Population of Triaxial Rotor Levels in ^{182}Os

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A K-isomeric state in ^{182}Os with spin $I=(20\pm2)\hbar$ and half-life equal to 100 ns is found to decay in flagrant violation of the usual K-selection rules. The observations—still preliminary—are on the other hand readily understood if it is assumed that the yrast configuration of ^{182}Os becomes triaxial above the backbend, and that the decay proceeds via the numerous collective levels of the triaxial rotor.

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The development of sizable gamma deformations in rotating nuclei, and hence real triaxiality, has been invoked to explain anomalous signature splittings and $E2$-transition rates in several rare-earth nuclei.[1–5]

Breaking the axial symmetry will have two particularly conspicuous consequences. (i) The K-selection rule in its accustomed form will break down because the conservation of the angular momentum projection K and hence K quantization is based on the existence of axial symmetry.[6] (ii) The system of collective levels will become considerably more extensive: For doubly even nuclei of ellipsoidal shape, every intrinsic, triaxial configuration will give rise to $(I+2)/2$ levels for each even-spin value and $(I-1)/2$ levels for each odd-spin value,[6] instead of a simple rotational band with just one state for each spin value I.

In this Letter we are presenting some preliminary but highly suggestive experimental results where, for the first time, these two effects appear to be born out.

In a search for isomeric states with high K values in W and Os nuclei, performed at the UNILAC laboratory, Gesellschaft für Schwerionenforschung, Darmstadt, a pulsed beam of ^{136}Xe with an energy of 4.3–4.8 MeV/u was used to bombard thin targets of ^{48}Ca and ^{48,50}Ti. Possibly isomeric nuclei were allowed to recoil through a hole in a 10-cm Heavy-Met (i.e., tungsten) shield and collected onto a ^{208}Pb catcher foil placed 15 cm downstream. An array of ten NaI and two Ge detectors viewing the catcher recorded the multiplicity, delay time, and gamma-ray energy of the decaying isomers, within a range from 5 ns to several hours after they were produced. A total of six new isomers were identified,[7,8] but here we shall concentrate on the new 100-ns isomer in ^{182}Os. The results obtained with this isomer are summarized in Fig. 1(b).

The conditions of the experiment did not permit the recording of extensive gamma-gamma coincidences, and therefore the decay pattern is not yet known in detail. What is known is that the isomer decays with an average multiplicity of at least twelve through emission of at least thirty gamma rays, out of which nine belong to the yrast band in ^{182}Os. The four lowest-lying transitions of equal intensity are coincident with all the remaining ones and the energy of the isomer, estimated by summing the intensity-weighted energies, is greater than or equal to 4.7 MeV. For this estimate to be reliable the absolute intensities have to be known. We have assumed the four lower yrast transitions to have 100% absolute intensity and used this for the intensity calibration of the remaining lines. In addition, the well-known[12] 0.8 ms isomer with $K,I^{\pi}=8,8^{-}$ is observed in the experiment.

In order to appreciate the highly unusual decay mode of the new isomer we compare it in Fig. 1(a) to the decay pattern[9] of the K isomers in ^{176}Hf. This pattern exemplifies the workings of the K-selection rule for axially symmetric even nuclei. Bandheads, and only those, can have long lifetimes. The larger the difference in K value between initial and final state, the longer the lifetime. Therefore the decay proceeds stepwise, with intermittent delays, and always keeping the difference between I and K as small as possible.

As a consequence, only the low-spin states of the $K=0$ ground state band are being fed in the decay, even in the case where the initial isomeric state has very high spin.

This is contrasted with the results for the new ^{182}Os isomer, Fig. 1(b). With a multiplicity of at least twelve and feeding into a spin-$18\hbar$ level, the isomeric configuration cannot fail to be rotating with high angular momentum [presumably $(20\pm2)\hbar$]; and yet it radiates slowly compared to a typical transition rate of 0.5 ps for a rotational $E2$ transition. Classically and also quantum mechanically such a hindrance is only possible if the charge (and hence mass) is distributed symmetrically around the angular momentum axis. The most reasonable interpretation is therefore that the isomer is a bandhead of prolate, axially symmetric configuration, with quantum numbers $I=K$, just like the isomers in ^{176}Hf. Nevertheless this configuration is found to decay without intervening delays to the spin-$(18-10)\hbar$ members of the yrast band that has $\langle K\rangle=0$. This takes place by the emission of 21 gamma rays, with typical intensities of 20%, i.e., through five parallel or intertwined cascades.

A decay pattern of this type cannot be understood within the standard framework used to explain ^{176}Hf for example. It is on the other hand what one should expect if the unknown intermediate states populated in ^{182}Os were part of the collective level system of an intrinsically triaxial configuration. As mentioned initially, there are several levels for each spin value in this case. For each spin the levels will be ordered with the expectation value of the spin projection $\langle K\rangle$ increasing in steps of approximately $2\hbar$ as the energy increases.[6,11] The result is a system of collective levels that provide a relatively easy decay path for the isomer with its $K=I=(20\pm2)\hbar$, as observed. In Fig. 1(c) we have sketched how the level spectrum of a rigid triaxial rotor may look (dashed lines).

With the long lived $I,K^\pi=8,8^-$ isomer, also found

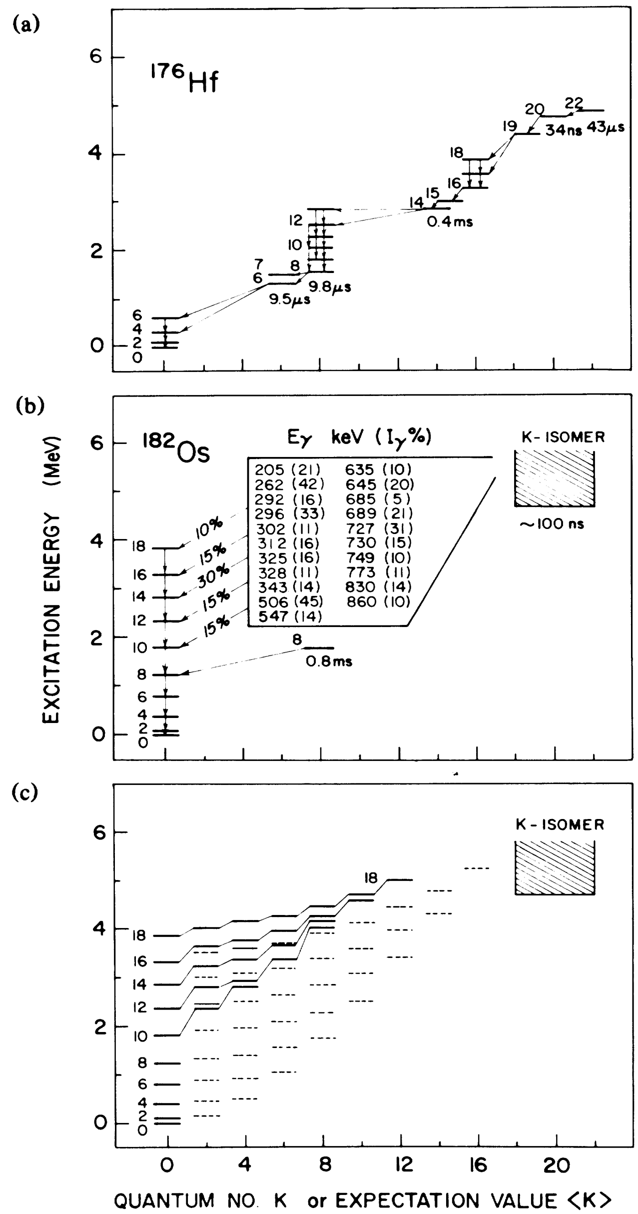

FIG. 1. (a) Decay paths of high-K isomers in ^{176}Hf, based on Ref. 9, The ground-state-band levels are known up to spin $18\hbar$ (and there is a slight upbend, indicating some alignment of two $i_{13/2}$ quasi neutrons), but in the depopulation of the isomers there is zero feeding of yrast levels above spin $6\hbar$. (b) Decay of K isomer in ^{192}Os. Summary of experimental results. The level assignments and multipolarities are based on the in-beam studies of Ref. 10, whereas the intensities are those observed presently during the decay of the isomer. Unassigned transitions (and intensities) are placed in the irregular box. The intense population of the $I=18\hbar$, $\langle K\rangle=0$, and lower yrast levels is a conspicuous feature signaling a breakdown of the ordinary K-selection rules associated with axially symmetric intrinsic states. (c) Schematic diagram showing triaxial rotor levels with spin projections $\langle K\rangle>0$, relative to the experimental yrast line ($\langle K\rangle=0$). Dashed lines are calculated with fixed moments of inertia $J_1=60.0$ MeV^{-1}, $J_2=52.6$ MeV^{-1}, and $J_3=31.3$ MeV^{-1}, corresponding to an essentially fixed intrinsic configuration. The solid lines are freely drawn to sketch the suggested position of relevant levels of a dynamic rotor commensurate with axial symmetry at low spin (as evidenced by the normal, long lifetime of the $8,8^-$ isomer) followed by increasing triaxiality as the spin increases towards $18\hbar$. At this spin value the moments of inertia corresponding to the dashed lines are adopted. For simplicity, levels with odd-spin values are omitted. The levels with even spin are ordered according to increasing mean values of $\langle K\rangle$ of the spin projection, but there are considerable fluctuations about the mean (Ref. 11) (especially for low $\langle K\rangle$ values). Levels of the same spin are connected by thin lines. The position of the isomer is also indicated.

in ^{182}Os, there is no sign of an anomalously enhanced decay rate. [The seven times hindered $E1$ transition to the yrast band has a hindrance factor of 6×10^{11} as expected for an axially symmetric nucleus, and in agreement with the isomeric transition rates observed in ^{176}Hf, Fig. 1(a)]. Clearly, it is only the higher spin members of the yrast band of ^{182}Os that appear to develop the triaxial level system. These are the states above the backbend, where two $i_{13/2}$ quasineutrons gradually align.[10] The nucleus ^{182}Os is known to be soft towards gamma deformations, with a vibrational frequency $\hbar\omega_\gamma$ as low as 891 keV.[12] Thus the appreciable gamma deformation indicated here, and actually also in ^{180}Os and ^{183}Os (Ref. 8), appears to be the result of the polarizing effect of aligned quasiparticles on a relatively soft core.[5,10] (One should note that a similar effect does not seem to occur in ^{176}Hf, which is less soft with a $\hbar\omega_\gamma$ of 1341 keV[12]). The actual triaxial-rotor spectrum will be highly distorted by dynamical alignment effects, compared to a rigid triaxial configuration; this is also indicated in a qualitative manner in Fig. 1(c) (solid lines).

There is nothing that prevents the population of the triaxial rotor levels in the decay of a compound nucleus, and thus nothing prevents observation of these levels in prompt in-beam gamma spectroscopy. On the other hand, the decay of a high-K isomer is particularly favorable for bringing the triaxial levels—with their increasing $\langle K\rangle$ values—in evidence in a selective fashion.

In summary, we have observed a novel and unusual decay mode for a high-K isomer in ^{182}Os. It appears to signal the appearance in nuclear spectroscopy of the triaxial rotor spectrum with its extensive collective level structure.

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[1]I. Hamamoto and B. R. Mottelson, Phys. Lett. **127B**, 281 (1983).

[2]G. B. Hagemann, J. D. Garrett, B. Herskind, J. Kownacki, B. M. Nyakó, P. J. Nolan, J. F. Sharpey-Schafer, and P. O. Tjøm, Nucl. Phys. **A424**, 365 (1984).

[3]S. Frauendorf and F. R. May, Phys. Lett. **125B**, 245 (1983); S. Frauendorf, in Proceedings of the Fifth Nordic Meeting on Nuclear Physics, Jyväskylä, March, 1984 (to be published).

[4]H. Emling, E. Gross, R. Kulessa, S. Schwalm, and H. J. Wollersheim, Nucl. Phys. **A419**, 187 (1984).

[5]R. Bengtsson, H. Fristen, F. R. May, and J. A. Pinston, Nucl. Phys. **A415**, 189 (1984); R. Bengtsson, Y.-S. Chen, J.-Y. Zhang, and S. Åberg, Nucl. Phys. **A405**, 221 (1983).

[6]A. Bohr and B. R. Mottelson, *Nuclear Structure* (Benjamin, London, 1975), Vol. 2, pp. 175–198.

[7]J. Pedersen, F. Azgui, B. B. Back, S. Bjørnholm, J. Borggreen, H. Emling, H. Grein, G. Seiler-Clark, G. Sletten, W. Spreng, P. Walker, and H. J. Wollersheim, in Proceedings of the Fifth Nordic Meeting on Nuclear Physics, Jyväskylä, March, 1984 (to be published).

[8]J. Pedersen, B. B. Back, S. Bjornholm, J. Borggreen, G. Sletten, F. Azgui, H. Emling, H. Grein, G. Seiler-Clark, W. Spreng, H. J. Wollersheim, and P. Walker, to be published.

[9]T. L. Khoo, F. M. Bernthal, R. G. H. Robertson, and R. A. Warner, Phys. Rev. Lett. **37**, 823 (1976); T. L. Khoo, F. M. Bernthal, R. A. Warner, G. G. Bertsch, and G. Hamilton, Phys. Rev. Lett. **35**, 1256 (1975).

[10]R. M. Lieder, G. Sletten, J. Borggreen, and J. Pedersen, Nucl. Phys. **A375**, 291 (1982).

[11]M. Diebel (unpublished).

[12]*Table of Isotopes,* edited by M. Lederer and V. S. Shirley (Wiley, New York, 1978), 7th ed.