High-Spin Spectroscopy of $^{162}\text{Hf}$


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Excited states in $^{162}\text{Hf}$ were investigated up to spin $I \approx 38$ using the anti-Compton-spectrometer array HERA with 21 detectors. In addition, some information was obtained on $^{161}\text{Hf}$. The analysis of triple coincidences was crucial for the construction of the level schemes. The results are interpreted within the framework of the cranked shell model and are compared to neighbouring isotopes and isotones, showing Fermi level and deformation effects. The systematic behaviour of the band crossings in the Hf isotopes and the $N=90$ isotones is discussed.

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1. Introduction

With the new multi-detector arrays of Compton-suppressed Ge-detectors which are being built in several laboratories, good statistical accuracy can be obtained in $\gamma\gamma$-coincidence experiments. This allows the spectroscopy of transitions with intensities down to $\sim 1\%$ of the transitions between the low-spin states, and the structure of rapidly rotating nuclei can be studied up to spins larger than $30\hbar$. In particular, the interesting effects which are caused by the interplay between the Coriolis and pairing forces can be investigated at high rotational frequencies and can be compared to predictions of the cranked shell model. A lot of information exists on the decoupling and rotation-alignment of the first pair of high-$j$ particles (usually $1s_{3/2}$ neutrons in the rare-earth region), but similar systematic information on four and more particle alignments is still lacking.

In this work we report on an investigation of the high-spin states in $^{162}\text{Hf}$. Some limited results are obtained for $^{161}\text{Hf}$. These are the lightest Hf isotopes studied to date. They lie far from the line of stability and are only weakly deformed. It is of interest to follow the high-spin properties from the strongly deformed heavier Hf isotopes down to the very light ones. Parallel to our work, information on $^{162}\text{Hf}$ has been reported by Bingham et al. [1]. A preliminary report on our work has been given elsewhere [2]. In the following section we describe the experimental procedure and present the results. In Sect. 3 we discuss the results within the framework of the cranked shell model [3] and compare them to neighbouring nuclei.

2. Experimental Techniques and Results

2.1. Experimental Techniques

High-spin states in the light-mass Hf isotopes were populated in the reaction $^{126}\text{Te}(^{40}\text{Ca}, xn)^{160,161,162}\text{Hf}$ at the 88" cyclotron of the Lawrence Berkeley Laboratory. At a beam energy of 195 MeV the $4n$ reaction channel was dominant, but the $5n$- as well as $pxn$- and $xxn$-channels were also strong. Three- and higher-fold coincidence data were taken with the Berkeley High Energy-Resolution Array HERA [4] which consists of 21 Compton-suppressed Germanium detectors. Two foils of 0.44 mg/cm$^2$ of $^{126}\text{Te}$ evaporated onto 0.37 mg/cm$^2$ Au-backings (the Au-backings facing the beam) were used as target such that the evapo-
2.2. Analysis of Triple Coincidences

The requirement of three- and higher-fold events discriminates efficiently against low-multiplicity processes such as Coulomb excitation and radioactivity. In fact, the Coulomb excitation lines of the Au backings which are very strong in the two-fold spectra disappear completely with three-fold coincidences. The main advantage of the triple coincidences is, however, that they can be used to select the final nucleus and even specific bands in one nucleus. In our case of the very neutron-deficient Hf isotopes, where the evaporation of charged particles competes with neutron emission from the compound system, the γ-ray spectra are extremely complicated due to the large mixture of final nuclei, and the use of triple coincidences was crucial in the analysis.

In a first step of the analysis all three- and higher-fold events were broken up into ordinary double γ-coincidences and sorted into two-dimensional $E_γ - E_γ$ matrices, both for the measurement with the thin and with the thick Au-backed targets. Coincident γ-ray spectra were obtained by setting gates on the lines in these “full matrices”. It turns out that the majority of lines are composed of multiple transitions making assignments very difficult, in particular for the low-intensity high-spin transitions. Four examples of relatively clean doubles coincidence spectra obtained from the full matrix of the thin-target experiment are shown in Fig. 1.

In order to make use of the resolving power of the triple coincidences, 30 “gated matrices” (including two background matrices, one for the low- and one for the high-energy region) were produced with gates on specific γ-lines. The four- and higher-fold coincidences were first broken up into triple coincidences for this purpose. After subtraction of the background matrices (which were properly scaled to the background area underneath the peaks) these gated matrices contain predominantly transitions belonging to one nucleus or even to one single band. They also show a greatly improved peak-to-background ratio. To illustrate this, the total projections of the full matrix and the gated matrix with six yrast gates above the first band crossing are compared in Fig. 2. The peak-to-background ratio for the 931 keV 34$^+$ → 32$^+$ transition for example is improved from 1/10 in the full matrix to about 1/1 in the gated matrix. On the other hand, this selectivity has to be bought at the expense of statistics, the typical loss being a factor of 10 to 100 when working with the gated matrices. Usually the statistical accuracy can be improved by adding several gated matrices or triple-coincidence spectra because they generally show little contamina-

Fig. 1a–d. Double coincidence spectra (from resolved three- and higher-fold events) measured in the reaction $^{126}$Te($^{40}$Ca, 4$n$)$^{162}$Hf with the thin stacked targets. a Sum of gates on the 285 keV 2$^+ → 0^+$ and 444 keV 4$^+ → 2^+$ lines showing all transitions assigned to $^{162}$Hf; b sum of gates on the 501 keV 16$^+ → 14^+$, 585 keV 18$^+ → 16^+$ and 725 keV 22$^+ → 20^+$ lines showing the (+, 0) yrast transitions; c sum of gates on the 330 keV 11$^+ → 9^+$ and 429 keV 13$^+ → 11^+$ lines showing the (+, 1) side-band transitions; d gate on the 407 keV 12$^+ → 10^+$ line showing the (+, 0) side-band transitions.

Fig. 2a and b. Total projections (from 100 to 1100 keV) of a a matrix with gates on the 14$^+ ... 24^+$ yrast transitions for the thin-target experiment and b the full matrix.