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Alpha-Gamma Angular Correlations in Three Heavy Odd-A Nuclides*

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Angular correlations between alpha particles and gamma rays have been measured in liquid sources of three separate nuclides, americium-243, uranium-233, and neptunium-237. The angular-correlation functions were experimentally determined for five transitions, and the relative angular-momentum mixing ratios for these transitions were deduced. The mixing ratios of $L=2$ and 0 agree with theory, but the $L=4$ and 2 mixing ratios are somewhat higher than predicted. Upper limits of the half-lives of 99-keV and 45-keV states in Th^{229} were measured, respectively, as 0.8×10^{-9} and 1.2×10^{-9} sec. From a comparison of the attenuated angular correlation in Am^{243}, and a previously measured angular correlation in Am^{241}, it is deduced that an extranuclear interaction occurs whose time duration is less than 1.2×10^{-9} sec.

INTRODUCTION

Few measurements of the α-particle partial-wave branching in transitions from ground states in odd-A nuclides have been reported in the literature.[1–3] Such measurements are of interest, since they give information about the process of α-particle formation in the nucleus.

Alpha-particle partial-wave branching can be found from α-γ angular-correlation data. Measurements of the α-γ angular correlations of three nuclides, uranium-233, neptunium-237, and americium-243, are described here. It will be shown that the intensities of the partial waves are generally in agreement with predictions based on the unified model of the nucleus.[4] It will be seen that relative signs of the amplitudes of the partial waves agree with predictions by Mang[5] and by Rasmussen.[6]

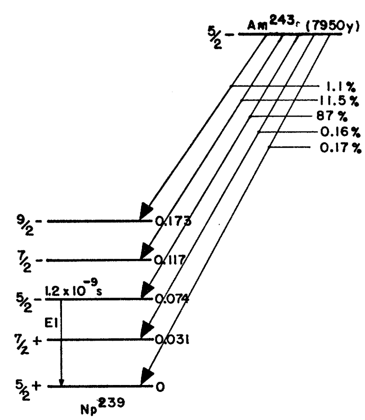

Fig. 1. Decay scheme of Am^{243}.

* Based on a thesis submitted to the Department of Physics and Astronomy of the University of Maryland in partial fulfillment of the requirements of the Ph.D. degree.

[1] F. Falk, S. Tornkvist, J. E. Thun, H. Snellman, K. Siegbahn, and F. Asaro (private communication).

[2] E. S. Murphy, Argonne National Laboratory Report No. ANL-6685, 1963 (unpublished).

[3] E. Flamm, University of California Radiation Laboratory Report No. UCRL-9325, 1960 (unpublished).

[4] A. Bohr, P. O. Froman, and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 29, No. 10 (1955).

[5] H. J. Mang, Ann. Rev. Nucl. Sci. 14, 1 (1964).

[6] J. O. Rasmussen, University of California Radiation Laboratory Report No. UCRL-2431, 1953 (unpublished).

THEORY

It can be shown that the α-γ angular correlation $\omega(\theta)$ is of the form[7]

$$\omega(\theta)=\sum_\nu G_\nu A_\nu P_\nu(\cos\theta). \tag{1}$$

In this equation ν is even; $P_\nu(\cos\theta)$ are the Legendre polynomials; θ is the angle between α particle and γ ray; A_ν are coefficients which are known functions of the partial-wave branching ratios, the spins of the nuclear-energy levels in the decay, and the angular momenta of the α particles; and G_ν is the attenuation coefficient which expresses the influence upon the angular correlation of interaction between extranuclear fields, and the electric and magnetic moments of intermediate-state nuclei.

The products of the coefficients $G_\nu A_\nu$ are determined by means of a fit of the experimental data to Eq. (1). Values of G_ν are estimated by making use of previous measurements performed on sources of even-even nuclides, and the theory of perturbed angular correlations (see Appendix A). A_ν are determined and partial-wave amplitudes g_L with angular momenta L can be calculated using angular-momentum theory (see Appendix B).

The simple barrier-penetration theory of Gamow,[8]

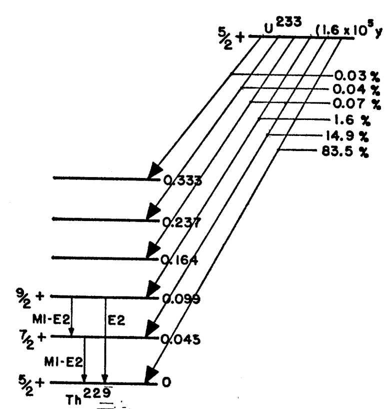

Fig. 2. Decay scheme of U^{233}.

[7] K. Alder, Helv. Phys. Acta 25, 235 (1952).

[8] G. Gamov, Z. Physik 51, 204 (1928).

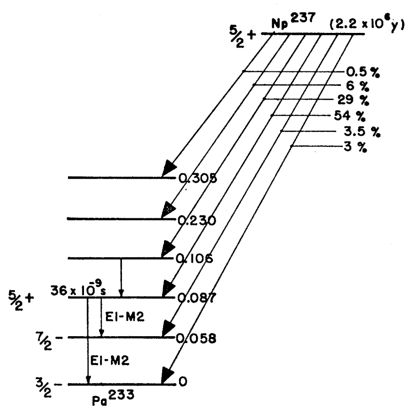

FIG. 3. Decay scheme of Np^{237}.

and of Condon and Gurney,[9] gives predictions for g_L. In general, g_0/g_L is greater than predicted by a factor of C_L, which is called the hindrance factor. Using the unified model, Bohr, Froman, and Mottelson[4] (BFM) have derived the following relationship between $(g_L/g_{L'})^2$ in odd-A nuclei and C_L values in nearby even-even nuclei:

$$(g_L/g_{L'})^2=\frac{C_L}{C_{L'}}\frac{(I_iLKO|IK)^2}{(I_iL'KO|IK)^2}, \qquad (2)$$

where $(I_iLKO|IK)$ is a Clebsch-Gordan coefficient coupling the initial-state spin I_i with the α-particle angular-momentum L, to form the intermediate-state spin I; and K is the projection of the nuclear spin on the axis of symmetry of the nucleus. The equation is given for favored transitions for which K does not change. C_L values in even-even nuclei can be obtained from intensity measurements.

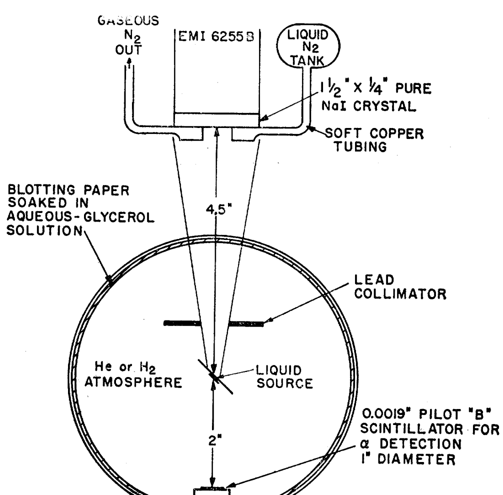

FIG. 4. Source chamber (schematic) in the π position. To attain the $\frac{1}{2}\pi$ position, the chamber, with the alpha-particle detector attached, is rotated $\frac{1}{2}\pi$ clockwise; the source, lead collimator, and pure-NaI crystal remain stationary.

[9] E. U. Condon and R. W. Gurney, Phys. Rev. **33**, 127 (1929).

Chasman and Rasmussen[10] (CR) have considered the effect of quadrupole coupling on Eq. (2) in U^{233} for $L=0$ and 2, and have concluded that, for this case, the right-hand side of the equation should be multiplied by 1.2. Theories have been proposed by both Mang[5] and Rasmussen[6] which explain the variation of g_L/g_0 with atomic number Z. Both authors predict that g_4/g_2 should pass from positive to negative values in the vicinity of $Z=96$, and that g_2/g_0 should remain positive for all presently known Z. Mang[5] assumes that the alpha-particle surface amplitudes can be found from the overlapping of shell-model wave functions. Rasmussen[6] calculates the influence of quadrupole coupling upon an alpha-particle wave function, which is an assumed δ function at the nuclear surface.

EXPERIMENTAL ARRANGEMENT

The partial-decay schemes of the nuclides which were chosen for the experiment are shown in Figs. 1, 2, and 3. For Am^{243} (Refs. 11–13) and Np^{237} (Ref. 14), $I=I_i$, $L=0$ is allowed, and g_0 and g_2 are measured for these two

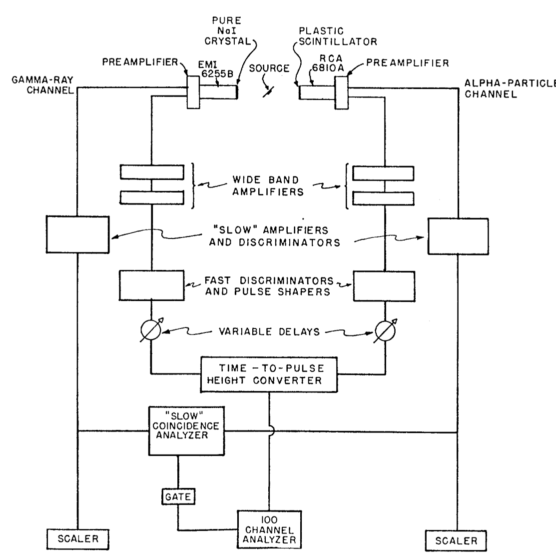

FIG. 5. Fast-slow coincidence circuit used in the angular-correlation and half-life measurements.

[10] R. R. Chasman and J. O. Rasmussen, Phys. Rev. **115**, 1260 (1959).

[11] J. P. Hummel, University of California Radiation Laboratory Report No. UCRL-3456, 1956 (unpublished).

[12] D. Strominger, J. M. Hollander, and G. T. Seaborg, Rev. Mod. Phys. **30**, 585 (1958).

[13] F. S. Stephens, F. Asaro, and J. Perlman, Phys. Rev. **113**, 212 (1959).

[14] S. A. Baranov, V. M. Kulakov, P. S. Samoilov, A. G. Zelenkov, and Yu. F. Rodionov, Zh. Eksperim. i Teor. Fiz. **41**, 1733 (1961) [English transl.: Soviet Phys.—JETP **14**, 1232 (1962)].

TABLE I. Summary of results for α-γ angular-correlation measurements.[a]

Nuclide	Theoretical A_2 (BFM)[b]	g_2/g_0 (BFM)	Theoretical A_2 (BFM with CR correction)[c]	g_2/g_0 (BFM with CR correction)[c]	Expt. G_2A_2	Expt. A_2	G_2	γ-ray mixing ratio $\frac{\langle I\Vert H_2(l)\Vert I_f\rangle^2}{\langle I\Vert H_2(l')\Vert I_f\rangle^2}$	γ-ray mixture
Am^{243}	−0.36	+0.47	−0.40	+0.55	−0.364±0.015	−0.41±0.02	0.88	Pure	$E1$
	+0.30	−0.47	+0.33	−0.55					
U^{233} (99 keV)	+0.27	+0.37			+0.18 ±0.04	+0.20±0.04	0.90	Pure	$E2$
	+0.42	−0.37							
U^{233} (43 keV)	+0.01	+0.17			−0.02 ±0.04	−0.02±0.04	0.80	+0.163	$M1/E2$
	+0.06	−0.17							
Np^{237} (87 keV)	+0.17	+0.52	+0.18	+0.62	+0.11 ±0.04	+0.12±0.04	0.88	$+2.8\times10^{-3}$	$M2/E1$
	−0.13	−0.52	−0.13	−0.62					
Np^{237} (29 keV)	+0.14	+0.52	+0.15	+0.62	+0.25 ±0.15	+0.28±0.17	0.88	$+1.4\times10^{-4}$	$M2/E1$
	−0.11	−0.52	−0.12	−0.62					

[a] Quoted errors correspond to uncertainties in the counting statistics of one standard deviation.
[b] See Ref. 4.
[c] See Ref. 10.

nuclides; for U^{233} (Refs. 15–17), $I\neq I_i$, $L=0$ is not allowed, and only g_2 and g_4 are found from this experiment.

A schematic diagram of the experimental arrangement is shown in Fig. 4. Liquid sources ($1N$ $HClO_4$ for Am^{243} and U^{233}, and $3N$ H_2SO_4 for Np^{237}) were used, because attenuation of the angular correlation is reduced in the liquid state. The sources were prepared by depositing approximately 10 μl of the active solution onto a stretched, 0.125-in.-thick polyester membrane. A glass disk was laid on the aliquot, and vacuum grease was spread around the edges to contain the solution. A cooled, pure-NaI detector was used in the gamma-ray channel to give good time and energy resolution, which were needed both to reduce accidental coincidences and to discriminate with respect to γ-ray energy.

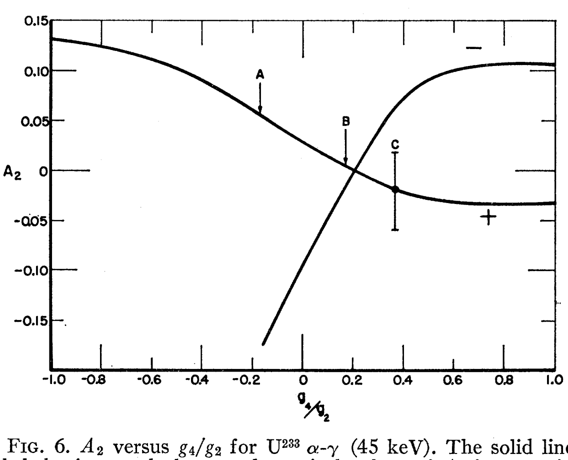

FIG. 6. A_2 versus g_4/g_2 for U^{233} α-γ (45 keV). The solid lines labeled minus and plus are theoretical values of A_2 for negative and positive $E1/M2$ phases, respectively. A is the BFM (Ref. 4) prediction with $g_4/g_2<0$; B is the BFM prediction with $g_4/g_2>0$; C is the experimental value found in this work, $G_2=0.88$. The positive $E1/M2$ phase is in better agreement with the result shown in Fig. 7 than is the negative phase.

[15] J. O. Newton, Nucl. Phys. 3, 345 (1957).
[16] J. O. Newton, Nucl. Phys. 5, 218 (1958).
[17] L. L. Gol'din, G. I. Novikova, and E. F. Tretyakov, Phys. Rev. **103**, 1004 (1956).

The fast circuitry is shown in Fig. 5. The time resolution ($2\tau_R$) with 5-MeV α particles and 74-keV gamma rays is less than 4 nsec. The source chamber was lined on the inside with blotting paper soaked in an aqueous glycerol solution adjusted to give the same water-vapor pressure as the sources. The chamber was filled with either H_2 or He to improve the α-particle detection efficiency.

The angular correlation was measured as follows: Time-to-pulse-height spectra were taken at π and $\frac{1}{2}\pi$. Counts under the coincidence peak were summed, accidental background counts were subtracted, and the result was divided by the α-channel rate. The equation

$$\frac{\omega(\pi)}{\omega(\frac{1}{2}\pi)}=\frac{1+G_2A_2P_2(\cos\pi)}{1+G_2A_2P_2(\cos\frac{1}{2}\pi)} \tag{3}$$

was solved for G_2A_2. P_4, P_6 and higher terms are zero for the transitions measured in the Am^{243} and Np^{237}, and have an insignificant effect on $\omega(\pi)/\omega(\frac{1}{2}\pi)$ for the two angular correlations studied in U^{233}.

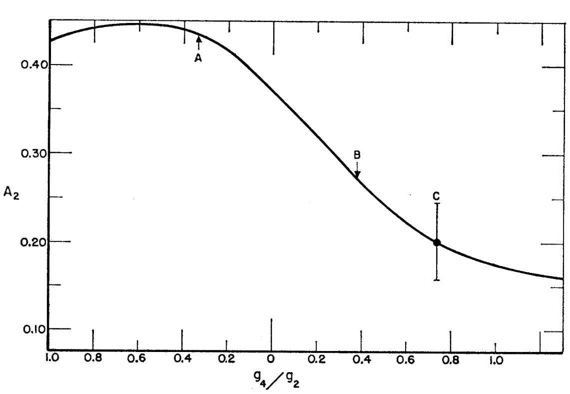

FIG. 7. A_2 versus g_4/g_2 for U^{233}, α-γ (99 keV). A, B, and C are as in Fig. 6. This experiment establishes $g_4/g_2>0$ as predicted by Rasmussen (Ref. 6) and Mang (Ref. 5), and also appears to give g_4/g_2 significantly greater than the BFM (Ref. 4) values.

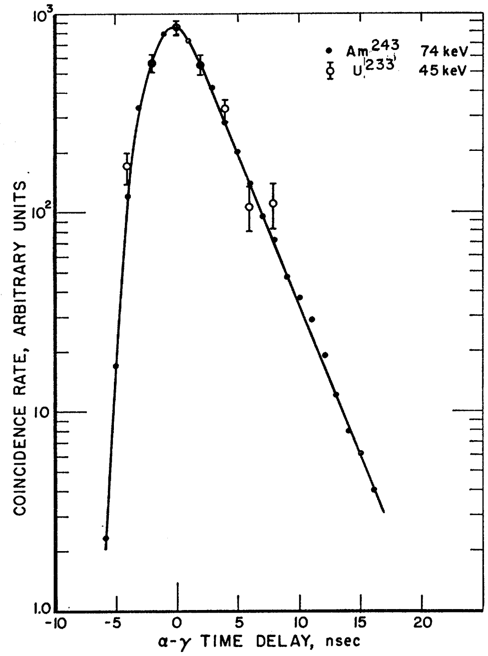

FIG. 8. Time-to-pulse-height spectrum of U^{233} α-γ (45 keV) compared to that of α-γ (74 keV) Am^{243}, showing that the 45-keV state has a half-life ≤ 1.2 nsec.

RESULTS

The results of the angular-correlation measurements are shown in Table I and Figs. 6 and 7. The time-to-pulse-height spectra for U^{233} are shown in Figs. 8 and 9.

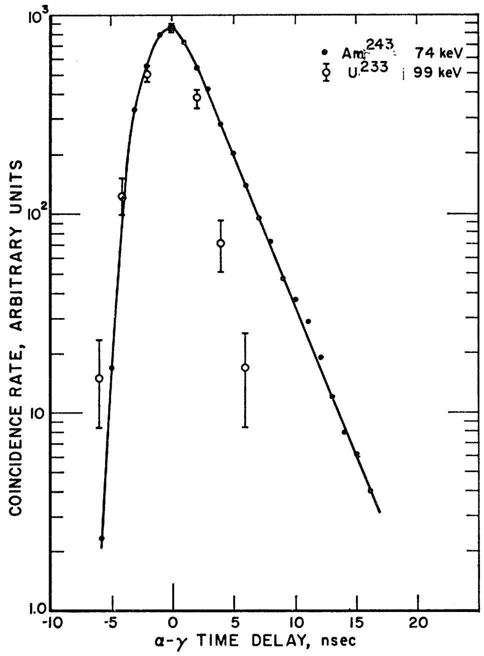

FIG. 9. Time-to-pulse-height spectrum of U^{233} α-γ (99 keV), showing that the 99-keV state has a half-life <0.8 nsec.

For comparison, the spectrum of Am^{243}, with an intermediate-state half-life of 1.2×10^{-9} sec, is also shown. The half-lives of the 99- and 45-keV levels of Th^{229} are found to be less than 0.8×10^{-9} sec and 1.2×10^{-9} sec, respectively. Attenuation coefficients calculated as described in Appendix A are listed in Table I.

A correction was made to G_2A_2 for Am^{243} to account for α-γ (74-keV) background-coincidence pulses arising from the sequential transitions $\frac{5}{2}-\rightarrow\frac{7}{2}-\rightarrow\frac{5}{2}-\rightarrow\frac{5}{2}+$. Flamm[3] has calculated that the angular correlation in this case is very close to isotropic, and that the resulting multiplicative correction factor is 1.13. Similar correction factors in Np^{237}, due to triple cascades through the 106-keV level in Pa^{233}, were calculated and applied here. Coincidences resulting from the triple cascades were assumed to be isotropic because of strong interaction of the nucleus in the 87-keV state with the singly ionized L shell resulting from the L-electron conversion in the 106-keV state.

G_2A_2 coefficients in Np^{237} were determined as a function of time delay between the α particle and γ ray. Somewhat surprisingly, no systematic decrease in G_2A_2 was detected with increasing time delay.[18] Nevertheless, the results of the two Np^{237} experiments are consistent if $G_2\simeq0.88$. If G_2 is chosen much different, the value of g_2/g_0 in the two experiments are in disagreement.

DISCUSSION AND CONCLUSIONS

The following conclusions can be drawn from Table I and Figs. 6 and 7:

(1) Values of A_2 measured in the Am^{243} and Np^{237} experiments are in good agreement with the BFM[4] theory corrected for quadrupole coupling. Recently, Falk *et al.*[1] have measured the α-γ angular correlation in solid sources in a high-decoupling magnetic field, and found $A_2=-0.404\pm0.010$ in Am^{243}, in agreement with this experiment.

(2) Experimental values of $(g_4/g_2)^2$ in U^{233} are somewhat higher than predicted by the BFM[4] theory. This effect may be due to quadrupole coupling, but cannot be tested here because no such calculations have been made for $L=4$ waves.

(3) Comparison of G_2 for Am^{243} and for Am^{241}, observed in a previous experiment, implies strong extranuclear interaction over the first nanosecond or less, and weaker interaction thereafter. The reasoning is as follows: Krohn, Novey, and Raboy[19] have found G_2 to decrease exponentially as a function of time delay between alpha particle and gamma ray for Am^{241} in $1N$ $HClO_4$ with a decay constant of $\lambda=13.6\times10^6$ sec^{-1}.

[18] This result perhaps seems reasonable from a consideration of the liquid environment of the Pa^{233} nucleus in the intermediate state. The Pa^{233} atom exists in acid solutions as Pa^{+5}. Surrounding the Pa is a sphere of H_2O molecules. It can be expected that high symmetry of the coordination sphere of H_2O molecules, combined with the loss of all electrons above the spherically-symmetric radon core, will produce low-field gradients at the nucleus.

[19] V. E. Krohn, T. B. Novey, and S. Raboy, Phys. Rev. **105**, 234 (1957).

To account for the present results in Am^{243}, a decay constant of $\lambda=1.0\times10^{8}$ sec^{-1} is required. The observed interactions are clearly different. The time development of G_2 must be the same for both nuclides (equal moments and similar chemical environments). Both correlations must therefore undergo a strong initial, but temporary ($\lesssim 1.2$ nsec), attenuation, and also a weaker, long-term attenuation. The long-term interaction is not detected in Am^{243} because of the short half-life of the intermediate state (1.2 nsec). The 60-nsec state in Np^{237}, to which Am^{241} decays, is fortuitously long from this standpoint. The above interpretation of the data implies that previously published values of A_2 for Am^{241} are low.

(4) In all cases, the phase choices of Mang[5] and of Rasmussen[6] for g_2/g_0 and g_4/g_0 (here all positive) agree with the experimental results.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to R. W. Hayward, who suggested this problem and provided help in many ways. I am indebted to J. Whittaker for his help with the fast circuitry, Mrs. D. Walker for her assistance with the neptunium experiment, and R. Scharenburg for drawings of his pure-NaI system.

APPENDIX A: ATTENUATIONS OF ANGULAR CORRELATIONS

Extranuclear electric and magnetic fields interact with, and disturb the orientation of, nuclei in their intermediate states. The angular correlation is therefore changed from the field-free case. Alder[7] has shown that perturbations of the angular correlations, due to interactions in the intermediate states, can be represented by attenuation coefficients G_ν, as shown in Eq. (1). Abragam and Pound[20–22] have derived analytic expressions for G_ν as follows:

$$G_\nu=1/(1+\lambda_\nu\tau)\,, \tag{4}$$

where τ represents the mean interaction time; λ_ν for electric interaction with the nuclear quadrupole is

$$\lambda_\nu=\frac{3}{80}\left(\frac{eQ}{\hbar}\right)^2 \times\frac{\langle(\partial\mathcal{E}_z/\partial z)^2\rangle\nu(\nu+1)[4I(I+1)-\nu(\nu+1)]\tau_c}{I^2(2I-1)^2}. \tag{5}$$

In this equation, $\langle(\partial\mathcal{E}_z/\partial z)^2\rangle$ is the mean-square value of the electric-field gradient, Q is the quadrupole moment of the nucleus, and τ_c is the correlation time, roughly defined as the time for which the liquid presents a static environment. Equation (4) holds for interacting fields which vary rapidly compared to frequencies of precession of the moments with the field. Murphy[2] has measured G_2 for several nuclides, U^{232}, Th^{230}, and Ra^{226} in $1N$ $HClO_4$. His G_4/G_2 ratios are consistent with Eqs. (4) and (5).

Murphy's[2] measurements show that G_2, and also G_4, for even-even nuclides, are approximately equal for three chemically different nuclides. The interaction frequencies $(eQ/\hbar)^2\langle(\partial\mathcal{E}_z/\partial z)^2\rangle$, and therefore the times of interaction τ are almost equal for the three cases. Assuming the same τ for Am^{243}, Eq. (4) gives

$$\frac{G_2(\mathrm{Am}^{243})}{G_2(\text{even-even})}\cong\frac{1+\lambda_\nu(\text{even-even})\tau}{1+\lambda_\nu(\mathrm{Am}^{243})\tau}. \tag{6}$$

Using λ_ν calculated from Eq. (5), and measured values of G_2(even-even)$=0.75$, one obtains $G_2=0.88$, which agrees with the experiment of Falk *et al.*[1]

Values of G_2 for U^{233}, listed in Table I, were calculated using the measured G_2 in U^{232} and Eq. (6). $(eQ/\hbar)^2\langle(\partial\mathcal{E}_z/\partial z)^2\rangle$ is equal within 10% for the two experiments. For Np^{237}, only a rough estimate of G_2 is necessary. The measured attenuation coefficients are not strongly dependent upon the chemical nature of the recoiling atom. G_2 is therefore assumed to equal G_2 in Am^{243} for which the intermediate-state spin was the same. The assumption is supported by the fact that values of g_2/g_0 disagree for the two measurements in Np^{237}, if G_2 is much different.

APPENDIX B: ANGULAR-MOMENTUM THEORY

From the theory of angular momentum, Eq. (1) can be put in the form[23]

$$\omega(\theta)=\mathrm{const}\times\sum_\nu(-1)^{I_i}\{\sum_{L,L'}(-1)^{I_i-I-1}[(2I+1)(2L+1)(2L'+1)]^{1/2}W(IILL'KI_i)(LOL'O|KO)\cos(\Delta_L-\Delta_{L'}) \times[\langle I\|H_1(L)\|I_i\rangle\langle I\|H_1(L')\|I_i\rangle^*\sum_{ll'}F_\nu(ll'I_fI)\langle I\|H_2(l)\|I_f\rangle^*\langle I\|H_2(l')\|I_f\rangle\}\,, \tag{7}$$

where H_1 and H_2 are the interaction Hamiltonians connecting the states with spins I_i and I, and I and I_f, respectively, and L and l refer to α-particle and γ-ray angular momenta, respectively.

The factors

$$[(2I+1)(2L+1)(2L'+1)]^{1/2} \times W(IILL'KI_i)(LOL'O|KO)$$

[20] A. Abragam and R. V. Pound, Phys. Rev. **89**, 1306 (1953).
[21] R. V. Pound and A. Abragam, Phys. Rev. **90**, 993 (1953).
[22] A. Abragam and R. V. Pound, Phys. Rev. **92**, 943 (1953).
[23] H. Frauenfelder, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 531.

and

$$F(ll'I_fI)=[(2I+1)(2l+1)(2l'+1)]^{1/2}\times W(IIll'KI_f)(l-1l'1|KO)$$

are numerical coefficients obtained from published tables. $\mathrm{Cos}(\Delta_L-\Delta_{L'})$ is a factor due to the differing effect of the Coulomb barrier on waves of different angular momenta. For alpha particles emitted well below the height of the Coulomb barrier, Seed and French[24] have shown that

$$\Delta_{L+2}-\Delta_L=\tan^{-1}\left[\frac{n}{L+2}\right]+\tan^{-1}\left[\frac{n}{L}\right], \qquad (8)$$

where

$$n=2Ze^2/\hbar v,$$

v being the alpha-particle velocity.

It can be shown that

$$\frac{g_L}{g_{L'}}=\frac{\langle I\|H_1(L)\|I_i\rangle}{\langle I\|H_1(L')\|I_i\rangle}\cos(\Delta_L-\Delta_{L'}). \qquad (9)$$

[24] J. Seed and A. P. French, Phys. Rev. 88, 1007 (1952).

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Decay of ^{124}Sb to ^{124}Te†

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The γ rays from 60-day ^{124}Sb have been measured with a Ge γ-ray detector. γ-γ coincidence and correlation measurements were made with a Ge detector and a NaI scintillation detector. β-γ coincidences were made using a Ge detector and anthracene scintillation detector. The Ge detector was placed in a large NaI annulus detector to provide both anticoincidence Compton-suppressed spectra and high-resolution γ-ray pair spectra. A total of 25 γ rays were observed. A level scheme is proposed which contains 13 levels. Angular-correlation measurements (a) confirm a spin-4 assignment to the 1247.6-keV state and (b) show that the spin of the 1325.0-keV state is 2 and that the 722.5-keV γ ray to the first 2^+ state has a mixture $\delta\equiv(E^2/M1)^{1/2}=3.4\pm0.6$. Two levels at 1956.5 and 2038 keV have properties which are consistent with a three-phonon collective-state interpretation.

I. INTRODUCTION

Many investigations have been made of the rather complicated decay of 60-day ^{124}Sb. It was partly because it had been so well studied that we chose this activity to test the power of Ge γ-ray detectors to yield new information on decay schemes. In addition to the straightforward high-resolution singles spectra obtained with a Ge detector, other more complex arrangements were used. Gamma-gamma coincidence and correlation measurements were made with one Ge detector and one NaI scintillation crystal. Beta-gamma coincidences were made with the Ge γ-ray detector and an anthracene scintillation detector. In another arrangement, the Ge detector was put inside a large NaI annular detector which was operated in anticoincidence to suppress pulses from unwanted Compton events produced in the Ge detector. Finally, the Ge detector was put inside the NaI annulus and the annulus was operated as two optically isolated halves. By requiring coincident 511-keV pulses from each half of the annulus one had a very effective high-resolution pair spectrometer for detection of the higher-energy γ rays.

The ^{124}Te nucleus exhibits a "vibrational" type of level structure. The known spin of 3 for ^{124}Sb and the large available decay energy suggest that there might be an appreciable population of the postulated 2^+, 3^+, and 4^+ members of a three-phonon quintet of collective states. It is expected that one of the most sensitive "signatures" for this type of state will be the peculiar intensities of the γ rays resulting from the decay of these states to lower states in analogy to the well-known peculiar decay of the second 2^+ state in vibrational-type nuclei. We hoped to find this type of information for states in ^{124}Te. Yoshizawa[1] has pointed out that there is some evidence for states in other vibrational nuclei which have γ-ray decay characteristics that are consistent with the concept of three-phonon-type states.

There has been a disagreement on the value of δ $[\delta=\pm(E2/M1)^{1/2}]$ for the decay of the second 2^+ state (1325 keV) to the first 2^+ state in ^{124}Te. Lindquist and Marklund,[2] Paul,[3] and Raghavan *et al.*[4] found that $\delta\approx1$. This value of δ is smaller than those usually found for nuclei similar to ^{124}Te. On the other hand, Glaubman and Oberholtzer[5] found $\delta=+4.1\pm0.6$ and Dorikens-

† Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

[1] Y. Yoshizawa, Phys. Letters 2, 261 (1962).
[2] T. Lingqvist and I. Marklund, Nucl. Phys. 4, 189 (1957).
[3] H. Paul, Phys. Rev. 121, 1175 (1961).
[4] R. S. Raghavan, Z. W. Grabowski, and R. M. Steffen, Phys. Rev. 139, 1 (1965).