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CROSS SECTIONS FOR THE PRODUCTION OF FRAGMENTS WITH Z≥8 BY FRAGMENTATION OF 9≤Z≤26 NUCLEI

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Confirming Abstract:

We investigated charge changing nuclear collisions in plastic nuclear track detectors using a new experimental technique of automatic track measurement for etched tracks in plastic detectors. Partial cross sections for the production of fragments of charge Z≥8 were measured for projectile nuclei of charge 9≤Z≤26 in the detector material CR39 and in silver. For this purpose three independent experiments were performed using Bevalac beams. The first one was an exposure of a stack of CR39 plastic plates to 1.8 GeV/nucl. ^{40}Ar nuclei. The second one was an exposure of another CR39 stack to 1.7 GeV/nucl. ^{56}Fe projectiles. In the third experiment a mixed stack of CR39 plates and silver foils was irradiated with 1.7 GeV/nucl. ^{56}Fe nuclei. Thus the measurement of nuclear cross sections in a light target (CR39 = $C_{12}H_{18}O_7$) and as well in a heavy target (silver) was possible.

The scanning and measuring of the plastic detectors was performed using the Siegen automatic measuring system for nuclear track detectors /1/. The charges of the fragments are determined from the measured areas of the particle tracks in the etched plastic detectors. After the measuring procedure the trajectory of each individual particle is reconstructed from the particle tracks through the whole stack. A nuclear interaction with ΔZ≥1 is detected by a change in the measured area of the particle tracks of one trajectory. Altogether more than 33600 charge changing nuclear interactions of beam particles and about 15600 interactions of fragments produced in nuclear collisions were analyzed. Partial cross sections σ_{PT}^{F} for the production of fragments F with 8≤Z≤25 from projectiles P of 9≤Z≤26 in the target T (CR39 and silver) were determined.

Based on the assumption of a factorization of the partial nuclear cross sections /2, 3/ we scaled the semi-empirical formula of Silberberg & Tsao /4/ for cross sections in hydrogen target to heavier targets using the following expression:

$$(1) \qquad \sigma_{PT}^{F} = \gamma_{PT} \cdot \gamma_{H}^{-1} \cdot \sigma_{(ST)}^{F},$$

where $\sigma_{(ST)}^{F}$ is the Silberberg-Tsao cross section, γ_{PT} and γ_H are target factors for heavy targets T and hydrogen target respectively.

In figure 1 the ratio R of measured cross sections σ_{PT}^{F} and calculated Silberberg-Tsao cross sections $\sigma_{(ST)}^{F}$ are plotted versus the mean fragment mass for Fe-projectiles and for the silver target (□). Taking into account the factorization in the form (1), this ratio R gives the product $\gamma_{PT} \cdot \gamma_{H}^{-1}$. Since γ_{PT} is a constant in this case, figure 1 shows the dependence of the inverse hydrogen target factor γ_{H}^{-1} on the fragment mass. There is an increase of this inverse hydrogen target factor for light fragments. For heavier fragments R is constant giving the heavy target factor $\gamma_{P,T=Ag}$, if γ_{H}^{-1} is set equal to one. The same behaviour has also been reported for the fragmentation of Cu and Ag nuclei /5, 6, 7/. Furthermore for C and O nuclei an increase of γ_{H}^{-1} for lighter fragments was observed /2/. The dependence of γ_{H}^{-1} on the fragment mass seen in our data for Fe-projectiles nicely fits between the existing data for lighter and heavier nuclei. The high value of R for Z=25 fragments in silver target is due to the increase of the cross section by the photonuclear effect. For CR39 plastic the partial cross section is a weighted sum over the constituents of the target and can be calculated according to (1) from

$$\text{(2)} \qquad \sigma_{P,CR39}^{F} = \sigma_{(ST)}^{F} \cdot [g_H + \gamma_H^{-1} (g_O \cdot \gamma_{P,O} + g_C \cdot \gamma_{P,C})] \, ,$$

where g_H, g_O, g_C are the relative fractions of the three elements H, O, C in CR39. In figure 2 the ratio R as defined above is plotted for CR39 target and Fe-projectiles (Δ, X). From this and from equation (2) we get a similar dependence of γ_{H}^{-1} on the fragment mass for the CR39 target like for the silver target: an enhancement of light fragments and a constant value for fragments with $\langle A_F \rangle \gtrapprox 2/3\, A_P$.

Fragmentation cross sections were measured for the breakup of beam particles Fe and Ar and all their fragments detectable in the plastic. The ratio R as defined above is calculated and summed over all secondary fragments with $\langle A_F \rangle \geqq 2/3\, A_P$, where γ_{H}^{-1} is set to one. These calculated values are plotted versus the projectile nuclear radius for silver (figure 3) and CR39 (figure 4) target. Since γ_{H}^{-1} is constant in this case, we get from these figures the dependence of the heavy target factor γ_{PT} on the projectile radius. In addition to our measured data (plotting symbols □, Δ, x) values from earlier experiments are shown (plotting symbol Ⅹ, /2, 3/).

For nuclear fragmentation cross sections, the concepts of "strong" and "weak" factorization have been developed /8/. In the picture of strong factorization the heavy target factor γ_{PT} does not depend on the projectile nucleus, thus giving a constant R in figures 3 and 4. Although the data are, within statistics, consistent with a constant value ($\chi^2 = 54.1$ for 37 degrees of freedom in figure 3, $\chi^2 = 19.7$ for 20 degrees of freedom in figure 4), there is an indication for a slight dependence of

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R on the projectile radius in a way, that R is smaller for large projectiles than for medium nuclei. This dependence can be described in the picture of weak factorization /9/.

We are presently developing analytical expressions for γ_{PT} and for γ_H^{-1} that allow the calculation of partial cross sections by scaling the Silberberg-Tsao cross sections for hydrogen target to heavier targets. Without presenting here the final version of the cross section formula, it can already be said, that the distribution of differences between measured and calculated cross sections has a variance of about 25% of the measured cross sections. Since the cross sections for hydrogen target can be calculated within this accuracy, it can be concluded, that no major uncertainties originate from the scaling of these cross sections to heavier targets.

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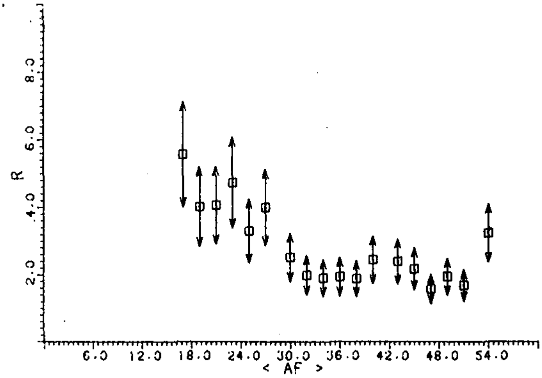

Figure 1: Ratio R of measured cross section σ^F_{PT} and Silberberg-Tsao cross section $\sigma^F_{(ST)}$ for Fe-beam and Ag-target.

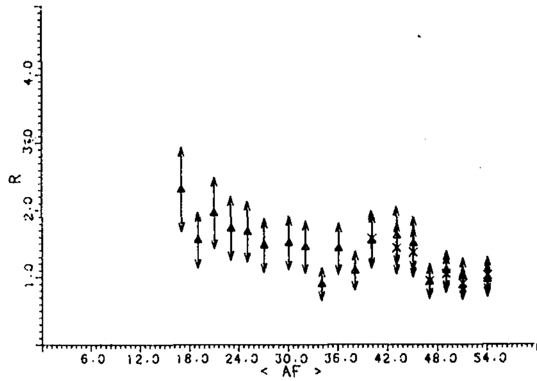

Figure 2: Ratio R of measured cross section σ^F_{PT} and Silberberg-Tsao cross section $\sigma^F_{(ST)}$ for Fe-beam and CR39-target. (Δ: CR39-Ag mixed stack, X pure CR39 stack)

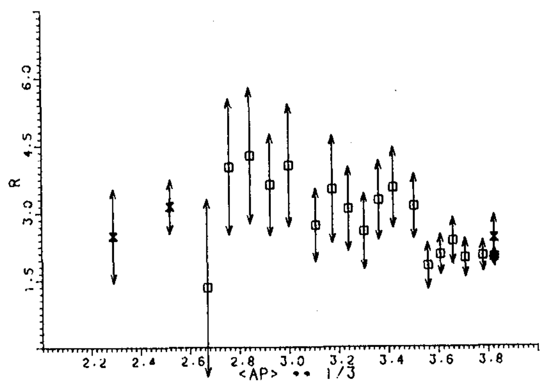

Figure 3: Ratio R of measured cross section σ^F_{PT} and Silberberg-Tsao cross section $\sigma^F_{(ST)}$ summed over all fragments with $\langle A_F \rangle \geq 2/3\ A_P$ for Ag-target (Ⳳ: data points from refs. 2 and 3)

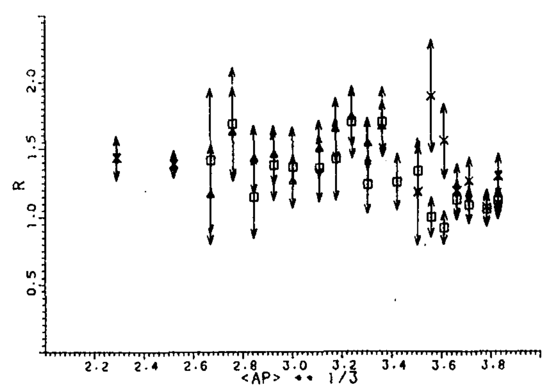

Figure 4: Ratio R of measured cross section σ^F_{PT} and Silberberg-Tsao cross section $\sigma^F_{(ST)}$ summed over all fragments with $\langle A_F \rangle \geq 2/3\ A_P$ for CR39-target (Δ: Ar-beam, □: Fe-beam in CR39-Ag mixed stack, X: Fe-beam in pure CR39 stack, Ⳳ: data points from refs. 2 and 3)