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Lifetimes of ground-band states in ^{192}Pt and ^{194}Pt

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The lifetimes of members of the ground-state bands in ^{192}Pt and ^{194}Pt have been measured by the Doppler-shift recoil-distance technique. These states were Coulomb excited by 149 MeV ^{40}Ar ions and measurements were carried out in coincidence with backscattered projectiles. The half-lives of the 2^+, 4^+, and 6^+ states in ^{192}Pt and of the 2^+ and 4^+ states in ^{194}Pt are 48.5 ± 2.5, 4.2 ± 0.2, 1.8 ± 0.7, 45.0 ± 2.4, and 3.7 ± 0.2 ps, respectively.

[NUCLEAR REACTIONS ^{192,194}Pt(^{40}Ar, ^{40}Ar′γ), E= 149 MeV; measured lifetimes of 2^+, 4^+, and 6^+ states in ^{192}Pt and of 2^+ and 4^+ states in ^{194}Pt; deduced $B(E2)$ values, compared with theory.]

I. INTRODUCTION

Recent investigations[1-3] of the ground bands of the even $^{188-194}$Pt isotopes have revealed strong irregularities in the rotational-like band structures, i.e., there exists a pronounced compression of the energy spacing between the 10^+ and 12^+ states. Lifetime measurements[3] of the $12^+ \rightarrow 10^+$ transition in ^{192}Pt indicate a $B(E2)$ value of (0.33 ± 0.06) $e^2 b^2$ which is only about 50% of the rotational limit.

It is shown in Ref. 3 that by using an intrinsic quadrupole moment Q_0 corresponding to an average of those values determined[4-8] for the ground-state transition in ^{192}Pt, the $B(E2; 12^+ \rightarrow 10^+)$ value is satisfactorily reproduced within the rotation-alignment (RA) model.[9,10] Although this is not a serious test of the validity of the RA model, it does raise the interesting question of whether it is possible to describe all transition probabilities in the ground band in this simple manner. The $4^+ \rightarrow 2^+$ transition is the only other one for which experimental data are available for comparison. Here the $B(E2)$ value deduced from the lifetime measurements of Schwarzschild[4] is less than half the value predicted by the RA model which, as expected, is essentially the same as the rotational limit.

In view of this discrepancy with the $B(E2; 4^+ \rightarrow 2^+)$ value in ^{192}Pt, it seemed important to remeasure the lifetime of this state. Further, an examination of the data in Table I reveals a rather wide spread in the reported values for the lifetime of the 2^+ state in this nucleus as well as in ^{194}Pt. Thus, we have carried out lifetime measurements on the low-lying members of the ground-state band in both ^{192}Pt and ^{194}Pt by utilizing the Doppler-shift recoil-distance technique.

II. EXPERIMENTAL PROCEDURES AND RESULTS

The Doppler-shift recoil-distance (DSRD) method is a very effective tool for the determination of the short nuclear lifetimes in the range of 10^{-12} to 10^{-10} s expected in this work. The apparatus (commonly referred to as the plunger) employed has been described in detail by Johnson *et al.*[11] so that only a brief account of the method will be given here.

The beam of 149-MeV ^{40}Ar ions from the Oak Ridge isochronous cyclotron was directed onto the target through a 2.7-mm diameter tantalum collimator which passes through an annular silicon surface-barrier detector. This detector intercepted the backscattered projectiles within a cone of 159° to 175°. A coaxial Ge(Li) γ-ray detector (18% efficient relative to a 7.6-cm × 7.6-cm NaI detector for 1332 keV at 25 cm) was placed 5.0 cm from the target at 25° with respect to the beam direction (some measurements were also made at 0°). The various components of the apparatus are shown schematically in Fig. 1. The stopper (B) consisted of a tantalum sheet that was lapped to a surface-finish tolerance of ~ 3 μm.

TABLE I. Half-life and $B(E2)$ values for ^{192}Pt and ^{194}Pt.

	Transition	E_γ (keV)	$T_{1/2}$ (ps) Previous work	Present work	α_T [a]	$B(E2)$ (e^2b^2)
^{192}Pt	$2^+\to 0^+$	316.49	35.3 ± 2.8 [b]	48.5 ± 2.5	0.0831	0.34 ± 0.02
			33.6 ± 4.5 [c]			
			45.1 ± 0.5 [d]			
			42.8 ± 1.5 [e]			
			39.3 ± 2.2 [f]			
	$4^+\to 2^+$	468.06	11.8 ± 2.1 [b]	4.2 ± 0.2	0.0287	0.58 ± 0.03
	$6^+\to 4^+$	580.80		1.8 ± 0.7	0.0172	0.47 ± 0.18
^{194}Pt	$2^+\to 0^+$	328.50	37.7 ± 1.8 [f]	45.0 ± 2.4	0.0746	0.31 ± 0.02
			50.5 ± 2.2 [g]			
			41.8 ± 1.0 [h]			
			41.8 ± 0.5 [d]			
			34.7 ± 3.5 [i]			
			41.8 ± 2.9 [j]			
	$4^+\to 2^+$	482.65	4.4 ± 0.7 [f]	3.7 ± 0.2	0.0267	0.57 ± 0.03

[a] Total internal conversion coefficients taken from Refs. 21 and 22 have been reduced by 2% to account for possible deviations from theory found in this region by Stelson and Raman (Ref. 23).

[b] Value from Schwarzschild (Ref. 4) determined by delayed coincidence method.

[c] Value from Beraud *et al.* (Ref. 5) determined by centroid-shift method.

[d] Calculated from (α,α') Coulomb excitation $B(E2)$ values of Ronningen *et al.* (Ref. 6).

[e] Value from Smith and Simms (Ref. 7) determined by centroid-shift method.

[f] Calculated from the Coulomb excitation $B(E2)$ value of Milner *et al.* (Ref. 8).

[g] Recoil-distance measurement by R. H. Nord, [Ph.D. thesis, Univ. of Wisconsin, 1971 (unpublished)].

[h] Calculated from $(^{16}O, ^{16}O')$ and (p,p') Coulomb excitation $B(E2)$ values of Glenn *et. al.* (Ref. 24).

[i] Value from Berkes, *et al.* determined by centroid-shift method [I. Berkes, R. Rougny, M. Meyer-Levy, R. Chery, G. Lhersonneau, and A. Troncy, Phys. Rev. C 6, 1098 (1972)].

[j] Calculated from inelastic α-particle scattering work of Baker *et al.* (Ref. 25).

Fast timing pulses derived from the γ rays and the backscattered ^{40}Ar projectiles were used for start-stop requirements of a time-to-amplitude converter (TAC). The pulse height information from the TAC and from the γ-ray and heavy-ion detectors was digitized by a fast analog-to-digital converter and stored in the event-by-event mode on magnetic tape with the aid of a PDP-11/05 computer.

The target employed in these measurements was a 3.1-mg/cm^2 metallic platinum foil enriched to 57.3, 26.1, 11.0, 4.7, and 0.9% in mass 192, 194, 195, 196, and 198, respectively. α-particle energy-loss measurements were used to determine the target thickness. The presence of the ^{192}Pt and ^{194}Pt isotopes in high comparable enrichment permitted the simultaneous measurement of the half-lives in these two nuclides. The platinum foils were deposited by a standard electroplating technique[12] onto tin disks from a dinitroso-platinum II complex. The tin backing was then removed with 2 *M* nitric acid.

The average recoil velocity imparted to the recoiling platinum ions when the ^{40}Ar backscattered ions were detected in coincidence with the annular silicon detector was determined by two methods. In the first method a weighted average value of

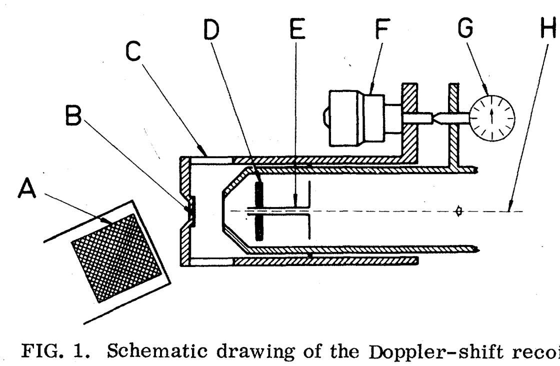

FIG. 1. Schematic drawing of the Doppler-shift recoil-distance apparatus. Legend: (A) Coaxial Ge(Li) detector at 25° to the beam direction; (B) tantalum stopper; (C) plastic section for viewing target; (D) annular silicon surface-barrier detector; (E) tantalum collimator with front face coated with lead; (F) Boekler micrometer; (G) Null meter; and (H) ^{40}Ar beam.

v/c was determined from the energy difference between the unshifted and shifted peaks of the 316.49- and 328.47-keV transitions in ^{192}Pt and ^{194}Pt, respectively, when the Ge(Li) detector was located at 0° with respect to the beam direction. The expression used in this calculation was that given by Quebert *et al.*[13] It considers deviations from axial symmetry and is second order in v/c. The average value of v/c here was 0.0244 ± 0.0005. In the second method we used the expression of Guidry *et al.*[14] which considers the recoil velocity at the front edge of the target and accounts for changes that occur as a recoiling nucleus traverses the target in the forward direction. This calculation yields a value of $v/c = 0.0254 \pm 0.0005$ for ^{192}Pt and $v/c = 0.0253 \pm 0.0005$ for ^{194}Pt. In our lifetime calculations we used a single weighted average value of $v/c = 0.0249 \pm 0.0004$ for both nuclei.

This recoil velocity leads to a large separation between the shifted and unshifted peaks of the $4^+ \to 2^+$ transitions and makes it somewhat difficult to resolve the shifted peak of the 468.06-keV transition in ^{192}Pt from the unshifted peak of the 482.65-keV transition in ^{194}Pt. In order to reduce this problem the Ge(Li) spectrometer was moved to an angle of 25° with respect to the beam direction for the lifetime measurements. The four peaks are then readily resolved as can be seen in Fig. 2(b). Figure 2(a) shows portions of the γ-ray spectra containing $2^+ \to 0^+$ transitions in ^{192}Pt and ^{194}Pt at some of the selected target-stopper distances. Note that the shifted peaks in these spectra are somewhat broader than the unshifted components. This results primarily from the velocity spread of the recoiling platinum ions brought about by the relatively thick (3.1 mg/cm^2) target.

From the raw data in Fig. 2 it is possible to obtain half-lives that are accurate to about 10–15% by a rather simple analysis. It is easily shown that the intensities of the shifted (I_s) and unshifted (I_u) peaks are related exponentially to

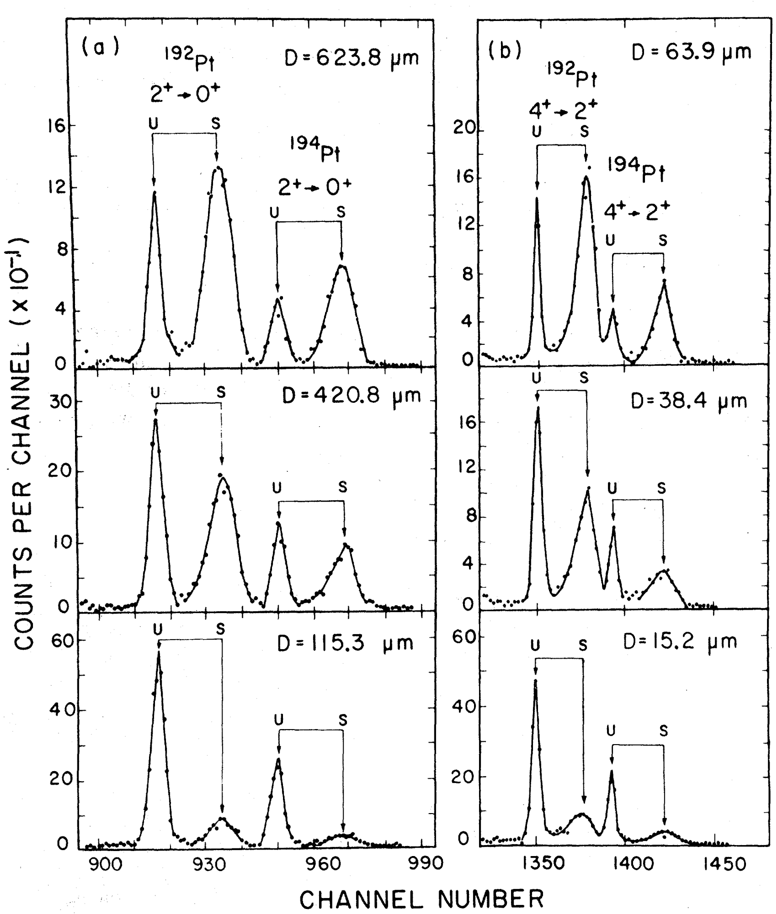

FIG. 2. Portions of the γ-ray spectra displaying the shifted and unshifted γ rays of (a) the $2^+ \to 0^+$ and (b) the $4^+ \to 2^+$ transitions in ^{192}Pt and ^{194}Pt taken at several target-stopper separations.

the half-life $T_{1/2}$ of a state by

$$R \equiv \frac{I_u}{I_u+I_s} = \exp -\left(\frac{\ln 2 \cdot D}{\bar{v} \cdot T_{1/2}}\right), \quad (1)$$

where D is the target-stopper distance and $\bar{v}$ is the average velocity of the recoiling ions.

In order to achieve accuracy higher than 10–15% a number of corrections must be applied. The various effects that give rise to perturbations for which corrections must be made to the data have been discussed at some length in Refs. 11 and 15. These corrections have been incorporated into a computer code ORACLE, developed by Sturm and Guidry.[15] In this program corrections are applied for (a) the positional dependence of the solid angle for the shifted component, (b) the relativistic contribution to the solid angle of the shifted component, (c) the variation of detector efficiency with distance for the shifted and unshifted peaks, (d) the effect of feeding from higher-lying states, and (e) the effect of perturbations of the nuclear alignment from hyperfine interactions which alter the angular distribution of the γ rays. The program ORACLE applies the corrections in an iterative procedure to arrive at the final half-lives. All the data analyzed have been corrected in a consistent manner by this program. (See Fig. 3.)

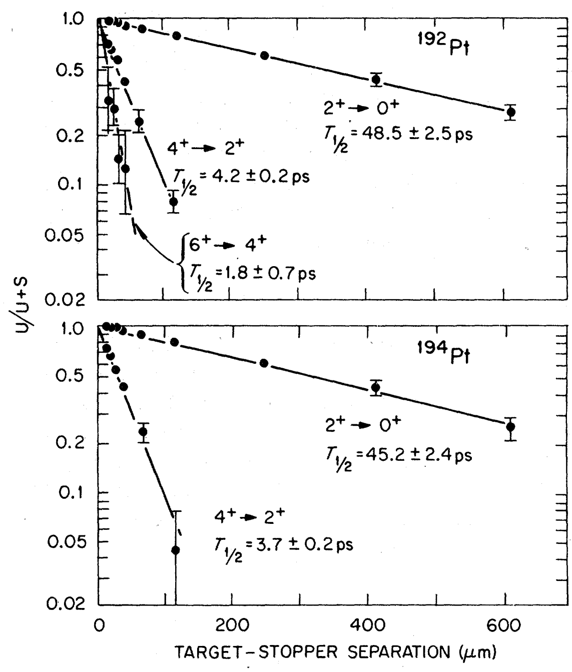

FIG. 3. Plots of the ratios of unshifted to the sum of the unshifted and shifted γ-ray intensities as a function of target-stopper distance for ^{192}Pt and ^{194}Pt. The half-lives given are those obtained after the corrections as discussed in the text.

The perturbations of the nuclear alignment of recoiling ions in vacuum have been considered in some detail by Johnson *et al.*[11] We apply the same considerations here with the frequently used treatment of Abragam and Pound[16] for the alignment loss. This treatment proposes that if the angular distribution for a γ ray emitted from an aligned nucleus is given by

$$W(\theta) = 1 + \sum_{k=0}^{k=2n} A_k G_k P_k(\cos\theta), \quad (2)$$

then the G_k coefficients represent a statistical attenuation as a function of time, i.e.,

$$G_k(t) = e^{-t/\tau_k}, \quad (3)$$

where τ_k is a relaxation constant of order k.

There is no pertinent angular distribution information available on ^{192}Pt and ^{194}Pt and, thus, we have used that from the Winther-de Boer[17] coupled equations computer program for a rigid rotor as a reasonable approximation. Values of 25 and 100 ps for $\tau_2(\tau_4 = \frac{1}{3}\tau_2)$ were used in separate calculations and the maximum variation in the half-life of any state was 3%. The half-lives quoted in Table I were computed for $\tau_2 = 25$ ps and the errors quoted for the half-lives account for the uncertainty in this value.

For such experiments as these it is also necessary to consider the possible effects of Coulomb-nuclear interference on the γ-ray angular distributions and on the intensities of feeding cascades. At a bombarding energy of 149 MeV, the distance of closest approach between the surfaces of the target and projectile nuclei was 4.8 fm if spherical surfaces with radii of $1.25A^{1/3}$ fm are assumed. Based on the data in Refs. 18–20 it was concluded that Coulomb-nuclear interference effects play no major role in the analysis of the data at this separation.

III. DISCUSSION AND COMPARISON WITH THEORY

The half-lives determined in this work are summarized in Table I, together with the deduced $B(E2)$ values. Internal conversion coefficients of Hager and Seltzer[21] with contributions for N and higher shells based on the work of Dragoun, Plajner, and Schmutzler[22] were used. In addition, these values of α_T were then reduced to account for the observation by Stelson and Raman[23] that the theoretical values may be too large by about 2% in this region.

For comparison, we also show in Table I half-life values extracted from previous measurements. The wide variation in the values of the 2^+ state in both ^{192}Pt and ^{194}Pt is most noticeable. Our values for the 2^+ states are in best agreement with the values from the inelastic scattering experiments.[6,24,25]

The most striking feature observed in Table I is the large difference in our half-life measurement of the $4^+ \to 2^+$ transition and the measurement reported[4] previously. The present value differs from that of Schwarzschild[4] by more than a factor of 2.

As was mentioned in Sec. I, it is interesting to see if our $B(E2)$ values for the $2^+ \to 0^+$, $4^+ \to 2^+$, and $6^+ \to 4^+$ transitions yield the same intrinsic quadrupole moment Q_0 as the $B(E2; 12^+ \to 10^+)$ value. In order to perform the calculations in a consistent manner, $B(E2)/Q_0$ is calculated within the RA model for each of these transitions. Within this model the $B(E2)$ values are expressed as

$$B(E2; I \to I-2) = \frac{5}{16\pi} e^2 Q_0^2 \Big[\sum_{\Omega_1 \Omega_2} C^I_{K\Omega_1\Omega_2} C^{I-2}_{K\Omega_1\Omega_2} \langle IK20 | I-2, K \rangle \Big]^2, \tag{4}$$

where $K = \Omega_1 + \Omega_2$ and the $C^I_{K\Omega_1\Omega_2}$ are the amplitudes which expand the total wave function in terms of the basis states given by

$$|\Omega_1\Omega_2\rangle^I_m = \left(\frac{2I+1}{16\pi^2}\right)^{1/2} [\mathfrak{D}^I_{MK} \alpha^\dagger(\Omega_1)\alpha^\dagger(\Omega_2) + (-1)^{I+K} \mathfrak{D}^I_{M-K} \alpha^\dagger(\overline{\Omega}_1)\alpha^\dagger(\overline{\Omega}_2)], \tag{5}$$

where $\alpha^\dagger(\Omega)$ creates a quasiparticle with spin projection Ω on the symmetry axis and $\alpha^\dagger(\overline{\Omega})$ a quasiparticle moving in the time reversed orbital and $\mathfrak{D}$ is the rotational wave function.

In the calculations it was assumed that there is an oblate deformation ($\epsilon_2 = -0.18$), that there is alignment of two $i_{13/2}$ neutrons, and that the pairing strength G is 0.102 MeV. A comparison with the measured $B(E2)$ values yields a weighted mean of the intrinsic quadrupole moment Q_0 of 4.26 G. As can be seen from Fig. 4, good agreement is obtained for all points within this common value of Q_0 and the RA model. However, as shown by the dashed line in Fig. 4, for the $2^+ \to 0^+$, $4^+ \to 2^+$, and $6^+ \to 4^+$ transitions, there is also good agreement with the values from the rotational limit. This is not a surprising result; but in the considerations discussed here, the most noteworthy point seems to be that when applied to the RA model, the value $Q_0 = 4.26$ G reproduces the $B(E2)$ values for both the low spin transitions and the $12^+ \to 10^+$ transition.

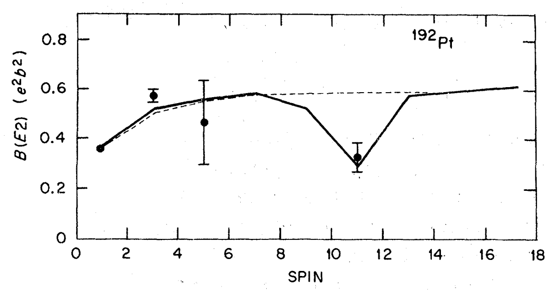

FIG. 4. Comparison of experimental (points) and calculated $B(E2)$ values in ^{192}Pt for the downward transitions. The solid line shows values from the rotation-alignment model and the dashed line shows values from the rotational limit. Note that points are plotted halfway between initial and final spins.

If the ideas of Piiparinen *et al.*[2] are applicable, then a more meaningful test of the interpretation of ^{192}Pt within the framework of the RA model may be possible. They[2] have suggested that the $(\pi h_{11/2})_{10}^{-2}$ configuration is the main component in the wave function of the 10^+ state, while the $I \geq 12^+$ states are primarily described by the $\nu i_{13/2}$ configuration. Calculations[3] in the RA model indicate that if this is the case then the $B(E2; 10^+ \to 8^+)$ as well as the $B(E2; 12^+ \to 10^+)$ will be reduced considerably such that the lifetime of the 10^+ state would be about 1 ps. Further lifetime measurements following Coulomb excitation with still heavier projectiles are planned in the hope of exciting the 10^+ state and perhaps providing a more rigorous test of the rotation-alignment model.

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[1]L. Funke, P. Kemnitz, G. Winter, S. A. Hjorth, A. Johnson, and Th. Lindblad, Phys. Lett. 55B, 436 (1975).

[2]M. Piiparinen, J. C. Cunnane, P. J. Daly, C. L. Dors,

F. M. Bernthal, and T. L. Khoo, Phys. Rev. Lett. 34, 1110 (1975).
[3]S. A. Hjorth, A. Johnson, Th. Lindblad, L. Funke, P. Kemnitz, and G. Winter, Nucl. Phys. A262, 328 (1976).
[4]A. Schwarzschild, Phys. Rev. 141, 1206 (1966).
[5]R. Beraud, I. Berkes, R. Chery, R. Haroutunian, Michele Levy, G. Marguier, G. Marest, and R. Rougny, Phys. Rev. C 1, 303 (1970).
[6]R. Ronningen, R. B. Piercey, A. V. Ramayya, J. H. Hamilton, W. K. Dagenhart, S. Raman, and P. H. Stelson, Bull. Am. Phys. Soc. (to be published).
[7]G. J. Smith and P. C. Simms, Nucl. Phys. A202, 409 (1973).
[8]W. T. Milner, F. K. McGowan, R. L. Robinson, P. H. Stelson, and R. O. Sayer, Nucl. Phys. A177, 1 (1971).
[9]F. S. Stephens and R. S. Simon, Nucl. Phys. A183, 257 (1972).
[10]F. S. Stephens, P. Kleinheinz, R. K. Sheline, and R. S. Simon, Nucl. Phys. A222, 235 (1974).
[11]N. R. Johnson, R. J. Sturm, E. Eichler, M. W. Guidry, G. D. O'Kelley, R. O. Sayer, D. C. Hensley, N. C. Singhal, and J. H. Hamilton, Phys. Rev. C 12, 1927 (1975).
[12]A. G. Gray, *Modern Electroplating,* (Wiley, New York, 1953), pp. 358–360.
[13]J. L. Quebert, K. Nakai, R. M. Diamond, and F. S. Stephens, Nucl. Phys. A150, 68 (1970).
[14]M. W. Guidry, P. A. Butler, P. Colombani, I. Y. Lee, D. Ward, R. M. Diamond, F. S. Stephens, E. Eichler, N. R. Johnson, and R. Sturm, Nucl. Phys. A266, 228 (1976).
[15]R. J. Sturm and M. W. Guidry, Nucl. Instrum. Methods 138, 345 (1976).
[16]A. Abragam and R. V. Pound, Phys. Rev. 92, 943 (1953).
[17]A. Winther and J. de Boer, *Coulomb Excitation,* edited by K. Alder and A. Winther (Academic, New York, 1966), p. 303.
[18]P. R. Christensen, J. Chernov, E. E. Gross, R. Stokstad, and F. Videbaek, Nucl. Phys. A207, 433 (1973).
[19]C. E. Bemis, Jr., P. H. Stelson, F. K. McGowan, W. T. Milner, J. L. C. Ford, R. L. Robinson, and W. Tuttle, Phys. Rev. C 8, 1934 (1973).
[20]E. E. Gross, H. G. Bingham, M. L. Halbert, D. C. Hensley, and M. J. Saltmarsh, Phys. Rev. C 10, 45 (1974).
[21]R. S. Hager and E. C. Seltzer, Nucl. Data A4, 397 (1968).
[22]O. Dragoun, Z. Plajner, and F. Schmutzler, Nucl. Data A9, 119 (1971).
[23]P. H. Stelson and S. Raman (private communication).
[24]J. E. Glenn, R. J. Pryor, and J. X. Saladin, Phys. Rev. 188, 1905 (1969).
[25]F. T. Baker, A. Scott, T. H. Kruse, W. Hartwig, E. Ventura, and W. Savin, Phys. Rev. Lett. 37, 193 (1976).