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A STUDY OF THE LOW-LYING STATES IN ^{178}Hf THROUGH THE NEUTRON CAPTURE REACTION *

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The decay of the low-lying states of ^{178}Hf was investigated using: (1) High-resolution curved crystal spectrometry of the secondary γ-rays using the GAMS-1 and GAMS 2/3 facilities at the ILL, (2) Measurements of the secondary (n,e^-) transitions using the Electron Spectrometer BILL at the ILL, (3) Measurements of the primary γ-transitions following thermal neutron capture with the pair-spectrometer at the ILL and (4) Average Resonance Capture (ARC) measurements at the neutron energies of 2 keV and 24 keV, using the tailored beam facilities at BNL.

A level scheme including 69 levels and 270 transitions up to an excitation energy of 2.1 MeV was constructed. Most of the levels were ordered in 18 different rotational bands. The levels assigned to rotational bands along with the deexcitation modes of the γ-band (inset), are displayed in Fig. 1. The level scheme of ^{178}Hf seems to be complete below 2 MeV for spins between 2 and 5.

In order to determine which, if any, of the numerous 0^+ bands are collective, approximate absolute B(E2) values to the ground state band were estimated from the measured inter to intra band transition intensities using the plausible assumption that the intraband intrinsic matrix elements were similar to the ground

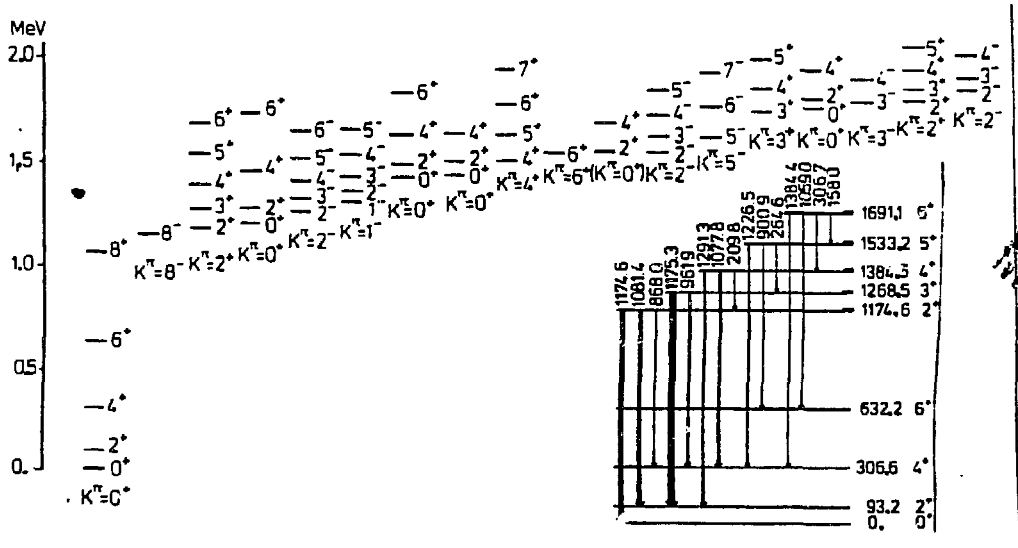

Fig. 1 Experimental rotational bands in ^{178}Hf (inset; γ-band decay)

Table - 1 ESTIMATED ABSOLUTE B(E2) VALUES (IN W.U.) FOR TRANSITIONS FROM EXCITED K=0$^+$ BANDS IN ^{178}Hf TO THE GROUND STATE BAND[a)]

I_i — I_f	1199 keV Band	1434 keV Band	1443 keV Band	1500 keV Band
$2^+ \rightarrow 0^+_g$	———	0.0032(4)	0.00084(7)	———
$4^+ \rightarrow 2^+_g$	0.124(28)	———	0.0218(22)	0.0033(4)
$4^+ \rightarrow 6^+_g$	1.243(75)	———	———	———
$6^+ \rightarrow 4^+_g$	———	0.019(2)	———	———
$6^+ \rightarrow 8^+_g$	0.195(16)	———	———	———

a) $$\frac{\langle I_i K=0||E2||I_g\rangle}{\langle I_i K=0||E2||I_f K=0\rangle_{Intra}} \cdot \overline{\langle I_g||E2||I_g-2\rangle_{Intra}} \quad \text{in W.U.}$$

band. The results are shown in Table-1. It is apparent that the only candidate for a β-band is the band at 1199 keV.

The extensive nature of the data provides an opportunity for a detailed test of the IBA model[1]. The Consistent Q Formalism (CQF) (Ref. 2) was used. The Hamiltonian has the form

$$H = -\kappa Q.Q - \kappa' L.L$$

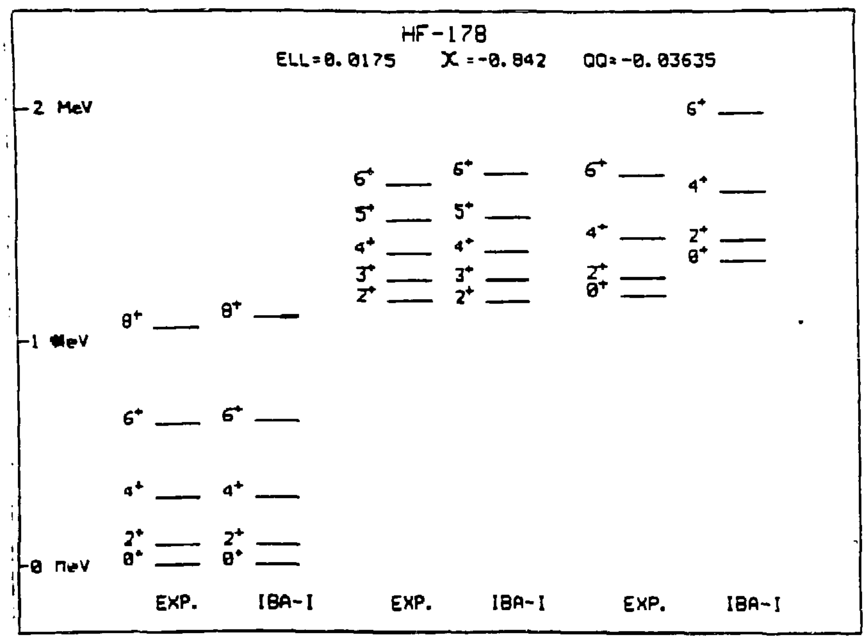

Fig. 2 Energy fit for the ground state, γ and β bands (for χ = -0.62; the IBA-energies of the beta-band lie ~200 keV higher)

Table - 2 DECAY PROPERTIES OF THE GAMMA AND BETA BANDS IN ^{178}Hf

E_i	$I_i,K_i=2$	E_f	I_f,K_f	I_γ (rel.)[a)]	B(E2) Expt.	Alaga	B(E2) IBA[b)] $\chi=-0.62$	$\chi=-0.842$
				γ - band				
1174.6	2_2^+	0.0	$0_g^+,0$	25.02 ±2.46	100	100	100	100
		93.2	$2_g^+,0$	18.87 ±0.41	145±20	143	178	168.2
		306.6	$4_g^+,0$	0.369±0.020	9.34±1.3	8	13.2	11.6
1268.5	3_1^+	93.2	$2_g^+,0$	29.53 ±3.28	100	100	100	100
		306.6	$4_g^+,0$	5.95 ±0.21	56±8	40	63.4	57.2
1384.5	4_2^+	93.2	$2_g^+,0$	6.36 ±0.21	0.821±0.162	1.55	0.888	1.033
		306.6	$4_g^+,0$	13.95 ±0.41	4.56±0.84	4.56	4.56	4.56
		1174.6	$2_2^+,2$	0.082±0.021	100	——	69.4	174.5
1533.2	5_1^+	306.6	$4_g^+,0$	9.02 ±0.41	4.33±0.78	6.78	3.29	3.86
		632.2	$6_g^+,0$	1.723±0.123	3.87±0.75	3.87	3.87	3.87
		1268.5	$3_1^+,2$	0.185±0.041	100	——	130.1	347.1
1691.1	6_2^+	306.6	$4_g^+,0$	0.882±0.082	0.531±0.10	0.93	0.362	0.473
		632.2	$6_g^+,0$	1.497±0.123	3.45±0.63	3.45	3.45	3.45
		1384.5	$4_2^+,2$	0.082±0.021	100	——	102.9	256.6
				β- band				
1276.7	2_3^+	0.0	0_g^+	1.477±0.082	0.17±0.01	0.38	0.29	0.30
		93.2	2_g^+	7.998±0.615	——c)	0.56	0.342	0.350
		306.6	4_g^+	2.256±0.205	1	1	1	1
1450.4	4_3^+	93.2	2_g^+	0.677±0.082	0.063±0.004	0.63	0.352	0.387
		306.6	4_g^+	10.66 ±0.82	——c)	0.57	0.127	0.125
		632.2	6_g^+	0.861±0.082	1	1	1	1
		1276.7	2_3^+	0.103±0.010	$(0.27\pm0.03)\cdot10^3$	——	$5.58\cdot10^3$	$21.6\cdot10^3$
1731.1	6_3^+	632.2	6_g^+	0.287±0.041	——c)	0.59	0.009	0.005
		1058.6	8_g^+	0.041±0.004	1	1	1	1
		1450.4	4_3^+	1.025±0.062	$(2.12\pm0.29)\cdot10^3$	——	$5.41\cdot10^3$	$18.8\cdot10^3$

a) Normalised to 100 for I_γ $(2_g^+ \rightarrow 0_g^+)$
b) For χ=−0.62(−0.842); ELL=0.01378(0.0175),QQ=−0.0463(−0.03635)
c) For $\Delta I=0$ transitions the M1 components could not be extracted

where $Q = (s^\dagger\tilde{d} + d^\dagger s)^{(2)} + \chi(d^\dagger\tilde{d})^{(2)}$. The corresponding parameters for the IBA code PHINT1 (ref. 3) are QQ=-4κ, ELL=$-2\kappa'$. The E2 transition operator is $T(E2)=\alpha Q$, where α determines the absolute scale. χ varies from $-\sqrt{7}/2$ to 0 associated with the symmetry limits SU(3) and O(6).
Two calculations were performed. 1) χ = −0.62 : this gives the best results for the relative B(E2) values for the inter and

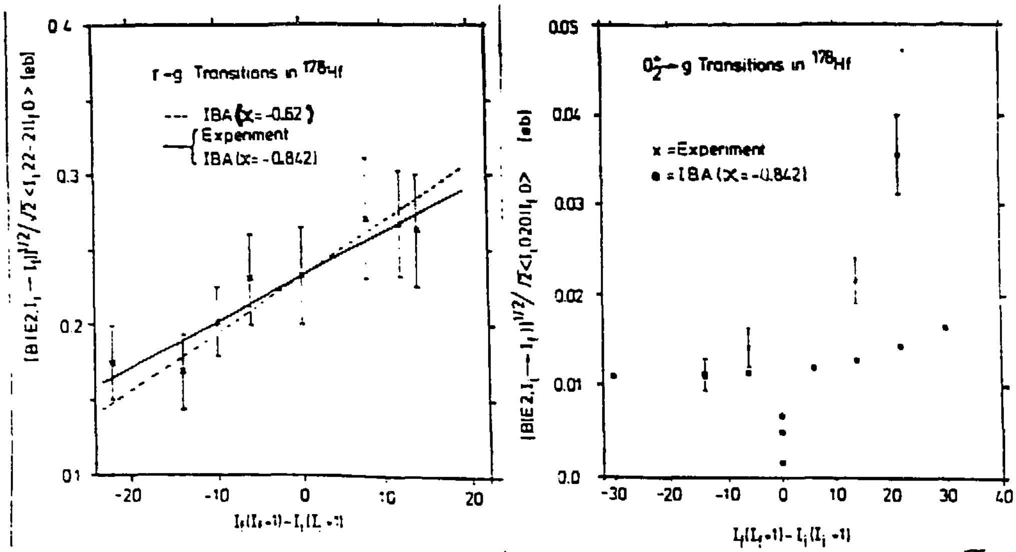

Fig. 3 Mikhailov plots for the γ ⟶ g and ß ⟶ g transitions. The straight lines are least square fits to the data and the IBA

intraband transitions for the γ-band. 2) χ = −0.842 : this gives a straight line on a Mikhailov plot of γ ⟶ g transitions which is identical to the experimental one. The wave functions depend only on χ . x and κ' were required to fit the excitation energies only. The energy fit is shown in fig. 2 for calculation 2. Table 2 gives the results for B(E2) values and fig. 3 gives Mikhailov plots for the γ ⟶ g and ß ⟶ g transitions. The results show excellent agreement for the ground and γ-bands, qualitative accord for the energy of the lowest 0^+ band, and little or no agreement for the B(E2) values of this band. Both the data and the IBA calculations for this band suggest that its decay is more complicated than can be accounted for by simple 2-band mixing. From the γ ⟶ g Mikhailov plots one can extract the following values for the bandmixing parameter Z_γ (ref. 4) :

Z_γ : Exp. 0.0249(17) ; IBA: 0.0249 (χ = −0.842) & 0.0314 (χ = −0.62)

The experimental value is consistent with regional systematics[2].

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