I. 3. Total Reaction Cross Section and Forward Glory Scattering in Heavy Ion Collisions

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The possibility of a model independent determination of the total reaction cross sections were experimentally shown by the measurements forward glory phenomena at extremely forward angles in the heavy-ion elastic scattering.

The observations of glory scattering in molecular and atomic collisions have been successful. In the nuclear collisions, an existence of forward glory phenomena has theoretically been predicted by many theorests[1-4], and the many data have been analyzed to deduce the forward glory phenomena in the nuclear collisions[5-10].
However these data are synthetic, i.e the angular distributions measured in a limitted angular range which is not involve the forward angles.

Elastic cross sections in a foward angular range up to θ_{Lab} =1.6° have been measured at E/A=1~2 MeV [11-12] in the ^{12}C + ^{12}C scattering system, and an possibility of observation of the forward glory in the nuclear collision have been shown from the experimental data. However, the ^{12}C + ^{12}C system in this energy region should be considered appreciable effects of resonances for the total reaction cross sections or the nuclear scattering amplitudes.

The forward glory for the scattering system of ^{12}C, ^{15}N, ^{16}O+ ^{28}Si have been observed at the energies E/A=4~5 MeV[13] in a forward angular range up to 1.2°. However, the measurements in such a limitted angle range are not enough for the purpose to deduce the high 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° for the scattering systems, ^{12}C, ^{13}C, ^{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 downstream a large scattering chamber. A distance between the target position and a defined slit of the detector system was 1599mm.

The detector system consists of two 25 μ m totally depleted silicon detectors and a 240 μ m 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 was defined solid angles of 3.1 × 10^{-7} sr. and the differential angles of $\Delta\theta$ =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 measureing the symmetry of the slight small deflective patterns on the Rutherford scattering yields with the beam axis. Differences between yields at symmetrical points are within pm 0.0003°. The beam was doubly collimated to a spot diameter less than 0.4mm on the target. The target was a self-supporting natural Si metal of 180 μ g/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 contaminate material of about 3.7 × 10^{-3}% in the Si target which is estimated a mass number of 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 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 sum-of-differences (SOD) cross sections were calculated using the measured angular distribution. The resulting function $\sigma_{SOD}(\theta_0)$ were renormalyzed as the median of the upper and lower envelopes of $\sigma_{SOD}(\theta_0)$ became a horizontal line. These $\sigma_{SOD}(\theta_0)$ functions exhibt a certain osillation at small angles. The additional fingerprint for a forward glory is an undulating envelope of the oscillating σ_{SOD} function $|f_N(\theta_0)| = f_N(0) J_0(l_g \sin\theta)$ as predicted by the semiclassical scattering theory, which the envelope of the oscillation part behaves like the Bessel function $J_0(l_g \sin\theta)$ if a forward nuclear glory exist. The $\sigma_{SOD}(\theta_0)$ obtained from data are compared in Fig.1 with the $J_0(l_g \sin\theta)$ function caluculated with glory angular momenta of l_g =30, 30, 40, and 45 for ^{12}C, ^{13}C, ^{15}N and ^{16}O projectile nuclei, respectively. These glory angular momenta correspond to the grazing angular momenta, respectively. In Table 1, the values of the total reaction cross sections sigma σ_R are listed together with the $|f_N(0)|$ and the glory angular momenta.

References

1) Holdman J. T. Holdeman and Theler R. M., Phys. Rev. Lett. **14** (1965) 81.
2) Marty C., Z. Phys. A **309** (1983),261; Z. Phys. A **322** (1985) 499.
3) Hussein M. S. et al., Phy. Lett. **114B** (1982) 1.
4) Hussein M. S., Phys. Lett. **127B** (1983) 165.
5) Oeschler H. et al., Nucl. Phys. **A325** (1979) 463.
6) Hussein M. S. et al., Phys. Rev. Lett. **52** (1984) 511.
7) BarretteJ. and Alamanos N., Phy. Lett. 153B, **208** (1985); Nucl.Phys. **A441** (1985) 733.
8) Hnizdo V., Phys. Lett. **167B** (1986) 26.
9) Lipperheido R. H., Nucl. Phys. **A469** (1987) 190.
10) Villari A. C. C. et al., Nucl. Pfys. **A501** (1989) 605.
11) Ostrowski A. N. et al., Phys. Lett. **B232** (1989) 46.
12) Ostrowski A. N. et al., Phy. Rev. **C44** (1991) 2082.
13) Yamaya T. et al., Proc. of 3rd-IN2P3-RIKEN Symposium on Heavy Ion Collision, Kawagoe, Saitama, Oct. 1994. pp23-33.
14) Yamaya T. et al., Phys. Rev. **C37** (1988) 2585.

Table 1. Results from the SOD analyses.

projectiles	SOD (mb)	OMP (mb)
^{12}C	1490±50	1510±300
^{13}C	2090±80	1960±390
^{15}N	1650±50	1906±380
^{16}O	1600±30	1520±304

In the Table 2 the total reaction cross sections obtained from the SOD methode are compared with the results from the optical model potential analyses[14].

Table 2. Comparison between the reaction cross sections deduced from the SOD and OMP analyses.

projectiles	^{12}C	^{13}C	^{15}N	^{16}O
E_{lab}(MeV)	65	60	85	75
wave number k (fm^{-1})	4.28	4.17	5.08	4.83
coulomb parameters η	5.68	6.16	6.26	8.14
total reaction cross sections σ_R (mb)	1490±50	2090±80	1650±50	1600±30
nuclear scattering amplitudes |f(0)| (fm)	10±2	21±4	48±20	35±5

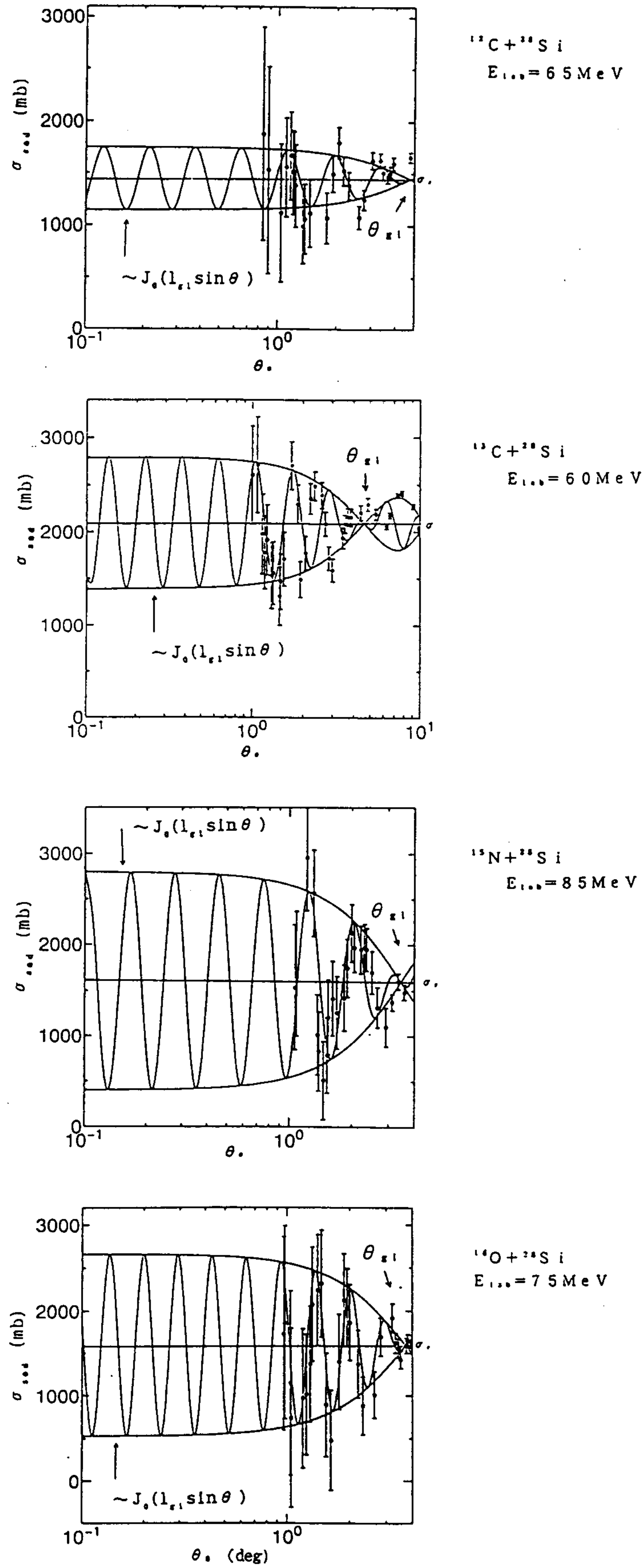

Fig. 1 The Sum of differences cross sections $\sigma_{SOD}(\theta_0)$ obtained from the present data.
Solid curves are the results of the χ^2 fit. The holizontal lines give the total reaction cross sections σ_R as obtained from χ^2 fit.

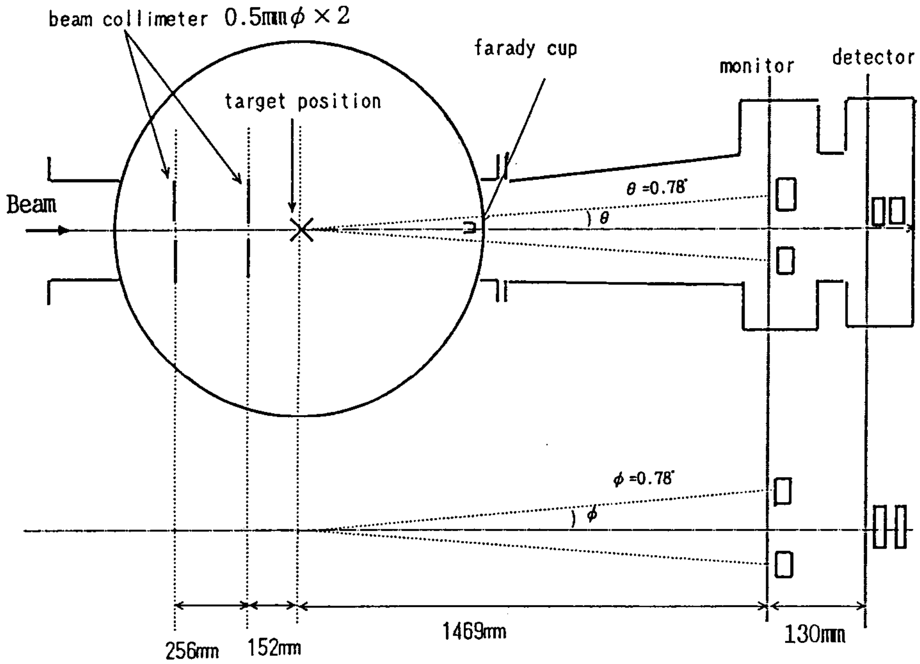

Fig. 2 Trapezoidal scattering chamber for the measurments at exteremely forward angles.