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Deformation Parameters in Sm^{154} and Sm^{148} Obtained from Coupled-Channel Analysis of Proton Scattering*

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Differential cross sections for 16-MeV protons scattering from Sm^{154} and Sm^{148} were reanalyzed using the coupled-channel computer program JUPITOR-1 written by Tamura. The results of this analysis yield a better fit to the data using a value of $\beta_2 = 0.250$ for Sm^{154} than with the value of 0.351 obtained from Coulomb excitation studies. The same optical-model paramters which were used for Sm^{154} yield a good fit for Sm^{148} with vibrational deformation parameters $\beta_2 = 0.120$ and $\beta_3 = 0.150$.

INTRODUCTION

Angular distributions of 16-MeV protons scattered elastically and inelastically from Sm^{154} and Sm^{148} were measured in 1967 by Stoler *et al.*,[1] and analyzed within the framework of the collective model by Tamura[2] using coupled-channel theory.[3] The analysis assumed Sm^{154} to have a permanently deformed axially symmetric ground state, with rotational low-lying excited states. The quadrupole deformation parameter β_2 was taken as 0.351 which is the value obtained from Coulomb excitation studies that are reported in the compendium of Stelson and Grodzins.[4] Sm^{148} was assumed to be spherical in its ground state, with vibrational-like low-lying excited states.

On the other hand, Hendrie *et al.*[5,6] reported a coupled-channel analysis of 50-MeV α particles scattered elastically and inelastically from these same isotopes. They obtained a best fit to the Sm^{154} data using a $\beta_2 = 0.230$ and $\beta_4 = 0.050$.

With these results in mind, we used the coupled-channel code (JUPITOR-1) of Tamura[7] to reanalyze the Sm^{154} and Sm^{148} proton scattering data. The quadrupole deformation parameter β_2 was varied to find the best fit to the data.

RESULTS

Figure 1 shows the angular distributions obtained by Tamura[2] using $\beta_2 = 0.351$ for Sm^{154}. The optical-model parameters which were used[8] are shown in Table I.

The most striking feature of Fig. 1 is that the experimental elastic-scattering cross section undu-

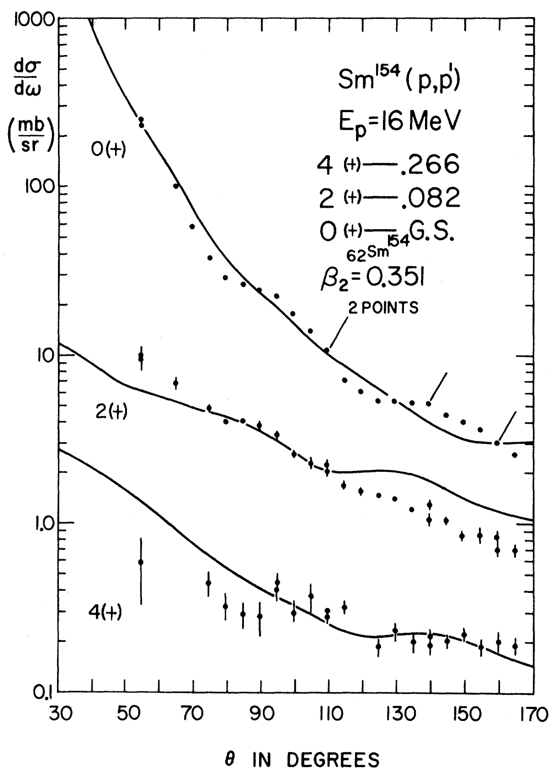

FIG. 1. Scattering of 16-MeV protons from Sm^{154}. Experimental points are from Ref. 1. Solid curves are theoretical results obtained in Ref. 2. 0(+), 2(+), and 4(+) indicate angular distributions of scattered protons with residual nucleus in the state indicated.

TABLE I. Optical-model parameters for Sm^{154} as used with $\beta_2 = 0.351$ in the coupled-channel calculations of Tamura. The symbols used are those of Ref. 3.

V (MeV)	W_d (MeV)	V_{so} (MeV)	r_0 (F)	$\bar{r}_0$ (F)	r_c (F)	a (F)	$\bar{a}$ (F)
54.03	10.31	7.50	1.204	1.243	1.204	0.715	0.667

TABLE II. Optical-model parameters for Sm^{154} as used with $\beta_2 = 0.250$ and $\beta_4 = 0.050$ in the coupled-channel calculations. Symbols are those used in Ref. 3.

V (MeV)	W_d (MeV)	V_{so} (MeV)	r_0 (F)	$\bar{r}_0$ (F)	r_c (F)	a (F)	$\bar{a}$ (F)
54.03	7.50	7.50	1.204	1.243	1.204	0.715	0.667

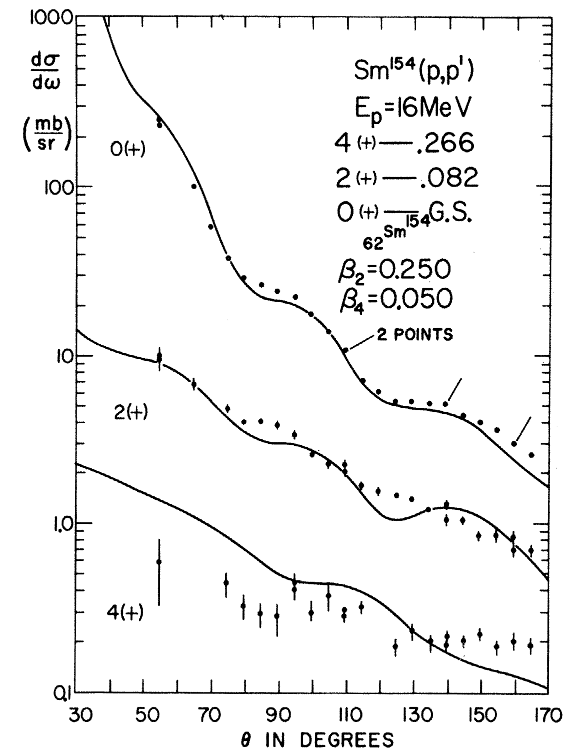

FIG. 2. Scattering of 16-MeV protons from Sm^{154}. Experimental points are from Ref. 1. Solid curves are results of the present study. 0(+), 2(+), and 4(+) indicate angular distributions of scattered protons with residual nucleus in the state indicated.

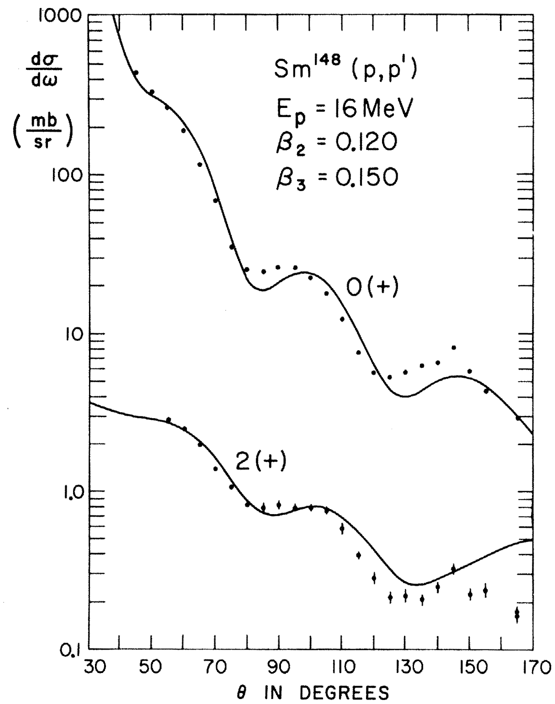

FIG. 3. Scattering of 16-MeV protons from Sm^{148}. Experimental points are from Ref. 1. Solid curves are results of the present study. 0(+) and 2(+) indicate angular distributions of scattered protons with residual nucleus in the 0(+) and 2(+) states, respectively.

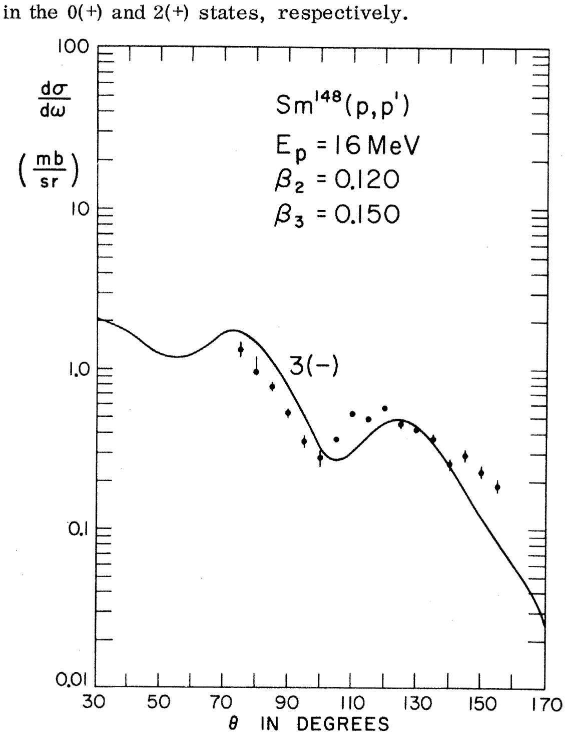

FIG. 4. Inelastic scattering of 16-MeV protons from Sm^{148} leaving the residual nucleus in the 3(-) vibrational state. Experimental points are from Ref. 1. Solid curves are the results of the present study.

lates considerably more than the theoretical curve. This is to be expected if the β_2 used in the calculations is too large. Note also the surface absorption potential parameter $W_d = 10.31$ MeV which was used. Considering that the collective states are explicitly taken into account, this value seems somewhat large. Figure 2 shows the results of the fit of theory to experiment obtained in this study. The deformation parameters used were $\beta_2 = 0.250$ and $\beta_4 = 0.050$. The optical-model parameters used are shown in Table II. The small positive β_4 serves to raise the 4(+) cross section (most noticeably at larger angles). The effect of including a β_6 on the 4(+) cross section was not explored. The fit in Fig. 2 (especially the elastic scattering) is noticeably improved over Fig. 1. The deformation parameters agree closely with those reported by Hendrie *et al.*[5,6]

Figures 3 and 4 show the comparison to experiment of a coupled-channel calculation with vibrational deformation parameters $\beta_2 = 0.120$ and $\beta_3 = 0.150$ for the scattering of 16-MeV protons from Sm^{148}. The optical-model parameters used were the same as those for Sm^{154} as shown in Table II.

It can be seen in Figs. 2, 3, and 4 that the coupled-channel theory predicts the changes in cross section between Sm^{154} and Sm^{148} in close agreement with experiment solely on the basis of changes in the deformation parameters. A similar observation was made by Glendenning, Hendrie, and Jarvis[9] in an analysis of the previously referred to α-particle scattering results.[5,6]

DISCUSSION

The above analysis indicates that in the case of 16-MeV protons scattering from Sm^{154} and Sm^{148} a value of β_2 less than the value obtained from Coulomb excitation studies seems to be called for. Some possible reasons for such a discrepancy have been pointed out in Ref. 6 and by Bromley and Weneser.[10] Coulomb excitation measures only the distribution of nuclear charge. The distribution of nuclear mass which gives rise to the nuclear potential need not be the same as that of nuclear charge. Also, the shape of the optical model and of the nucleus may not be rigidly connected. In this particular case the reaction is nearly adiabatic and the incoming particle sees the target nucleus as a static deformed shape. Thus, the reaction should be relatively independent of nuclear dynamics.

Finally, a more exhaustive parameter search together with inclusion of a β_6 term should quantitatively improve the over-all fit, and especially the 4(+) fit.

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Relation Between the $2I+1$ Rule and Channel Correlation

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The fluctuation cross section is derived as a function of the reduced-width correlation coefficient and also as a function of the channel cross correlation, with the resulting indication that the fluctuation cross section depends strongly on the channel cross correlation. The total average cross section is shown to be proportional to the quantity $2I+1$ only when the total level width is sufficiently large. Finally, the author suggests that only for experiments in the region of very large Γ_μ should the total cross sections be compared with the $2I+1$ rule. In order to get the above condition, low energy with a high Q value are highly desirable.

This is one of a series of discussions of the $2I+1$ rule which indicates that the average total cross section is proportional to the quantity $2I+1$, where the spin I is that of the residual nucleus in a compound-nuclear reaction.

Recently,[1] four conditions for improving the $2I$