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Reaction cross sections for intermediate energy alpha particles from optical folding-model calculations

H. Abele,[1] U. Atzrott,[1] A. Auce,[2] C. Hillenmayer,[1] A. Ingemarsson,[2,3] and G. Staudt[1]
[1]*Physikalisches Institut der Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[2]*Department of Radiation Science, Uppsala University, Box 535, S-75121 Uppsala, Sweden*
[3]*The Svedberg Laboratory, Box 533, S-75121 Uppsala, Sweden*
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Reaction cross sections for ^{16}O, ^{40}Ca, and ^{208}Pb are calculated from optical potentials in the folding-model approach for alpha particles in the energy region 80–170 MeV. The values obtained are systematically higher than the experimental values.

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Recently experimental results were reported for reaction cross sections for ^{12}C, ^{16}O, ^{28}Si, ^{40}Ca, ^{48}Ca, ^{58}Ni, ^{60}Ni, ^{124}Sn, and ^{208}Pb for alpha particles at five energies between 80 and 192 MeV [1]. Comparisons between the experimental values and predictions from optical model calculations with Woods-Saxon potentials showed that the calculations systematically overestimated the reaction cross sections by about 10%. The same discrepancy has also been observed by Dubar *et al.* [2] for 100 MeV alpha particles. Warner *et al.* [3] have made the same observation in their study of the ^{14}N+Si reaction cross section, but Warner *et al.* also reported cases where the reaction cross section is well reproduced by a Woods-Saxon potential [4].

The diffractive pattern as well as the reaction cross section are mainly sensitive to the phase shifts for large l values. Therefore it is rather surprising that optical model calculations with Woods-Saxon potentials can reproduce the angular distributions quite accurately and at the same time predict too large reaction cross sections. It seemed reasonable to assume that this might be an indication on a limitation of the often questioned Woods-Saxon parametrization. For this reason we decided to investigate whether reaction cross sections calculated from folded potentials, which earlier have been found to reproduce the elastic angular distributions very accurately, are in better agreement with the experimental results. The calculations were performed essentially in the same way as described in Ref. [5] for ^{16}O and in Ref. [6] for ^{40}Ca and ^{208}Pb. The optical potential in the folding model is given by

$$U(r)=V_c(r)+\lambda V_f(r)+iW(r) \tag{1}$$

where $V_c(r)$ is the Coulomb potential which is calculated from a homogeneously charged sphere. The real central nuclear potential $V_f(r)$ is calculated by a double folding procedure [6] using a realistic effective nucleon-nucleon interaction. The factor λ is a scaling factor, which allows for an adjustment of the potential depth. In the cases of ^{16}O and ^{40}Ca, the imaginary potential $W(r)$ was given by a Fourier Bessel expansion according to

$$W(r)=\sum_{n=1}^{k} a_n j_0\left(\frac{n\pi R}{R_c}\right). \tag{2}$$

In the case of ^{208}Pb a squared Woods-Saxon potential was used.

The final results were obtained by varying the scaling factor λ and the parameters of the imaginary part of the potential. In this way a very good agreement was obtained between the experimental differential cross sections and the calculated values in a large energy range. We refer to Refs. [5] and [6] for details of the calculations and illustrations of the quality of the fits.

The results for the reaction cross sections for ^{16}O, ^{40}Ca, and ^{208}Pb are shown in Fig. 1 as a function of energy per nucleon. The solid circles show the experimental data from Ref. [1]. The open circles show the results obtained with the Woods-Saxon potentials and the triangles those extracted from the calculations with the folded potentials. In the case of ^{16}O the calculated reaction cross sections are in even worse agreement with the data than those obtained with Woods-Saxon potentials. Otherwise, there is no systematic difference. The calculated values reproduce neither the magnitude of the reaction cross sections nor the energy dependence.

It is very surprising that good fits to the angular distribu-

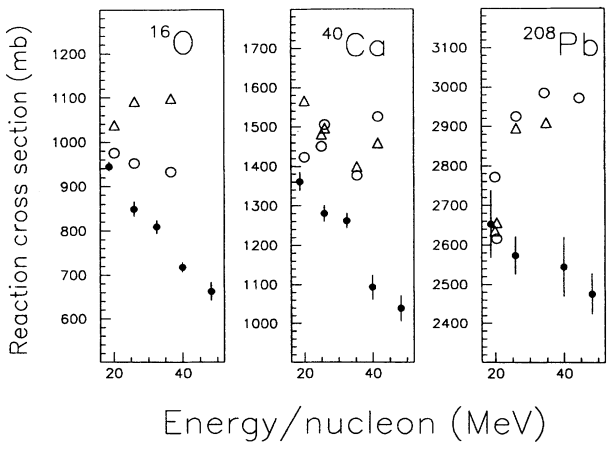

FIG. 1. Reaction cross sections for alpha particles vs the energy per nucleon. The experimental data are from Ref. [1]. The triangles show the values obtained with folding-model potentials and the open circles show those obtained with Woods-Saxon potentials.

tions for the differential cross section do not guarantee realistic values of reaction cross sections. This fact implies that conclusions from many folding calculations have to be questioned. The result is very confusing. In proton scattering it has been pointed out [7,8] that nonrelativistic folding calculations seem to give larger values for the reaction cross section than relativistic models. Without any spin-orbit interaction it seems less likely to assume that the discrepancies for the reaction cross section are due to relativistic effects. Terms in the relativistic models, however, such as the nuclear-Coulomb cross term, which are quadratic in the potential shape, might be of crucial importance.

The discrepancies we have stressed here, seem much more reasonable if one reads the report of Hussein, Rego, and Bertulani [9] on the microscopic theory of reaction cross sections. Their illustrations of the refractive effects, for example, in ^{12}C-^{12}C scattering, show very clearly our limited knowledge about the strong effects of the real central and of the Coulomb potential with regard to reaction cross sections. They also show that these effects are rapidly varying with energy in the energy region we have studied.

Our results show that in future folding-model calculations the reaction cross section as well as the angular distributions should be included in the fitting procedure. It will be very interesting to see to what extent conclusions on the effective interaction from earlier calculations have to be modified due to this constraint.

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