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Irregularities in Side-Feeding Patterns, Energies, and Multipolarities in the ^{154}Er Yrast Cascade to Spin 36

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States of ^{154}Er were studied by means of the (^{16}O,$4n$) and (^{64}Ni,$4n$) reactions. Beginning with a 40-nsec isomeric state [$J^\pi = (10^-, 11^-)$], an intensely populated unusual cascade of $\Delta J = 2$ and $\Delta J = 1$ transitions was established up to spin (35,36) and 12.5 MeV excitation. On an E vs $I(I+1)$ plot the yrast levels form a series of straight-line segments with side feeding occurring primarily at the ends of segments. A second cascade of even-spin, even-parity levels from the ground state to $J^\pi = 18^+$ (quasi-ground-state band) does not exhibit these properties.

Interesting data generated in part by searches for high-spin isomeric states,[1] or "yrast traps," have recently appeared for nuclei with $A \approx 150$. Calculations[2] predict oblate shapes for $I < 40$ in nuclei with neutron number $N = 84-88$, making this a likely region for yrast traps. Isomers have been found here, and an isomeric state has been reported in ^{154}Er by Aguer *et al.*[3]

The present work confirms part of the decay scheme of ^{154}Er as presented in Ref. 3, but it reorders several transitions and assigns spins to some low-lying levels. A quasi-ground-state band is extended beyond the previous highest spin state (14^+) to spin 18^+ and, most importantly, a high-spin yrast cascade is extended by six levels up to spin (35,36) and excitations over 12 MeV. The detailed structure of the yrast cascade differs significantly fron an yrast cascade reported by Khoo *et al.*[4] from spin (36,37) in the $N = 86$ isotone ^{152}Dy. The present study of ^{154}Er extends our investigations of high-spin states from the deformed "rotational" Er nuclei[5] down through the transitional region[6] to the near-closed-shell nuclei.

^{154}Er was produced by means of the reactions (^{16}O,$4n$) on ^{142}Nd at 95–102 MeV and (^{64}Ni, $4n$) on ^{94}Zr at 270 and 275 MeV. Targets of ^{142}Nd (4 mg/cm^2) and ^{94}Zr (3 mg/cm^2) were backed with ^{208}Pb. Ge-Li detectors with ~15% efficiencies and ~2-keV resolution at 1.33 MeV were used for γ-γ coincidence and angular-distribution studies. A pulsed ^{16}O beam was used to obtain delayed γ spectra, and some results of these measurements are shown in Fig. 1. A decay scheme based on these data is shown in Fig. 2.

The sequence of states in the quasi-ground-state band up to spin 18^+ was inferred from singles and coincidence data. Angular distributions for these transitions are consistent with a cascade of stretched $E2$'s. This cascade is composed of transitions which up to level 16^+ do not differ more than ±12% from a mean energy of 615 keV. A 432- and 796-keV side cascade of transitions feeds into the 6^+ level. Angular-distribution data are consistent with a $\Delta J = 1$ and a $\Delta J = 2$ assignment to the 432- and 796-keV transitions, respectively. This sequence is characterized as proceeding between levels with spin $9 \to 8' \to 6^+$. The order is established by a weak 254-keV transition which takes place between the $8'$ level and the 8^+ member of the quasi-ground-state band. A parallel sequence, 554 keV ($\Delta J = 2$) and 674 keV ($\Delta J = 1$), originates at the spin-9 level, ends at the 6^+ state, and is thus characterized as being $9 \to 7 \to 6^+$. A third transition, 686.5 keV ($\Delta J = 1$), originates at the 9 level and proceeds to the 8^+ level of the quasi-ground-state band.

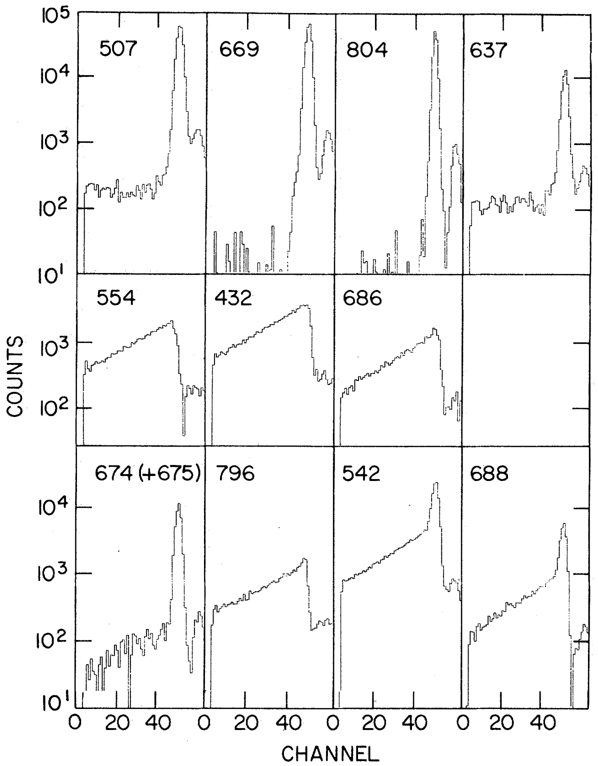

FIG. 1. Time distributions relative to beam pulse for selected γ rays in ^{154}Er. The time scale is approximately 2.7 ns/channel. The relative position of γ rays in the decay scheme is shown in Fig. 2. The prompt component in the 674-keV spectrum is mainly due to the 675-keV line.

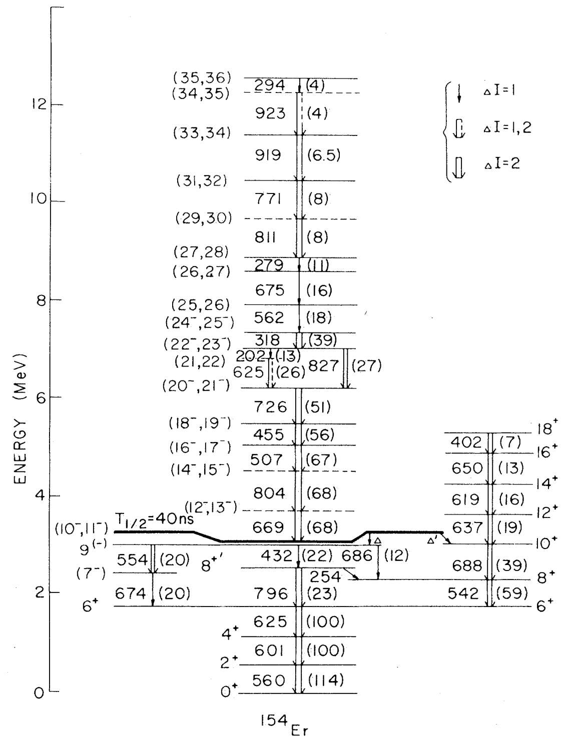

FIG. 2. Decay scheme for ^{154}Er. Relative intensities are given in parentheses to the right of the energies. Broken horizontal lines indicate uncertainty in order of transitions.

Figure 1 shows the presence of an isomeric state with half-life $T_{1/2} = 40 \pm 3$ ns.[3] There is a delayed component with this half-life in the time spectrum of the 688-keV $10^+ \rightarrow 8^+$ transition along with a prompt component. The 432-, 554-, and 686-keV transitions also show this half-life with no prompt component in their time spectra, while the time spectra of the succeeding γ rays do show prompt components.[7] This observation is used to help determine the ordering within these pairs of transitions originating at the spin-9 level. If one assumes that only one isomeric state is involved, then the isomer must be a state above the spin-10^+ state of the quasi-ground-state band, the spin-9 state must have negligible side feeding, and the isomer must decay with two parallel and as-yet-undetected low-energy transitions to the spin-9 and -10^+ levels, respectively. The lack of transitions to levels with spins lower than 9 and the transitions to the spin-9 and spin-10^+ levels suggest spin 10 or 11 for the isomeric state.

The lower-energy levels of ^{154}Er can be understood more readily by comparing ^{154}Er with the isotones[8] ^{148}Sm, ^{150}Gd, and ^{152}Dy. In all three isotones a well-developed sequence of odd-spin, odd-parity levels has been seen based on 3^- level. The negative parity of the 7^- state in ^{150}Gd has been established by Haenni and Sugihara.[9] The systematic appearance of spin-7 and spin-9 levels in the isotones and the negative-parity assignment in ^{150}Gd allows a negative-parity assignment to these levels in ^{154}Er. Considerations of the observed transitions from the isomeric state and the lack of transitions to the 8^+ level in the quasi-ground-state band strongly favors a negative-parity assignment to this state although 10^+ is not completely excluded.

The cascade of discrete yrast transitions from spin (35, 36) which feeds into the isomeric level in ^{154}Er may be compared with the high-spin portion of the ^{152}Dy decay scheme. A plot of energy versus $I(I+1)$ for ^{152}Dy shows that the yrast energies increase linearly with $I(I+1)$ on the average, and the authors in Ref. 4 interpret these

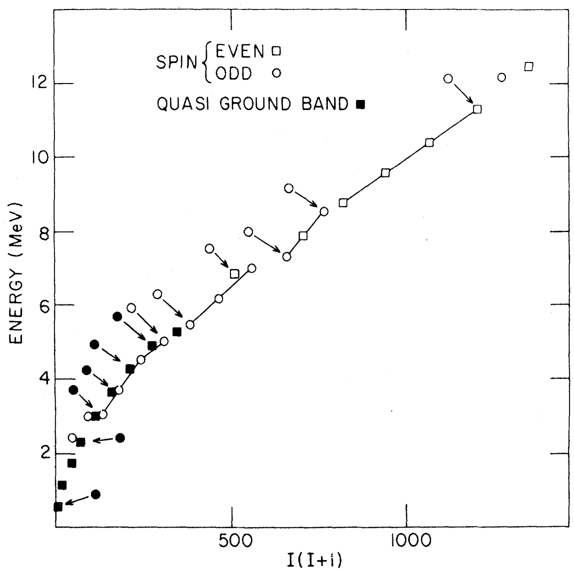

FIG. 3. E vs $I(I+I)$ plot for ^{154}Er. Both the quasi-ground-state band and the long cascade feeding the isomeric state are plotted. States associated with the equal-intensity sequences in the latter cascade are joined by solid lines. Arrows with open dots or filled dots indicate side feeding into levels of the cascade based on the isomeric state or the quasi-ground-state band, respectively. Strictly speaking, the straight line representing the quadrupole transitions to the level just above 6 MeV should not be there since it does not equal in intensity the transition out of this level. However, this is due to the accidental presence of a parallel cascade which has side feeding in it. The important consideration is the lack of sidefeeding into the level at 6 MeV. In constructing this figure, the spin of the isomeric state was taken to be 11.

states to be aligned individual particle states which they analyze in the framework of the Fermi-gas model. A similar plot for ^{154}Er, Fig. 3, shows a structure in the yrast levels not apparent in the ^{152}Dy data. The yrast levels of ^{154}Er are not randomly distributed about a straight line as in ^{152}Dy, but fall on a series of connected straight-line segments.

In both nuclei the yrast cascades contain both $L = 2$ and $L = 1$ transitions. In ^{154}Er some sequences contain γ rays which are of almost equal intensity.[10] When states which are connected by equal-intensity transitions are joined with straight lines in Fig. 3, one sees that these levels lie on small straight segments of the borken line. All transitions in a segment are of the same multipolarity. Side feeding, indicated by arrows, occurs at the break points in the yrast line. These two- or three-step sequences contain transitions of energies comparable with those of collective vibrational transitions in the $N = 86$ isotones (~500 to ~700 keV) and lower-energy transitions connect these "bandlike" sequences. At one of these break points (spin 18,19) there is a decided change in the alignment of the nuclei. The m-state distribution parameter,[11] σ/J, averages 0.25(2) for three transitions above the (18,19) level and 0.32(2) for the four following transitions. One may expect under these circumstances that isomers would appear at these break points. These isomers, however, are not the high-multipolarity yrast traps discussed by Døssing[2] since the latter involve $\Delta J \geqslant 3$. The quasi-ground-state sequence, in contrast to the high-spin yrast levels, shows the side-feeding pattern common in the region of deformed nuclei. Yet, where the two cascades overlap in Fig. 3, their levels fall close to each other along an yrast region up to spin 18. The distribution and nature of states above and on the yrast line must be such that in the very same region of yrast levels, side feeding is concentrated at specific levels in one cascade but is continuous in the other.[12]

There are similarities between the behavior of the yrast transitions in ^{154}Er (energy spacings, side-feeding patterns, and short seemingly collective sequences based on intrinsic states) and predictions of particle-vibration coupling models[13] or the competition between collective and noncollective transitions as discussed by Liotta and Sorensen.[14] Whatever the mechanism is which is affecting the side feeding to the yrast levels at high spin, it is important in the deexcitation process of the compound nucleus since, at about 5.5 MeV excitation, 51% of the strength of the reaction proceeds down through the high-spin yrast cascade, which is at least 7 times that which passes through the level at this excitation in the quasi-ground-state band.

There is one interesting similarity in the yrast cascades of ^{152}Dy and ^{154}Er. The Fermi-gas analysis of the ^{152}Dy yrast cascade defines for this nucleus an effective moment of inertia $\mathscr{G}_{eff} = 142$ MeV^{-1} and implies a deformed shape with $\beta = 0.3$. A similar analysis of the ^{154}Er yrast cascade yields an $\mathscr{G}_{eff} = 140$ MeV^{-1} and also $\beta = 0.3$. This moment of inertia is larger than that of a rigid sphere[4] so that the two nuclei under question may be considered to be oblate, in agreement with predictions by Døssing *et al.*[2] who also predict that the probability of finding low-spin ($I < 40$) yrast traps in ^{154}Er ($N = 86$) becomes less likely as β changes from 0.1 to 0.4. The validity of this kind of analysis of the ^{154}Er yrast cascade is not clear, but it suggests that the cascade may be composed of sequences of two- or three-step related transitions based on occasional intrinsic states which scatter around a straight line reminiscent of the Fermi-gas model. No $\Delta J \geq 3$ transition (yrast trap) was observed.

In summary, we have found in ^{154}Er a series of yrast levels from spin (35,36) which, on an E vs $I(I+1)$ plot, fall on straight segments of a broken line with side feeding occurring mainly at the break points of the line (Fig. 3), resulting in transitions of equal intensities between states on straight segments of the yrast line. Transitions within the segments are either all quadrupole or all dipole. Angular-distribution data indicate an abrupt reduction of alignment at one of these break points so that it is expected that isomers might exist at these points. This cascade differs from a quasi-ground-state band up to spin 18^+ which shows side feeding at all levels, as is the usual case in the deformed region of nuclei.

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New Infrared Absorption Bands of Alkali Vapors

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We have identified two new infrared absorption bands in potassium vapor. The band between 1.1 and 1.6 μm is attributed to the K_2 ($^3\Sigma_u^+ \rightarrow {}^3\Sigma_g^+$) transition, the absorption analog of the intense emission continuum of H_2. The absorption at wavelengths longer than 1.6 μm is probably due to trimers.

In this paper we report on a new region of absorption of infrared radiation by alkali-metal vapors. Recently, Chertoprud[1] has reported that absorption exists in saturated potassium vapor at wavelengths well beyond the edge of the A band (1.1 μm), and the absorption extends at least as far as 2.5 μm. Chertoprud[1] assigns this absorption to the intercombination transition ($X^1\Sigma_g^+ \rightarrow {}^3\Sigma_u^+$). Our recent experiments confirm that absorption does exist in the alkali vapors potassium, rubidium, and cesium at wavelengths at least as long as 2.5 μm. However, our observations differ considerably from those of Chertoprud[1] since we find at least two distinct absorption bands, a much smaller attenuation coefficient at low temperatures, a complex dependence on wavelength, and a temperature dependence which unambiguously rules out the assignment of

