Denoting by $P$ the probability distribution function, we have

$$\sigma_\nu^2(A,E_K)=\int P_{A,E_K}(\nu)[\nu-\bar{\nu}(A,E_K)]^2 d\nu. \quad (9)$$

$\sigma_\nu^2(A,E_K)$ will be equal to $\sigma_\nu'^2(A,E_K)$ if we assume that $\sigma_\nu^2(A,E_K)=0$ for fixed $E_T$ [the distribution of $\nu(A,E_K)$ is determined entirely by $E_T$]. In this case we transform variables from $\nu$ to $E_T$ using $P_{A,E_K}(\nu)d\nu=P_{A,E_K}(E_T)dE_T$. In addition we have

$$\nu(A,E_K,E_T)=\nu(A,E_K,\bar{E}_T)+\left(\frac{\partial\nu}{\partial E_T}\right)(A,E_K,\bar{E}_T)(E_T-\bar{E}_T)\simeq\bar{\nu}(A,E_K)-\left(\frac{\partial\bar{\nu}}{\partial E_K}\right)(A,E_K)(E_T-\bar{E}_T); \quad (10)$$

using Eqs. (7) and (8) we obtain

$$\sigma_\nu'^2(A,E_K)\simeq\int P_{A,E_K}(E_T)\left[\left(\frac{\partial\bar{\nu}}{\partial E_K}\right)(A,E_K)(E_T-\bar{E}_T)\right]^2 dE_T=\left(\frac{\partial\bar{\nu}}{\partial E_K}\right)(A,E_K)\sigma_T^2(R,E_K). \quad (11)$$

$\sigma_T^2(R,E_K)$ is by definition a symmetric function of the mass with respect to $A=A_0/2=126$, whereas $(\partial\bar{\nu}/\partial E_K)(A,E_K)$ is seen (Figs. 2 and 3) to be a highly asymmetric function of $A$ (with respect to $A_0/2$). It follows that $\sigma_\nu'^2(A,E_K)$ must also be asymmetric with respect to $A_0/2$. Yet the experimental results of $\sigma_\nu^2(A,E_K)$ and $\bar{\sigma}_\nu^2(A)$ do not show any pronounced asymmetry as would be expected if $\sigma_\nu^2(A,E_K)\simeq\sigma_\nu'^2(A,E_K)$. It follows that $\sigma_\nu^2(A,E_K)\neq\sigma_\nu'^2(A,E_K)$, i.e., $\sigma_\nu^2(A,E_K)$ at fixed $E_T$ is an important factor of the variance (the correlation coefficients are substantially less than +1) for at least some portions of the fragment mass-ratio distribution.

[1]J. Terrel, in *Proceedings of the Symposium on the Physics and Chemistry of Fission, Salzburg, 1965* (International Atomic Energy Agency, Vienna, Austria, 1965), Vol. 2, p. 3.

[2]H. R. Bowman, J. C. D. Milton, S. G. Thompson, and W. J. Swiatecki, Phys. Rev. 129, 2133 (1963).

[3]J. C. D. Milton and J. S. Fraser, in *Proceedings of the Symposium on the Physics and Chemistry of Fission, Salzburg, 1965* (International Atomic Energy Agency, Vienna, Austria, 1965), Vol. 2, p. 39.

[4]E. Nardi and Z. Fraenkel, Phys. Rev. Lett. 20, 1248 (1968).

[5]H. W. Schmitt, W. E. Kiker, and C. W. Williams, Phys. Rev. 137, B837 (1965).

# $E4$ Moments in $^{152}$Sm and $^{154}$Sm†

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The $E4$ transition moments between the ground state and the $4^+$ rotational state in $^{152}$Sm and $^{154}$Sm have been determined from Coulomb excitation experiments with 10–12-MeV $^4$He projectiles. Quantum mechanical corrections have been applied to the calculations used in the analysis of the data. The resulting $E4$ moments are about twice those expected from previously measured $\beta_4$ deformations.

In a previous paper[1] we have reported results on the $E4$ transition moment of $^{152}$Sm determined by comparing the experimental and calculated yields of the $4^+$ rotational state following Coulomb excitation with $^4$He projectiles. This moment is of particular interest since it is likely to result from the intrinsic shape of $^{152}$Sm and, if so, can give rather detailed information about that shape. Although data were taken on $^{154}$Sm during the original experiments, these could not be interpreted because of the lack of a sufficiently accurate value for $B(E2;4\to2)$. This $B(E2)$ value now has been measured with sufficient accuracy and, in addition, the best value for the $B(E2;2\to0)$ of $^{152}$Sm has been reviewed and adjusted slightly from the previously used value. Finally, the quantum-mechanical corrections to the cross sections have recently been calculated by Alder, Morf, and Roesel[2] for both $^{152}$Sm and $^{154}$Sm. Thus, the intent of this note is to present and discuss the current best values for the $E4$ moments of these two Sm nuclei.

The experiments consisted of an accurate comparison of the cross sections of the $4\to2$

transitions in $^{152}$Sm and $^{154}$Sm with those of the $2\to0$ transitions in $^{150}$Sm and $^{152}$Sm from the same (natural samarium) targets following Coulomb excitation with $^4$He projectiles. The cross sections of the $2\to0$ transitions could be calculated from the known $B(E2; 2\to0)$ values, and these transitions thus served as two independent internal standards, against which the cross sections for production of the $4^+$ states in $^{152}$Sm and $^{154}$Sm could be evaluated. Separate results were obtained from the singles $\gamma$-ray spectra and from those in coincidence with backscattered $^4$He projectiles. These results depend differently on many of the corrections entering the analysis, so that their consistency as to the extracted $E4$ moment lends considerable support to our analysis. Isotopically enriched targets of $^{152}$Sm and $^{154}$Sm were also used, and in the case of $^{152}$Sm, its $2\to0$ transition again provided an internal standard. However, the $2\to0$ transition of $^{154}$Sm was not at a convenient energy to act as such a standard, so that normalization was achieved relative to natural samarium targets by means of the number of $\alpha$ particles scattered through 90° from the target into a solid-state detector. Additional details of the experiments can be found in Ref. 1. A somewhat different experimental method has been considered in a paper by Winkler.[3]

The ground-band $B(E2)$ values are the most important quantities for determining the calculated yield of the $4^+$ states. For $B(E2; 2\to0)$ we now prefer to use the accurately measured lifetimes of the $2^+$ states[4,5] together with the calculated total conversion coefficients,[6] which give $(0.272 \pm 0.010,\ 0.670\pm0.015,\ \text{and}\ 0.843\pm0.019)e^2\,\text{b}^2$ for $^{150,152,154}$Sm. These $B(E2)$ values for $^{152}$Sm and $^{154}$Sm are significantly lower ($\approx 2$ and $\approx 10\%$, respectively) than the direct Coulomb-excitation results of Elbek and co-workers[7] but seem to be in better accord with the other $B(E2)$ values in the ground band. For the values of $B(E2; 4\to2)$ in $^{152}$Sm and $^{154}$Sm, we have used recent recoil-distance measurements[4,8]: $(0.989\pm0.035$ and $1.186 \pm0.039)e^2\,\text{b}^2$. One of the largest corrections applied in the $^{152}$Sm case was that for the feeding of the $4^+$ level from higher "vibrational" states which are populated by direct $E2$ or $E3$ excitation. For $^{154}$Sm, such corrections are about 3 times smaller relative to the direct excitation of the $4^+$ level than for $^{152}$Sm. The properties[9] $E$ (in MeV), $I^\pi$, $B(E\lambda; 0\to I)$ (in $e^2\,\text{b}^\lambda$), and $f(4^+)$, the branching fraction to the $4^+$ state, of four vibrational states included in the calculations for $^{154}$Sm were taken to be, respectively, 1.178, $2^+$, 0.020, 0.27; 1.437, $2^+$, 0.069, 0.013; 1.011, $3^-$, 0.077, 0.3; and 1.581, $3^-$, 0.054, 0.7. We have taken the uncertainty in each feeding branch to be 50%. Other corrections and uncertainties are similar to those discussed previously[1] for $^{152}$Sm.

Figure 1 shows the measured $4^+$ total (differential) cross sections for $^{154}$Sm, $\sigma$ ($d\sigma$), divided by those calculated using the semiclassical Coulomb-excitation program[10] with the above-indicated input data, $\sigma_0$ ($d\sigma_0$), versus the bombarding energy. The cross sections include the feeding from higher-lying levels. The data do not vary significantly with type of target, type of measurement, or bombarding energy in the range from 10–12.5 MeV. If we ignore the very small variation with bombarding energy which is expected in the ratio $\sigma/\sigma_0$ ($d\sigma/d\sigma_0$), then we can form average results which are $1.11\pm0.02$ ($1.11\pm0.04$) for $^{152}$Sm and $1.21\pm0.03$ ($1.20\pm0.09$) for $^{154}$Sm. The error limits quoted for these ratios are the rms deviation of the results from the mean value, and

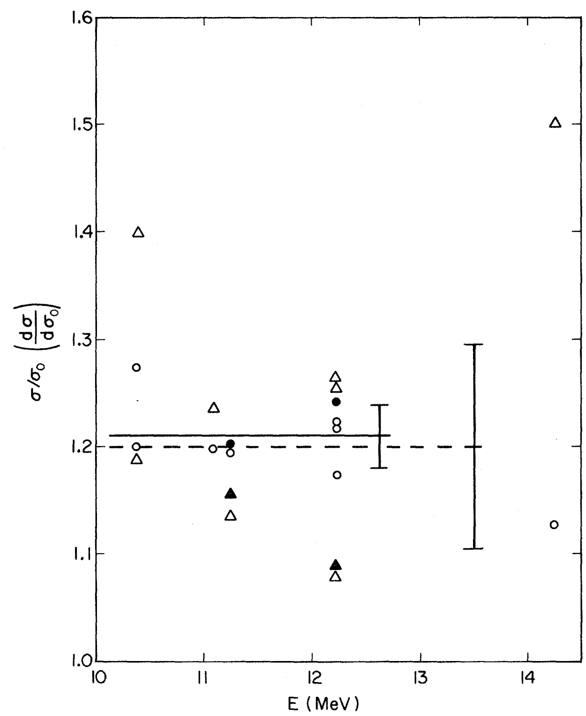


FIG. 1. Ratio of experimental to calculated (semiclassical) cross sections for $^{154}$Sm versus the bombarding energy. The triangles are backscattering coincidence measurements and the circles are singles measurements. The open and closed symbols correspond to natural and enriched Sm targets, respectively. The solid and dashed lines are the average of the singles and coincidence points, respectively, for energies below 12.5 MeV. The error bars indicate the rms deviation of the points from the lines.

therefore do not contain any of the systematic uncertainties.

For the interpretation of these results in terms of an $E4$ moment, the semiclassical calculated cross sections must be corrected for quantal effects. These have recently been calculated,[2] and amount to a reduction of the calculated $4^+$ cross sections by about 7% in both $^{152}$Sm and $^{154}$Sm. The quantal corrections to the calculated $2^+$ cross sections, which serve as the normalization, are less than 1%. Thus the ratios of the measured cross sections to the quantal cross sections are about 6% larger than those to the semiclassical cross sections given above. The quantum mechanical calculations show that the fractional change of the cross section due to $E4$ moments is adequately represented by the semiclassical calculation. For the analysis of the present data, the ratios of cross sections given above were therefore increased by 6% and then evaluated in terms of $\langle 0^+ \| \mathfrak{M}(E4) \| 4^+ \rangle$ by the semiclassical calculations as was done previously.[1] The results for $^{152}$Sm and $^{154}$Sm are $(+0.45 \pm 0.09$ and $+0.67 \pm 0.08)e\ \text{b}^2$. The error limits correspond to about 5% uncertainty in the combined ratios $\sigma/\sigma_0$ and $d\sigma/d\sigma_0$, which is our best estimate of the experimental uncertainties and those coming from the parameters entering the analysis. The $^{152}$Sm value is about 30% higher than our previous number, a result due almost entirely to the quantal corrections. A more detailed account of the important sources of uncertainty was given in Ref. 1.

If, as previously, the nucleus is assumed to be a rigid, uniformly charged rotor with a sharp surface defined by

$$R = R_0(1 + \beta_2 Y_{20} + \beta_4 Y_{40}),$$

then $\beta_2$ and $\beta_4$ can be evaluated from the measured $E2$ and $E4$ transition moments. Using $R_0 = 1.2A^{1/3}$ F, we find values for $\beta_2$ and $\beta_4$ of $+0.248$ and $+0.09 \pm 0.03$ for $^{152}$Sm and $+0.261$ and $+0.13 \pm 0.03$ for $^{154}$Sm. In Fig. 2 this shape for $^{154}$Sm is shown together with (a) the shape that has $\beta_4 = 0$ and the same $E2$ moment and (b) the sphere having the same $R_0$. These $\beta_4$ values for the nuclear charge distribution are about twice those obtained for the nuclear field from $(\alpha, \alpha')$ measurements above the Coulomb barrier.[11-13] They are also somewhat larger than expected on the basis of present calculations of nuclear shapes.[14] This conclusion differs from that in our previous paper[1] since (1) the value for $^{154}$Sm is considerably larger than that for $^{152}$Sm, and (2) the quantal corrections for $^{152}$Sm cause a 50% increase in $\beta_4$ for that nucleus.

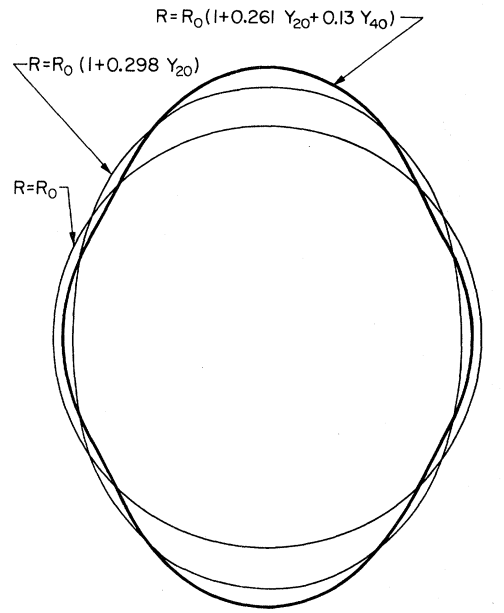


FIG. 2. The shape of $^{154}$Sm indicated by the present measurements (heavy line), together with the shape having no $Y_{40}$ term but the same $B(E2;0\to2)$, and a sphere with the same $R_0$.

It is possible that the difference in the $\beta_4$ values given by the two methods is due to an error in one of them. The analysis of the Coulomb-excitation data is rather unambiguous, but the experiment is difficult since a difference of only 5–10% in the ratio $\sigma/\sigma_0$ $(d\sigma/d\sigma_0)$ could remove the discrepancy. In this regard, some independent experimental results would be valuable, both on the $4^+$ cross sections and on the input $B(E2)$ values. The $(\alpha, \alpha')$ experimental results are known with sufficient accuracy, but the analysis of these data is much more complex than that for pure Coulomb excitation. However, the most straightforward explanation is that the different $\beta_4$ values represent a slightly different shape for the charge distribution and the nuclear field in these nuclei. Figure 2 shows the difference between $\beta_4 = 0$ and $\beta_4 = +0.13$; and the difference between $\beta_4$ from $(\alpha, \alpha')$ data and ours is only about half this large —variations of about $\pm 0.2$ F in the nuclear surface—if $R_0$ and $\beta_2$ are similar to those in Fig. 2. It does not seem implausible to us that such differences could exist. Thus, the exact meaning of these $\beta_4$ values seems to us to be an open and very interesting problem.

In conclusion, our results suggest rather unexpectedly large values of $\beta_4$ for the intrinsic charge distributions in $^{152}$Sm and $^{154}$Sm. Fortunately, there are at least two rather direct approaches open to test our $E4$ moments. First, according to the trend of the $E4$ moments indicated by other results[11] and by calculations,[14] effects on the cross sections due to these moments should be small in the Yb-W region so that measurements there should agree with the calculations without any significant ambiguity due to $E4$ contributions. The second approach is to use slightly heavier ions in order to excite higher states. The size of the $E4$ effects relative to the multiple $E2$ processes goes down with increasing projectile charge, but up strongly with the spin of the excited state. For example, with Li projectiles (if breakup can be avoided) it should be possible to observe the decay of the $6^+$ state, where $E4$ effects of about 50% are expected to occur in these samarium nuclei. Effects of around a factor of 2 should be observable in the excitation of the $8^+$ state with boron projectiles. Although many other effects become important with heavier ions, making the interpretation more difficult, the expected $E4$ effects are large and this approach seems very promising. It is, therefore, unlikely that the present uncertainties about these $E4$ moments will persist for long.

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[1]F. S. Stephens, R. M. Diamond, N. K. Glendenning, and J. de Boer, Phys. Rev. Lett. 24, 1137 (1970).

[2]K. Alder, R. Morf, and F. Roesel, Phys. Lett. 32B, 645 (1970), and private communication.

[3]P. Winkler, in *Proceedings of the International Conference on Nuclear Reactions Induced by Heavy Ions, Heidelberg, Germany, 1969,* edited by R. Bock and W. R. Hering (North-Holland, Amsterdam, 1970), and private communication.

[4]R. M. Diamond, F. S. Stephens, K. Nakai, and R. Nordhagen, Phys. Rev. C 3, 344 (1971).

[5]F. W. Richter, J. Schütt, and D. Wiegandt, Z. Phys. 213, 202 (1968); P. J. Wolfe and R. P. Scharenberg, Phys. Rev. 160, 866 (1967).

[6]H. Chr. Pauli, private communication.

[7]E. Veje, B. Elbek, B. Herskind, and M. C. Olesen, Nucl. Phys. A109, 489 (1968).

[8]R. M. Diamond, G. D. Symons, J. Quebert, K. Nakai, H. Maier, J. Leigh, and F. S. Stephens, to be published.

[9]B. Elbek *et al.*, J. Phys. Soc. Jap., Suppl. 24, 180 (1968).

[10]A. Winther and J. de Boer, unpublished, and in *Coulomb Excitation,* edited by K. Alder and A. Winther (Academic, New York, 1966), p. 303; A. Halm *et al.*, private communication.

[11]D. L. Hendrie, N. K. Glendenning, B. G. Harvey, O. N. Jarvis, H. H. Duhm, J. Saudinos, and J. Mahoney, Phys. Lett. 26B, 127 (1968).

[12]N. K. Glendenning and R. S. Mackintosh, Phys. Lett. 29B, 626 (1969).

[13]A. A. Aponick, Jr., C. M. Chesterfield, D. A. Bromley, and N. K. Glendenning, Nucl. Phys. A159, 367 (1970).

[14]S. G. Nilsson, C. F. Tsang, A. Sobiczewski, Z. Szymanski, S. Wycech, C. Gustafson, I.-L. Lamm, P. Möller, and B. Nilsson, Nucl. Phys. A131, 1 (1969).

## Measurement of the Far-Infrared Background Radiation in the Night Sky*

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A rocket-borne radiometer measurement of background radiation in the spectral range from 6 to 0.08 mm has yielded a flux which corresponds to an equivalent backbody temperature of $3.1_{-2.0}^{+0.5}$ K.

A superfluid-helium–cooled rocket-borne far-infrared radiometer was launched from the Kauai Test Range Facility, Kauai, Hawaii, at 00:48 HST, 29 May 1971. Photometric measurements of the night-sky background were successfully made in two of the three spectral regions in which measurements were attempted. The present paper describes the results in the passband between approximately 6 and 0.8 mm. The results obtained in the other passband, centered at 100 $\mu$m, will be discussed in a separate publication.

The proposed 2.7-K blackbody cosmic radiation[1]