Measurements of the Total Reaction Cross Section in 12C, 13C, 14N, 15N, 16O + 28Si Systems

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I. 1. Measurements of the Total Reaction Cross Section in ^{12}C, ^{13}C, ^{14}N, ^{15}N, ^{16}O + ^{28}Si Systems

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A model independent determination of the total reaction cross sections has been experimentally made using the sum-of-differences method[-3)] in ^{12}C, ^{13}C, ^{14}N, ^{15}N, ^{16}O + ^{28}Si elastic scattering. The measurements of the total reaction cross section σ_R address a problem of deep significance to studies of nuclear reaction mechanism, since it contains information about all the possible channels of a scattering system. For example, the absorption term of the optical model potential (OMP) is quite sensitive to σ_R. The real part of OMP can be calculated using microscopic method with realistic nucleon-nucleon interaction data. However, other experimental data which are sensitive only to the imaginary part of the potential have hardly ever been found. Therefore, one of the fundamentally important experiments in nuclear physics is an accurate determination of total reaction cross sections.

Recently, Ostowski et al[4,5)] have measured elastic cross sections in the forward angular range with the smallest angle of θ_{lab}=1.6° in the ^{12}C+^{12}C scattering at E/A=1-2 MeV, and they determined the total reaction cross sections model-independently. Elastic Cross sections of ^{12}C, ^{15}N, ^{16}O + ^{28}Si have been measured at the energies E/A = 4-5 MeV[6)] in the forward angular range up to 1.2°. However, the measurements in such a limited angle range are not enough for the purpose to deduce the highly precise total reaction cross sections or the nuclear amplitudes at θ=0°.

In the present work, the measurements of elastic differential cross sections were extended to the forward angular region up to 0.6° in the scattering systems, ^{12}C, ^{13}C, ^{14}N, ^{15}N and ^{16}O on ^{28}Si. The result of the precise experiments showed undoubted oscillations and undulating envelope shape in the sum-of-differences cross sections(SOD), as shown in Fig. 1.

For the measurements at extremely forward angles(θ =0.6°-4.0°), a trapezoidal scattering chamber was designed and installed at the down stream of a large scattering chamber. The distance between the target position and a defining slit of the detector system was 1592mm. The detector system consists of two 25μm totally depleted silicon detectors and a 240 μm position-sensitive silicon detector. The telescope was mounted by a thin tantalum plate with three slit apertures of 0.4×2 mm^2 in front of the ΔE detectors. Each slit aperture defined a solid angle of 3.1×10^{-7}sr. and a differential angle of Δθ=0.014° assuming a point beam spot on the target. The accuracy of angle setting was 5×10^{-4} degree. Four solid-state detectors were symmetrically situated with respect to the beam axis, to monitor the deflection of the beam intensity distribution in the beam spot. These monitor detectors were symmetrically placed on a circle with a small corn angle of θ_{lab}=1.1°with the incident beam axis. This monitor system was movable on the scattering plane and an accuracy of absolute scattering angles was 0.02°. The absolute scattering angles was determined by measuring the symmetry of the slight small deflective patterns on the Rutherford scattering yields with the beam axis. The precision of the absolute scattering angle is ±0.001°. The beam was doubly collimated to a spot of diameter less than 0.4mm on the target. The target was a self-supporting natural Si metal of 180μg/cm^2 thickness.

The contributions from the target contaminations have to be taken into account in order to keep the resulting error small. We found a contaminant material of about 3.7×10^{-3}% in the Si target, which is estimated to have a mass number near A=180; it may be Au, from the elastically scattered energy spectra at the large angles.

As the physical effects for the elastic scattering data at very forward angles, the multiple scattering, the electron screening and the vacuum polarization should be considered. The effects of the first and second terms were negligible for the data at angles larger than 0.2° at least. However, the effect of the third term was taken into account for the data. The calculation of the vacuum polarization was done using the first order approximation to the equation proposed by Uehling[7]. The finite size effect of nuclei for the vacuum polarization has been calculated by Roesel et al[8]. The results show that the finite size effect is clearly sensitive to muonic atoms but can be neglected in heavy-ion scattering.

The sum-of-differences cross sections were calculated using the measured angular distribution. The resulting function $\sigma_{SOD}(\theta_0)$ were renormalyzed so that the median of the upper and lower envelopes of $\sigma_{SOD}(\theta_0)$ became a horizontal line. These $\sigma_{SOD}(\theta_0)$ functions exhibit a certain oscillation at small angles. The diffraction pattern at forward angles can be described by a Bessel function $J_0(L_g \sin\theta)$ with L_g being an angular momentum near the grazing angular momentum[9]. The $\sigma_{SOD}(\theta_0)$ obtained from data are compared in Fig.1 with the $J_0(L_g \sin\theta)$ function calculated with glory angular momenta of L_g = 30, 30, 40, 40 and 35 for ^{12}C, ^{13}C, ^{14}N, ^{15}N and ^{16}O projectile nuclei, respectively. In table 1, the values of the total reaction cross sections σ_R are listed together with the $f_N(0)$ and L_g. The uncertainty of total reaction cross sections obtained is within 5% except for ^{15}N projectile. In the case of ^{15}N projectile, the accuracy of the σ_R is about 11%. This large uncertainty may results from the measurement of σ_{SOD} in the angular range which is not sufficiently small to obtain the constant amplitude of oscillating σ_{SOD} function.

In Table 1, the total reaction cross sections obtained from the SOD method are compared with the results from the optical model potential analyses[10]. The total reaction cross sections from the OMP analyses are in good agreement with the results by SOD method.

References

1) Holdeman J. and Theler R., Phys. Rev. Lett. **14** (1965) 81.
2) Marty C., Z. Phys. A309 (1983) 261; Z. Phys. **A322** (1985) 499.
3) Barrette J. and Alamanos N., Phy. Lett. 153B (1985) 203; Nucl. Phys. **A441** (1985) 733.
4) Ostrowski A. et al., Phys. Lett. **B232** (1989) 46.
5) Ostrowski A. et al., Phys. Rev. **C44** (1991) 2082.
6) Yamaya T. et al., Proc. of 3rd-IN2P3-RIKEN Symposium on Heavy Ion Collision, Kawagoe, Saitama, Oct. 1994. p23-33.
7) Ueling E., Phys. Rev. **48** (1935) 55.
8) Rosel F. and Trautman D., Nucl. Phys. **A292** (1955) 523.
9) Ueda M, and Takigawa D., Nucl. Phys. **A598** (1996) 273.
10) Yamaya T. et al., Phys. Rev. **C37** (1988) 2585.

Table. 1. Results from the SOD analyses. k is the wave number, η is the Sommerfeld parameter; σ_R from SOD is the total reaction cross section from the SOD method, and σ_R from the OMP is the one from the OMP analyses.

Projectile	^{12}C	^{13}C	^{14}N	^{15}N	^{16}O
E_{lab}[MeV]	65	60	84	85	75
k[fm^{-1}]	4.28	4.17	5.00	5.08	4.83
η	5.68	6.16	6.30	6.26	8.14
σ_R from SOD [mb]	1490 ± 50	2090 ± 80	1970 ± 90	1600 ± 180	1600 ± 70
$\mid f_N(0) \mid$ [fm]	10 ± 2	21 ± 4	46 ± 14	48 ± 20	35 ± 5
σ_R from OMP[mb]	1630	2011	1901	1623	1519

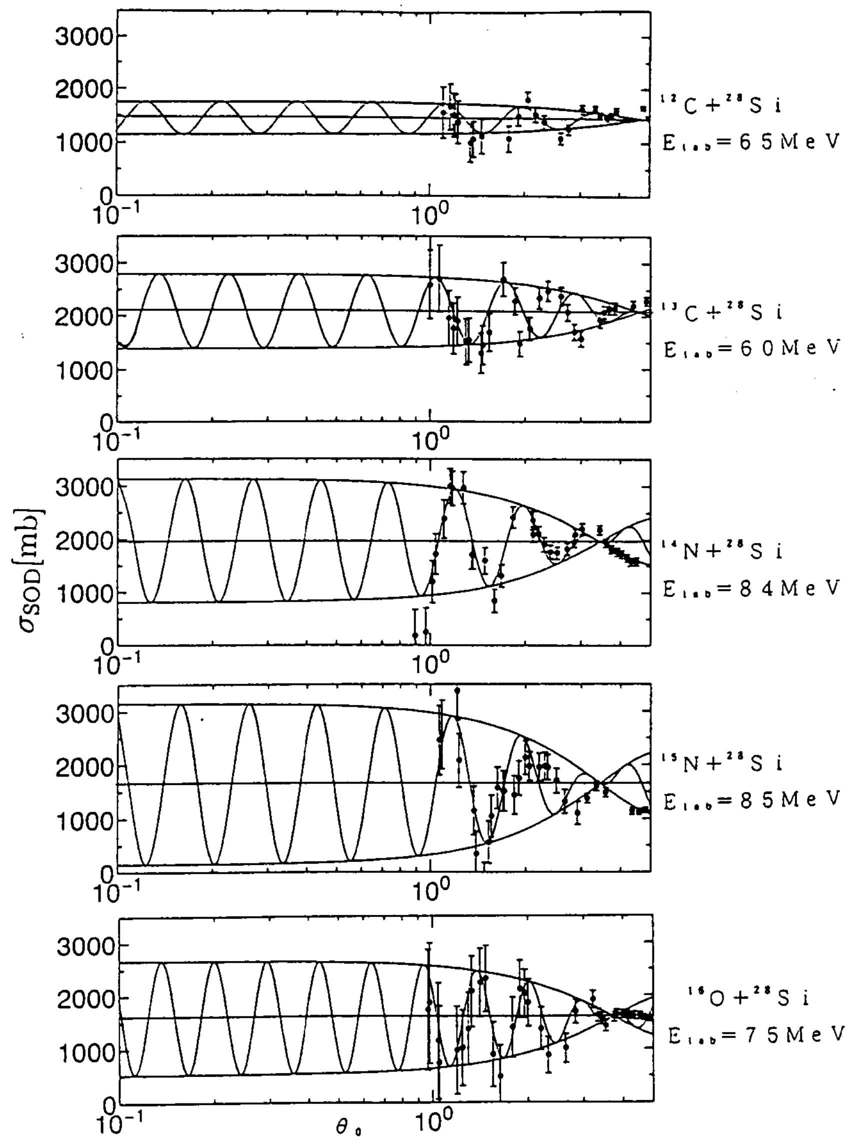

Fig. 1. The Sum-of-differences cross sections $\sigma_{SOD}(\theta_0)$ obtained from the present data. Solid curves are the results of the χ^2 fit. The holizontal lines give the total reaction cross sections σ_R as obtained from χ^2 fit.

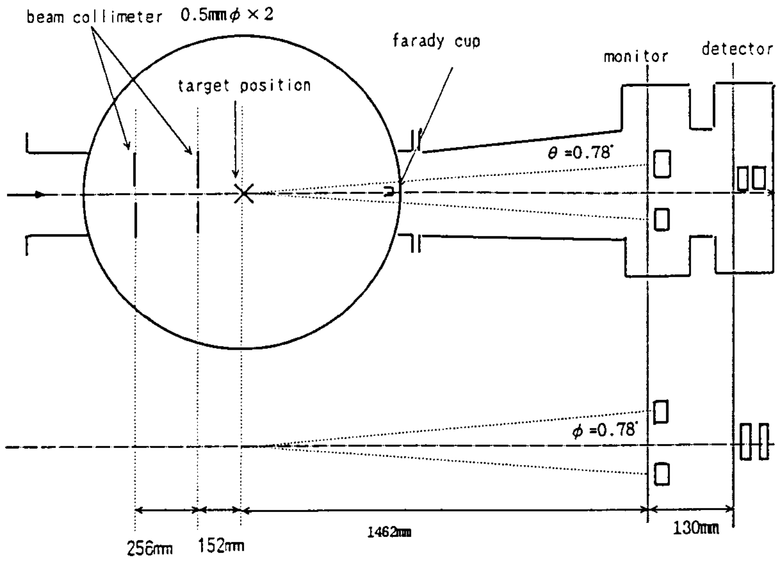

Fig. 2. Trapezoidal scattering chamber for the measurments at exteremely forward angles.