Shape implications of unhindered $\frac{11}{2}^- \rightarrow \frac{11}{2}^-$ β decays in the region with $N<82$ and $Z>50$

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Unhindered $\frac{11}{2}^- \rightarrow \frac{11}{2}^-$ β-ray transitions with logft values of 5.0 to 5.4 have been observed in the decay of ^{139}Eu, ^{139}Sm^m, and a new isotope ^{135}Pm. These transitions show no noticeable retardation and are not "shape forbidden." The shape of $\frac{11}{2}^-$ states with odd N is not very different from the (prolate) shape of adjacent $\frac{11}{2}^-$ states with odd Z.

[RADIOACTIVITY β decay between $\frac{11}{2}^-$ states of ^{139}Eu, ^{139}Sm, ^{139,137,135}Pm, ^{137,135}Nd. Deduced logft values and shape differences.]

The nuclei with atomic number $Z>50$ and neutron number $N<82$ cover both a region for nuclear deformation and an "island of $\frac{11}{2}^-$ isomerism." The rotation-aligned coupling scheme of Stephens[1] proposes a prolate shape for the deformed $\frac{11}{2}^-$ states with odd Z. This scheme has been applied to La nuclei in Ref. 1, to Pr nuclei by Klewe-Nebenius *et al.*,[2] and to ^{139}Pm by ourselves.[3] The odd-N isomers have multihole configurations and their shape is not simple to predict.[4] For two of them, ^{135}Ce and ^{137}Nd, Gizon *et al.*[5] deduced, as we will, a prolate shape. Recently, Ragnarsson *et al.*[6] calculated the deformation of even-even nuclei, and obtained the ϵ_{th} contours of Fig. 1.

We considered β-decay rates as possible indicators of shape differences in a region with disputed deformations, expecting that pronounced differences would give poor overlap of the wave functions and therefore large hindrance factors for the β decay. Conversely, low log ft values would suggest similarity in the shape of the initial and final states. We therefore searched for $\frac{11}{2}^- \rightarrow \frac{11}{2}^-$ decays in the deformed region and found three cases; a fourth one, ^{137}Pm, is taken from a decay scheme presented by a collaborating group in Karlsruhe.[7] In Fig. 1 these $\frac{11}{2}^- \rightarrow \frac{11}{2}^-$ transitions are indicated by heavy arrows; three originate from odd-Z nuclei far from stability and one, more difficult to observe, is the decay of the odd-N isomer ^{139}Sm^m. The three odd-Z isomers decay predominantly by the $\frac{11}{2}^- \rightarrow \frac{11}{2}^-$ branch.

The $\frac{11}{2}^-$ states occur throughout this mass region. They are comprised of $h_{11/2}$ particles (odd Z) or holes (odd N) and are strongly produced by (α, xn) activations. Without any known exception, the odd-Z isomers have $J^\pi = \frac{11}{2}^-$. The assignments to ^{139}Eu and ^{135,137}Pm are supported by allowed β-ray decay to known $\frac{11}{2}^-$ (and $\frac{13}{2}^-$) states; the one to ^{139}Pm^m is established by more extensive spectroscopic evidence following below.

Targets of isotopically enriched ^{144}Sm and ^{142}Nd and of natural Pr were bombarded with α beams from the Kernfysisch Versneller Instituut cyclotron at energies from 80 to 140 MeV. The induced activities were studied in a low-background area after pneumatic transport of the activated targets. Ge(Li) spectra of γ rays were accumulated in a multispectrum-scaling mode to obtain information on the half-lives. The β-ray branches have been deduced from intensity balances of transitions to and from the $\frac{11}{2}^-$ states. Some β-γ coincidences were measured with a plastic scintillator and a Ge(Li) detector. Conversion electrons were ob-

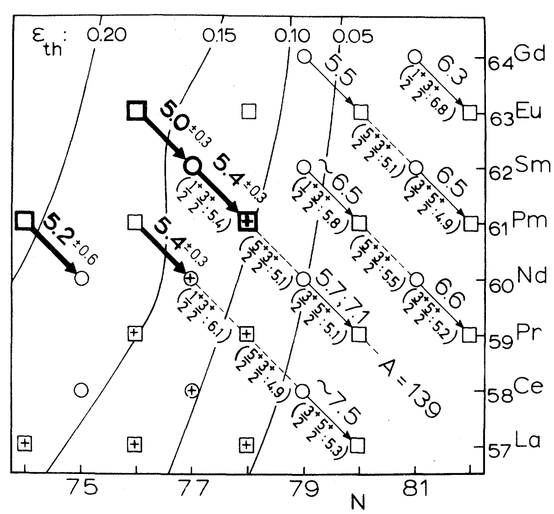

FIG. 1. Logft values for $\frac{11}{2}^- \rightarrow \frac{11}{2}^-$ decays (above the arrows) and for low-spin decays (below the arrows). Squares are odd-Z, circles are odd-N isomers. Nuclei for which spectroscopic evidence indicates a prolate shape have been indicated with a + sign. Contours for ϵ_{th} are as calculated for even-even nuclei in Ref. 6.

served in beam[2,3] and off beam with a mini-orange spectrometer.[8] The log ft values were computed with the tables and prescriptions of Gove and Martin,[9] after basic decay schemes (Figs. 2 and 3), partial half-lives, and disintegration energies E_d were established.

Moderately far from stability some E_d values were determined through measurements of end-point energies of β^+ spectra gated by known γ-ray transitions. These values agree well with values E_G, from the mass tables of Garvey *et al.*[10] After correction for finite resolution and for summation with annihilation radiation [triangles in Fig. 2(a)] we found E_d (^{139}Sm^g) = 5.2 ± 0.4 MeV (E_G = 5.56 MeV), E_d (^{136}Pr) = 5.35 ± 0.3 MeV (E_G = 5.29 MeV), and E_d (^{139}Pm) = 4.55 ± 0.2 MeV (E_G = 4.40 MeV). Based on this agreement we adopt Garvey's values[10] for ^{139}Eu and ^{135}Pm as accurate to within 1 MeV. This accuracy is not critical, since a deviation of even 2 MeV does not change the resulting log ft values by more than 0.9.

Prior to this investigation ^{139}Pm^m was known by its isomeric transition[11] with a half-life of ≤0.5 s. In this work we measured $t_{1/2}$ = 180 ± 20 ms. The mini-orange spectrometer[8] showed conversion electrons of the isomeric transitions of 188.7 and 190.2 keV in ^{139}Pm and ^{139}Sm with K/L ratios of 1.02 ± 0.07 and 1.03 ± 0.06, respectively. These values agree with $E3$ transitions (theoretical K/L : 1.01 for ^{139}Pm and 0.98 for ^{139}Sm, while all other multipolarities would give ratios below 0.37 or above 3.0). The spin of ^{139}Pm^g has not yet been measured, but we expect $J^\pi = \frac{5}{2}^+$ in analogy with the ground-state spins of ^{143}Eu, ^{141}Pm, ^{139}Pr, and ^{137}Pr. The assignment is consistent with the facts that we found no decay of ^{139}Sm^g ($\frac{1}{2}^+$) to ^{139}Pm^g within an accuracy of about 5% and that ^{139}Pm^g itself decays with log ft = 5.1 to ^{139}Nd^g ($\frac{3}{2}^+$). The $E3$ multipolarity of the isomeric transition and J^π(^{139}Pm^g) = $\frac{5}{2}^+$ establish that J^π(^{139}Pm^m) = $\frac{11}{2}^-$.

A Ge detector with high resolution showed that the 188.7-keV transition occurs also in the 9.5-s decay[12] of ^{139}Sm^m. Its intensity was always the

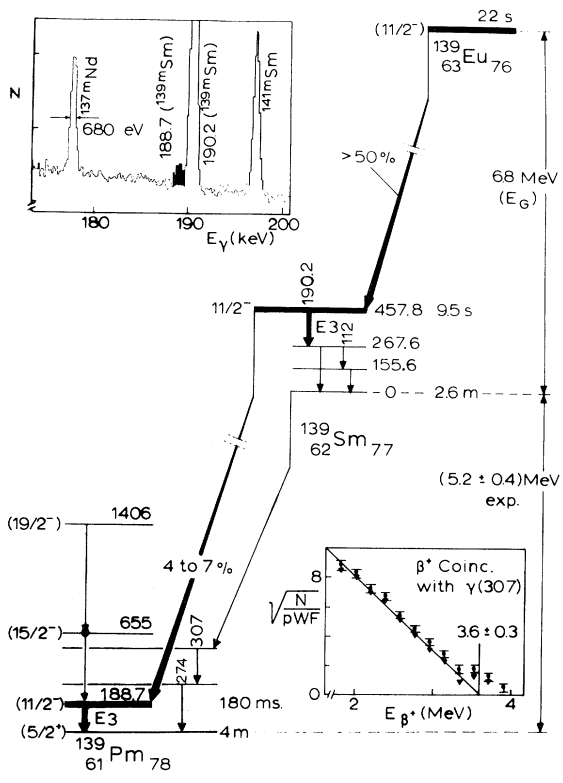

FIG. 2. Part of the decay chain with A = 139, together with (a) Kurie plot from β-γ coincidences, (b) part of a Ge spectrum with the 188.7-keV transition separated from the 190.2-keV transition and accumulated from 6 to 16 s after 90 activations of ^{142}Nd. The 307-keV transition of ^{139}Pm has been tentatively placed in coincidence with the 274-keV transition.

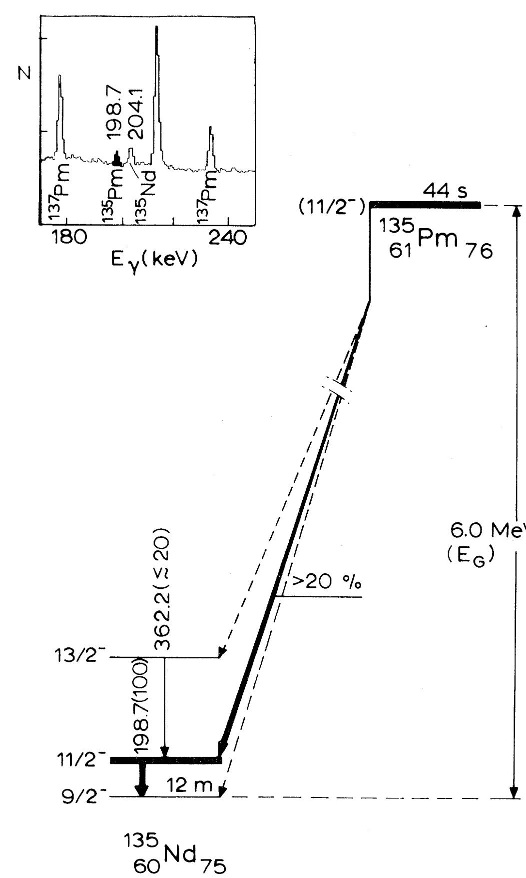

FIG. 3. Partial decay scheme of ^{135}Pm, together with part of a Ge(Li) spectrum of γ rays.

same relative to the intensity of the isomeric 190.2-keV transition. The spectrum of Fig. 2(b) gives $I(188.7)/I(190.2) = 0.068 \pm 0.005$. We assume that the level at 188.7 keV is populated mainly by β rays and conclude that a feeding via possibly unknown higher levels in ^{139}Pm is less than one-half of the β-decay rate of ^{139}Sm^m, because no other γ rays of ^{139}Pm were found in the 9.5-s decay.

Similarly an $\frac{11}{2}^- \to \frac{11}{2}^-$ branch of more than 50% is proposed for the decay of ^{139}Eu, an isotope previously known only through its 112-keV transition.[11]

The isotope ^{135}Pm, not reported before, was identified by its β decay to the known[5] level at 198.7 keV in ^{135}Nd. It has a half-life of 44 ± 9 s and was produced by ^{141}Pr(140 MeV α, $10n$)^{135}Pm. β decay to the ground state of ^{135}Nd is likely to occur but will not dominate the other branches by more than a factor of 5 (Fig. 3), as can be concluded from the observed growth rate of ^{135}Nd and from activation curves of the $^{135-140}$Pm isotopes.

The known[11] $\log ft$ values for the $\frac{11}{2}^- \to \frac{11}{2}^-$ decays are written above the arrows in Fig. 1. The present four values, though not super-allowed, are consistent with *no* significant retardation (i) when compared with the average value of 5.0 quoted by Sakai and Yoshida[13] for this region, (ii) when compared in Fig. 1 with $\log ft$ values for decays between low-spin states, and (iii) certainly, when compared with transitions between $\frac{11}{2}^-$ isomers near closed shells.[14] Qualitatively this suggests that there occur no large changes in deformation in the $\frac{11}{2}^- \to \frac{11}{2}^-$ β decays investigated.

To obtain a semiquantitative estimate of the possible shape hindrances, we followed Redlich and Wigner,[15] who calculated a limit for the hindrance of a β-ray transition from a cubic to a parallelopiped shape as a simplification of the transition from a spherical to a spheroidal shape. We modified this approach by considering a transition from an initial state β of a bar to a final state α of a somewhat differently stretched bar of equal volume, and calculated to first order the overlap integral

$$\langle \alpha | \beta \rangle = \prod_{i=1}^{A-1} \langle \alpha n_i | \beta n_i \rangle$$

with n_i, the quantum numbers for a square well with infinitely high walls. The increase of $\log ft$, $\Delta \log ft = 2 \log |\langle \alpha | \beta \rangle|$, is shown in Table I for some deformation differences.

The hindrance is essentially negligible for steps in $|\epsilon_i - \epsilon_f|$ of 0.02 or 0.03. Such values are suggested by the contours for even-even nuclei and for adjacent odd nuclei with low spin and no Coriolis decoupling. However, if we consider possibly larger changes in deformation between prolate[1,2] $\frac{11}{2}^-$ states with odd Z and disputed $\frac{11}{2}^-$ states with odd N, then Table I suggests $\log ft$ values much larger than the observed ones if $|\epsilon_i - \epsilon_f| \gg 0.1$ in the simplified model of permanent axially symmetric deformation. Softness and triaxiality[16,17] may greatly reduce these extreme retardations, but we expect that a noticeable effect will remain. Ragnarsson and Nilsson[18] mentioned the selectivity of an $h_{11/2}$ proton for a pronounced shape, giving γ-ray retardations of up to a factor of 100 for decay from $\frac{11}{2}^-$ states to soft and triaxial ground states. The equivalent $\Delta \log ft = 2$ is not compatible with the finding of no retardation of $\frac{11}{2}^- \to \frac{11}{2}^-$ transitions in the deformed region. Thus, the main conclusion of this communication is that the shape of the $\frac{11}{2}^-$ isomers with odd N will not be very different from the shape of the isomers with odd Z.

TABLE I. Calculated hindrance factors for initial and final deformations ϵ_i and ϵ_f for a nucleus undergoing β decay with $Z = 62$ and $N = 77$.

ϵ_i	0.17	0.18	0.20	0.25	0.12
ϵ_f	0.14	0.12	0.10	0.05	−0.12
$\Delta \log ft$	0.17	0.6	1.7	7	9

In addition the low $\log ft$ values imply that the transitions are not much hindered by selection rules[19] which forbid transitions with a large change in the quantum number Ω for strongly deformed nuclei with axial symmetry. Without explaining the fast $\frac{11}{2}^- \to \frac{11}{2}^-$ transitions from the point of view of the deformed shell model we remark that a considerable amount of triaxiality is not excluded by the rotation-alignment model.[17] This triaxiality with $\gamma < 30°$ may perhaps enhance[20] transitions between states with different Ω values if they occur with a small amplitude in the wave function of the aligned $h_{11/2}$ proton.

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$$|a'(j'j'n')|^2 .$$

We discuss relative logft values and disregard possible variations of this factor.

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