SYSTEMATICS OF ENERGY SIGNATURE SPLITTING FOR $\pi h_{9/2}[541\ 1/2^-]$ ROTATIONAL BANDS IN ODD-Z RARE-EARTH NUCLEI *

H.J. JENSEN[a], W.F. MUELLER[b], W. NAZAREWICZ[b,c], W. REVIOL[b], L.L. RIEDINGER[b], J.-Y. ZHANG[b]

[a]Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich, Germany
[b]Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA
[c]Joint Institute for Heavy-Ion Research, Oak Ridge, Tennessee 37831, USA

(Received December 10, 1996)

Systematics of the energy signature splitting, $\Delta e'$, for rotational bands built on the $\pi h_{9/2}[541\ 1/2^-]$ Nilsson intruder configuration in the $Z = 69$–79 region are presented. Predictions from Cranked Shell Model calculations, based on frequency adiabatic configurations, are compared with the experimental data for isotopes of Tm, Lu and Ta.

PACS numbers: 21.10. -k; 21.60. -n; 27.70. +q

1. Introduction

The Cranked Shell Model is known to be a rather successful tool for describing many features of deformed nuclei. However, this mean field approach seems in general to fail when applied to band structures built on intruder configurations in the rare-earth region (*i.e.* the configurations $\pi h_{9/2}[541\ 1/2^-]$ and $\pi i_{13/2}[660\ 1/2^+]$). Pronounced deviations between the experimental and predicted rotational frequency, $\hbar\omega_c$, and gain in aligned angular momentum, Δi_x, at the crossing with the S-band, in which the first pair of $i_{13/2}$ quasineutrons have aligned, was discussed for the $\pi h_{9/2}[541\ 1/2^-]$ configuration at the XXIX Zakopane School of Physics [1].

In order to get a better understanding of the special features of rotational bands built on the $\pi h_{9/2}[541\ 1/2^-]$ configuration, which so far remain unexplained, another experimental quantity — the energy signature splitting, $\Delta e' \equiv e'(\alpha_u) - e'(\alpha_f)$, between the two signatures of rotational bands built

* Presented at the XXXI Zakopane School of Physics, Zakopane, Poland, September 3-11, 1996.

on the $\pi h_{9/2}[541\ 1/2^-]$ configuration — has been included in the investigations. $\Delta e'$ is expected to depend on several factors like nuclear deformation, pairing correlations and the position of the Fermi level. The success of a calculation of $\Delta e'$ is therefore strongly dependent on how well these correlations are understood. An improved method, using the Cranked Shell Model approach based on a Woods–Saxon potential [2], for calculating $\Delta e'$ in $\nu i_{13/2}$ rotational bands among odd-N rare-earth nuclei was presented by W.F. Mueller *et al.* [3]. The method, which proved to be quite successful in calculating the trend in $\Delta e'$ for isotopes of Dy through Os [3], takes into account a possible difference in deformation and/or pairing for the two signatures, the monopole pairing gap is treated in a self-consistent way, and blocking of appropriate signatures are used. The nuclear deformation parameters, $(\beta_2, \beta_4, \gamma)$ are extracted from Total Routhian Surface (TRS) calculations [4] at the rotational frequency of interest for both the unfavoured and favoured signature. This method has been used for the present investigation and we refer to [3] for further detail.

2. Experimental systematics for $\pi h_{9/2}$ bands

The known experimental signature splitting, $\Delta e'$, for $\pi h_{9/2}[541\ 1/2^-]$ rotational bands in the rare-earth region are presented in Fig. 1[1]. The signature splitting, $\Delta e'$, was extracted at a rotational frequency $\hbar\omega = 0.2$ MeV, using experimental routhian diagrams. To avoid the well-known problems for frequency adiabatic CSM calculations [5] in the band crossing region, the analysis was restricted to a rotational frequency well below the AB-band crossing frequency, which for the $\pi h_{9/2}[541\ 1/2^-]$ band is around $\hbar\omega \sim 0.30 - 0.35$ MeV, for the nuclei studied.

The systematic trend of $\Delta e'$ is seen to be a smooth function of both neutron and proton numbers. Three major observations — which all should be reproduced in a satisfactory model — can be made:

1. an increasing signature splitting as a function of the neutron number, N, within each isotopic chain,
2. a decreasing signature splitting as a function of the proton number, Z, for isotopes of Re, Ir and Au, and
3. a "saturation" in signature splitting for the Tm, Lu and Ta isotopes with a comparable signature splitting for the isotones.

The signature splitting is expected to increase with increasing quadrupole deformation, β_2, and β_2 is expected to increase with N and decrease with Z. A qualitative understanding of observation 1 and 2 is therefore possible in terms of the correlation between β_2 (or equivalently the position of the Fermi

[1] A list of references for the data in Fig. 1 will be given in a future paper.

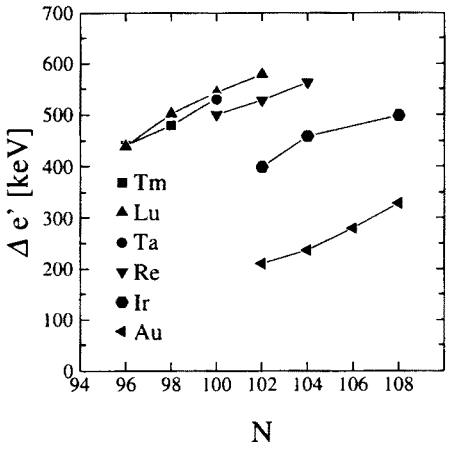

Fig. 1. Experimental energy signature splitting, $\Delta e'$ (in keV), for $\pi h_{9/2}[541\ 1/2^-]$ rotational bands in the rare-earth region extracted at rotational frequency $\hbar\omega = 0.2$ MeV.

level) and N and Z. An explanation for observation 3 is less obvious, but the saturation effect could, for these nuclei, be associated with a cancellation of contributions to $\Delta e'$, which arise from small differences in nuclear shape, pairing and the position of the Fermi level relative to the $\pi h_{9/2}[541\ 1/2^-]$ configuration.

3. Comparison between data and predictions

Signature splittings for $\pi h_{9/2}[541\ 1/2^-]$ rotational bands in Tm, Lu and Ta isotopes were calculated at $\hbar\omega = 0.2$ MeV using the method outlined in [3]. Due to problems in extracting reliable deformation parameters for the Re, Ir and Au isotopes predictions for only the lighter rare-earth nuclei were possible. In Fig. 2 the experimentally determined signature splittings (solid lines) are compared with predicted values (dashed lines).

An apparent good agreement between data and predictions is seen for ^{165}Tm and ^{167}Lu, whereas the predicted values are smaller than the experimental values in all other cases. It is important to emphasize that the experimental uncertainties on $\Delta e'$ are typically as small as 3–5 keV, whereas the predicted values are believed to have much larger uncertainties[2], which in the present case were estimated to be as large as 70 keV. Consequently it is not possible to predict the splittings with the same accuracy. A good

[2] The uncertainties on the predicted values were discussed by Mueller *et al.* [3] and they were found to be related mainly to the extracted deformation parameters from the used TRS calculations.

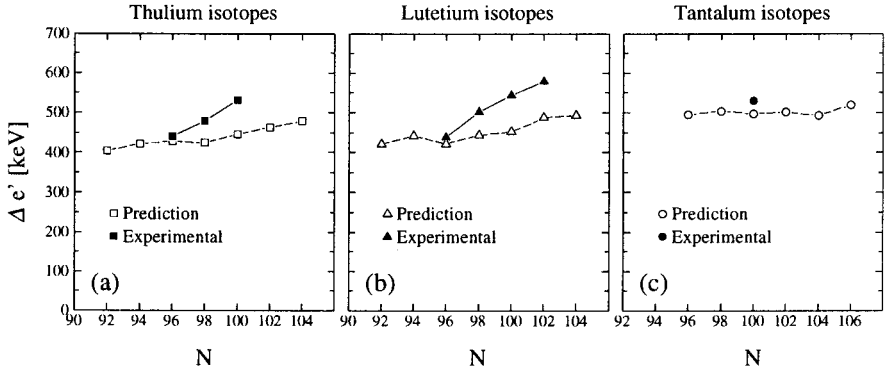

Fig. 2. Experimental (filled symbols) and predicted (open symbols) signature splitting, $\Delta e'$ (in keV), for Thulium (a), Lutetium (b) and Tantalum (c) isotopes for the $\pi h_{9/2}[541\ 1/2^-]$ rotational band at rotational frequency $\hbar\omega = 0.2$ MeV.

agreement between predictions and data for isolated nuclei might therefore be accidental. We, therefore, rather focus on the systematic trends, like the three observations discussed above, which gives a more crucial test of the model.

The first observation — an increase in $\Delta e'$ as a function of N within each isotopic chain — is reproduced by the model, but not with the same slope. The predicted values are almost independent of N. The second observation — a decrease in $\Delta e'$ as a function of Z for isotopes of Re, Ir and Au — is impossible to check, since the calculations were performed for Tm, Lu and Ta isotopes only. These nuclei do not have this feature. Finally, it seems that the model fails to predict the third observation — the saturation effect. For the $N = 96$, 98 and 100 isotones the data for Tm, Lu and Ta are identical within ~ 20 keV, whereas the predicted signature splitting increase between 50 and 80 keV when going from $Z = 69$ to 73. Therefore, one must conclude that discrepancies between data and predictions exist when the systematic trends are investigated.

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