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The ^{158}Gd(p, t)^{156}Gd Reaction

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The ^{158}Gd(p, t)^{156}Gd reaction has been measured at 51.9 MeV of incident energy. The excited states of 1.83 MeV 2$^+$, 2.01 MeV (0$^+$+2$^+$), 2.22 MeV 2$^+$, 2.37 MeV 2$^+$, 2.60 MeV (4$^+$), and 3.29 MeV (6$^+$) have been newly observed. The possibility of the new rotational band of k=0 is discussed. One of the quadrupole pairing vibrational states is pointed out.

I. INTRODUCTION

The (p, t) and the (t, p) reactions on the even-even nuclei in the rare earth region were measured by some groups.[1~15]

In the measurements[1~4,6~9,11,12] on the nuclei in the transitional region, the rotational band structures of k=0 were observed at the excited states of the nearly spherical nuclei in the ground states and also the existence of the nearly spherical states at the excited states of deformed nuclei in the ground states became clear.

In the ^{176}Yb(p, t)^{174}Yb reaction some excited rotational bands of k=0, each moment of innertia of which was almost the same as that of the ground band, were observed.[5]

In the (p, t) reactions on Nd isotopes, the pairing vibrational 0$^+$ states[16,17] and the quadrupole pairing vibrational 2$^+$ states were measured[13~15] and theoretically analyzed.[18]

We have measured again the (p, t) reactions systematically in the rare earth region at the incident energy of 51.9 MeV to study the higher excited states than those reported in Ref. 10. This high incident energy is useful for the measurement of the high spin states and highly excited states. Here we report the higher excited states of ^{156}Gd than already measured states by (p, t) reaction.[10~12]

II. EXPERIMENTAL PROCEDURE AND RESULTS

51.9 MeV proton beam for this experiment was provided by the Institute for

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Nuclear Study synchrocyclotron, and the emitted tritons were analyzed with the magnetic analysis system and detected by a proportional-counter array.[19] The target of isotopically enriched oxide Gd_2O_3 (97.58%) was deposited on a mylar backing by a centrifugal setting method and the thickness was 1.82 mg/cm². The overall energy resolution was about 90 keV FWHM.

Figure 1 shows a triton momentum spectrum. Above the excitation energy of about 1.9 MeV this spectrum has a background due to the high level density in this region. This kind of background is also seen in the spectra measured with a high resolution[6,8] and is reasonably considered by the energy gap. This background prevents reliable cross section measurements for the peaks in higher excitation energy than 2 MeV. The differential cross sections for the peaks were extracted by subtracting this background which is given in Fig. 1 by a broken line and is smoothly continuous to the spectrum measured till about 10 MeV excitation energy. Subtracted background had almost the same shape of the angular distribution as that corresponding to the higher excitation energy region where no peaks were observed.
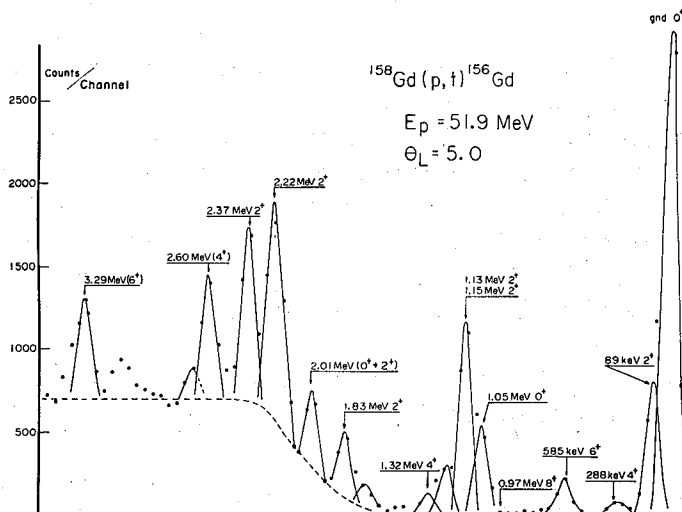

Fig. 1. A typical momentum spectrum of tritons. A broken line gives the background due to the high level density.

The differential cross sections for the peaks at 1.83, 2.01, 2.22, 2.37, 2.60, and 3.29 MeV excitation energies are shown in Fig. 2 together with those for the members of the ground state band to compare the shapes. In Ref. 10, angular distributions for the ground band 4⁺ states were very different in the deformed region.

The solid lines in Fig. 2 are the DWBA predictions. All the theoretical fits are arbitrarily normalized.

The DWBA analysis for the ground state band members measured by us[10] were already performed by two groups.[20~23] In both cases the best fit parameters of the optical potential are almost the same. In Ref. 20 the value of β_4 affected not only the magnitude but also the shape of the differential cross section for the ground band 4⁺ state, but in Ref. 23 the value of β_4 affected only the magnitude. In Fig. 2 DWBA curve for the 4⁺ state is given with $\beta_4=0$ in Ref. 20, and all the DWBA curves
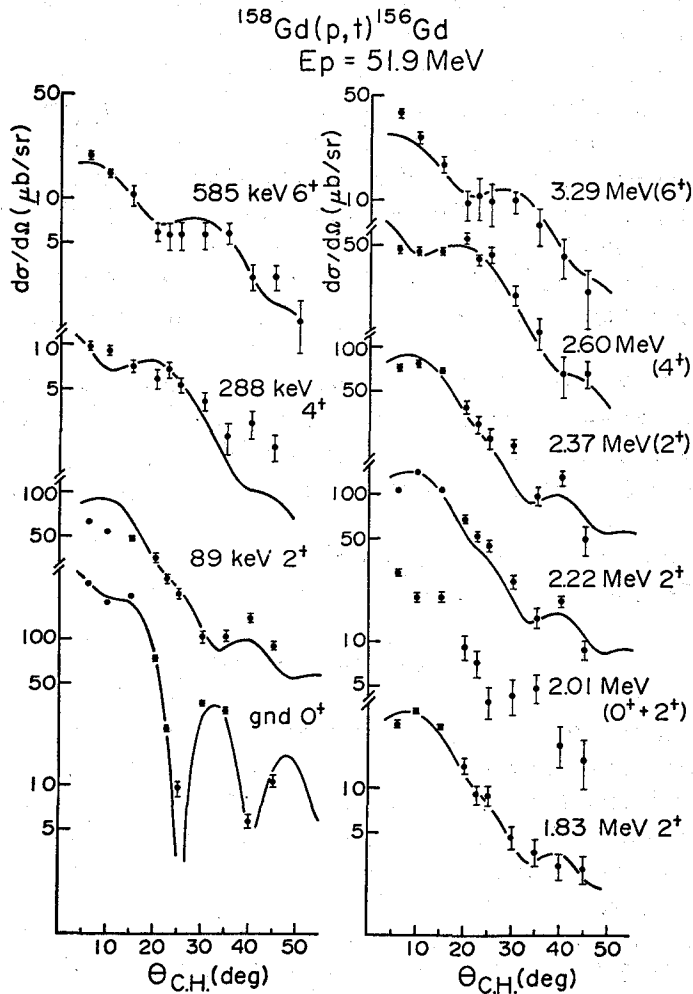
^{158}Gd(p,t)^{156}Gd
Ep = 51.9 MeV

Fig. 2. Experimental and theoretical angular distributions obtained from the
^{158}Gd (p, t) ^{156}Gd reaction at $E_p = 51.9$ MeV. The solid curves are
the DWBA predictions calculated in Ref. 20–23.

given for the newly observed states are the same as those for the ground state band
members.

III. DISCUSSION

From the DWBA calculations we have deduced that the newly observed peaks at
1.83, 2.01, 2.22, 2.37, 2.60, and 3.29 MeV correspond to the states of 2^+, $(0^+ + 2^+)$,
2^+, 2^+, (4^+), and (6^+) respectively. Because of the weak resolution of our measurement
it is less accurate that each of these peaks in Fig. 1 corresponds to only one state,
compared to high resolution measurement. But the measurement with high resolution
and high incident energy is not yet performed.

It is very interesting that the level spacing of the (0^+) component of 2.01 MeV

state, 2.22 MeV 2^+ state, 2.60 MeV (4^+) state and 3.29 MeV (6^+) state is very like to be that of the rotational band of k=0. In all the excited bands of k=0 measured by (p, t) reactions at the incident energies of nearly 20 MeV,[3~8] 0^+ state member has the larger sum of the differential cross sections at measured angles (summed cross section) than any one of the other members. In the measurement at 51.7 MeV reported in Ref. 10 and in this experiment at 51.9 MeV the 1.13 MeV β vibrational 2^+ state and 1.15 MeV γ vibrational 2^+ state of ^{156}Gd are not resolved, and the sum of the cross sections for these two 2^+ states is much larger than the cross section for the β vibrational 0^+ state. The above mentioned situation is the same for 2.01 MeV 0^+ and 2.22 MeV 2^+ states, and 2.22 MeV 2^+ state has the larger cross section than that for 2.01 MeV 0^+ state.

However, if the states of 2.01, 2.22, 2.60, and 3.29 MeV construct the rotational band, special mechanism of excitation by the (p, t) reaction should be considered.

The 2.37 MeV 2^+ state has also the large cross section. We consider this state to be one of the quadrupole pairing vibrational states which will be connected to those observed in Nd isotopes.[13,14,18] Our systematic measurements of the states which look to be the quadrupole pairing vibrational states in ^{148}Sm, ^{150}Sm, ^{152}Sm, ^{156}Gd, ^{162}Dy, and ^{170}Yb will be reported elsewhere.[24]

ACKNOWLEDGMENTS

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