Local Extension of the Grodzins Systematics in the Actinide Mass Region

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A very successful empirical systematics in the first minimum was first developed by Grodzins, correlating the reduced electric quadrupole transition probabilities $B(E2)\uparrow$ from the ground state to the first excited 2^+ state in even-even nuclei with its excitation energy E_{2^+}, resulting in a characteristic A and Z dependence, which can be expressed in its most recent parameterization [1] as

$$B(E2)\uparrow = (2.57 \pm 0.45) E^{-1} Z^2 A^{-2/3} \qquad (1)$$

A simple theoretical model to understand the trends in the $B(E2)\uparrow$ values is the Single-Shell Asymptotic Nilsson Model, where the $B(E2)\uparrow$ values (in units of e^2b^2) are expressed via the intrinsic quadrupole moment Q_0 by

$$B(E2)\uparrow = \frac{5}{16\pi}|eQ_0|^2 \qquad (Q_0 \neq 0)\ . \qquad (2)$$

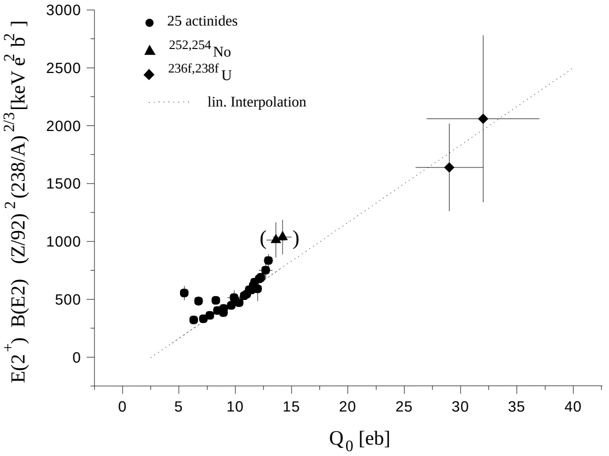

Fig. 1: Local Grodzins systematics (normalized to ^{238}U) in the region of the actinides (25 nuclei with $Z \geq 88$ and $E(2_1^+)$ <200 keV: circles). Triangles: data for ^{252,254}No from extrapolated $E(2_1^+)$ energies. Diamonds: data from fission isomers ^{236f,238f}U.

The fairly good global description of a wide range of nuclei by the presented improved Grodzins systematics can be illustrated by reminding that about 90% of 300 measured $B(E2)\uparrow$ values from nuclei in the first minimum with deformations ranging from near-spherical to $\beta \sim 0.3$ can be described by this systematics within a factor of two. However, when focusing on the local properties in the region of the actinides, the expected picture of a rather constant behaviour of the product between $E(2^+)$ and $B(E2)\uparrow$ changes into a rising trend when plotted versus the intrinsic quadrupole moment Q_0 as shown in Fig. 1 (normalized to ^{238}U). The circular data points represent 25 actinide nuclei with $Z \geq 88$ and $E(2^+)$ <200 keV.
An even more significant evidence for the rather linear increase of the Grodzins systematics with the quadrupole moment in the actinides is revealed when adding the data points from the shape isomers in the Uranium isotopes ^{236,238}U, which are the only fission isomers where 2_1^+ energies and quadrupole moments have been measured. These data have been added as diamond data points to Fig. 1, nicely fitting into the systematic trend already revealed by the less deformed nuclei.

A linear fit to the data results in the dotted curve added to Fig. 1, allowing to parameterize the dependency of the Grodzins systematics (normalized to ^{238}U) on the quadrupole moment Q_0 as

$$E(2^+)B(E2)\cdot(Z/92)^2(238/A)^{2/3} =$$
$$(66.77 \pm 4.44)\cdot Q_0 - (171.47 \pm 45.86) \quad [\mathrm{keV\ e^2b^2}]\ .$$

An explanation of this remarkable behaviour may be found in the reduction of the pairing interaction when approaching the rigid rotor limit at large nuclear deformations. Of even larger practical use is the correlation between the 2^+ excitation energy and the quadrupole moment Q_0 as displayed in Fig. 2 (for the same data as included in Fig. 1 and normalized to ^{238}U), allowing to deduce the quadrupole moment Q_0 from a measured value for the 2_1^+ transition energy. Exploiting Eq. (2) the fit curve in Fig. 1, corresponding to Eq. (3), has been converted into

$$E(2^+)\cdot(Z/92)^2(238/A)^{2/3} =$$
$$(66.77 \pm 4.44)/Q_0 - (171.47 \pm 45.86)/Q_0^2 \qquad [\mathrm{keV}]$$

and added to Fig. 2. Two theoretical calculations of the moment of inertia as a function of deformation for ^{240}Pu using Nilsson and Woods-Saxon potentials have been converted into the functional dependence between the $E(2^+)$ energy and the quadrupole moment in order to include them to Fig. 2 (solid and dashed curve).

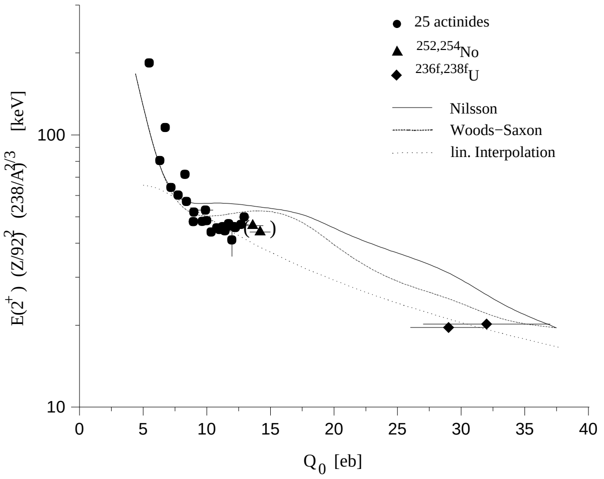

Fig. 2: Correlation between the measured excitation energy of the first 2^+ state and the intrinsic quadrupole moment Q_0 normalized to the Z and A dependence of the Grodzins systematics and to ^{238}U. The same data as in Fig. 1 are displayed. The linear fit to the data of Fig. 1 has been converted according to Eq.(3) and added as the dotted curve. The solid and dashed curves represent calculations of the moment of inertia for ^{240}Pu as a function of deformation (see text).

Interestingly the deviation of the experimental data from the linear interpolation for quadrupole moments in the range of 10-15 eb to somewhat larger 2^+ energies also occurs in the theoretical calculations which take the change of the pairing interaction with deformation into account.

[1] P.G. Thirolf and D. Habs, Prog. Part. Nucl. Phys. **49** (2002) 325 and references therein