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Experimental studies of the neutron-deficient gadolinium isotopes: $^{145}Gd^{m_1}$ and $^{145}Gd^{m_2}$

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An isomer in ^{145}Gd at 27.3 keV is reported with a half-life of 11.5 ± 0.3 nsec and an internal conversion coefficient $\alpha_L = 16.9 \pm 1.4$. This state is described as substantially the $\nu d_{3/2}$ single-neutron state which is fed by the $^{145}\text{Gd}^{m_2}$ $\nu h_{11/2}$ isomer and which deexcites through the $\nu s_{1/2}$ ground state. The isomeric transition from $^{145}\text{Gd}^{m_1}$ is found to be 99.2 ± 0.2% $M1$ + 0.8 ± 0.2% $E2$, indicating a hindrance factor of 100 in the $M1$ and an enhancement factor of 40 in the $E2$ over the single-particle estimates. Recent information on the $N = 81$ $\frac{11}{2}^-$ isomers is presented for ^{133}Te through ^{147}Dy showing the systematic changes in experimental energies and $M4$ matrix elements.

RADIOACTIVITY $^{145}\text{Gd}^{m_1}$; measured $T_{1/2}$, E_γ, ICC, $\gamma\gamma$ coin; deduced $B(M1)$, $B(E2)$. Ge(Li) detector, 550 eV at 127 keV; Ge(Li) detector, 2.0 keV at 1332 keV. $^{133}\text{Te}^{m_1}$, $^{135}\text{Xe}^{m_2}$, $^{137}\text{Ba}^{m_2}$, $^{139}\text{Ce}^{m_2}$, $^{141}\text{Nd}^{m_2}$, $^{143}\text{Sm}^{m_2}$, $^{145}\text{Gd}^{m_2}$, $^{147}\text{Dy}^{m_2}$; deduced $B(M4)$.

In their early work on $^{145}\text{Gd}^{m_2}$ decay,[1] Eppley, McHarris, and Kelly (hereafter EMK) reported a weak β-decay branch and a 721.4-keV $M4$ isomeric transition to a state of indeterminate energy. This state lay at low energy in the ^{145}Gd level scheme, and the transition out of it was unobserved at that time. The $M4$ nature of the transition into the first excited state was verified by measuring the conversion coefficients α_K and α_K/α_L. The 85-sec half-life of $^{145}\text{Gd}^{m_2}$ made the study of this isomer difficult in the early experiments, but it was established to be the $h_{11/2}$ single-neutron (hole) orbit. The first excited state was then presumed to be a $d_{3/2}$ single neutron (hole), while the ground state was suggested to be the $s_{1/2}$ neutron (hole).[2] This was later verified by atomic beam studies.[3]

In the present work, the $^{145}\text{Gd}^{m_1}$ state was found by x-γ coincidence techniques to lie at 27.3 ± 0.1 keV excitation. The conversion coefficient α_L was measured, as was the half-life. This extends the systematic information about the $h_{11/2}$ single-neutron states to a seventh $N=81$ odd-A isotone.

Subsequent to the completion of these experiments, information on the eighth $N=81$ odd-A isotone, $^{147}\text{Dy}^{m_2}$, was reported by Rainis, Toth, Newman, Bingham, Carter, and Schmidt-Ott.[4] These authors also determined the energy of the 27.3-keV state in ^{145}Gd. We have extracted the radial matrix element $|M|^2$ for the $M4$ transition in ^{147}Dy and compared this with the other $N=81$ $M4$ transitions. The turnover in the $|M|^2$ vs A curve for this matrix element predicted by EMK at this isotope is clearly substantiated.

A standard fast-slow megachannel coincidence experiment[5] was performed with a planar high-resolution Ge(Li) detector gating on the 3–50-keV energy range and a coaxial 18% efficient (relative to a 7.6-×7.6-cm NaI) Ge(Li) detector gating on the energy region above 500 keV. Pairs of coincidence events were gathered on magnetic tape along with information about the time between the events. The coincidence time resolution on prompt events was ≈10 nsec full width at half-maximum. Sources of $^{145}\text{Gd}^{g+m}$ were prepared from $^{148}\text{Sm}(\tau, 6n)^{145}\text{Gd}$ reaction recoils transported by a He-jet thermalizer system[6] and collected on a programmable moving tape surface which brought the source in front of the detector.

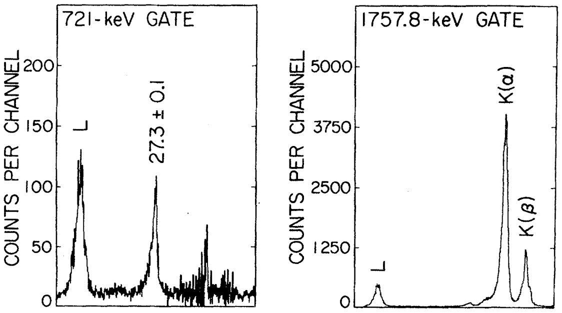

FIG. 1. Spectrum of the 27.3-keV γ ray in coincidence with the 721.4-keV transition from $^{145}\text{Gd}^{m_2}$ (left). The L x rays arise from internal conversion. A calibration spectrum (right) is also shown for $K+L$ x rays in coincidence with the 1757.8-keV γ ray from $^{145}\text{Gd}^{g}$ decay.

TABLE I. Internal conversion coefficients for the 27.3-keV first isomeric transition in ^{145}Gd.

	Experimental	$M1$	$E2$
α_L	16.9± 1.4	11.8 [a]	621 [a]
%	···	99.2± 0.2	0.8± 0.2

[a] R. S. Hager and E. C. Seltzer, Nucl. Data A4, 1 (1968).

Figure 1 shows an x-ray spectrum obtained by gating on the 721.4-keV γ ray from ^{145}Gd^{m_2}. This spectrum contains both the 27.3-keV γ rays coincident with the $M4$ transition and the 6–8-keV L x rays associated with L conversion from the 27.3-keV state. An accurate efficiency calibration was made for this spectrum using theoretical and experimental K/L capture ratios for x rays in coincidence with β-decay events during this same experiment. A spectrum obtained for calibration is shown at the right of Fig. 1 for β decay of ^{145}Gd^g to the 1757.8-keV state in ^{145}Eu. The experimental and theoretical conversion coefficients for $M1$ and $E2$ transitions are given in Table I. The measured conversion coefficient is significantly larger than that for a pure $M1$, so the relative mixing of $M1$ and $E2$ is also presented in Table I.

In Fig. 2 a TAC (time-to-amplitude converter) spectrum is shown corresponding to the time between 27.3-keV γ rays and 721.4-keV γ rays. The centroid shift, corrected for walk, in this TAC peak from a prompt TAC peak is equal to the mean life τ of the 27.3-keV state. From this the half-life, $t_{1/2} = 11.5 \pm 0.3$ nsec, was extracted for the 27.3-keV state. Combining these data with the internal conversion data and the EMK data, a more complete decay scheme for the ^{145}Gd$^{m_1+m_2}$

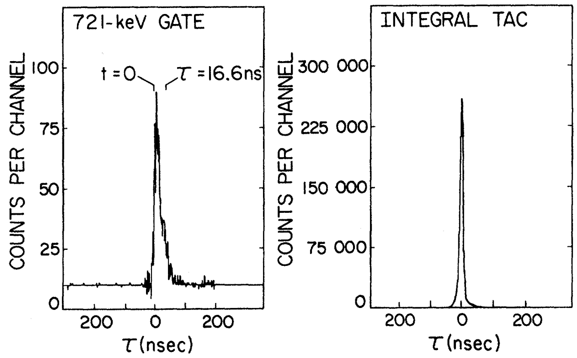

FIG. 2. Timing spectrum for 721.4–27.3-keV coincidence (left). Centroid shift is corrected for walk in the prompt TAC (right).

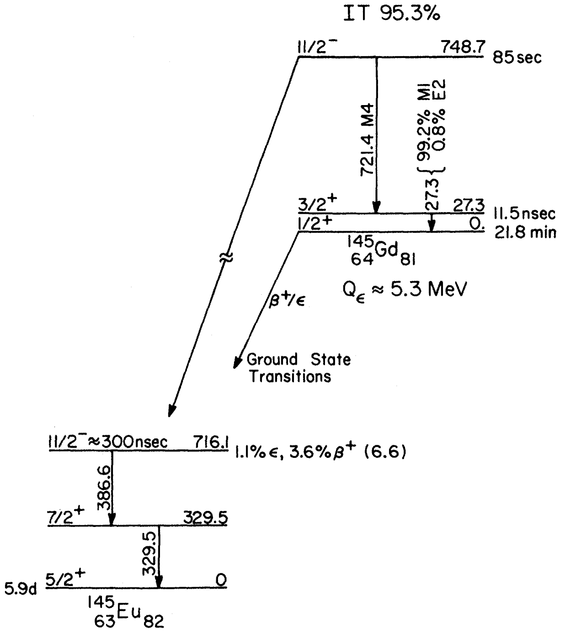

FIG. 3. Decay scheme of ^{145}Gd$^{m_1+m_2}$.

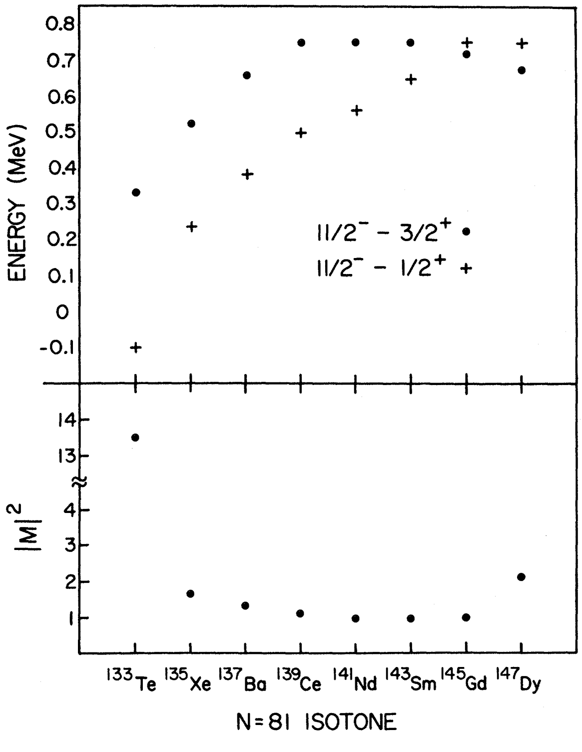

FIG. 4. Plots of the $h_{11/2}$-$d_{3/2}$ and $h_{11/2}$-$s_{1/2}$ energy differences, and the squares of the experimental radial matrix elements for the $M4$ isomeric transitions that connect these states in the $N = 81$ odd-mass isotones.

is presented in Fig. 3.

The extended systematics of the $N=81$ $M4$ isomers is presented in Fig. 4. In the upper part of this figure the $h_{11/2}$-$d_{3/2}$ and $h_{11/2}$-$s_{1/2}$ energy separations are presented. The nuclei at ^{139}Ce and above are all notable in that the $h_{11/2}$ level stays nearly constant at 752.7 ± 4.0 keV. This is despite the fact that the $s_{1/2}$ and $d_{3/2}$ states cross at ^{145}Gd. Such a phenomenon may not be surprising in high-spin negative-parity levels which cannot effectively mix with the other nearby low-spin positive-parity states. On the other hand, the $s_{1/2}$ and $d_{3/2}$ states may mix strongly with other low-spin states and the core. Thus, their relative positions may be rather meaningless in a simple shell-model picture, whereas the $h_{11/2}$ state should be a rather pure shell-model state.

In the lower half of Fig. 4 the matrix elements extracted from the experimental half-lives and energies are presented for the $N=81$ $M4$ transitions.[7] The constant density model[8] yields the simple matrix-element prediction of 10.7, which is exceeded only for ^{133}Te. This is not unusual because most $M4$ transitions have significant hindrance factors.[9] The ^{133}Te case may be explained by the fact that this nucleus is very near the $Z=50$ $N=82$ doubly closed shell, where it is expected to be a good shell-model example. The other $N=81$ nuclei have nearly constant $|M|^2$ values which must indicate the strong similarity of these transitions. This and the constant energy of these states, despite a changing ground state, are difficult to explain in the shell-model picture. No other low lying $\frac{11}{2}^-$ states are expected to be found, because the mixing of the 3^- core vibration with the $s_{1/2}$ or $d_{3/2}$ states yields only lower-spin states. Perhaps a slight deformation of these nuclei would explain the hindrance of the $M4$ and $M1$ transitions (as appears to be the case in $N=80$ nuclei[10]), but the constant energy phenomenon is not easily interpreted.

For the 27.3-keV $M1$ transition, $|M|^2_{M1}=0.0204$, far less than the constant-density value, $|M|^2_{\rm CD}=2.05$. Such hindrances are common for $M1$ transitions, and may relate to the l forbiddenness of $d_{3/2} \rightarrow s_{1/2}$ as well as $d_{5/2}$ mixing in the 27.3-keV state wave function. The small $E2$ admixture is not surprising in that the $M1$ is strongly hindered while $E2$ transitions are generally enhanced. Here $|M|^2_{E2}=208$, which is much larger than the constant-density estimate $|M|^2_{\rm CD}=5.25$. Further work on the similar ^{147}Dy 72.0-keV $M1$ or the ^{143}Sm 107.7-keV $M1$ would also be useful for comparing these transitions because these isomers may offer strong insights into the shell-model characteristics of nuclei near $N=82$.

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[7] These values differ slightly in magnitude from EMK because of an error regretfully carried over from S. A. Moszkowski, in *Alpha-, Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland, Amsterdam, 1965), p. 881.

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