CONF-800213--8

MASTER

REDUCED E1, E2, AND E3 TRANSITION PROBABILITIES FOR TRANSITIONS IN $^{156-160}$Gd AND $^{160-164}$Dy

F. K. McGowan, W. T. Milner, and P. H. Stelson
Oak Ridge National Laboratory*, Oak Ridge, Tennessee 37830

ABSTRACT

Direct E2 and E3 Coulomb excitation of 2^+ and 3^- states with 13.5-MeV ^{4}He ions on isotopically enriched targets of $^{156-160}$Gd and $^{160-164}$Dy has been measured by means of γ-ray spectroscopy. Several 2^+ states and 3^- octupole vibrational states were identified in each nucleus. The $B(E\lambda, 0 \to J = \lambda)$ is obtained for excitation of each state, and information is given on the reduced transition probabilities for the different decay modes of these states. The experimental results are compared with theoretical predictions of nuclear models describing these states.

EXPERIMENTAL RESULTS AND DISCUSSION

Gamma-ray spectra were observed at $\theta_\gamma = 0°$, 55°, and 90° with respect to the beam direction with a 91-cm^3 Ge(Li) detector at 10 cm from the target. Experimental results for the reduced transition probabilities, $B(E\lambda, 0 \to J = \lambda)$, are summarized in Table I. Several of the γ-rays emitted during the slowing down of the recoiling nucleus in the target are Doppler broadened. The mean lifetimes, obtained from a Doppler broadened line shape analysis for the $3^- \to 2^+$ and $3^- \to 4^+$ transitions of the lowest 3^- state in ^{156,158,160}Gd and ^{160}Dy, are (0.11 ± 0.03), (0.78 ± 0.21), (0.074 ± 0.020), and (0.32 ± 0.09) ps, respectively.

The experimental $B(E2, 0 \to 2)$ for $^{156-160}$Gd are compared with recent theoretical calculations by Kumar and Gupta[1] based on a dynamic deformation theory combined with the pairing-plus-quadrupole model. In the case of the $K, J^\pi = 2, 2^+$ γ-vibrational state the B(E2) values are reproduced reasonably well by the predictions. However, the B(E2) values for β-vibrational state are not reproduced satisfactorily by these calculations.

Collective 3^- states have been identified in each of the $^{156-160}$Gd and $^{160-164}$Dy nuclei and the results are compared with the theoretical calculations of Neergård and Vogel[2] in Table I. Although the general features of the experimental information are reproduced by the calculations of Neergård and Vogel, the experimental values of $B(E3, 0 \to 3)$ in most cases tend to be somewhat larger than the predictions. Reduced E1 matrix elements have been obtained from an analysis using Coriolis coupled octupole states' wave functions.[2] For $^{156-160}$Gd and ^{160}Dy the E1 matrix elements $\langle 0^+ | M'(E1;0) | 0^- \rangle$ are found to be nearly equal, viz. 10.8 ± 1.3, 12.8 ± 1.7, 10.9 ± 1.4,

*Operated by Union Carbide Corporation under contract W-7405-eng-26 with the U. S. Department of Energy.

Table I. Experimental results for $B(E\lambda, 0 \rightarrow J = \lambda)$

Nucleus	Level (keV)	K,J^π	$E\lambda$	$B(E\lambda, 0 \rightarrow J)$ $(e^2 \cdot b^\lambda)$	$\left(\frac{B(E\lambda)}{B(E\lambda)_{s.p.}}\right)^a$	Theory $B(E\lambda, 0 \rightarrow J)$ $(e^2 \cdot b^\lambda)$
^{156}Gd	1129.4	$0,2^+$	$E2$	$(1.58 \pm 0.09) \times 10^{-2}$	0.63	2.0×10^{-2}
	1154.1	$2,2^+$	$E2$	$(1.11 \pm 0.06) \times 10^{-1}$	4.46	1.43×10^{-1}
	1258.0	$0,2^+$	$E2$	$(7.7 \pm 0.7) \times 10^{-3}$	0.31	2×10^{-3}
	1276.1	$1,3^-$	$E3$	$(17.1 \pm 0.9) \times 10^{-2}$	16.9	15.2×10^{-2}
^{158}Gd	1041.6	$1,3^-$	$E3$	$(12.4 \pm 0.7) \times 10^{-2}$	11.9	7.8×10^{-2}
	1187.1	$2,2^+$	$E2$	$(8.48 \pm 0.49) \times 10^{-2}$	3.34	8.3×10^{-2}
	1259.8	$0,2^+$	$E2$	$(8.01 \pm 0.56) \times 10^{-3}$	0.32	6.7×10^{-3}
	1402.9	$0,3^-$	$E3$	$(2.28 \pm 0.26) \times 10^{-2}$	2.2	3.3×10^{-2}
	1517.4	$0,2^+$	$E2$	$(9.33 \pm 0.93) \times 10^{-3}$	0.36	1×10^{-3}
^{160}Gd	988.2	$2,2^+$	$E2$	$(8.82 \pm 0.44) \times 10^{-2}$	3.42	10.3×10^{-2}
	1289.3	$?,3^-$	$E3$	$(11.8 \pm 0.7) \times 10^{-2}$	11.0	11.3×10^{-2}
^{160}Dy	966.2	$2,2^+$	$E2$	$(1.22 \pm 0.06) \times 10^{-1}$	4.73	
	1286.7	$1,3^-$	$E3$	$(17.1 \pm 1.0) \times 10^{-2}$	16	12.9×10^{-2}
	1349.5	$0,2^+$	$E2$	$(1.84 \pm 0.15) \times 10^{-2}$	0.71	
	1642	$?,3^-$	$E3$	$(6.5 \pm 1.0) \times 10^{-2}$	6.1	1.6×10^{-2}
^{162}Dy	888.2	$2,2^+$	$E2$	$(1.18 \pm 0.06) \times 10^{-1}$	4.50	
	1210.2	$2,3^-$	$E3$	$(10.4 \pm 0.7) \times 10^{-2}$	9.6	8.6×10^{-2}
^{164}Dy	761.8	$2,2^+$	$E2$	$(1.14 \pm 0.06) \times 10^{-1}$	4.26	
	1039.3	$2,3^-$	$E3$	$(8.8 \pm 0.6) \times 10^{-2}$	7.9	6.4×10^{-2}

$^a B(E\lambda)_{s.p.} = \frac{2\lambda+1}{4\pi}\left(\frac{3}{\lambda+3}\right)^2 (0.12A^{1/3})^{2\lambda}\ e^2 \cdot b^\lambda$ for $J_i = 0$, $J_f = \lambda$.

and $10.3 \pm 1.3 \times 10^{-15}$ e cm. In contrast the matrix elements $\langle 0^+ | M'(E1;-1) | 1^- \rangle$ have the values $-(0.91 \pm 0.06)$, $-(0.46 \pm 0.05)$, $-(0.123 \pm 0.011)$, and $-(0.36 \pm 0.05) \times 10^{-15}$ e cm.

The B(E2) values for the different decay modes of the 2^+ states for $^{156-160}$Gd and $^{160-164}$Dy are compared with theoretical predictions from the Interacting Boson Model in Table II. These calculations were done using the IBA computer code[3] PHINT. The energy level spectrum of ^{156}Gd is frequently cited as an example of a spectrum with SU(3) symmetry. These experimental results provide comprehensive tests of nuclei approximating the SU(3) limit. In the calculations the parameters E2SD and E2DD in the E2 transition operator were adjusted to reproduce the experimental $B(E2, 0_1 \rightarrow 2_1)$ and $B(E2, 0_1 \rightarrow 2_3)$. For the $K,J^\pi = 2,2^+$ state the B(E2) values for the $2 \rightarrow 2$ and $2 \rightarrow 4$ transitions are reproduced reasonably well by the IBA predictions. On the other hand, the B(E2) values for decay of the $K,J^\pi = 0,2^+$ state in ^{156,158}Gd and ^{160}Dy are not reproduced by the IBA calculations. In fact the limits of the $B(E2, 0 \rightarrow 2)$ for excitation of $K,J^\pi = 0,2^+$ states in ^{160}Gd, ^{162}Dy, and ^{164}Dy are 5, 50, and 34 times smaller than the IBA predictions, respectively. Finally, Iachello[4] has offered the suggestion that the $K,J^\pi = 0,2^+$ states at 1258 keV in ^{156}Gd and 1517 keV in ^{158}Gd could be due to a subshell closure at $Z = 64$ giving rise to another pairing and quadrupole pairing mode.

Table II. Experimental and calculated B(E2) values

Nucleus	Initial State K_i, J_i^π	Initial State E(keV)	Final State K_f, J_f^π	Final State E(keV)	$B(E2, J_i \rightarrow J_f)$ (10^{-50} e^2 cm^4) Exp	$B(E2, J_i \rightarrow J_f)$ (10^{-50} e^2 cm^4) IBA
^{156}Gd	$0,2^+$	1129.4	$0,0^+$	0	.32 ± .02	.19
			$0,2^+$	89.0	2.04 ± .14	.26
			$0,4^+$	288.2	1.71 ± .16	.68
	$2,2^+$	1154.1	$0,0^+$	0	2.22 ± .11	2.22
			$0,2^+$	89.0	3.55 ± .19	3.62
			$0,4^+$	288.2	.32 ± .03	.23
	$0,2^+$	1258	$0,0^+$	0	.15 ± .01	
			$0,2^+$	89.0	.21 ± .14	
			$0,4^+$	288.2	2.27 ± .27	
^{158}Gd	$2,2^+$	1187.1	$0,0^+$	0	1.70 ± .10	1.70
			$0,2^+$	79.5	3.16 ± .07	1.85
			$0,4^+$	261.4	.11 ± .02	.36
	$0,2^+$	1259.8	$0,0^+$	0	.16 ± .01	1.56
			$0,2^+$	79.5	.123± .015	2.27
			$0,4^+$	261.4	.62 ± .06	.20
	$0,2^+$	1517.4	$0,0^+$	0	.19 ± .02	
			$0,2^+$	79.5	.20 ± .04	
			$0,4^+$	261.4	.19 ± .03	
^{160}Gd	$2,2^+$	988.2	$0,0^+$	0	1.76 ± .09	1.77
			$0,2^+$	75.3	2.98 ± .18	2.06
			$0,4^+$	248.2	.16 ± .01	.32
^{160}Dy	$2,2^+$	966.2	$0,0^+$	0	2.44 ± .13	2.44
			$0,2^+$	86.8	4.45 ± .28	7.85
			$0,4^+$	283.8	.30 ± .03	.00
	$0,2^+$	1349.5	$0,0^+$	0	.37 ± .03	1.48
			$0,2^+$	86.8	.37 ± .19	7.40
			$0,4^+$	283.8	.89 ± .09	.013
^{162}Dy	$2,2^+$	888.2	$0,0^+$	0	2.37 ± .12	2.36
			$0,2^+$	80.7	4.46 ± .27	2.40
			$0,4^+$	265.7	.47 ± .05	.54
^{164}Dy	$2,2^+$	761.8	$0,0^+$	0	2.27 ± .11	2.28
			$0,2^+$	73.4	4.11 ± .25	2.51
			$0,4^+$	242.2	.46 ± .04	.45

REFERENCES

1. K. Kumar and J. B. Gupta, Nucl. Phys. A304, 295 (1978).
2. K. Neergård and P. Vogel, Nucl. Phys. A145, 33 (1970) and private communications.
3. Computer Code PHINT, written by O. Scholten, KVI Groningen, The Netherlands.
4. F. Iachello, private communication 1979.