}, with 10.5-second half-life and 111-kev transition energy, is designated $M3$. The isomeric transition in Ho^{163}, with 0.8-second half-life and 299-kev transition energy, is designated $E3$.

I. INTRODUCTION

An isomer in Tb^{158} of half-life 11 sec and one in Ho^{163} of half-life 0.8 sec have been reported by Hammer and Stewart.[1] These isomers have been further studied to determine the modes of decay, energies, K-conversion coefficients, and hence the multi-polarities. With 65 and 67 protons, respectively, terbium and holmium are approximately midway between closed shells at 50 and 82. In this region relatively large nuclear deformations are found and hence the isotropic shell model must be replaced by a distorted model such as that used by Nilsson,[2] or by Gottfried.[3] In such a model the angular momentum of the last unpaired nucleon is not a constant; the levels are identified by the component of the angular momentum along the nuclear symmetry axis.

II. APPARATUS

The irradiations were performed with x-rays from the University of Illinois 22-Mev betatron. The energy of this instrument is continuously variable below 24 Mev. A sealed-off ceramic doughnut with an internal Ni target was employed. The source holder was taped onto the doughnut in the position of maximum x-ray intensity. The source was moved from the betatron to the detector through a $\frac{1}{4}$-inch Tygon[4] tube by air pressure. With an air pressure of 100 psi the source was able to make the 22-foot journey to the detector in about $\frac{1}{4}$ second, indicating an average speed of 60 mph. The air switch was reversible and synchronized with the betatron injector voltage so that cyclic operation was possible. Two features of the arrangement, as compared with stationary source techniques, are that

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* The authors gratefully acknowledge the loan of 100 mg of pure terbium metal by the Ames Laboratory of Iowa State College.

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[4] Product of U. S. Stoneware Company, Akron, Ohio.

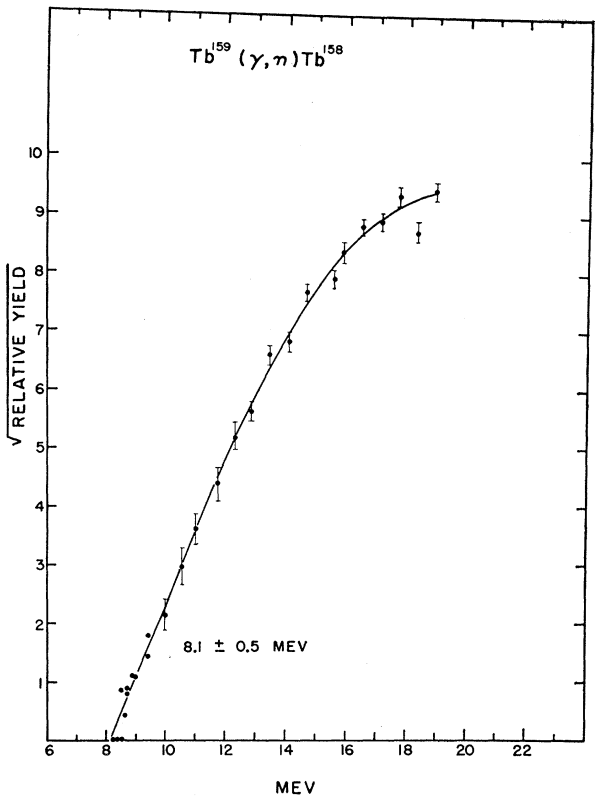

FIG. 1. Activation curve for terbium.

the source-holder is closer to the betatron and the detector is farther from the betatron.

The radiations were detected with a NaI crystal and with a proportional counter filled with argon or krypton. Standard high voltage, photomultiplier, and amplifier circuits were used. The low-noise pre-amplifier was modified from a circuit by Enslein and Brainerd.[5] The pulse heights were measured and recorded in an RIDL 100-channel analyzer.[6] This device uses an analog-to-digital-converter and a 1600-ferrite-toroid memory. A scope circuit provides visual observation during and after data-taking.

III. TERBIUM-158

Tb^{158} was produced by a (γ,n) reaction on stable Tb^{159}. The observed threshold for this reaction is 8.1 ± 0.5 Mev by comparison with O^{16}(17.15 Mev) and Cu^{63}(10.17 Mev). The activation curve is shown in Fig. 1. The half-life was measured with a Geiger counter and pen recorder which indicated the time of every thirty-second count. The average of five measurements is $t_{\frac{1}{2}}=10.5\pm0.3$ seconds. The value of Hammer and Stewart is 11.0 ± 0.1 seconds.

The prominent radiation from Tb is at 44.3 ± 0.5 kev, indicating a Tb x-ray. The energy determination was done with a proportional counter by comparison with K x-ray energies of Hf, Sm, and Gd. This result agrees with Hammer and Stewart's critical absorption experiment. The NaI spectrum in Fig. 2 calibrated with Pd^{109}, Ta^{180}, Eu^{152}, and Ce^{144}, shows a weak gamma ray at 111 ± 2 kev. The two unmarked peaks are considered to be due to escape of iodine x-rays from the detector. By comparison of the gamma-ray and the x-ray intensities the K-conversion coefficient was found to be 61 ± 9, after correction for fluorescence yield, escape of iodine x-ray from the NaI detector, crystal efficiency, and self-absorption in the 100-mg terbium source. Upon using theoretical K-conversion coefficients of Sliv,[7] the best agreement is for $M3$ ($\alpha_K=55$), followed by $E5$ ($\alpha_K=42$) and $E3$ ($\alpha_K=3.1$). The half-life formula of Weisskopf, when corrected for K and L conversion,[8] indicates either an $M3$ or $E3$ assignment. Considering both the K-conversion coefficient and the half-life, the 111-kev transition in Tb^{158} is designated as $M3$.

Assuming that the deformation of Tb^{158} is the same as that of Tb^{159} ($\delta=0.31$), the level scheme of Nilsson predicts that the last proton is in the $\Omega_p=\frac{3}{2}+$ state and the last neutron is in the $\Omega_n=\frac{3}{2}-$ state, where Ω, as employed by Nilsson, is the projection of the nucleon's angular momentum on the nuclear symmetry axis. The two possible resultant values are $\Omega=0-$ or $3-$ so that a transition between the two lowest levels could well be

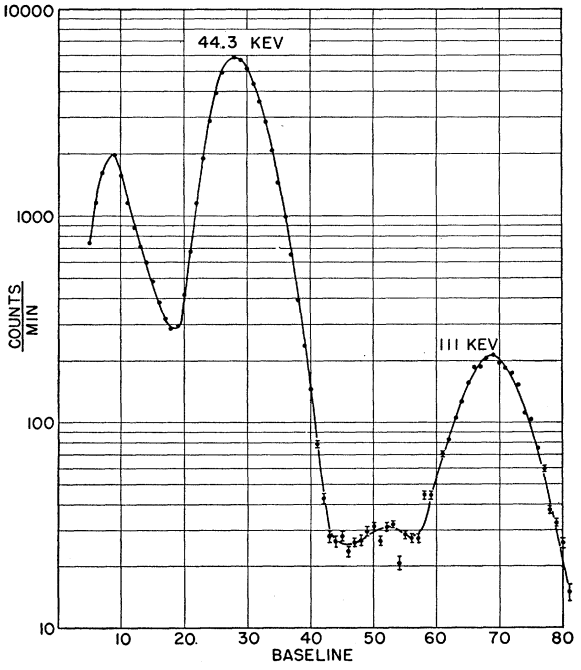

FIG. 2. Photon spectrum for Tb^{158m}.

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$M3$, in agreement with the above result. In Gottfried's level scheme the last proton is in the $\frac{1}{2}-$ or $\frac{3}{2}+$ state, while the last neutron is in the $\Omega_n=\frac{3}{2}+$ state. If $\Omega_p=\frac{1}{2}-$, the ground state is either 1− or 2− and the transition is $M1$; if $\Omega_p=\frac{3}{2}+$, the ground state is 0+ or 3+ and the transition is again $M3$.

IV. HOLMIUM-163

The observed threshold for the 0.8-second activity in Ho is 16.2±0.5 Mev indicating a $(\gamma,2n)$ reaction. The activation curve is shown in Fig. 3. The (γ,n) reaction leading to the known 37-minute activity[9] in Ho^{164} was observed in the present work to have a threshold of 8.0±0.5 Mev. The photon spectrum of Ho^{163} after a two-second irradiation is shown in Fig. 4. The energy of the gamma ray was found to be 299±3 kev by comparison with Eu^{152}, Hg^{203}, Cr^{51}, and Sn^{113}. The energy reported by Hammer and Stewart is 305 kev using Ba^{133} as a calibration.

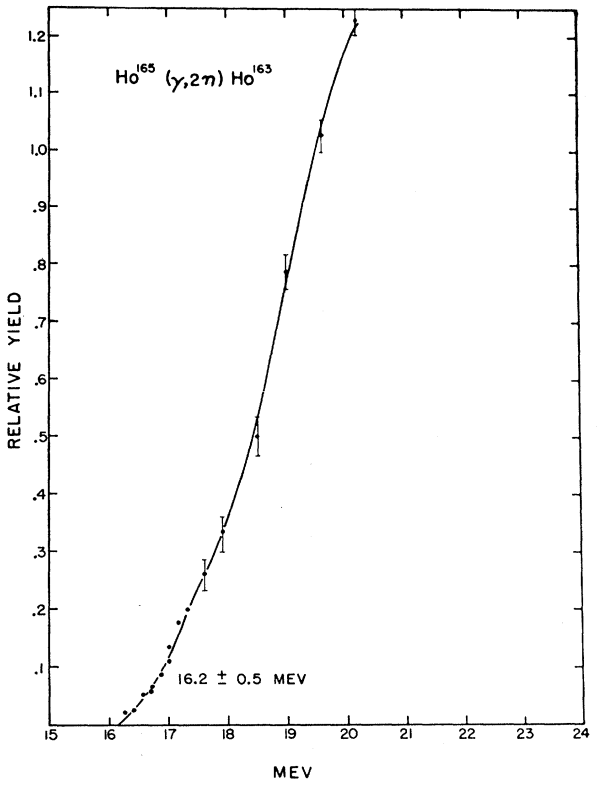

FIG. 3. Activation curve for holmium.

[9] H. N. Brown and R. A. Becker, Phys. Rev. **96**, 1372 (1954).

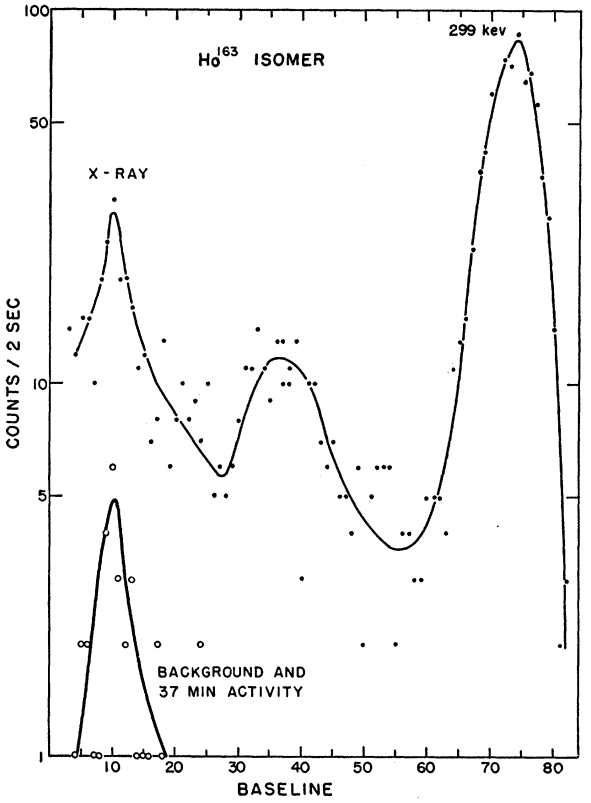

FIG. 4. Photon spectrum for Ho^{163m}.

The K-conversion coefficient was found, by use of the same method as for Tb, to be 0.17±0.06. The Sliv values are 0.14 for $E3$, 0.10 for $M1$, and 1.3 for $M3$. Noting that the Weisskopf half-life is usually too small for $E3$ transitions, the half-life is consistent with both $M3$ and $E3$. Considering both the K-conversion coefficient and the half-life, the isomeric transition in Ho^{163} is designated $E3$.

Assuming that Ho^{163} has the same deformation as Ho^{165} Nilsson puts the last proton in the $\Omega_p=\frac{7}{2}-$ state. The 96 neutrons do not contribute to the spin. The first excited state is $\Omega_p{}^*=\frac{1}{2}+$ so that the transition would be $E3$, in agreement with the above result. In Gottfried's model the ground state of the last proton is again $\Omega_p=\frac{7}{2}-$. The first excited state is $\Omega_p{}^*=\frac{1}{2}-$, yielding an $M3$ transition instead of $E3$. The second excited state is $\Omega_p{}^*=\frac{1}{2}+$, so that if the two levels were reversed the transition would be $E3$.