Coulomb Excitation of Levels in Se^{77}

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An investigation has been made of the gamma rays which de-excite levels of Se^{77} that have been Coulomb excited by means of variable-energy alpha particles (2.1 to 8.0 Mev). The energies (in kev), spins and parities, and $B(E2)_{ex}$'s (in units of e^2 cm$^4\times10^{-50}$) found for the levels are: 242±2, $\frac{3}{2}-$, and 18.2±1.6; 248±5, $\frac{5}{2}-$, and 0.37±0.09; 440±4, $\frac{5}{2}-$, and 25.9±1.7; and 515±8, $\frac{3}{2}-$, and 1.0±0.2. New evidence for the two close-lying levels at 242 and 248 kev has been provided by coincidence studies. A comparison of the $B(E2)_{ex}$'s to the $B(E2)_{sp}$ suggests that the 242- and 440-kev levels result from collective excitations of the ground-state configuration, and that the 248- and 515-kev levels result from changes in the ground-state configuration. Besides the ground-state transitions from these Coulomb-excited levels, gamma rays with energies of 87, 161, 203, and 283 kev were observed. Excitation curves of the 87- and 161-kev transitions indicate that they cascade from the 248-kev level. From the measurements of the gamma-ray angular distributions, values for $(E2/M1)^{\frac{1}{2}}$ of 0.18±0.03 and 0.05±0.03 were obtained, respectively, for the 242-kev gamma ray and for the 203-kev gamma ray, which originates at the 440-kev level.

I. INTRODUCTION

THE properties of the low-lying levels of Se^{77} have been studied by means of the Coulomb excitation process. This work was prompted by two apparent incompatibilities of previous investigations regarding the level at 242 kev.[1] They are: (1) the value obtained for the ratio of intensities of the 87- and 242-kev gamma rays, which have been given as de-exciting the 242-kev level, depends on whether the level is populated by beta-ray decay of As^{77},[2–5] by orbital electron capture decay of Br^{77},[6] or by Coulomb excitation of Se^{77};[7] and (2) the Coulomb excitation studies of Temmer and Heydenburg[7] indicate the spin and parity of the 242-kev level is $\frac{3}{2}-$, whereas the 87-kev transition between this level and the $\frac{7}{2}+$, 161-kev level[8,9] favors an assignment of $\frac{5}{2}-$. To explain these experimental results, the Nuclear Data Group[10] suggested the possibility of two near-lying levels at 242 kev. In the present investigation new evidence has been found for this level doublet.

The yields of gamma rays from this doublet as well as from levels at 440 and 515 kev have been obtained as a function of the energy of the alpha particles which were employed to effect Coulomb excitation. These yields have been used to determine the reduced electric quadrupole transition probabilities for excitation of these levels. To derive information about the level spins and gamma-ray multipolarities, several gamma-ray angular distributions have been measured.[11]

II. EXPERIMENTAL PROCEDURE

A thick target of Se^{77}, which was isotopically enriched to 74.22%,[12] was bombarded with doubly-ionized helium ions obtained from the ORNL 5.5-Mv Van de Graaff generator. The target was an ~100-mg/cm^2 thick foil which had been sintered from metallic selenium powder. To prevent damage to the target, it was necessary to limit the beam current to 0.02 μa. The ensuing gamma rays were detected with 3 in.×3 in. NaI crystals which were coupled to DuMont 6363 photomultiplier tubes. The background was reduced by means of a lead shield with four-inch wall thickness. The geometry of the detectors and target and the methods of measuring yields and angular distributions of the gamma rays have been described previously.[13,14]

The energies of two of the gamma rays of Se^{77} were determined from a composite spectrum of Se^{77} and of gamma rays with known energies. The values found are 242±2 and 440±4 kev. These two gamma rays were then used as internal energy standards.

III. RESULTS

A. Gamma-Ray Spectra

The gamma-ray spectra which resulted from the bombardment of Se^{77} with fourteen different alpha-particle energies ranging from 2.1 to 8.0 Mev were measured. Representative spectra are given in Figs. 1 and 2. Several of the peaks in these figures are not due

[1] All energies quoted are those determined in the present work.
[2] M. E. Bunker, R. J. Prestwood, and J. W. Starner, Phys. Rev. **91**, 1021 (1953).
[3] F. Rasetti and E. C. Booth, Phys. Rev. **91**, 1192 (1953).
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[7] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).
[8] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[9] W. C. Rutledge, J. M. Cork, and S. B. Burson, Phys. Rev. **86**, 775 (1952).
[10] *Nuclear Data Sheets*, National Academy of Sciences, National Research Council (U. S. Government Printing Office, Washington, D. C.).
[11] A brief account of these measurements was presented at the 1961 Washington meeting of the American Physical Society [R. L. Robinson, F. K. McGowan, and P. H. Stelson, Bull. Am. Phys. Soc. **6**, 273 (1961)].
[12] The isotopically enriched sample was obtained from the Stable Isotopes Division of the Oak Ridge National Laboratory.
[13] P. H. Stelson and F. K. McGowan, Phys. Rev. **110**, 489 (1958).
[14] F. K. McGowan and P. H. Stelson, Phys. Rev. **106**, 522 (1957).

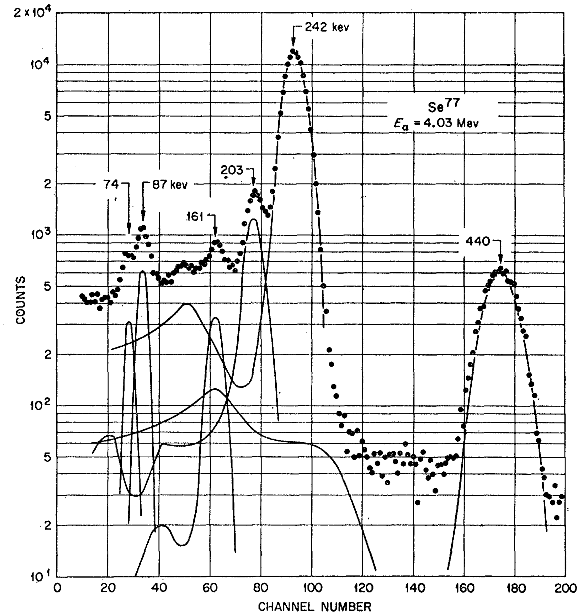

FIG. 1. Gamma-ray spectrum for 4.03-Mev alpha particles on Se^{77}. The distance between the target and detector was 5 cm. The detector was placed at an angle of 235° relative to the incident beam.

to transitions in Se^{77}. The peak at 74 kev is believed to be from K x rays of lead. The 859-kev gamma ray, which has also been observed with other targets, is probably the 871-kev transition from the $N^{14}(\alpha,p)O^{17}$ reaction. From the energies and yields of the 558-, 612-, and 662-kev gamma rays, it was concluded that they are ground-state transitions from the Coulomb-excited first 2+ levels of Se^{76}, Se^{78}, and Se^{80}, respectively.

All spectra were decomposed as illustrated in Figs. 1 and 2, and the gamma-ray yields were determined. The relative yields for the gamma rays of Se^{77} are plotted in Figs. 3 and 4 as a function of the energy of the bombarding particles. The absolute yields that were found from the spectrum observed when the target was bombarded with 5.04-Mev alpha particles are listed in Table I. The relative and absolute yields given for the 161-kev gamma ray, which originates at a 17.5-sec isomeric level,[9,15] were obtained from spectra taken when the beam was not on the target. This was accomplished by repetition of a cycle where the target was bombarded for 30 sec and then data were recorded for 30 sec.

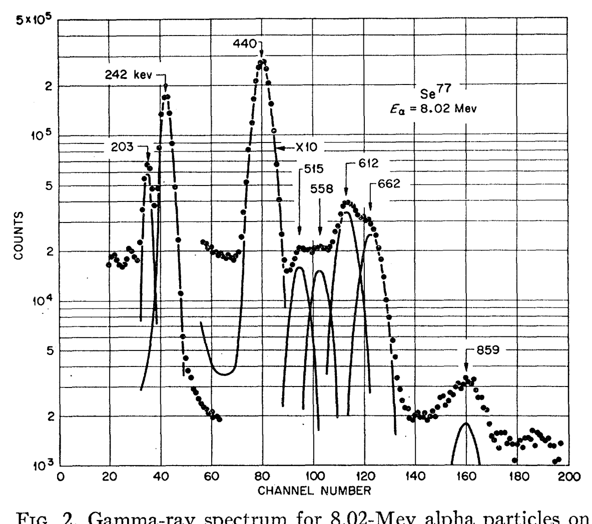

FIG. 2. Gamma-ray spectrum for 8.02-Mev alpha particles on Se^{77}. The distance between the target and detector was 10 cm. The detector was placed at an angle of 235° relative to the incident beam.

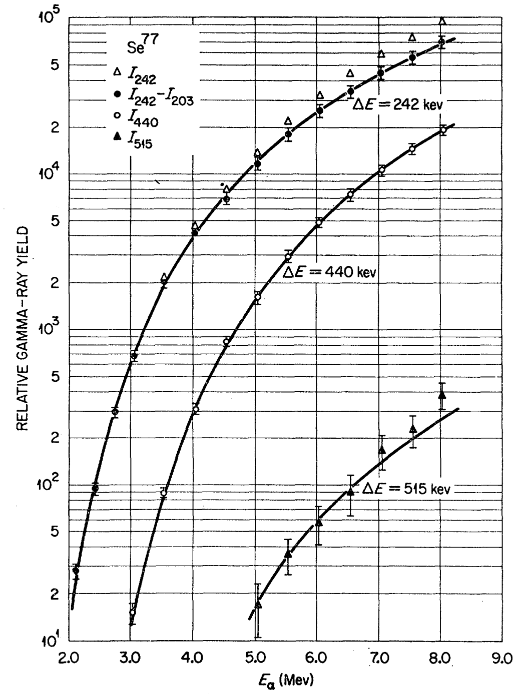

FIG. 3. Relative gamma-ray yields as a function of the alpha-particle energy. The solid curves give the energy dependence predicted for the yields of gamma rays from $E2$ Coulomb-excited states with energies ΔE above the ground state of Se^{77}.

The curves in Figs. 3 and 4 give the energy dependence predicted for the yields of gamma rays from electric quadrupole ($E2$) Coulomb-excited levels with energies ΔE above the ground state of Se^{77}. The curve for $\Delta E=242$ kev does not agree with the yields found for the 242-kev transition. However, it is compatible with the differences of the yields of the 242- and 203-kev transitions. This indicates that the 203-kev gamma ray terminates at the 242-kev level, as has been previously suggested.[6,7] Its position is confirmed by the good agreement of the yields for the 203-kev transition with the curve for $\Delta E=440$ kev.

The yields of the transition from the isomeric 161-kev level suggest it is populated primarily by a cascade

[15] J. R. Arnold and N. Sugarman, J. Chem. Phys. 15, 703 (1947).

gamma ray from a level at about 242 kev. The requirements for this cascade gamma ray are fulfilled by the 87-kev gamma ray. Besides having the proper energy, this transition has an intensity which is similar to that of the 161-kev transition.[16] Furthermore, its yields have the energy dependence given by the curve with $\Delta E=242$ kev.

The agreement between the lower curve in Fig. 3 and the experimental points for the yields obtained from the gamma-ray peak at 515 kev indicates that there is a Coulomb-excited level in Se^{77} at this energy. Unfortunately, this energy is very near that of annihilation radiation. Part of the 515-kev gamma-ray peak may have resulted from positrons of Br^{80} which were produced by an (α,p) reaction on Se^{77}. From the total reaction cross section calculations by Igo,[17] we estimated that the annihilation radiation from Br^{80} could account for as much as 10% of the 515-kev gamma-ray intensity at an alpha-particle energy of 8.0 Mev; however, for $E_\alpha \leqslant 6.5$ Mev, its contribution would be negligible.

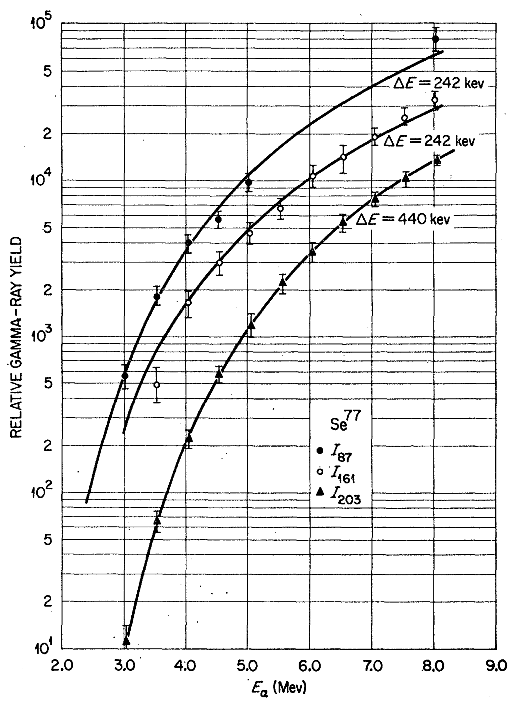

FIG. 4. Relative gamma-ray yields as a function of the alpha-particle energy. The solid curves give the energy dependence predicted for the yields of gamma rays from $E2$ Coulomb-excited states with energies ΔE above the ground state of Se^{77}.

Gamma-ray spectra in coincidence with the 242- and the 203-kev gamma-ray peaks have been observed for 8.02-Mev alpha particle excitation of Se^{77}. These are illustrated in Fig. 5. The presence of a peak at (283 ± 7) kev in the spectrum in coincidence with the gamma rays in the 242-kev gamma-ray peak supports the proposal of a Coulomb-excited level at 515 kev. The 203-kev gamma ray was found to be in coincidence with the 242-kev gamma ray, but not in coincidence with the 87-kev gamma ray. This was surprising since the yields of the 87-kev gamma ray attest that it de-excites a level with energy of about 242 kev. To satisfy these results it is necessary to have two close-lying levels at 242 kev.

It therefore seems likely that the peak at 242 kev in the singles spectra is composed of two ground-state transitions. Nevertheless, this peak was found to have the width expected for the full-energy peak of a single gamma ray in all spectra.

TABLE I. Gamma rays per microcoulomb of doubly-ionized, 5.04-Mev helium ions on a target of selenium containing 74.22% Se^{77}.

E_γ (kev)	Gamma rays/μcoul
87 ± 4	$(7.9\pm1.0)\times10^3$
161 ± 3	$(5.9\pm0.9)\times10^3$
203 ± 3	$(7.5\pm1.0)\times10^4$
242 ± 2	$(5.0\pm0.3)\times10^5$
440 ± 4	$(10.7\pm0.8)\times10^4$
515 ± 8	$(4.2\pm1.6)\times10^3$

B. Gamma-Ray Angular Distributions

The angular distributions of the 87-, 203-, 242-, and 440-kev gamma rays have been measured with respect to the incident beam for several alpha-particle energies. These distributions were fitted to the function $W(\theta)=1+a_2g_2A_2P_2(\cos\theta)+a_4g_4A_4P_4(\cos\theta)$, where the a_ν's and the g_ν's are the thick-target particle parame-

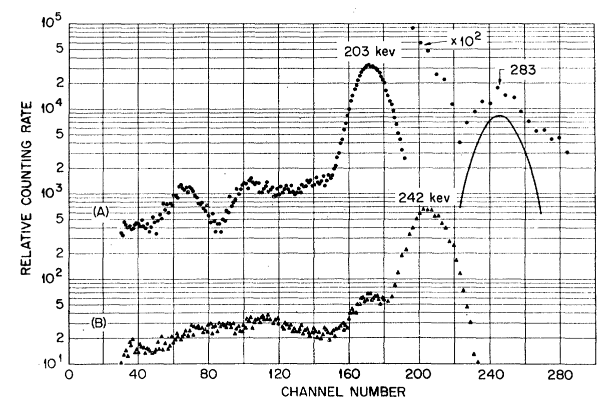

FIG. 5. Gamma-ray spectra in coincidence with the (A) 242- and (B) 203-kev gamma-ray peaks for 8.02-Mev alpha particles on Se^{77}. The single-channel window widths were 30 and 20 kev, respectively. For both spectra the distances between the detectors and the target were 6 cm. The detectors were placed at 0° and 90° relative to the incident beam.

[16] The average value found for the ratio of the 87- to the 161-kev gamma-ray intensities is 1.4 ± 0.3. If the 87- and 161-kev gamma rays are $E1$ and $E3$ transitions, respectively, the ratio of their intensities including internal conversion electron emission is 0.8 ± 0.2.

[17] G. Igo, Phys. Rev. **115**, 1665 (1959).

TABLE II. Gamma-ray angular correlation coefficients. The (1-3) 242-kev correlation coefficient is for the distribution of 242-kev gamma rays which are preceded by the 203-kev gamma rays. The 242-kev correlation coefficient is for the distribution of gamma rays of that energy which results from direct Coulomb excitation of the level doublet at 242 kev.

E_γ (kev)	A_2
87	0.00 ± 0.12
203	$-(0.145\pm0.034)$
242	$-(0.085\pm0.028)$
(1-3) 242	$-(0.15\pm0.12)$
440	0.265 ± 0.022

ters[14,18] and the corrections for the finite angular resolution of the detectors,[19] respectively. The average values of the experimental A_2 correlation coefficients are given in Table II. Because the values for a_4 were always small, the A_4 coefficients were very poorly determined and, consequently, do not provide any useful information.

Two A_2 correlation coefficients were obtained from the study of the angular distributions of the gamma rays in the peak at 242 kev as a function of the alpha-particle energy. These coefficients are for the distribution of the ground-state transitions which follow direct excitation of the level doublet at 242 kev and for the distribution of the 242-kev gamma rays which are preceded by the 203-kev gamma rays. One is able to determine both coefficients since the ratio of intensities of the 203- and 242-kev gamma rays varies with the energy of the bombarding particles.

IV. DISCUSSION

An energy level diagram which is compatible with our results is illustrated in Fig. 6. This is in good agreement with that presented in the *Nuclear Data Sheets*.[10] The two levels at 242 and 248 kev are necessary to explain the absence of coincidence between the 203- and 87-kev gamma rays.

The reduced $E2$ transition probabilities for excitation, $B(E2)_{\text{ex}}$'s, of the Coulomb excited levels have been determined from the gamma-ray yields by a procedure previously described.[20] Only the sum of the $B(E2)_{\text{ex}}$'s for the 242- and 248-kev levels could be obtained from our studies. This value is $(18.6\pm1.6)\times10^{-50}e^2$ cm^4. However, it is possible to evaluate the $B(E2)_{\text{ex}}$'s for both levels if the half-life of the 248-kev level is known. The half-lives for levels of the doublet at 242 kev have been reported as $(1.30\pm0.08)\times10^{-9}$ sec by Nainan[21] and $(6.9\pm3.5)\times10^{-11}$ sec by Holland and Lynch.[22] Since the two half-lives are substantially different, they are presumably for the different members of the level doublet. Even with the half-life of the 248-kev level known, there are still two pairs of $B(E2)_{\text{ex}}$'s of the 242- and 248-kev levels which will satisfy our experimental results. For a half-life of 1.30×10^{-9} sec for the 248-kev level, one pair of $B(E2)_{\text{ex}}$'s requires that the intensity of the 248-kev gamma ray, I_{248}, be equal to $3.5I_{242}$. However, this is incompatible with the limit $I_{248}\leqslant0.2I_{242}$ which can be established from a comparison of the quantity $I_{87}/I_{242}+I_{248}$ found in the present work with that given by other investigators from their studies of the decay of As^{77}.[2–5] The other pair of $B(E2)_{\text{ex}}$'s, which do satisfy this condition, are given in Table III. For these $B(E2)_{\text{ex}}$'s, $I_{248}=(6\pm2)\times10^{-3}I_{242}$. This gives a value of 33 ± 13 for the branching ratio of the 87- and 248-kev gamma rays.

If, instead, the value given by Holland and Lynch[22] is taken as the half-life for the 248-kev level, the half-life deduced for the 242-kev level from our results is either $(2.3\pm0.6)\times10^{-11}$ or $(6.5\pm0.7)\times10^{-10}$ sec. Since neither value is compatible with that presented by Nainan,[21] this half-life for the 248-kev level appears improbable.

The $B(E2)_{\text{ex}}$'s given for the four Coulomb-excited levels in Table III have been corrected for internal conversion of the gamma rays.[23,24] Our values for the 242- and 440-kev levels are in agreement with those reported by Temmer and Heydenburg[7] and Wisseman

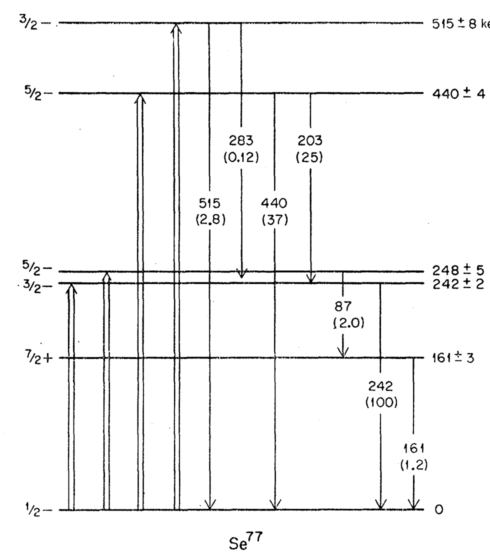

FIG. 6. Energy level diagram of Se^{77}. The pair of numbers associated with each transition gives its energy in kev and relative intensity. The intensities are those deduced from spectra which were observed for an alpha-particle energy of 8.02 Mev.

[18] K. Alder, A. Bohr, T. Huus, B. Mottelson, and A. Winther, Revs. Modern Phys. **28**, 432 (1956).
[19] M. E. Rose, Phys. Rev. **91**, 610 (1953).
[20] F. K. McGowan and P. H. Stelson, Phys. Rev. **116**, 154 (1959).
[21] T. D. Nainan, Phys. Rev. **123**, 1751 (1961).
[22] R. E. Holland and F. J. Lynch, Phys. Rev. **121**, 1464 (1961).

[23] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).
[24] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57ICC KI, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].

TABLE III. Summary of gamma-ray and level properties.

E_γ (kev)	$B(E2)_{ex}\times 10^{50}/e^2\,cm^4$	Transition	$B(E2)_d\times 10^{50}/e^2\,cm^4$	$B(E2)_d/B(E2)_{sp}$	δ	$B(M1)_d/(e\hbar/2Mc)^2$	$T_{\frac{1}{2}}$(sec)
203		$\frac{5}{2}\rightarrow\frac{3}{2}$	0.8	4	0.05 ± 0.03	0.079 ± 0.009	
242	18.2 ± 1.6	$\frac{3}{2}\rightarrow\frac{1}{2}$	9.1	47	0.18 ± 0.03	$0.12_{-0.04}^{+0.06}$	$(2\pm1)\times10^{-11}$
248	0.37 ± 0.09	$\frac{5}{2}\rightarrow\frac{1}{2}$	0.12	0.6			
440	25.9 ± 1.7	$\frac{5}{2}\rightarrow\frac{1}{2}$	8.6	44			$(2.4\pm0.2)\times10^{-11}$
515	1.0 ± 0.2	$\frac{3}{2}\rightarrow\frac{1}{2}$	0.50	2.6			$\leqslant 3\times10^{-10}$

and Williamson.[25] Because of the possibly conflicting annihilation radiation at high alpha-particle energies, only the yields for $E_\alpha\leqslant 6.5$ Mev were used to estimate the $B(E2)_{ex}$ of the 515-kev level. The sum of the $B(E2)_{ex}$'s of the four Coulomb-excited levels, which is $4.5\times10^{-49}e^2$ cm^4, is similar to the values of (4.8 and 3.9)$\times10^{-49}e^2$ cm^4 found for the $B(E2)_{ex}$'s of the first 2+ levels in Se^{76} and Se^{78}, respectively.[26] This suggests that all strong $E2$ transitions which originate at low-lying levels (i.e., with energies less than ~1 Mev) have been detected.[18]

The reduced $E2$ transition probabilities for decay, $B(E2)_d$'s, which are listed in Table III for the four ground-state transitions, were obtained by multiplication of the $B(E2)_{ex}$'s with the factor $(2I_0+1)/(2I+1)$, where I_0 and I are the spins of the ground state and excited state, respectively. These are compared in Table III to the reduced $E2$ single-particle transition probability, $B(E2)_{sp}$. We have taken $B(E2)_{sp}=(e^2/4\pi)|\frac{3}{5}R_0^2|^2$ with $R_0=1.2\times10^{-13}A^{\frac{1}{3}}$ cm.

Since the ground-state spin and parity of Se^{77} is $\frac{1}{2}-$,[27] the four levels which are excited by the $E2$ Coulomb-excitation process can only have spins and parities of $\frac{3}{2}-$ or $\frac{5}{2}-$. A spin assignment of $\frac{5}{2}$ for the 515-kev level seems unlikely in view of the thermal neutron capture studies of Kinsey and Bartholomew.[10,28] The angular distribution of the 87-kev gamma rays (see Table II) is consistent with a spin assignment of $\frac{3}{2}$ or $\frac{5}{2}$ for the 248-kev level. For spin $\frac{3}{2}$ the theoretical A_2 correlation coefficient is 0.07; for spin $\frac{5}{2}$ and a pure $E1$ 87-kev transition, the A_2 coefficient is -0.07. However, if the spin were $\frac{3}{2}$, the $M2$ transition probability of the 87-kev gamma ray would be greater than 10^4 that predicted by the single-proton model.[29] As there are no $M2$ transitions which are known to be even as fast as a single-proton transition, the 248-kev level has been assigned spin $\frac{5}{2}$. For this spin and with the half-life of the 248-kev level taken as 1.30×10^{-9} sec, the $B(E1)_d$ of the 87-kev gamma ray is $(4.5\pm0.7)\times10^{-30}e^2$ cm^2. This is a factor of 2600 smaller than the $B(E1)_{sp}$, where $B(E1)_{sp}$ was evaluated from the quantity $(e^2/4\pi)(\frac{3}{4}R_0)^2$.

The angular distribution of the 242-kev gamma rays which follow direct excitation establishes the spin of the 242-kev level as $\frac{3}{2}$. The experimental correlation coefficient for the distribution, $A_2=-(0.085\pm0.028)$, is compatible with a mixing ratio δ, where $\delta=(E2/M1)^{\frac{1}{2}}$ in the notation of Biedenharn and Rose,[30] of +0.18 or -2.8 for the 242-kev transition. The latter value is ruled out by the half-life which has been reported for the 242-kev level by Holland and Lynch.[22]

The angular distribution of the 440-kev gamma rays is consistent with a spin assignment of either $\frac{5}{2}$ (the theoretical A_2 coefficient for spin $\frac{5}{2}$ is +0.286) or $\frac{3}{2}$ for the 440-kev level. For spin $\frac{3}{2}$ the value of δ for the 440-kev gamma ray is +0.60 or +57. The angular distribution of the 203-kev gamma rays is also in agreement with either spin for the 440-kev level. For spin $\frac{3}{2}$ the mixing ratio of the 203-kev gamma ray is -0.49 or -4.9; for spin $\frac{5}{2}$ it is 0.054 or -4.2. With these values of δ for the 203-kev transition, the theoretical A_2 correlation coefficients for the distribution of the 242-kev gamma rays which are preceded by the 203-kev gamma rays were determined. A comparison of these with the experimental coefficient in Table IV shows that the best agreement is obtained when the spin assignment of the 440-kev level is $\frac{5}{2}$ and δ of the 203-kev transition is 0.054.

A stronger argument for this spin of the 440-kev level and δ of the 203-kev gamma ray is provided by the $B(E2)_d$ of the 203-kev gamma ray. In this case the ratio of its $B(E2)_d$ to the $B(E2)_{sp}$ is 4. For the other

TABLE IV. Experimental and theoretical A_2 correlation coefficients for the distribution of the 242-kev gamma rays which are preceded by the 203-kev gamma rays. For the theoretical coefficients the mixing ratio of the 242-kev transition has been taken as +0.18.

Spin of 440-kev level	δ of 203-kev gamma ray	A_2
Experimental		$-(0.15\pm0.12)$
$\frac{5}{2}$	0.054	-0.07
$\frac{5}{2}$	-4.2	+0.01
$\frac{3}{2}$	-0.49	0.00
$\frac{3}{2}$	-4.9	+0.05

[25] W. R. Wisseman and R. M. Williamson, Nuclear Phys. **23**, 532 (1961).

[26] P. H. Stelson and F. K. McGowan, Oak Ridge National Laboratory Report ORNL-2910, 12, 1960 (unpublished).

[27] S. P. Davis and F. A. Jenkins, Phys. Rev. **83**, 1269 (1951).

[28] B. B. Kinsey and G. A. Bartholomew, Can. J. Phys. **31**, 1051 (1953).

[29] S. A. Moszkowski, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), Chap. 13.

[30] L. C. Biedenharn and M. E. Rose, Revs. Modern Phys. **25**, 729 (1953).

five combinations of the spin of the 440-kev level and the mixing ratios of the 203- and 440-kev transitions, the $B(E2)_d$ would be a factor of 400 or more greater than the $B(E2)_{sp}$, whereas the enhancement of a $B(E2)_d$ is usually less than 50.

For the two transitions for which the mixing ratios are known, the $B(M1)_d$'s have been determined. These $B(M1)_d$'s, which are listed in Table III, are both smaller than that predicted for a transition between states of the single-particle model $[B(M1)_{sp} \cong (e\hbar/2Mc)^2]$. Also included in Table III are the level half-lives, $T_{\frac{1}{2}}$, found in this work. The value of $(2\pm1)\times10^{-11}$ sec given for the half-life of the 242-kev level is smaller than the value of $(6.9\pm3.5)\times10^{-11}$ sec reported by Holland and Lynch.[22] The half-life of the 248-kev level is, of course, just that given by Nainan[21] since use was made of it in the evaluation of the $B(E2)_{ex}$'s of the 242- and 248-kev levels.

The values for the ratios of $B(E2)_d/B(E2)_{sp}$ in Table III suggest that the 242- and 440-kev states result from collective excitations of the ground-state configuration and that the 248- and 515-kev states result from changes in the ground-state configuration. A possible explanation for the two collective states has recently been proposed by de-Shalit.[31] According to his model for a nucleus with a ground-state spin of $\frac{1}{2}$, excited states with spins $\frac{3}{2}$ and $\frac{5}{2}$ and the same parity as the ground state will result from the coupling of the first core excitation to the odd nucleon in its lowest state. His model predicts that the $B(E2)_d$'s of the ground-state transitions from these two levels will be equal and will also be the same as the $B(E2)_d$'s for the transitions from the first 2+ levels to the ground states in neighboring even-even nuclei. The values of (9.1 and 8.6)$\times10^{-50}e^2$ cm^4 found for the $B(E2)_d$'s of the 242- and 440-kev transitions are indeed in good agreement and are similar to the values of (9.6 and 7.7) $\times10^{-50}e^2$ cm^4 which have been reported for the $2+\rightarrow0+$ transitions in Se^{76} and Se^{78}, respectively.[26] The model of de-Shalit further predicts that if the $\frac{3}{2}-$, 242-kev level is a pure collective level, the $B(M1)_d$ of the ground-state transition from this level will be zero. Instead, our results indicate that it is only a few times smaller than that obtained from a single-particle estimate.

If the 440- and 242-kev levels are of the type described by de-Shalit, it is possible to deduce the quantity $(g_c-g_p)^2$, where g_c and g_p are the gyromagnetic ratios of the collective-motion and particle configuration, respectively, from the $B(M1)_d$ of the 203-kev gamma ray. With $B(M1)_d=(0.079\pm0.009)(e\hbar/2Mc)^2$, $(g_c-g_p)^2$ is 0.83 ± 0.10. If g_p is assumed to have the same value as that reported for the ground state,[32] g_c is $+0.16\pm0.06$ or $+1.98\pm0.06$. The theoretical estimate for g_c is Z/A or ~0.4.

If the origin of the 440-kev level is correctly predicted by de-Shalit's model, the $E1$ transition from the $\frac{5}{2}-$ level to the $\frac{7}{2}+$, 161-kev level should be hindered since this transition is then Δl forbidden. This transition was not observed. From the spectrum taken for an alpha-particle energy of 8.02 Mev, it was estimated that the intensity of such a gamma ray is $<0.015I_{440}$. Consequently, this $E1$ transition is slower than a transition of the single-particle model by a factor of more than 10^5.

Another gamma-ray intensity on which an upper limit can be placed is that for a transition between the levels at 440 and 248 kev. The failure to detect a gamma ray at 87 kev in the spectrum in coincidence with the 203-kev gamma-ray peak can be used to establish that its intensity is $\leqslant0.004I_{203}$. This limit requires that the $B(M1)_d$ of this transition be less than $4\times10^{-4}(e\hbar/2Mc)^2$.

[31] A. de-Shalit, Phys. Rev. **122**, 1530 (1961).

[32] S. S. Dharmatti and H. E. Weaver, Phys. Rev. **86**, 259 (1952)