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Proposed excited band with reduced moment of inertia in ^{156}Gd

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Excited states in ^{156}Gd were populated in the ^{158}Gd$(p,t)^{156}$Gd reaction with E_p = 18.0, 20.5, and 27.6 MeV. Our results do not confirm the existence of an excited rotational band with reduced moment of inertia compared to the ground state band which was suggested from a previous (p,t) experiment at E_p = 52 MeV.

[NUCLEAR REACTIONS ^{158}Gd(p,t), E_p=18.0, 20.5, and 27.6 MeV measured $\sigma(\theta)$. ^{156}Gd deduced levels. Enriched target.]

The ^{158}Gd $(p,t)^{156}$Gd reaction has been investigated previously at E_p = 18 and 52 MeV (Refs. 1–3). In the experiments at 18 MeV, only states up to an excitation energy of about 1.7 MeV were observed, whereas a number of states between 2 and 4 MeV were found to be strongly excited at E_p = 52 MeV. From the latter experiment Ishizaki[4] deduced the existence of an excited rotational band with excitation energies of 2.01 (0^+), 2.23 (2^+), 2.59 (4^+), 3.29 (6^+), and 4.13 MeV (8^+). The energies of these states roughly follow the $I(I+1)$ rule with a moment of inertia of about half the value for the ground-state band. This suggestion is surprising for the following reason. In two-nucleon transfer reactions, states with different deformations coexisting in the same nucleus were observed in ^{150,152}Sm and ^{152}Gd (Refs. 2, 5–7). However, these states were predominantly populated only from target nuclei with similar deformations. Thus, in the case of ^{156}Gd states with a deformation similar to that of ^{158}Gd, which is about 10% larger than for the ^{156}Gd ground state, are expected to be excited in the (p,t) reaction.

In the (p,t) experiment at 52 MeV the energy resolution was 90 keV. Since the level density above 1.5 MeV excitation energy is quite high, it was desirable to repeat the experiment with improved resolution. We have studied the ^{158}Gd-$(p,t)^{156}$Gd reaction with protons of 18.0, 20.5, and 27.6 MeV at the cyclotron of the Vrije Universiteit of Amsterdam. The tritons were detected in an Enge split-pole spectrograph using an array of six 3 cm long position sensitive detectors. The overall resolution was about 18 keV. A metallic target

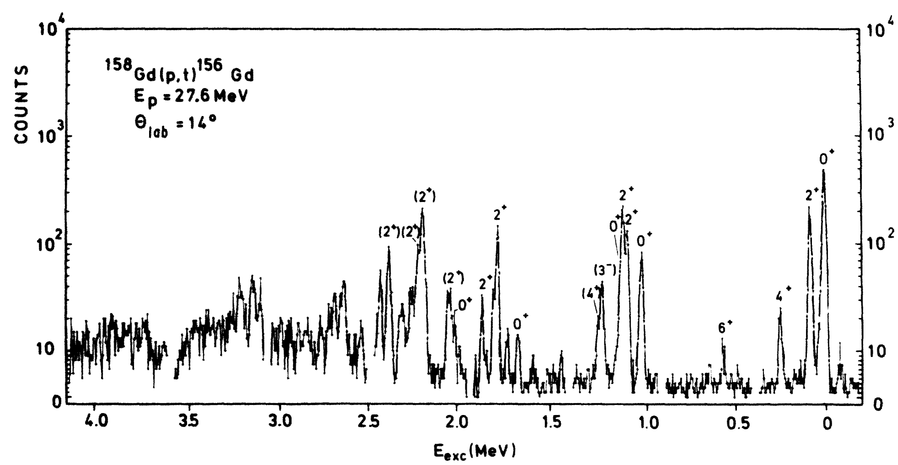

FIG. 1. Triton spectrum from the reaction ^{158}Gd$(p,t)^{156}$Gd at Θ_{lab} = 14° and E_p = 27.6 MeV.

TABLE I. Energies, summed cross sections, and spin-parity assignments of levels in ^{156}Gd.

E_{exc} (keV)	$\sum\sigma(\theta)$ (mb/sr)	I^{π}	E_{exc} (keV)	$\sum\sigma(\theta)$ (mb/sr)	I^{π}
0	4.23	0^+	2022	0.131	
89	0.639	2^+	2048	0.170	(2^+)
286	0.104	4^+	2175	0.112	
583	0.050	6^+	2192	0.804	(2^+)
1049	0.616	0^+	2218	0.279	(2^+)
1130	0.423	2^+	2255	0.251	
1155	0.713	2^+	2305	0.097	
1172	...	0^+	2323	0.081	
1251	0.041		2382	0.460	(2^+)
1277	0.141	(3^-)	2436	0.198	
1300	0.068	(4^+)	2497	0.075	
1459	0.045		2521	0.058	
1715	0.122	0^+	2596	0.163	
1772	0.046		2615	0.144	
1829	0.448	(2^+)	2649	0.085	
1853	0.135		3025	0.132	
1893	0.031		3055	0.193	
1915	0.071		3068	0.121	
1989	0.060	(0^+)	3138	0.128	

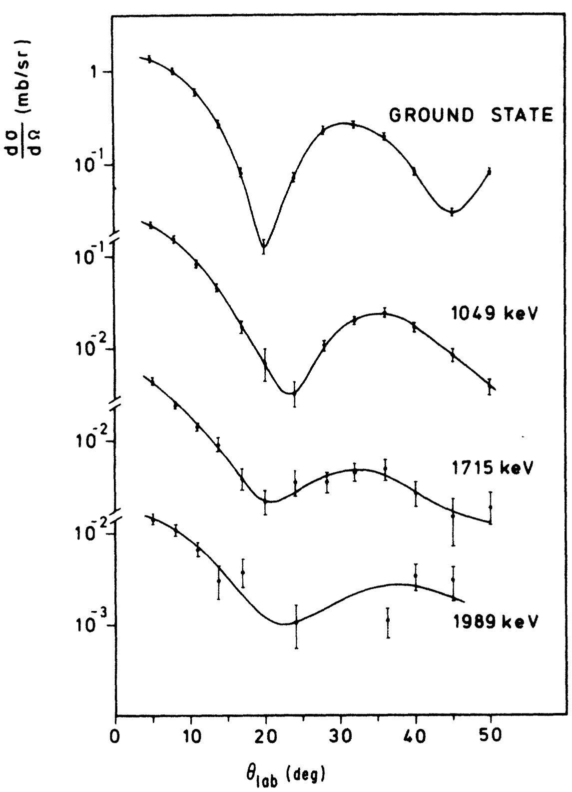

FIG. 2. $L=0$ angular distributions. The curves are drawn to guide the eye.

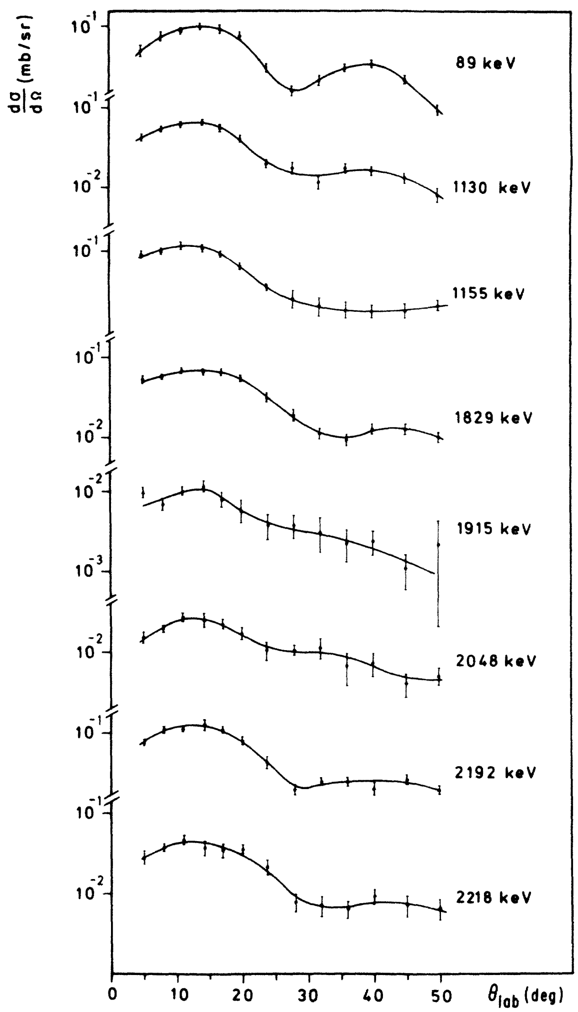

FIG. 3. $L=2$ or 3 angular distributions.

of enriched ^{158}Gd with a thickness of about 100 $\mu g/cm^2$ was used. The target thickness was determined by a comparison of the forward angle elastic proton scattering cross section with optical model predictions. The over-all uncertainty in the absolute cross section is about 10%. Angular distributions were measured at $E_p = 27.6$ MeV between 5 and 50°. Detailed information about the experimental setup and the data analysis is given in Refs. 8, 9.

One of the triton spectra is shown in Fig. 1. At the energies where Sugiyama *et al.*[3] observed strong peaks, we find multiplets of lines which, even in our high-resolution experiments, are only partially resolved. The excitation energies, summed cross sections (5–50°), and spin-parity assignments are given in Table I. The angular distributions of the lines up to 2.2 MeV which we assign to $L=0$ and $L=2$ or 3 transfers are shown in Figs. 2 and 3, respectively. The angular distributions for $L > 0$ for deformed nuclei do not allow safe spin assignments.[10] However, we can assign with reasonable certainty $I^{\pi} = 0^{+}$ to the 1715 keV and the 1989 keV states. Furthermore, the remaining strongly excited states between 1.5 and 3.0 MeV are probably 2^{+} or 3^{-} states.

In the (p, t) experiments of Refs. 1 and 2 using 18 MeV protons no excited states beyond 1.7 MeV were found. Therefore we repeated the experiment at 18.0 and 20.5 MeV, measuring only at two angles. At these proton energies the same states were excited as at 27.6 MeV, although the cross sections were much smaller.

Our data do not confirm the existence of a rotational band based on a 2.01 MeV 0^{+} state as proposed by Ishizaki.[4] With the higher energy resolution in our experiment we find that the level structure in this energy range is very complicated and a simple band structure does not appear. At 1.99 MeV we observe a 0^{+} state with about 1% of the ground state strength. At 2.2 MeV we find several strongly excited states with possible 2^{+} assignments. The strongest of these at 2.19 MeV is excited about as strongly as the 2^{+} ground-state band member. Because of these excitation intensities it is unlikely that the 1.99 and 2.19 MeV states are members of a rotational band. The same conclusion has to be drawn for the other proposed band members. From the data presently available it is not possible to draw any conclusions on the existence of rotational bands in this energy range.

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