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LIFETIMES OF GROUND-BAND STATES IN $^{148,150,152}Sm$*

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ABSTRACT

The lifetimes of a number of ground-band states in $^{148,150,152}Sm$ have been measured by the recoil-distance Doppler-shift method following Coulomb-excitation by back-scattered ^{40}Ar projectiles. The measured B(E2) values for ^{152}Sm are larger than the rigid-rotor values; in terms of the mixing or stretching parameter, α, the present experiments yield $\alpha = (+2.4 \pm 0.7) \times 10^{-3}$. For $^{148,150}Sm$ the measured B(E2) values are near those expected for vibrational nuclei.

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The stable samarium isotopes are well suited for the testing of current nuclear models and ideas, as they span the region from vibrators to rotors, and include soft nuclei as well as rigid ones. Much of the information on the nature of the ground-band has come from studies of the energy-level spacings. The lifetimes, or B(E2) values, of the excited states in the ground band constitute another source of information on the changes occuring in these levels as the spin increases.

The recoil-distance Doppler-shift method,[1] when combined with high resolution Ge detectors and heavy-ion beams, seems ideal for determining half-lives in the 10^{-9} - 10^{-12} s range.[2,3] However, an earlier study involving recoils from (^{40}Ar,4n) reactions indicated that the accuracy obtained might be only barely sufficient to distinguish, for example, rigid rotors from soft rotors. It would clearly help to obtain spectra with better peak-to-background ratios and to achieve larger recoil velocities. Both of these effects can be obtained by producing the recoiling nuclei by means of (multiple) Coulomb excitation with ^{40}Ar beams, rather than by compound-nucleus reactions. In the present study the de-excitation transitions from Sm targets were observed by a Ge detector set at 0° to the beam direction and operated in coincidence with the back-scattered ^{40}Ar projectiles observed in a Si ring counter (142 - 161°). Thus, multiple excitation of the higher spin states was maximized and a collimated beam of Sm recoils was produced with a high velocity (3.5% c) along the beam direction. These nuclei were stopped by a lead-covered plunger attached to a precision micrometer whose position could be adjusted to ± 0.002 mm. The targets were ~1 mg/cm^2 metal foils of the separated isotope stretched tightly over a holder assembly. By observation with a microscope, they appeared to be flat and parallel to the plunger surface within ± 0.01 mm.

As in the previous experiment,[4] the average recoil velocity could be obtained from the fractional energy difference of the Doppler-shifted and unshifted lines after correcting for the effective finite solid angle of the detector. Since all targets were nearly the same thickness, they all gave the same average recoil velocity, namely (3.45±0.04)% that of light. Some typical spectra for ^{152}Sm are shown in Fig. 1. We have integrated the areas under the shifted and unshifted peaks, and corrected for the small change in solid angle of the Ge counter for both shifted and unshifted transitions due to the change in position of the lead plunger. Small corrections also had to be made for the differences in Ge detector efficiency and in effective solid angle for the shifted transitions with respect to the unshifted ones due to the motion of the recoiling nuclei. These two effects are opposite in sign and tend to cancel, but the latter dominates and leads to a net reduction of 3-4% in the intensities of the shifted transitions.

For ^{152}Sm the fraction of each transition which is unshifted is plotted in Fig. 2 vs. the distance from the target. The solid lines are the calculated best fits from a computer program which allows feeding from one state higher than the one whose half-life is being determined. The amount of feeding was obtained both from the deBoer-Winther multiple excitation program[5] and from the experimental yield of the next higher transition; these agreed within 20%, and the lifetime does not depend very critically on the value used. The calculated fit also took into account the angular distribution of the gamma rays; the angular distribution parameters, A_K, were evaluated from the deBoer-Winter program, again allowing for the calculated feeding from higher-lying levels. Finite-solid-angle corrections for the Ge counter were made from the tables of Black and Gruhle.[6] These angular distribution results also had to be corrected for the attenuation caused by the interaction of the nuclear magnetic moment with the large hyperfine field arising from the unpaired electrons of the ionized product nucleus recoiling in vacuum.[7-9] The magnitude of this effect was determined from a comparison of the angular distributions obtained from a thin self-supporting ^{152}Sm target and a lead-backed one (yielding an unattenuated distribution).

In Table 1, we have listed the transitions studied, their energies in keV, the measured half-lives, values for the total conversion coefficients as interpolated from Hager and Seltzer,[10] and the values of B(E2; I → I-2) derived from the last two quantities. We believe that the systematic and instrumental errors in these measurements are small. The largest source of error, especially for the higher-lying transitions, is the statistical uncertainty in the peak integrations. In only one case, the $4+ \rightarrow 2+$ transition in ^{148}Sm, did we observe interference from another line in the spectrum. In this case the $3- \rightarrow 2+$ transition has an energy only 19 keV less than that of the $4+ \rightarrow 2+$ one, and so the shifted E1 line coincides with the unshifted $4+ \rightarrow 2+$ component, contributing a tail of $\sim$ 11% to the latter. This has been subtracted, but necessarily there is a greater uncertainty in this particular result.

The B(E2) values determined in this work are compared in Table 1 with values calculated for the rigid rotor, the harmonic oscillator, and the centrifugal stretching model of Davydov and Ovcharenko,[11] all normalized to the experimental B(E2; $2 \rightarrow 0$). For ^{152}Sm the $2+ \rightarrow 0+$ transition was not measured; the value listed in the Table is the weighted average of a number of literature values. It can be seen that more quantitative conclusions can be drawn from these measurements than from the previous experiments.

The ^{152}Sm nucleus which has energies somewhat similar to the previously studied ^{160}Er, has three new B(E2) values determined; it can be seen that each is about two standard deviations larger than that expected for a rigid rotor. The remarkable fit to the values calculated by Davydov and Ovcharenko for $\mu = 0.3$ and $\gamma = 10°$ is probably somewhat fortuitous, as the values of μ obtained from the ratios of the ground-band transition energies in ^{152}Sm are not constant but range from 0.40 - 0.28, indicating deviations from that model.

If we consider the increase in the B(E2) to be of the form

$$B(E2;I\rightarrow I-2) = B_0(E2;I\rightarrow I-2)\{1 + \frac{\alpha}{2}[I(I+1)+(I-2)(I-1)]\}^2 \quad ,$$

where $B_o(E2)$ is the rigid-rotor value, the ratio of any two measured $B(E2)$ values and the square of the corresponding Clebsch-Gordan coefficients yield a determination of the mixing or stretching parameter, α. The present work gives $\alpha = (+2.4 \pm 0.7) \times 10^{-3}$. This value for α can be related to the increase in deformation with spin (stretching) according to:

$$\frac{\Delta\beta_I}{\beta} \approx \alpha\, I(I+1) \quad .$$

The value of $\frac{\Delta\beta_2}{\beta}$ obtained from the present work is in reasonable agreement with those obtained from Mössbauer[12,13] and μ-mesic atom[14] measurements. Although it is not clear that these experiments are determining exactly the same quantity, this agreement lends considerable support to the concept that β is increasing with spin in ^{152}Sm. We can try to relate this increase in deformation with spin to the mixing of the beta-vibrational and ground-state bands in ^{152}Sm and to deviations from the $I(I+1)$ rule in the ground-band energies.[15,16] However, the E2 branching ratios from the beta-band states to the ground band are not entirely consistent with such an interpretation, nor are the ground-band energies. Thus we can only say that the range of values for the increase in deformation predicted from both of these sources overlaps that obtained from the present measurements. In view of the above internal inconsistencies, the significance of the agreement is not very clear; however, it probably supports the interpretation that centrifugal stretching is one of two or more important processes occurring with increasing spin. This topic is treated in greater detail in another paper involving multiple Coulomb-excitation studies of ^{152}Sm.[17]

The $B(E2)$ values for ^{148,150}Sm indicate nearly harmonic oscillator behavior as is already suggested by their energy-level spacings. The magnitude of the B(E2; 0 → 2) for ^{150}Sm, $(1.41 \pm 0.05)e^2 \times 10^{-48}\ cm^4$, agrees reasonably well with other recent values 1.44 ± 0.15 (Ref. 18) and 1.29 ± 0.07 (Ref. 19) although we find a somewhat larger value, 0.98 ± 0.06, for the B(E2; 4 → 2) than do the latter workers, 0.82 ± 0.10. Our value for B(E2; 0 → 2) for ^{148}Sm, $(0.79 \pm 0.05)e^2 \times 10^{-48}\ cm^4$, is in agreement with two other values, namely 0.79 ± 0.08 (Ref. 18) and 0.753 ± 0.007 (Ref. 20), but in disagreement with a third, 0.65 ± 0.05 (Ref. 19).

The present measurements show that application of the recoil-distance Doppler-shift method to nuclei recoiling from heavy-ion Coulomb excitation can give lifetimes of quasi-rotational ground-band levels with enough precision to differentiate among nuclear models for this band. This method compares very favorably with the conventional heavy-ion multiple Coulomb-excitation method based on yield measurements and, most importantly, is subject to fewer uncertainties. In the latter case, a desired B(E2) value (lifetime) may be significantly affected by: 1) other B(E2) values in the band, 2) higher multipole moments of the nucleus, 3) static moments, and 4) the excitation of other coupled states or bands. In many Coulomb-excitation yield experiments sufficient information is not available to make all these corrections unambigously. With the present method, none of these affect the result, apart from a small correction (which may be empirically made) due to feeding from higher states.

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REFERENCES

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1. S. Devons, G. Manning, and D. St. P. Bunbury, Proc. Phys. Soc. (London) A68, 18 (1955).
2. I. F. Wright, Bull. Am. Phys. Soc. 6, 285 (1961).
3. T. K. Alexander and K. W. Allen, Can. J. Phys. 43, 1563 (1965).
4. R. M. Diamond, F. S. Stephens, W. H. Kelly, and D. Ward, Phys. Rev. Letters 22, 546 (1969).
5. A. Winther and J. deBoer, California Institute of Technology Report, November 18, 1965.
6. J. L. Black and W. Gruhle, Nucl. Instr. and Methods 46, 213 (1967).
7. D. Ashery, N. Bahcall, G. Goldring, A. Sprinzak, and Y. Wolfson, Nucl. Phys. A101, 51 (1967).
8. I. Ben Zvi, P. Gilad, M. Goldberg, G. Goldring, A. Schwarzschild, A. Sprinzak, and Z. Vager, Nucl. Phys. A121, 592 (1968).
9. R. Nordhagen, G. Goldring, R. M. Diamond, K. Nakai, and F. S. Stephens, Nucl. Phys. (to be published).
10. R. S. Hager and E. C. Seltzer, California Institute of Technology Report CALT-63-60, June, 1967.
11. A. S. Davydov and V. I. Ovcharenko, Yadern. Fiz. 3, 1011 (1966) [translation: Soviet J. Nucl. Phys. 3, 740 (1966)].

12. D. Yeboah-Amankwah, L. Grodzins, and R. B. Frankel, Phys. Rev. Letters 18, 791 (1967); L. Grodzins, International Symposium on Nuclear Structure, Dubna, USSR (1968).

13. P. Steiner, E. Gerdan, P. Kienle, and H. J. Körner, Phys. Letters 24B, 515 (1967); P. Kienle, W. Henning, G. Raindl, H. J. Körner, H. Schaller, and F. Wagner, J. Phys. Soc. Japan Suppl. 24, 207 (1968).

14. S. Bernow, S. Devons, I. Duerdoth, D. Hitlin, S. W. Kast, E. R. Macagno, J. Rainwater, K. Runge, and C. S. Wu, Phys. Rev. Letters 18, 787 (1967).

15. A. S. Davydov and A. A. Chaban, Nucl. Phys. 20, 499 (1960).

16. R. M. Diamond, F. S. Stephens, and W. S. Swiatecki, Phys. Letters 11, 315 (1964).

17. F. S. Stephens, D. Ward, R. M. Diamond, J. deBoer, and R. Coveallo-Moro, Nucl. Phys. (to be published).

18. J. J. Simpson, D. Eccleshall, M. J. L. Yates, and N. J. Freeman, Nucl. Phys. A94, 177 (1967).

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

20. H. S. Gertzman, D. Cline, H. R. Gove, P. M. S. Lesser, and J. J. Swartz, Bull. Am. Phys. Soc. 13, 1471 (1968).

FIGURE CAPTIONS

Fig. 1. Spectra from ^{152}Sm Coulomb excited with back-scattered ^{40}Ar projectiles. The lead plunger is set at the indicated distances from the target. The positions of the unshifted (shifted) lines are given at the top (bottom) of the figure.

Fig. 2. The fraction of each transition in ^{152}Sm which is unshifted in energy vs. the distance between target and plunger. The symbols are the experimental points; the lines are the calculated best fits allowing for one stage of feeding.

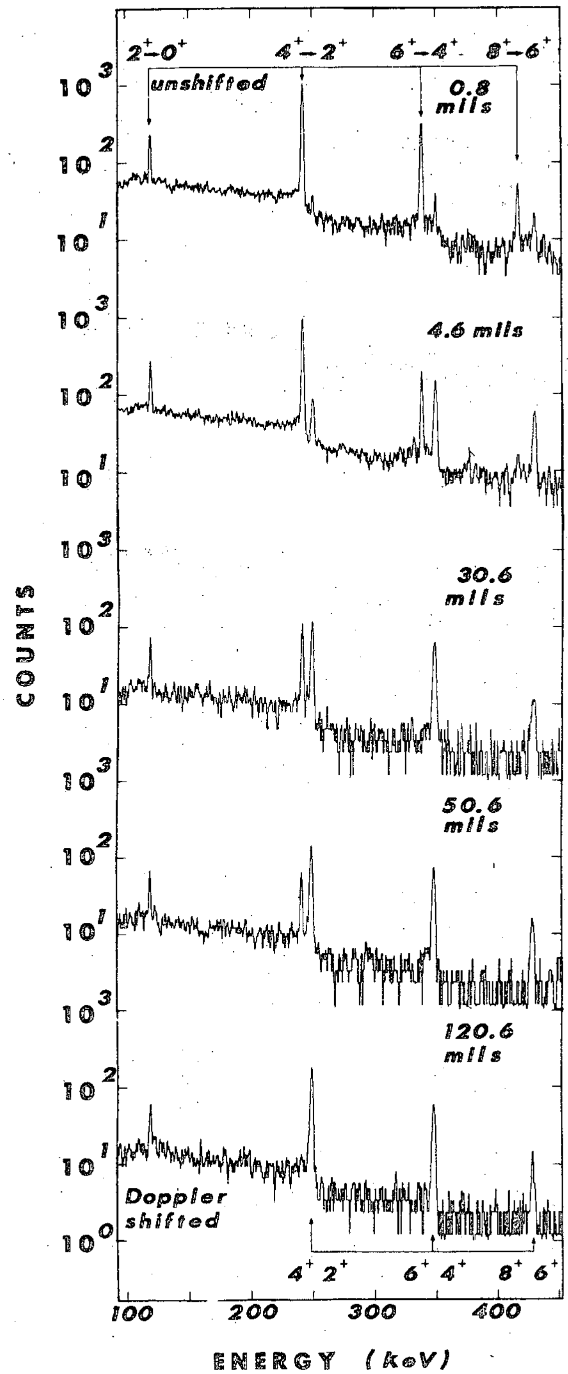
Table 1

Nucleus	Transition	Energy (keV)	$T_{1/2}$ (ps)	α_T [a]	$B(E2;I\to I-2)$ in $(e^2\times10^{-48}cm^4)$			
					experimental	rotor	vib.	D-C [c]
^{152}Sm	2 → 0	121.8			0.686±0.014 [b]	(0.686)	(0.686)	(0.686)
	4 → 2	244.6	57.3±1.8	0.112	1.009±0.033	0.981	1.372	1.036
	6 → 4	340.2	9.9±0.5	0.038	1.20 ±0.06	1.078	2.058	1.221
	8 → 6	418.7	3.0±0.3	0.021	1.42 ±0.14	1.133	2.744	1.406
^{150}Sm	2 → 0	334.0	46.8±1.6	0.042	0.278±0.010	(0.278)	(0.278)	
	4 → 2	439.4	6.3±0.4	0.019	0.54 ±0.04	0.398	0.556	
^{148}Sm	2 → 0	551	7.1±0.4	0.010	0.156±0.010	(0.156)	(0.156)	
	4 → 2	630	1.8±0.5	0.0072	0.31 ±0.08	0.223	0.312	

[a] Calculated as $\alpha_K + \alpha_L + 1.33\alpha_M$ from the tables of Hager and Seltzer, Ref. 10.

[b] Weighted average of literature values.

[c] These values have been taken from the calculations of Davydov and Ovcharenko, Ref. 11, for $\mu = 0.3$, $\gamma = 10^\circ$. See text.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4+-2+
6+-4+
8+-6+
unshifted
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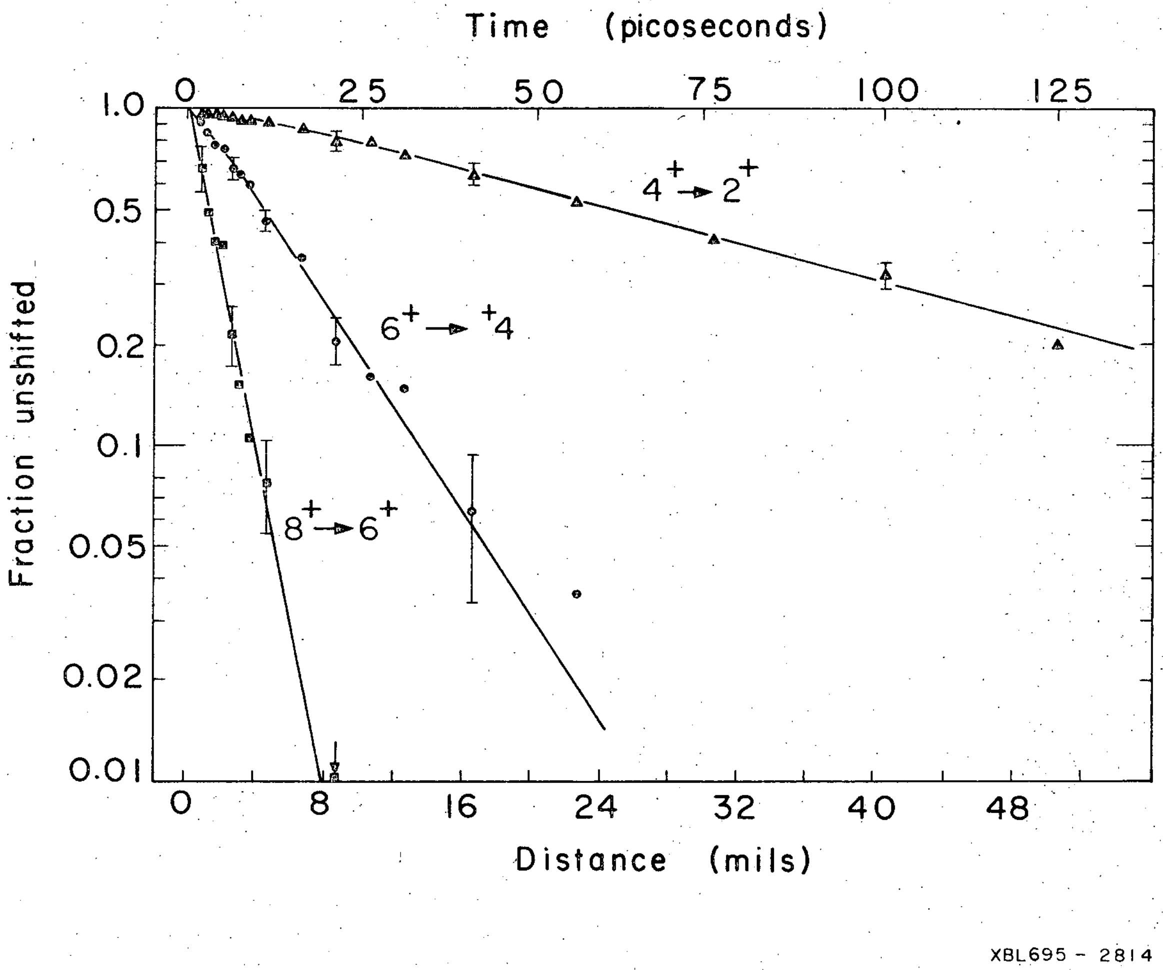
4.6 mils
30.6 mils
50.6 mils
120.6 mils
Doppler shifted
4+ 2+
6+ 4+
8+ 6+
COUNTS
ENERGY (keV)
100
200
300
400
XBL 6912-6333

Fig. 1


Time (picoseconds)
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0.5
0.2
0.1
0.05
0.02
0.01
Fraction unshifted
4+ → 2+
6+ → +4
8+ → 6+
0 8 16 24 32 40 48
Distance (mils)
XBL695 - 2814

Fig. 2

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