Total reaction cross section for ^{16}O-^{12}C at $E_{c.m.} = 60$, 93, and 135 MeV

M. E. Brandan and A. Menchaca-Rocha

Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364, México 20, D. F., México and Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

(Received 6 October 1980)

Values of the total reaction cross section σ_R for the system ^{16}O-^{12}C are obtained from the optical model analysis of elastic scattering data at c.m. energies equal to 60, 93, and 135 MeV. An averaging method based on the strong correlation found between σ_R and the imaginary diffuseness is presented and utilized to obtain σ_R and an estimate of its uncertainty. The derived values are consistent with calculations showing increased nuclear transparency.

[NUCLEAR REACTIONS ^{12}C(^{16}O,^{16}O)^{12}C, $E = 140$, 218, 315 MeV; measured $\sigma(E;\theta)$ for g.s.; optical model analysis. Deduced total reaction cross section.]

A recent publication[1] reports calculations based on nucleon-nucleon data showing increased nuclear transparency in proton and light nuclei interactions with nuclei at medium energies. Further calculations predict a similar effect for heavier composite systems[2] which should be observed as a rapid energy dependence in the total reaction cross section $\sigma_R(E)$ for medium- and high-energy heavy ion collisions. In this communication we report experimental data for the elastic scattering of ^{16}O from ^{12}C and the values of $\sigma_R(E)$ derived from them which, within uncertainties, agree with the aforementioned predictions.

In Fig. 1, we show the measured angular distributions for the elastic scattering ^{16}O-^{12}C at center-of-mass energies of 60, 93, and 135 MeV together with a representative optical model fit to the data. Details concerning the data acquisition and a complete description of the analysis leading to the optical model parameters referred to in this report will be given somewhere else.[3]

The total reaction cross section can be obtained from the analysis of elastic scattering data in terms of an optical potential, its value depending on the parametrization. But, as it is well known[4] for heavy ions, this is seldom uniquely determined by the data and therefore it is not possible to unambiguously derive a value for σ_R. We attempt to overcome this difficulty in our six-parameter optical potential analysis by following an averaging procedure to obtain $\sigma_R(E)$. This is explained next.

A strong correlation was found between the value of σ_R obtained from sets of optical parameters giving good fits (in terms of χ^2/N) to the data and the imaginary diffuseness a_i. This was understood noticing the effect of a_i on the transmission coefficients T_l from which σ_R is derived. Since T_l equals 1 for small wave numbers l, 0 for large l, and 0.5 for a value $l_{1/2}$ well determined by the

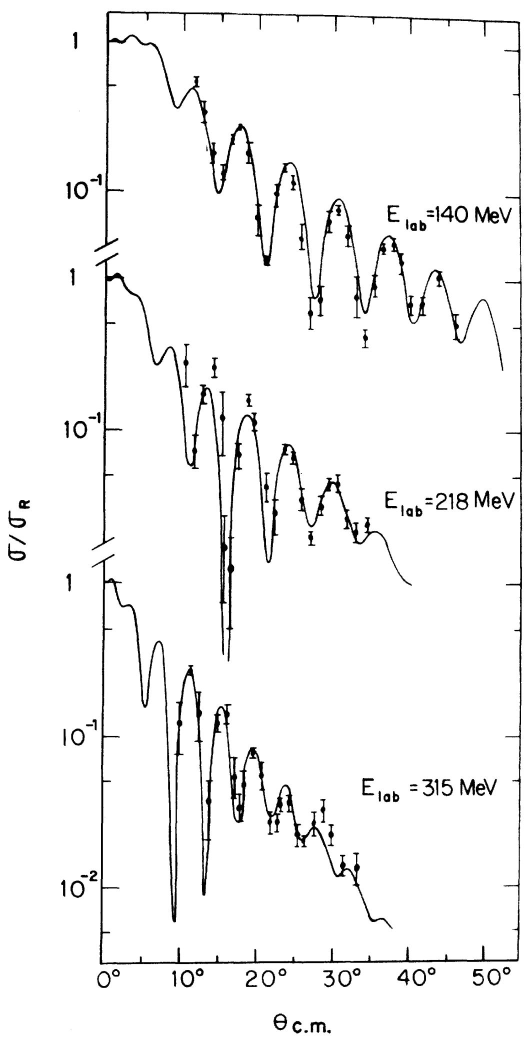

FIG. 1. Data and optical model calculations of the differential cross section (relative to Rutherford) for the elastic scattering of ^{16}O by ^{12}C.

data, it is the behavior of T_l in the region for small to large l that determined σ_R at a given energy. The width of this transition region is parameter dependent and it was found to be mostly determined by a_i for equally good parametrizations.

With a_i being the relevant parameter determining σ_R, a systematic five-parameter search for fixed values of a_i was undertaken. Several starting points as well as various combinations of parameters to be varied simultaneously were chosen, always repeating the same procedure for the different values of a_i. The value of $\sigma_R(E)$ obtained from the best fit (lowest χ^2/N) at each a_i was chosen as $\sigma_R(E, a_i)$. $\sigma_R(E)$ was then obtained as the weighted average of $\sigma_R(E, a_i)$, with weights proportional to the reciprocal of the square of its χ^2/N. Each average was assigned an uncertanity equal to the standard deviation of the sample of values. As a check for the internal consistency of the calculation, not only the best fit at each a_i, but all the sets giving a "reasonable" fit to the data (χ^2/N up to three times the minimum) were included in the average, each one weighted inversely proportional to the square of its χ^2/N. This new average agreed with $\sigma_R(E)$, within the uncertainties, for all energies. Also, the same calculations were repeated weighting each $\sigma_R(E, a_i)$ proportionally to the reciprocal of χ^2/N, obtaining weighted averages consistent with $\sigma_R(E)$ within the uncertainties.

Figure 2 shows the values of $\sigma_R(E)$ obtained as described above including values of $\sigma_R(E, a_i)$ for a_i between 0.2 and 1.0 fm at 0.1 fm intervals. Since this choice is rather arbitrary, the same calculations were repeated for a_i ranging from 0.3 to 0.9 fm and from 0.2 to 1.1 fm. The sets of three values of $\sigma_R(E)$ for all the choices follow the same trend, namely, the value of $\sigma_R(E)$ shows its maximum at 93 MeV. Also shown in Fig. 2 are values of $\sigma_R(E)$ calculated from optical model

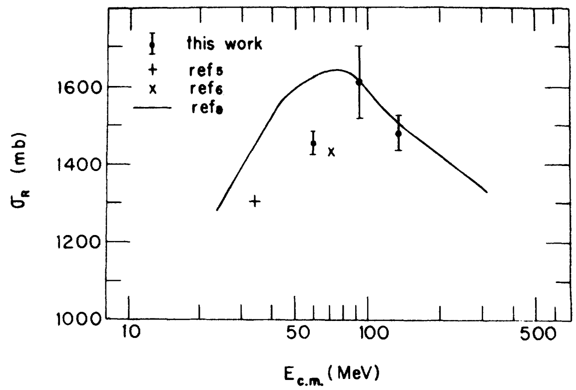

FIG. 2. Comparison between the calculated total reaction cross section and values deduced from optical model analyses of elastic scattering data.

potentials previously reported[5,6] for ^{16}O-^{12}C scattering at 80 and 168 MeV, respectively. No error bars have been assigned to these points. Our three experimental values are higher than the geometric limit of $\sigma_R(E)$ for the ^{12}C-^{16}O system, calculated from the rms radii[7] to be 1.39 b. This shows that $\sigma_R(E)$ does not simply level off and stay at the geometric value. The solid line in Fig. 2 corresponds to a parameter-free calculation[8] of the total reaction cross section based on nucleon-nucleon data, as discussed in Ref. 2.

We have presented a method for assigning an uncertainty to the values of $\sigma_R(E)$ calculated from elastic scattering data. It is concluded that, within the calculated uncertainties, our values for the ^{16}O-^{12}C system are consistent with the behavior predicted by calculations of $\sigma_R(E)$ based on nucleon-nucleon interactions.

We are much indebted to our colleagues at IFUNAM and at the LBL 88-inch cyclotron for the use of data not yet published. This work was partially supported by CONACyT, México.

[1]R. M. DeVries and J. C. Peng, Phys. Rev. Lett. 43, 1373 (1979).
[2]R. M. DeVries and J. C. Peng, Phys. Rev. C 22, 1055 (1980).
[3]M. E. Brandan, A. Dacal, A. Galindo, A. Menchaca-Rocha, B. G. Harvey, R. Legrain, J. Mahoney, M. Murphy, W. D. M. Rae, and T. J. M. Symons (unpublished).
[4]G. R. Satchler, in *Proceedings of the International Conference on Reactions between Complex Nuclei*, edited by R. L. Robinson, F. K. McGowan, J. B. Ball, and J. H. Hamilton (North-Holland, Amsterdam, 1974), p. 171.
[5]H. H. Gutbrod, R. Bock, W. von Oertzen, and U. C. Schlotthauer-Voos, Z. Phys. 262, 373 (1973).
[6]R. H. Bassel, G. R. Satchler, and R. M. Drisko, Nucl. Phys. 89, 419 (1976).
[7]C. W. DeJager, H. DeVries, and C. DeVries, At. Data Nucl. Data Tables 14, 479 (1974).
[8]R. M. DeVries and J. C. Peng (private communication).