AN l-DEPENDENT ABSORPTION IN THE OPTICAL-MODEL DESCRIPTION OF $^{40}Ca(\alpha, \alpha_0)^{40}Ca$ SCATTERING*

A. E. Bisson and R. H. Davis
Department of Physics, Florida State University, Tallahassee, Florida 32306
(Received 17 February 1969)

An l-dependent absorption has been introduced in an optical-model analysis of $^{40}Ca(\alpha, \alpha_0)^{40}Ca$ energy-averaged angular-distribution data in the bombarding-energy range 5.5-17.5 MeV. Above 10.5 MeV, a marked improvement in the description results with χ^2 values reduced to an average value of ~5. Below 10.5 MeV, the fits are not substantially improved over those obtained in a previous analysis.

In an analysis of $^{40}Ca(\alpha, \alpha_0)^{40}Ca$ scattering data measured between 12- and 18-MeV bombarding energy, Robinson et al.[1] fitted good-resolution angular distributions with the nuclear optical model. The fits to the data were reasonably good and at the same time illustrated several of the difficulties met in the optical-model analysis of alpha-particle scattering data below 20-MeV bombarding energy. John et al.[2] extended the experiment downward in energy to 5 MeV and were able to obtain good fits to energy-averaged angular distributions below 10.5 MeV provided that a compound-elastic-scattering term was included in the analysis. A continuation of this analysis upward in energy showed that the model was an inadequate description of the data above 10.5 MeV.

In this work an l-dependent factor is introduced in the absorption term of the optical model used in the analysis of John et al. The improved fits to the data are presented here. Advantageous ap-

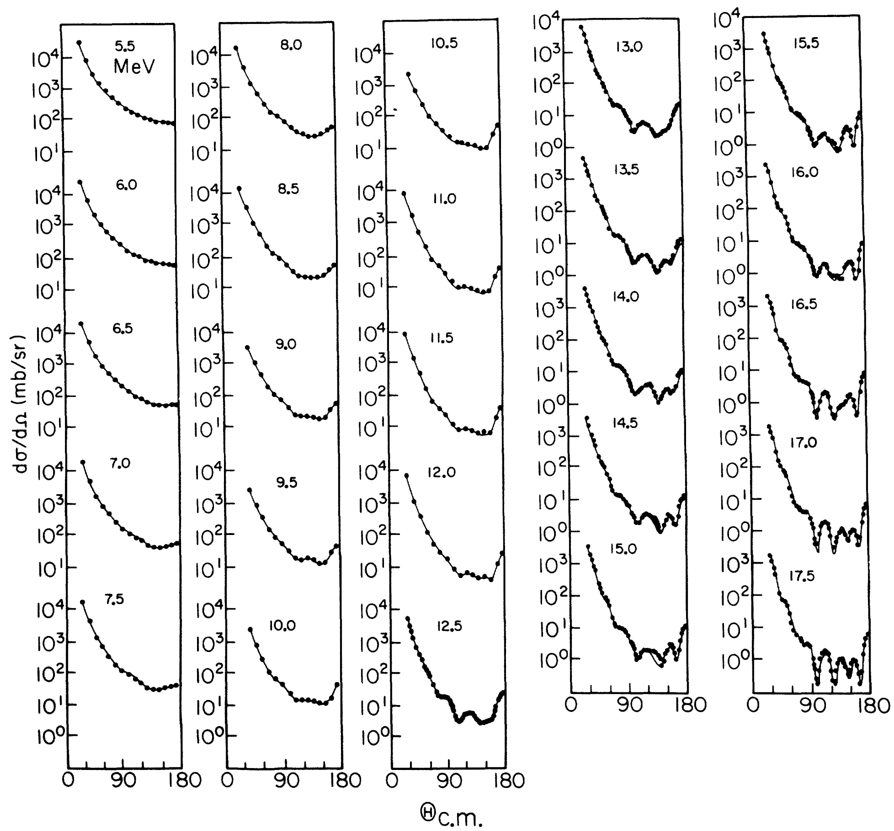

FIG. 1. Comparison of calculated and measured angular distributions in the bombarding-energy range 5.5-17.5 MeV. The points are the energy-averaged experimental values while the solid line is the result computed with an l-dependent absorption.

plication of this model to other alpha-particle scattering data is anticipated, especially those obtained with $4N$ target nuclei. Subsequent to the present work, an l-dependent absorption has been included in a recent analysis of heavy-ion–scattering data.[3]

In contrast to the l dependence of the real potential well found necessary in the analysis of alpha-alpha scattering data,[4] the necessary l dependence found here is a factor in the imaginary part of the potential. This factor reduces the imaginary strength as l increases, a behavior which is expected from the conservation of energy and momentum in the exit channels.[5] No l dependence of the real part is required to obtain good fits.

The experiments which produced the data analyzed here are discussed elsewhere.[1,2] In the energy range 5.0-12.5 MeV, 16 point angular distributions were measured every 10 keV and 64 point angular distributions every 100 keV. In the energy range 12.0-17.9 MeV, 16 point angular distributions were obtained every 25 keV and 64 point angular distributions every 100 keV. The angular distributions are backward peaked as is typically the case for scattering by $4N$ nuclei. Excitation curves showed rapid variations with energy.

Following the procedure of John et al.[2] the experimental cross sections were energy averaged using a Lorentzian weighting function. The averaging interval is limited to 2.0 MeV over the full energy range. In the energy range 5.0-12.5 MeV, the 16-angle 10-keV data were averaged. Because of the pronounced structure in the high-energy angular distributions, 64-angle data at 100-keV intervals were averaged in the energy range 12.0-17.9 MeV. The result is a set of energy-averaged angular distributions from 5.5 to 17.5 MeV.

The potential with an l-dependent imaginary term is given by the expression

$$V(r) = -Uf_R(r) - 4A_i F(l) W_D\, d[f_i(r) + V_C(r)]/dr, \qquad (1)$$

where the form factor $f(r)$ is of the Woods-Saxon type:

$$f(r) = [1 + \exp\{(r-R)/A\}]^{-1},$$

and V_C is the Coulomb potential of a uniformly charged sphere of radius R_C. The subscripts R, i, and C denote quantities used in the real, imaginary, and Coulomb parts of the potential. The quantity U is the real potential strength, W_D the surface imaginary potential strength, R the radius, and A the diffuseness.

The l-dependence is contained in the function $F(l)$:

$$F(l) = [1 + \exp\{(l - kR_R)/\Delta l\}]^{-1}, \qquad (2)$$

where k is the wave number of the incoming α particle and Δl is the diffuseness in l. As l increases, $F(l)$ decreases, the decrease being most rapid for $l \approx kR_R$. Through the dependence on k, some account is taken of the increase in the number of partial waves involved as the energy is increased. By assuming this form, the only new independent parameter is Δl.

The optical-model parameters used throughout the energy range are, approximately, $U = 138$ MeV, $R_R = 5.2$ F, $R_i = 5.0$ F, $R_C = 5.2$ F, $A_R = 0.53$ F, and $A_i = 0.30$ F. Different values of Δl were tried and good fits were obtained for Δl in the range 3.5-4.5. The lowest values of χ^2 result for $\Delta l = 4.0$ and this value is used throughout.

The angular distributions from 5.5 to 17.5 MeV are shown in Fig. 1. Values of χ^2 are 2 at the low energies and rise to approximately 9 at the high energies with an average value of about 5. A comparison of the fits to the data with and with-

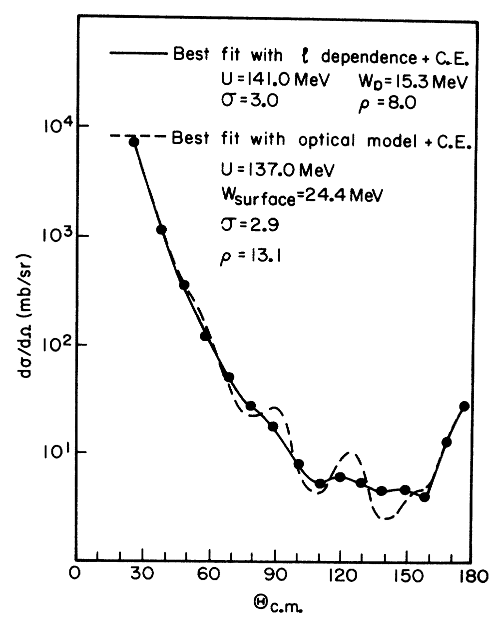

FIG. 2. Calculated angular distribution at 12.0 MeV with the l-dependent absorption (solid line) and without (dashed line). Both curves represent best fits to the data shown as dots.

out the l-dependent absorption is shown in Fig. 2 for the bombarding energy 12.0 MeV. With the l-dependence, χ^2 is about 5 and without, about 27. As the bombarding energy is increased, the improvement becomes more pronounced.

The statistical-model parameters which determine the incoherent compound-elastic-scattering term are modified by the introduction of the l-dependent absorption, but are still in reasonable agreement with those found by John et al. below 12 MeV. Again the maximum compound-elastic-scattering cross section is at a bombarding energy of about 9 MeV. The values and energy dependence of these parameters in the bombarding-energy range 5.5-12.5 MeV are consistent with the predictions of the Fermi-gas model.[6]

The authors wish to thank P. Robinson and J. John for the use of their data and W. Thompson for the use of the program BILSCAT. Special thanks are extended to D. Robson for helpful suggestions and informative discussions.

---

*Research supported in part by the Air Force Office of Scientific Research, Office of Aerospace Research, U. S. Air Force, under Grant No. AF-AFOSR-69-1674, and the National Science Foundation Grant No. NSF-GP-5114.

[1]C. P. Robinson, J. P. Aldridge, Joseph John, and R. H. Davis, Phys. Rev. 171, 1241 (1968).

[2]Joseph John, C. P. Robinson, J. P. Aldridge, and R. H. Davis, Phys. Rev. 177, 1755 (1969).

[3]R. A. Chatwin, J. S. Eck, A. Richter, and D. Robson, Phys. Rev. (to be published).

[4]P. Darriulat, G. Igo, H. G. Pugh, and H. D. Holmgren, Phys. Rev. 137, B315 (1965).

[5]D. Robson, private communication.

[6]K. A. Eberhard, A. E. Bisson, W. Thompson, and R. H. Davis, to be published.

ELECTROEXCITATION OF THE 10.8-MeV ($1^-;T=0$) LEVEL OF ^{12}C AND THE 7.12-MeV ($1^-;T=0$) LEVEL OF ^{16}O

Y. Torizuka, M. Oyamada, K. Nakahara, K. Sugiyama, Y. Kojima, T. Terasawa, K. Itoh, A. Yamaguchi, and M. Kimura

Laboratory for Nuclear Science, Tohoku University, Tomizawa, Sendai, Japan

(Received 3 October 1968)

Form factors for $E1$ ($\Delta T=0$) electroexcitation of the 10.8-MeV level of ^{12}C and the 7.12-MeV level of ^{16}O were obtained from inelastic electron scattering experiments. These form factors showed an anomalous q dependence relative to the usual $E1$ electroexcitation.

It has been shown that radiative electric dipole transitions with $\Delta T=0$ are forbidden by the isospin selection rule in self-conjugate nuclei. Eisenberg and Rose[1] have shown that the same rule can be applied to electroexcitation in the region $(qR)^2 \ll 1$, where q is the momentum transfer and R is the nuclear radius. They have also pointed out that in real nuclei the matrix element is nonvanishing because of (1) the presence of isospin impurity caused by Coulomb interactions and the neutron-proton mass difference, (2) the presence of higher order terms in $(qR)^2$, etc. From the second of these reasons it is supposed that inelastic scattering experiments using high-energy electrons may be useful in investigating the breakdown of the isospin selection rule of $E1$ $\Delta T=0$ transitions in $T_Z=0$ nuclei. On the basis of the particle-hole model, Seaborn and Eisenberg[2] have calculated the form factors for $E1$ $\Delta T=0$ transitions in ^{16}O. They have eliminated the effect of the spurious center-of-mass motion by carrying out the calculation using a set of basis vectors orthogonal to the spurious state. In this case the Coulomb radial reduced matrix element becomes

$$[f\|j_1(qr)\|i]=[f\|-(qr)^3/30+\cdots\|i],$$

where the first term $(\langle f\|qr\|i\rangle)$ in the power series expansion of $j_1(qr)$ has been eliminated, since it corresponds to the spurious center-of-mass motion. Therefore, it is expected that the q dependence of $E1$ transitions with $\Delta T=0$ in $T_Z=0$ nuclei may show $E3$-like behavior.

Both the 10.8-MeV level in ^{12}C and 7.12-MeV level in ^{16}O have been assigned to be $1^-, T=0$[3]. The present paper reports the electroexcitation of these states. The experiments were performed using the electron beam of the Tohoku 300-MeV linear accelerator. The incident electron energies were chosen to be 183 and 250 MeV, and the scattering angles were varied in the range from 35 to 115°. The targets were 104-mg/cm^2 graph-