COULOMB EXCITATION OF THE $K^\pi = 8^-$ ISOMERIC BAND IN ^{178}Hf*

P.J. Napiorkowski[a], J. Srebrny[b], T. Czosnyka[a], J. Gerl [c]
Ch. Schlegel[c], H-J. Wollersheim[c], D. Cline[d], C.Y. Wu[d]
R. Teng[d], K. Vetter[e], A. Macchiavelli[e], M. Devlin[f], J. deBoer[g]
J. Iwanicki[a], J. Kownacki[a], M. Loewe[g], and M. Wuerkner[g]

[a]Heavy Ion Laboratory, Warsaw University, Poland
[b]Institute of Experimental Physics, Warsaw University, Poland
[c]GSI Darmstadt, Germany
[d]University of Rochester, USA
[e]LBNL, USA
[f]University of St. Louis, USA
[g]University of Munich, Germany

(Received November 2, 2000; revised version February 7, 2001)

The Coulomb excitation experiment on the ^{178}Hf was performed using 650 MeV beam of ^{136}Xe. The first observation of discrete transitions in the $K^\pi = 8^-$ isomeric band, Coulomb excited from $K^\pi = 0^+$ ground state, is reported. The possible mechanisms of E1 coupling of the ground state band and the isomeric band is discussed.

PACS numbers: 23.20.Js, 25.70.De

1. Motivation

The $K^\pi = 8^-$ isomer population after Coulomb excitation of ^{178}Hf was firstly reported by Hamilton *et al.* [1] in the early eighties. The reaction mechanism of such phenomenon became a puzzle. In general, the strength of electromagnetic transitions between different rotational bands should be hindered according to K quantum number selection rule. The excitation of the isomeric band states via electromagnetic interaction indicates the existence of the strong weakening of K-forbiddeness between these bands [2]. It can be possible due to K mixing of wave functions of both bands. However, the isomeric band can be populated by decay of the intermediate state or

* Presented at the XXXV Zakopane School of Physics "Trends in Nuclear Physics", Zakopane, Poland, September 5–13, 2000.

states, which can be much easer accessible by Coulomb excitation. This reaction mechanism is proposed as an explanation of the K conservation rule violation in the reported depopulation of the $K^\pi = 9^-$ isomer in ^{180}Ta [3,4].

2. Experiment

A new experiment was performed to determine a way of the population of $K^\pi = 8^-$ isomeric band in ^{178}Hf after Coulomb excitation. The thin (0.51 mg/cm^2) target — enriched to 89.1 % of ^{178}Hf — was bombarded by 650 MeV ^{136}Xe beam provided by ATLAS accelerator facility at Argonne National Laboratory. The target material additionally contained 4.4 % of ^{177}Hf, 2.9% of ^{179}Hf, 3.1% of ^{180}Hf and less then 1% of ^{174}Hf and ^{176}Hf.

A prompt gamma decay followed the Coulomb excitation was detected by 100 GAMMASHERE detectors in coincidence with scattered ^{136}Xe projectiles and hafnium recoils registered by the position sensitive gas counter CHICO [5]. The measured scattering angles of both detected particles were used to determine the impact parameter and to perform event by event Doppler correction of the γ-ray energy.

In the presented analysis the experimental data from NORDBALL were also used. The Coulomb excitations of hafnium isotopes were performed with 67 MeV ^{19}F and 225 MeV ^{58}Ni beams at the Niels Bohr Institute Tandem Accelerator Laboratory. Based on these data the electromagnetic structures of ground state bands in ^{178}Hf and ^{179}Hf were fixed.

3. First results

The level scheme of rotational bands built on ground state and the 1147 keV 4 s isomer is well known [6] and shown in the Fig. 1. However the identification of the decay within $K^\pi = 8^-$ band was difficult because of ^{179}Hf target contamination. Energies of $10^- \rightarrow 8^-$, $10^- \rightarrow 9^-$ and $9^- \rightarrow 8^-$ transitions are identical with the ones observed within ground state band of ^{179}Hf, strongly populated by Coulomb excitation. Only 495 keV gamma line can be uniquely assigned to the $11^- \rightarrow 9^-$ transition in ^{178}Hf (see Fig. 2(a)). To prove the population of the $K^\pi = 8^-$ isomer γ–γ-particle coincidence data were used. Fig. 2(b) shows the spectrum gated on the 495 keV line. One can see the 217, 277, 574 and 650 keV transitions from the known level scheme of ^{178}Hf (see Fig. 1). It can be concluded that discrete lines in $K^\pi = 8^-$ band were observed in Coulomb excitation experiment for the first time. Moreover, because of a sharp shape of these peaks a delayed feeding via any other isomer was excluded.

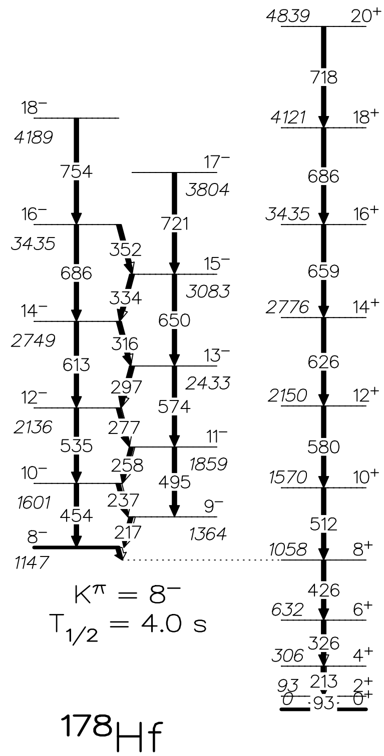

Fig. 1. Part of level scheme of ^{178}Hf taken from [6].

The observation of gamma-ray intensity above the isomer in the prompt γ-particle coincidence spectrum allowed to apply Coulomb excitation analysis using the Coupled Channel Coulomb excitation least-squares search code GOSIA [7].

A hypothesis of an E1 coupling between the ground state and 8^- isomeric bands was tested. Such coupling is important in excitation as well as in gamma decay process. An equal K admixture to wave functions of both bands was assumed. In each case of $0 \leq K \leq 8$, $B(\mathrm{E1})$ values in the order of 10^{-5} W.u. were needed to reproduce intensities of γ transitions observed in the isomeric band. Although estimated strength of E1 transitions are high, predicted intensities of interband gamma transitions remain below the experimental sensitivity limit.

The verification of other hypothesis like E3 direct excitation or via intermediate state(s), is in progress. Identification of the intermediate states, connecting the isomeric band with the ground state band via E3/E2 excitation would be the most comprehensive explanation of the experimental result.

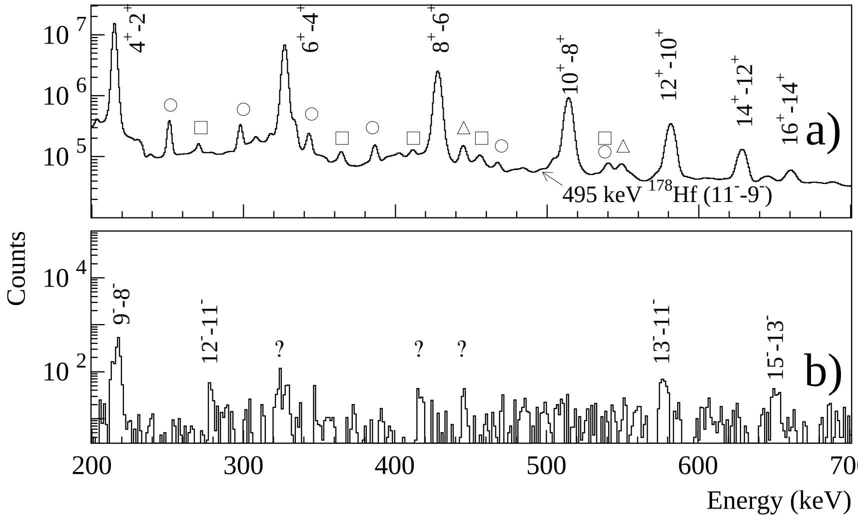

Fig. 2. The prompt γ-ray spectra observed in coincidence with particles for $\theta_{\rm Xe}^{\rm Lab} < 85$ deg: (a) total projection of γ-particle spectrum, (b) γ–γ-particle spectrum gated on 495 keV line. Gamma-lines labelled by spin assignment belong to ^{178}Hf and marked with ◯, □ and △ came from ^{177}Hf, ^{179}Hf and ^{180}Hf respectively. Lines tagged with "?" cannot be assigned to any transition within known level schemes of hafnium isotopes.

We wish to express our thanks to the ATLAS crew and Argonne National Laboratory for excellent working conditions.

REFERENCES

[1] J.H. Hamilton *et al.*, *Phys. Lett.* **112B**, 327 (1982).

[2] H. Xie *et al.*, *Phys. Rev.* **C48**, 2517 (1993).

[3] C. Schlegel *et al.*, *Phys. Rev.* **C50**, 2198 (1994).

[4] M. Loewe *et al.*, *Acta Phys. Pol.* **B30**, 1319 (1999).

[5] M.W. Simon *et al.*, Proc. of the Int. Conf. of Fission and Properties of Neutron-rich Nuclei, Sanibel Island, FL World Scientific Publishing Co., December 1997; D. Cline, *Acta Phys. Pol.* **B30**, 1291 (1999).

[6] S.M. Mullins *et al. Phys. Lett.* **393B**, 279 (1997); Erratum *Phys. Lett.* **400B**, 401 (1997).

[7] T. Czosnyka, D. Cline, C.Y. Wu, *Bull. Am. Phys. Soc.* **28**, 745 (1983).