TRIAXIAL AND TRIAXIAL SOFTENESS IN NEUTRON RICH Ru AND Pd NUCLEI

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The level structures of ^{108,110,112}Ru (Z=44) and ^{112,114,115,116,117,118}Pd (Z=46) have been significantly expanded through studies of prompt γ-γ-γ coincidences observed with Gammasphere following the spontaneous fission of ^{252}Cf. The softness to triaxiality perturbs the band structures of ^{108}Ru and even-N Pd isotopes. Two sets of odd-parity bands are identified in ^{112,114,116}Pd similar to but different from those in ^{110,112}Ru. These differences can be accounted for by interferences of the chiral doubling and softness to triaxiality. Also in ^{112}Ru, evidence for wobbling motion is found in the behavior of the γ vibrational band. Similar evidence for wobbling motion is found in ^{114}Pd, the N = 68 isotone of ^{112}Ru.

1. Introduction

Möller et al. [1] predicted a region centered around Z=44, N=64 to have the largest lowering of the nuclear ground state energy when axial symmetry is broken. Frauendorf and co-workers [2-4] proposed that rotating triaxial nuclei may exhibit chiral behavior with a superposition of right- and left- handed symmetry that gives rise to two $\Delta I=1$ sets of rotational levels with the same parity and degenerate in energy for the same spin. In addition to chiral doublet bands, triaxial nuclei can exhibit wobbling motion of their angular momentum. Wobbling motion involves a deviation of the axial collective motion away from the axis with the largest moment of inertia. This gives rise to a series of wobbling bands with quantum number $n_W=0, 1, 2, \ldots$ The H_20 molecule provides a classic example of such wobbling bands. We have studied the energy levels in $^{108\text{-}114}$Ru and $^{112\text{-}118}$Pd populated in the spontaneous fission of ^{252}Cf to search for evidence of triaxial shapes in these nuclei. The prompt γ-rays were observed in Gammasphere. The data revealed that it is not ^{108}Ru as predicted [1], but ^{112}Ru is the center of a stable region of triaxial deformation [5]. Well-defined chiral doublet bands are seen in ^{112}Ru as well as wobbling bands. The doublet bands seen in ^{108}Ru have a marked energy staggering to indicate a softness to a triaxial shape and no wobbling bands are seen. In ^{112,114,116}Pd, doublet bands are seen but exhibit varying softness to triaxial shapes, with wobbling motion seen only in ^{114}Pd, the isotone of ^{112}Ru with N=68 [6].

2. Experimental Procedures

A 62μCi source of ^{252}Cf was placed in Gammasphere with 101 high purity germanium detectors. A large data set with 5.7×10^{11} triple and higher fold coincidences was obtained [see ref. 7 for details on the experiment]. The 101 detectors were subdivided into 64 angular binds for angular correlation studies [8]. Gamma-gamma angular correlation measurements were carried out to determine spins of the highest level and transition multipolarities of transitions out of the highest levels by using as the lower transition a known E2 transition between two yrast levels, like $6^+ \rightarrow 4^+$. By determining branching ratios to the yrast levels and the multipolarities of the upper transitions, unique spins and parities were assigned to at least one level in each of the two sets of doublet bands found in ^{108,110,112}Ru [5, 9] and ^{112,114,116}Pd [6].

3. Chiral Band Results

From the analysis of multiple gates in each nucleus and γ-$\gamma(\theta)$ measurements of at least one level in each of the bands observed, the level of $^{108\text{-}112}$Ru and $^{112\text{-}118}$Pd were established. Details are found elsewhere [6, 9]. The doublet bands seen in ^{108,112}Ru are shown in Fig. 1 while the doublet bands in ^{110}Ru are found in [5, 9]. As seen in Fig. 1, there is an energy staggering in bands 4, 5 in ^{108}Ru that is not present in ^{112}Ru. The doublet bands in ^{112}Ru have all the properties expected for chiral doublets in a rigid triaxial nucleus while ^{108}Ru is best described as a γ-soft nucleus [5]. These data indicate that ^{112}Ru is the center of the region with broken axial symmetry not ^{108}Ru as proposed by Möller et al. [1].

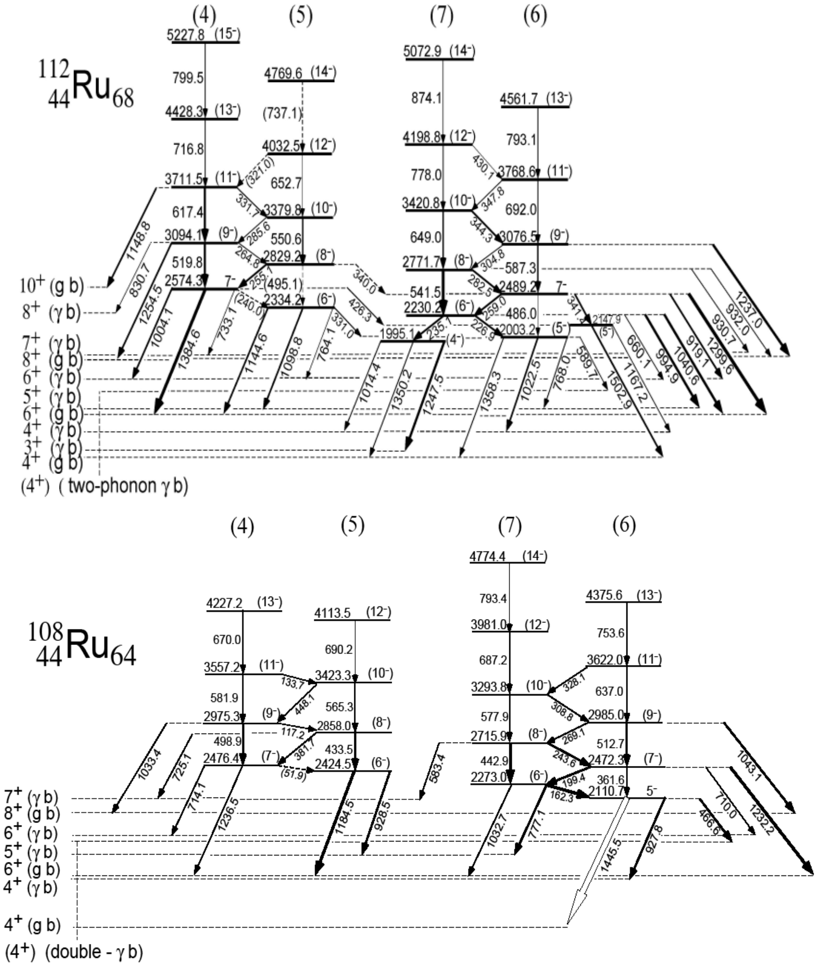
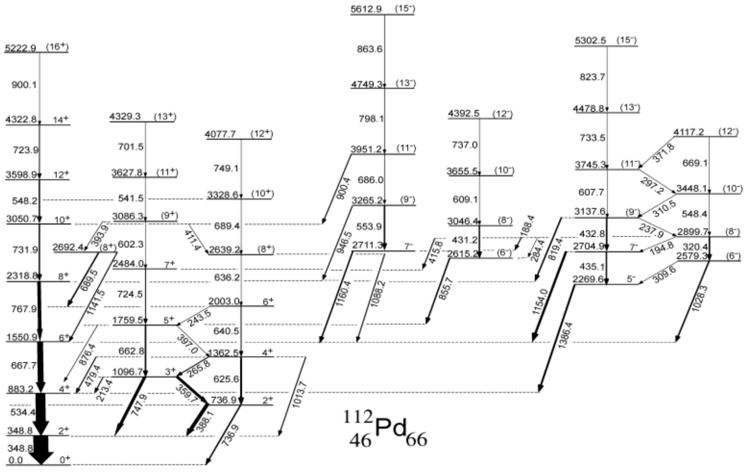


Fig. 1. Doublet bands in ^{108,112}Ru.

In our new study, ΔI=1 doublet bands are now seen in ^{112,114,116}Pd. The new level schemes for $^{112\text{-}118}$Pd are illustrated with those of ^{112,114}Pd shown in Fig. 2.

From γ-γ(θ) and branching ratios, the spins and parities is at least one member of each of the four bands in each nucleus were determined. At first glance these doublet bands in $^{112\text{-}114}$Pd look similar to those in ^{110,112}Ru that one would consider them as chiral doublets built on a rigid triaxial shape. However, as one examines the details of their energy level staggering, the absence of many crossing E1 transitions, and their signature splitting compared to ^{110,112}Ru, one sees that ^{112,114,116}Pd are more soft triaxial nuclei rather than rigid triaxial. This can be seen, for example, in Fig. 3 where the signature splitting for bands 4 and 5 in ^{110,112}Ru and $^{112\text{-}116}$Pd are compared. As expected for rigid triaxial nuclei, the splitting is essentially zero and constant with spin for ^{110,112}Ru, while there is considerable staggering in ^{112,114,116}Pd. Note ^{112,114}Pd are the N=66 and 68 isotones of ^{110,112}Ru, respectively. The differences between ^{110,112}Ru and ^{112,114,116}Pd can be understood by the latter having a less pronounced triaxial minimum than ^{110,112}Ru as predicted by Möller et al. [1]. Thus rigid triaxiality seen centered in ^{112}Ru is softened as Z increases from 44 to 46 in Pd. The soft triaxiality disturbs the structure of the chiral doublets.



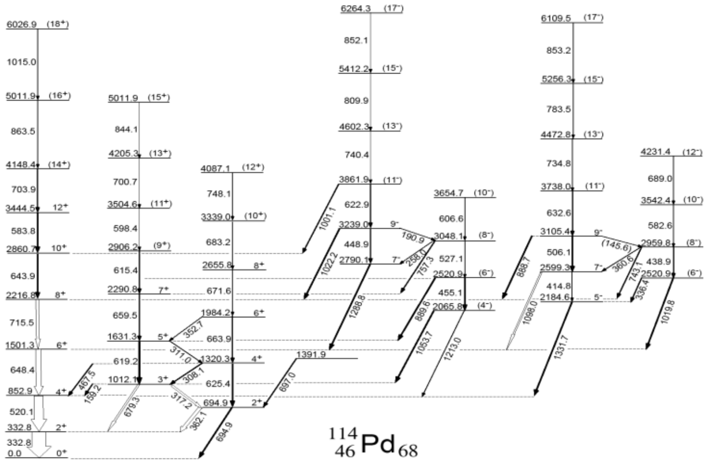


Fig. 2 Partial level schemes of ^{112,114}Pd with yrast, gamma and doublet bands.

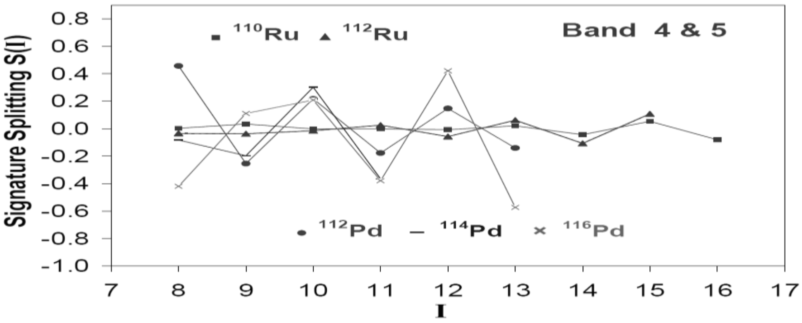


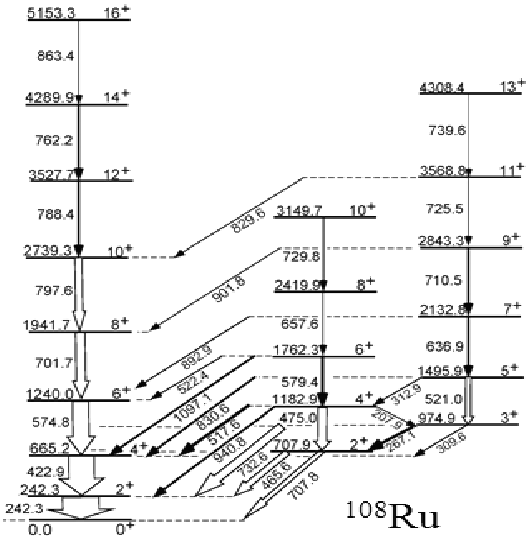
Fig. 3. Signature splitting in bands 4 and 5 in ^{110,112}Ru and ^{112,114,116}Pd.

4. Wobbling Motions

The wobbling excitations in a triaxial nucleus constitute a revolving motion of J about an axis of the triaxial nucleus. Wobbling motions were first identified in ^{161,163,165,167}Lu [10-13] and ^{167}Ta [14] at high spin. Wobbling excitations in a triaxial nucleus are expected to occur at moderate spins if the predicted triaxial shapes lead to different moments of inertia for the three principal axes [15]. Note ^{112}Ru was shown to have substantial triaxiality [5], and found to be the first even-even wobbler by our collaboration [15, 16]. The onset of wobbling motions in ^{112}Ru was identified by analyzing the signature splitting in the quasi-γ band. It is of interest to study the possible wobbling motions in Pd isotopes, especially in the isotopes around ^{114}Pd, the isotone of ^{112}Ru.

The yrast and γ-band structures in ^{108,112}Ru are shown in Fig. 4. Note the energy staggerings in the quasi-γ band of ^{108}Ru which are opposite to those in ^{112}Ru [5]. Very similar behavior is now found in ^{112,114}Pd. In our study of $^{112\text{-}118}$Pd, the data indicate an evolution of their shapes from triaxial prolate via triaxial oblate to oblate shape.

Caprio [17] has made new theoretical calculations of the consequences of this evolution of shapes toward increasing triaxiality for the collective excitation spectrum. A particularly clear signal is the even-odd staggering in the quasi γ band. For soft axial nuclei, the energies of the even spin members are lower than the odd spin members. For a well-developed triaxial minimum the odd-spin members are below the even-spin ones. In fact, for the well-developed triaxiality, the odd-spin members represent the one-phonon wobbling excitation, and the even-spin ones the two-phonon wobbling excitations. As expected, the calculations [17] indicate that when the shapes evolve from soft-prolate to stable-triaxial, there is an intermediate situation, when the even-odd staggering is near-zero.



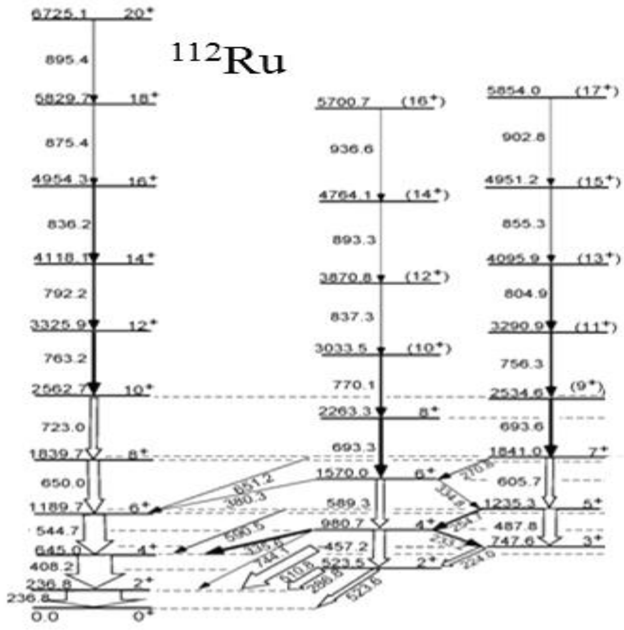


Fig. 4. Yrast and gamma bands in ^{108,112}Ru.

In the present work, the search for wobbling motions in ^{114}Pd, the N=68 isotone of ^{112}Ru, and in the neighboring Pd isotopes has yielded promising results. In Fig. 5, the excitation energies of the quasi-γ band levels were plotted against spins for N=68 isotones ^{112}Ru and ^{114}Pd (a), and N=64 isotones ^{108}Ru and ^{110}Pd (b), respectively. Note for the lighter N=64 isotones ^{108}Ru and ^{110}Pd, the α=1 odd-spin curve always lies above the α=0 even-spin curve which is normal behavior, to indicate that no wobbling motion is identified. Not shown in Fig. 5 the α=1 odd-spin curve of ^{112}Pd is higher than that of the α=0 even-spin curve until a crossing takes place at a spin as high as I=10, and in ^{110}Ru the two curves follow a similar trend, but they are very close to each other, and the crossing takes place at spin I=7. However, one can see in Fig. 5 that for the γ bands of both ^{112}Ru and ^{114}Pd the α=1 odd-spin curve (n=1_{wobble}) crosses the α=0 even-spin curve (n=2_{wobble}) at a spin as low as I=3.5, and then the latter becomes considerably higher than the former, as expected for wobbling motions. Thus, both ^{112}Ru and ^{114}Pd are identified as even-even wobblers.

These are the first evidence for wobbling motion at low-spin and in an even-even nucleus. All the data in Fig. 5 imply a transition from non-wobbling in the N=64 isotones to onset of wobbling in the N=68 isotones, and probably for N=70 (not shown), with the N=66 isotones being transitional with regard to wobbling motions. The observations of the different staggering, crossing spins and shapes of the two curves may also imply different degrees of triaxiality in the two isotones for N=64,66,68,70.

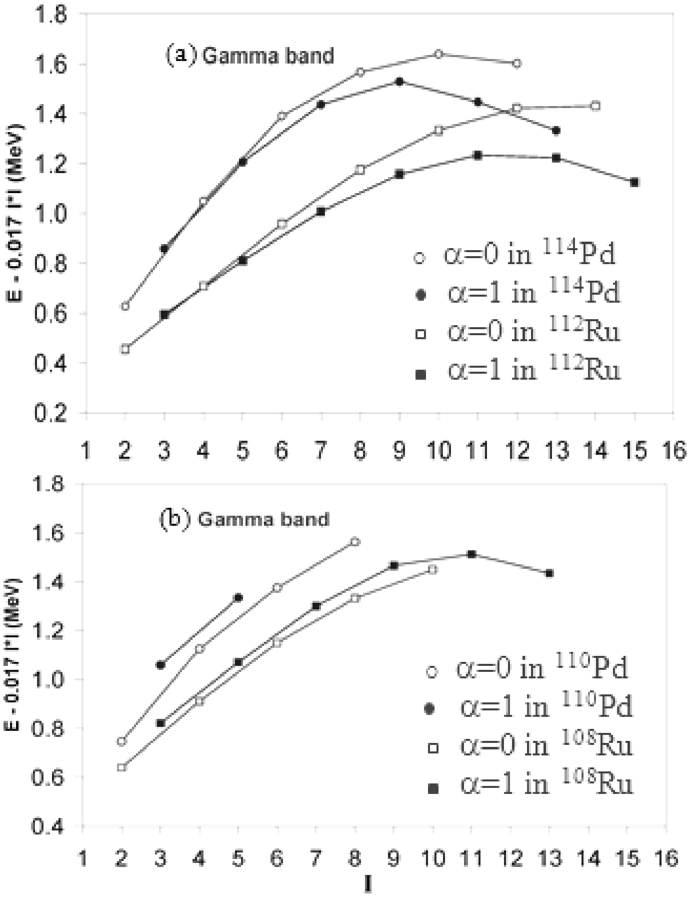


Fig. 5. Excitation energies vs. spins in gamma bands in ^{108,112}Ru and ^{110,114}Pd.

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