SYSTEMATICS OF K-ISOMERISM

M. S. RAJPUT AND M. L. SEHGAL

DEPARTMENT OF PHYSICS,
ALIGARH MUSLIM UNIVERSITY
ALIGARH, U.P. INDIA

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ABSTRACT. Experimental data on the hindrance factor of the *K*-forbidden transitions have been compiled. From the systematic study of *K*-forbidden transition in the mass region $160 \leqslant A \leqslant 190$, and $A > 230$, it has been found that log of hindrance factor per degree forbiddenness of the transition decreases with the increase in the value of degree of forbiddenness of the transition.

INTRODUCTION

No rigorous theory has so far been developed for the medium and heavy nuclei ($A > 150$), which explains all their properties. Shell model, (Mayor and Jensen, 1952), has been found to explain some of the observed properties of these nuclei with certain mass numbers. The general properties of these nuclei indicate that collective nucleon motion plays an important part. The shape of the nuclei in this region is deformed, (Nathan and Nilson, 1965; Mottelson and Nilson, 1959). In non-spherical nuclei, a simple type of excitation due to the rotation of the nucleus in space takes place without changing the symmetry. In this region ($160 \leqslant A \leqslant 190$ and $A > 230$) at low excitation energies, the nuclear spectra shows rotational bands. For each rotational band the component of total angular momentum along the symmetry axis is called K. This is characteristic of intrinsic configuration, associated with that band. The gamma transitions between different rotational bands depend also upon the change in quantum number K, in addition to the change in spin and parity, where,

$$\Delta I \geqslant \Delta K \quad \text{.. (I)}$$

The K-selection rule is obeyed strictly when K is a good quantum number, i.e., when the internal as well as the rotational motions are independent of each other. Actually there is a coupling between these two forms of motion and K is only an approximate quantum number. Therefore the K-selection rule results in decreasing the transition probabilities rather than in completely forbidding the transition. The degree of forbiddenness of the transition is given by,

$$\nu = |\Delta K| - L$$

where L is the angular momentum carried away by the radiation. In this investigation we are interested in the systematics of the K-forbidden transitions. The data on K-forbidden transitions have been compiled to correlate the K-forbiddenness with the hindrance factor.

All the experimental data on the K-forbidden transitions have been collected from various publications available recently. The data is presented in table I The various columns are self explanatory. We define the hindrance factor H.F.,

$$\text{H.F.} = \frac{T_{\frac{1}{2}}(\text{Exp})}{T_{\frac{1}{2}}(\text{S.P.})}$$

where $T_{\frac{1}{2}}$ (exp) is the experimental half life of the state after applying conversion coefficient and other corrections and $T_{\frac{1}{2}}$ (S.P.) is the value of the half life predicted by the single particle model, (Blatt and Weisskopf, 1952).

ANALYSIS OF DATA AND DISCUSSION

The electromagnetic transitions, forbidden by the K-selection rules, have been found to have half lives ranging from few microseconds to few hours. The highly forbidden transitions, (Burdue *et al*, 1966; Borgreen *et al*, 1957), occurs in Hf^{180}. The half life of the 1143 keV state from which 57 keV transition originated is 5.5 hours. This gives a hindrance factor $\approx 10^{16}$ as compared with the single particle estimate. Recently Burdue *et al* (1966) have discovered some more 8^- isomeric states giving K-forbidden transitions having hindrance factor $\approx 10^{12}$ to 10^{15} in the mass region $170 \leqslant A \leqslant 184$.

Curtis Michel (1964) suggested that the parity mixing may be responsible for the hindrance of K-forbidden transitions. If the spin and parity change in a particular transition allows the emission of photon of given multipolarity E_L, then the parity mixing allows a photon of multipolarity M_L to be also emitted. It was suggested by Curtis Michel that the parity mixed transition may be detected indirectly from the polarization of the radiation.

Goldhaber and McKeown (1966, 1967) measured the L-subshell conversion coefficient for the 57 keV transition in Hf^{180} and they found that the L subshell conversion coefficients are anomalous and the experimental results can be explained if one considers this transition as 90.5% E_1 and 9.5% M_1. Lawson and Segal (1966) and Bleumberg *et al* (1967) pointed out that the parity mixing is not the explanation for the delayedness of these transitions. Lawson and Segal (1966) also pointed out that the selection rules, that inhibits the emission of E_1 radiation, must also effect the decay of the state by M_1 radiation. Recently polarization experiments of Paull *et al* (1967) and Bleumberg *et al* (1967) have revealed that the possible explanation of the anomalous L subshell conversion coefficients of 57 keV transition in Hf^{180} and 1084 keV transition in Lu^{175} is not the parity mixing. They have suggested that this anomaly is due to the penetration effects. The penetration effect was also given the possible explanation for the hindrance of K-forbidden transitions by Hager and Seltzer (1966).

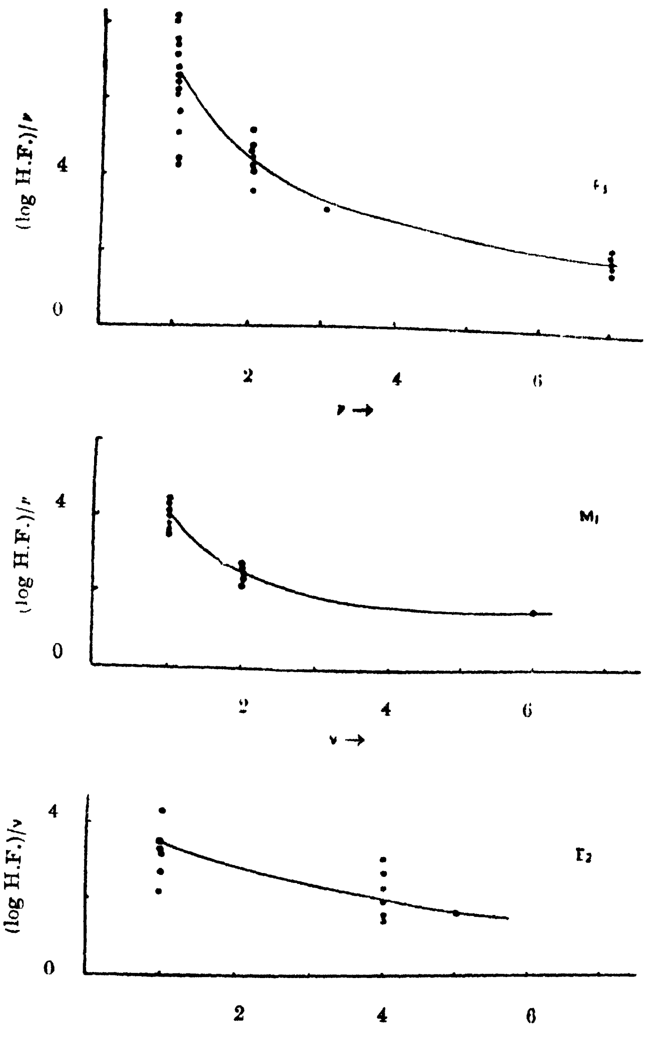

Figure 1. Vibration of (log H.F.)/ν with ν for different multipole transitions

Borggren *et al* (1957) have suggested that the isomeric states which decay via K-forbidden transitions are two quasi-particle states. The coupling between these two is responsible for the K-isomerism. However the aggreement between the experiment and the theory is not good. At present it is very hard to understand the hindrances of K-forbidden transitions in the absence of a rigorous theory.

Table 1 K-forbidden E_1 Transitions

Odd-Nuclei

Sl. No.	Nucleus	Gamma-ray energy in KeV	Initial State $I\ K\ \pi(NN_z\Lambda)$	Final State $I\ K\ \pi(NN_z\Lambda)$	ν	H.F.	Ref.
1.	Tb^{161}	361	7/2 7/2−(5 2 3)	5/2 3/2+(4 1 1)	1	4.2 (7)	1,2
		284	,,	7/2 3/2+(4 1 1)	1	1.6 (6)	,,
2.	Tm^{167}	152	7/2 7/2−(5 2 3)	7/2 1/2+(4 1 1)	2	1.7 (9)	3
		176	,,	5/2 1/2+(4 1 1)	2	1.6 (8)	,,
3.	Tm^{169}	241	7/2 7/2−(5 2 3)	7/2 1/2+(4 1 1)	2	1.7 (9)	4
		261	,,	5/2 1/2+(4 1 1)	2	1.6 (8)	,,
4.	Tm^{171}	296	7/2 7/2−(5 2 3)	7/2 1/2+(4 1 1)	2	5.1 (8)	3
		308	,,	5/2 1/2+(4 1 1)	2	4.8 (8)	,,
5.	Yb^{173}	395	3/2 1/2−(6 5 1)	5/2 5/2+(5 1 2)	1	5.4 (5)	5
6.	Lu^{173}	123	5/2 1/2−(5 4 1)	7/2 7/2+(4 0 4)	2	2.5 (8)	6
7.	Lu^{175}	345	7/2 7/2+(4 0 4)	5/2 1/2−(5 4 1)	2	2.5 (8)	6
8.	Re^{183}	382	9/2 9/2−(5 1 4)	7/2 5/2+(4 0 2)	1	2.24(6)	8
		236	,,	9/2 5/2+(4 0 2)	1	7.6 (6)	8
9.	Re^{187}	72	9/2 9/2−(5 1 4)	7/2 5/2+(4 0 2)	1	3.5 (6)	9
		552	5/2 9/2−(5 1 4)	,,	1	1.1 (6)	10
		686	,,	,,	1	1.8 (6)	10
10.	Pa^{231}	84	5/2 5/2+(6 4 2)	3/2 1/2−(5 3 0)	1	1.88(6)	11
		26	,,	7/2 1/2−(5 3 0)	1	3.1 (4)	11
11.	Pa^{233}	87	5/2 5/2+(6 4 2)	3/2 1/2−(5 3 0)	1	8.7 (5)	11
		29	5/2 5/2−(6 4 2)	5/2 1/2+(6 3 1)	1	3.8 (4)	11
12.	Np^{237}	267	3/2 1/2+(5 3 0)	5/2 5/2−(6 4 2)	1	6.4 (7)	12
13.	Pu^{239}	57	7/2 7/2−(7 5 3)	5/2 1/2+(6 3 1)	2	5.5 (8)	13
		76	,,	7/2 1/2+(6 3 1)	2	8.7 (8)	13
		316	,,	,,	2	9.4 (8)	14
		334	,,	5/2 1/2+(6 3 1)	2	8.4 (8)	14
14.	Er^{167}	267	5/2 5/2+(5 3 2)	3/2 1/2−(5 2 1)	1	1.5 (5)	16
		323	,,	1/2 1/2−(5 2 1)	1	1.5 (5)	16
15.	Hf^{177}	55	23/2 23/2−(?)	21/2 7/2+(4 0 4)	7	5.0 (13)	30
				Even Nuclei			
1.	Er^{168}	1016	3 3 −	2 0 +	2	1.1 (10)	18
		831	,,	4 0 +	2	3.7 (9)	18
		1464	,,	2 0 +	2	1.5 (9)	19
		1280	,,	4 0 +	2	1.6 (8)	19
2.	Yb^{176}	93	8 8 −	8 0 +	7	6.0 (13)	16, 23
3.	Lu^{176}	200	1 1 −	7 7 +	5	1.1 (15)	20, 22
4.	Hf^{176}	89	8 8 −	8 0 +	7	1.9 (13)	17, 23

Table 1 (contd.) *K*-forbidden M_1 Transitions

Even Nuclei

Sl. No.	Nucleus	Gamma-ray energy in KeV	Initial State $I\ K\ \pi(NN_z\Lambda)$	Final State $I\ K\ \pi(NN_z\Lambda)$	ν	H.F.	Ref.
5.	Yb^{176}	94	8 8 −	8 0 +	7	6.6 (13)	17
6.	Hf^{180}	57	8 8 −	8 0 +	7	2.8 (16)	23
7.	W^{180}	390	8 8 −	8 0 +	7	1.44(12)	23
8.	W^{182}	1189	2 2 −	0 0 +	1	3.0 (7)	25
		1273	3 2 −	2 0 +	1	3.3 (8)	26
		1045	,,	4 0 +	1	2.5 (8)	26
9.	Os^{182}	552	8 8 −	8 0 +	7	6.5 (11)	23
10.	Pt^{184}	610	8 8 −	8 0 +	7	2.13(12)	23
11.	U^{234}	355	5 5 −	4 2 +	2	1.6 (8)	28
		287	,,	5 2 +	2	5 1 (8)	28
		208	,,	6 2 +	2	1.65(7)	28

K-forbidden M_1 Transitions

Sl. No.	Nucleus	Gamma-ray energy in KeV	Initial State $I\ K\ \pi(NN_z\Lambda)$	Final State $I\ K\ \pi(NN_z\Lambda)$	ν	H.F.	Ref.
1.	Tm^{167}	63	7/2 7/2+(4 0 4)	5/2 1/2+(4 1 1)	2	4.1 (5)	3
		37	,,	7/2 1/2+(4 1 1)	2	5 3 (5)	3
2.	Tm^{169}	177	7/2 7/2+(4 0 4)	7/2 1/2+(4 1 1)	2	8.3(5)	3
		198	7/2 7/2+(4 0 4)	5/2 1/2+(4 1 1)	2	6.6 (5)	3
3.	Yb^{169}	104	5/2 5/2+(5 1 2)	3/2 1/2+(5 2 1)	1	1.3 (4)	31
		92	,,	5/2 1/2+(5 2 1)	2	7.6 (3)	31
4.	Yb^{171}	122	5/2 5/2+(5 1 2)	1/2 1/2+(5 2 1)	1	1.2 (4)	31
		56	,,	3/2 1/2+(5 2 1)	1	6.7 (4)	31
5.	Yb^{172}	917	3 3 +	4 0 +	2	5.0 (6)	21
		1004	4 3 +	4 0 +	2	7.6 (6)	21
		1076	3 3 +	2 0 +	2	4.0 (5)	21
6.	Yb^{173}	465	3/2 1/2+(5 2 1)	5/2 5/2+(5 1 2)	1	7.5 (3)	5
7.	Hf^{177}	14.2	23/2 23/2−(?)	21/2 9/2−(6 2 4)	6	6.6 (10)	30
8.	W^{183}	41	7/2 7/2−(5 0 3)	7/2 3/2−(5 1 2)	1	1.2 (4)	24
		161	,,	5/2 3/2−(5 1 2)	1	3.8 (4)	24
		144	,,	9/2 1/2−(5 1 0)	2	9.6 (4)	24
		246	,,	7/2 1/2−(5 1 0)	2	4.5 (4)	24
		354	,,	5/2 1/2−(5 1 0)	2	3.3 (5)	24
9.	Np^{237}	29	3/2 1/2+(5 3 0)	5/2 5/2+(5 2 3)	1	8.4 (3)	12
10.	Pu^{239}	278	5/2 5/2+(6 2 1)	3/2 1/2+(6 3 1)	1	6.0 (4)	14
		228	,,	5/2 1/2+(6 3 1)	1	4.7 (4)	14
		210	,,	7/2 1/2+(6 3 1)	1	9.1 (3)	14
11.	Cf^{251}	58.5	7/2 7/2+(6 1 3)	5/2 1/2+(6 2 0)	2	3.4 (4)	32
12.	Fm^{255}	58.3	7/2 7/2+(6 1 3)	5/2 1/2+(6 2 0)	2	1.5 (5)	15

Table 1 (contd.) *K*-forbidden E_2 Transitions

Sl. No.	Nucleus	Gamma-ray energy in keV	Initial State $I\ K\ \pi(NN_z\Lambda)$	Final State $I\ K\ \pi(NN_z\Lambda)$	ν	H.F.	Ref.
1.	Tm^{167}	169	7/2 7/2+(4 0 4)	3/2 1/2+(4 1 1)	1	1.8 (3)	3
2.	Tm^{169}	308	7/2 7/2+(4 0 4)	3/2 1/2+(4 1 1)	1	1.8 (3)	4
3.	Yb^{172}	917	3 3 +	4 0 +	1	1.8 (3)	17
		1095	3 3 +	2 0 +	1	2.9 (3)	17
4.	Yb^{174}	994	6 6 +	6 0 +	4	8.6 (7)	17
		1265	6 6 +	4 0 +	4	7.0 (9)	17
5.	Hf^{176}	737	6 6 +	6 0 +	4	4.6 (5)	17
		1045	6 6 +	4 0 +	4	4.8 (6)	17
6.	Hf^{177}	229	23/223/2−(?)	19/2 9/2−(6 2 4)	5	1.0 (8)	30
7.	W^{182}	144	7/2 7/2−(5 0 3)	5/2 1/2−(5 1 0)	1	2.5 (2)	24
		246	,,	7/2 1/2−(5 1 0)	1	1.1 (2)	24
		354	,,	5/2 1/2−(5 1 0)	1	6.9 (2)	24
		407	,,	3/2 1/2−(5 1 0)	1	4.4 (3)	24
8.	Cm^{244}	900	6 6 +	4 0 +	4	1.0 (11)	29
		746	6 6 +	6 0 +	4	0.5 (12)	29
		540	6 6 +	8 0 +	4	1.0 (12)	29

Notation : 4.4(3) means 4.4×10^3

From the present systematic study of the hindrance factors (H.F.) with the forbiddenness number, it is found that in the case of E_1 and M_1 transitions, log of hindrace factor (log H.F.) per- degree forbiddenness of the transition decreases, as the degree of forbiddenness increases from $\nu = 1$ to $\nu = 7$. Theoretically, (Bohr and Mottelson 1963), it is not possible to explain such a large variation in log H.F. per degree forbiddenness of the transition. In the case of E_2 transitions, log of hindrance factor per degree forbiddenness of the transitsion decreases at a slower rate in comparision with E_1 and M_1 transitions.

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