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**A MEASUREMENT OF CROSS SECTIONS FOR ^{32}S INTERACTIONS
WITH Al, Fe, Cu, Ag AND Pb AT 200 GEV/c PER NUCLEON**
NA 36 COLLABORATION

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ABSTRACT

Cross sections for charge changing and particle production are measured for ^{32}S collisions with Al, Fe, Cu, Ag and Pb targets at 200 GeV/c. The measured difference between the two cross sections is discussed. Results are compared with data obtained with an ^{16}O beam.

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INTRODUCTION

Recently, acceleration of sulfur and oxygen ions in the CERN-SPS has provided the first opportunity to study nuclear collisions with stationary targets in the beam momentum range 60-200 GeV/c per nucleon. A good understanding of all details of these reactions is needed; the most basic information is contained in the cross sections.

At high energies cross section measurements have been performed with ^{16}O beams [1-4]. In refs. [1,4] events where at least 1 unit of charge is removed from the incident beam (charge changing reactions) were counted; the production cross section was then estimated based upon some theoretical assumptions. The resulting production cross sections of ref. [1] tend to be larger than those at low energies [5] and those reported in [2,4]. In order to clarify the situation, both the charge changing ($\sigma_{\Delta Z}$) and production (σ_{prod}) cross sections, for ^{32}S projectiles were measured and are presented here.

EXPERIMENTAL SET-UP

Most of the detectors in the present experiment were used previously in the European Hybrid Spectrometer [6]. Only the detectors relevant for the cross section measurements are described here. Sulphur ions in the incident beam are identified by a scintillator counter (T0) and by a silicon detector BT (500 μm thick). These counters are positioned at distances of 17m and 0.15 m respectively from the target. It is to be noted that the position of BT was changed between the oxygen and the sulfur beam data configurations [1]. In the present set-up BT is much closer to the target than in the previous one. The beam traverses most of the distance between T0 and BT in a vacuum pipe. Downstream of the target remaining sulphur ions or projectile fragments are again identified by a Cerenkov counter (FC) [6] placed at 16 m from the target. This detector covers the size of the beam and the angular range of beam fragments [7]. Between the target and FC the beam traverses a multiwire proportional chamber (W2) and five drift chambers (D1-D2, D4-D6) [2]. In addition, there are two intermediate calorimeters (electromagnetic: IGD, hadronic : INC) to measure transverse energy and two forward calorimeters to detect the energy flow close to a polar angle of zero degrees. (electromagnetic : FGD, hadronic : FNC) [6]. These calorimeters cover the laboratory pseudorapidity range $\eta_{\text{lab}} > 3$.

EXPERIMENTAL PROCEDURE

The method used to extract the cross sections consists in measuring the transmission (T) of the beam defined as:

$$T_i = \frac{N_i^{\text{out}}}{N_i^{\text{in}}} = \frac{N_i^{\text{in}} - N_i^c}{N_i^{\text{in}}}$$

where i stands for the target, N_i^{out} (N_i^{in}) is the number of outgoing (incoming) sulfur ions and N_i^c is defined as the number of collisions. The quantities T_i include the interactions produced in the target as well as those coming from the materials between the detectors. This background can be corrected for by using targets with different thicknesses. The transmission can be factorized :

$T_i = t_i t_b$, where t_i corresponds to the target and t_b is the background contribution.

The cross section (σ) is given by the relation between the target transmission (t_i) and thickness (L_i) through the expression :

$$\ln t_i = \ln t_b - L_i \frac{\sigma}{C}, \quad (1)$$

where $C = \frac{A}{N_a \rho}$, N_a is the Avogadro's number, A the atomic mass and ρ the density of the target. An empty target ($L_i = 0$) was used to measure the background contribution t_b directly .

If, for a given target type (including the empty target) only two thicknesses are used, the cross section is given by $\sigma = \frac{A}{N_a \rho} \frac{\ln (T_1/T_2)}{L_2 - L_1}$. In case of more than 2 thicknesses, σ is obtained by fitting the expression (1) to the experimental data.

The number of incoming ^{32}S beam particles (N_i^{in}) has been determined using the detectors placed upstream from the target (T0 or BT). N_i^{in} corresponds to the number of particles with pulse height within ± 1.5 RMS standard deviations about the peak position. A typical measured pulse height distribution for the silicon detector BT is displayed in fig. 1.a.

Cross sections for the two following classes of reactions were determined :

- (a) Charge changing collision ($\sigma_{\Delta Z}$) : The Cerenkov counter FC is used to measure the charge Z of the projectile or its fragments in the range $Z = 10$ to 16 . This allows the calculation of inclusive yields of projectile fragments. This analysis is in progress [8].

In the present analysis the number N_i^{out} of identified outgoing ions is given by the number of incident ^{32}S (identified by T0 or BT) with pulse height in the Cerenkov FC exceeding a certain threshold which is adjusted such that the contribution of phosphorous ($Z = 15$) ions is less than a few per cent. A small amount of low pulse height sulphur ions are removed in this way. This effect is corrected for by using the gaussian fit shown in fig. 1.b. None of the subsequent results exhibit any significant variation if the selection criteria for incoming and outgoing sulfur ions are modified within the used limits. The cross section $\sigma_{\Delta Z}$ includes all processes where there is a difference between the charge of the projectile and charge of its heaviest fragment. It does not include reactions where no protons are removed from the projectile.

- (b) Particle production (σ_{prod}) : The calorimeters have been used to determine whether any secondary particle was produced. N_i^{c} is the number of events with an identified incoming sulphur ion and at least one particle hitting any of the 4 calorimeters excluding the region where projectile fragments go. As an example, fig. 1.c. shows the number of reconstructed clusters in IGD. Similar distributions were obtained from the other calorimeters. The measured quantities N_i^{c} tend to underestimate the number of collisions producing secondary particles due to the limited acceptance of these devices. This effect was simulated for each reaction using the event generator IRIS [9]. It is worth mentioning that IRIS predictions of multiplicity distributions are compatible with experimental data [2]. Some events with less than about 15 secondary particles are not detected. Corrections of the order of 5% are included in the production cross sections σ_{prod} .

Information on the targets and on the event samples used in the analysis are shown in table I. The thick targets, marked in the table by an asterisk, were used only for the determination of charge changing cross section, where reinteractions of the projectile fragments do not affect the results. For the measurements of production cross sections thick targets were excluded. Thus one strongly reduces a contribution of cases where projectile fragments produced in a first interaction produce secondary particles in a subsequent collision. Critical target thicknesses were determined from a simulation.

RESULTS AND DISCUSSIONS

The measured values of $\sigma_{\Delta Z}$ are listed in table II. They are in good agreement with measurements in ref. [10]. The square root of the charge changing cross sections $\sigma_{\Delta Z}$ is given in fig. 2 as function of $A_T^{1/3} + A_P^{1/3}$ where A_T (A_P) is the atomic mass of the target (projectile) nucleus.

The corrected production cross sections σ_{prod} are also included in table II. The square root of σ_{prod} is displayed in fig. 3 as a function of $A_T^{1/3} + A_P^{1/3}$, along with low energy data [5], results obtained for the oxygen beam [1, 2] and a fit of the expression $\sigma_{\text{prod}} = \sigma_0 (A_T^{1/3} + A_P^{1/3} - \delta)^2$, with $\sigma_0 = (75 \pm 15)$ mb, $\delta = 1.4 \pm 0.7$. The cross sections for ^{32}S projectiles exhibit the characteristic dependence on the atomic mass. They tend to be slightly lower than those obtained in reference [1] for an ^{16}O beam. This is probably due to an underestimation [4] of the correction for electromagnetic processes in ref. [1]. Due to a modification of the calorimeter configuration after the oxygen run identical measurements cannot be made for ^{16}O and ^{32}S projectiles. One concludes that there is no significant dependence of σ_{prod} on the beam momenta between 4.5 and 200 GeV/c/A.

The difference between the two cross sections, $\sigma_{\text{dif}} = \sigma_{\Delta Z} - \sigma_{\text{prod}}$, is shown in fig. 4 as function of $\ln A_T$. The cross section σ_{dif} corresponds to charge changing processes without production of secondary particles; it is probably dominated by electromagnetic processes [11]. One finds that σ_{dif} increases strongly for heavier target nuclei. Qualitatively, such a dependence is expected from electromagnetic projectile fragmentation [11]. A determination of the electromagnetic cross section σ_{em} is being performed in ref. [8] based upon a systematic study of charge flow at small production angles. Calculations of σ_{em} [10] are in rather good agreement with the measured values of σ_{dif} .

A further contribution to σ_{dif} might be pure nuclear projectile fragmentation (i.e. no production of secondary particles). In contrast to the case of ^{16}O collisions [1], the cross section σ_F of such a contribution cannot be estimated empirically due to the absence of relevant data. The analysis in ref. [12] indicates only that $2\sigma_F(^{16}\text{O } A_T) > \sigma_F(^{32}\text{S } A_T) > \sigma_F(^{16}\text{O } A_T)$ at low energies. At 200 GeV/c/A, $\sigma_F(^{16}\text{O Pb}) = 0.27$ b was estimated. Hence, one may guess that $\sigma_F(^{32}\text{SPb}) < 0.54$ b at 200 GeV/c/A.

Finally, one may also consider processes in which the target nucleus does not break up (coherent process [13]). These reactions are expected to be of more importance for larger values of A_T . They would probably give rise to events of rather small multiplicity. Since they are not incorporated into IRIS [9], σ_{prod} does not contain the relevant corrections such that σ_{dif} may include this contribution.

SUMMARY

Cross sections $\sigma_{\Delta z}$ and σ_{prod} for charge changing and particle production processes induced by ^{32}S projectiles at 200 GeV/c/A were measured for various targets. The production cross sections exhibit the familiar dependence on atomic mass. One finds rather large differences $\sigma_{\text{dif}} = \sigma_{\Delta z} - \sigma_{\text{prod}}$, strongly increasing with the atomic mass of the target nucleus. Electromagnetic dissociation of the ^{32}S projectiles may fully account for this observation.

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TABLE I

Targets Used

<u>Target</u>	<u>Thickness</u> (g/cm ²)	<u>Events</u>
Empty	0.00	53186
Al	3.66	20567
	27.00*	31818
	67.36*	33143
Fe	77.64*	33176
	156.22*	15670
Cu	3.96	42520
Ag	7.31	15534
Pb	7.99	21079
	56.26*	16572
	226.43*	32437

TABLE II

Cross sections (in barns) and statistical errors

Target	$\sigma_{\Delta z}$	σ_{prod}	σ_{dif}
Al	1.86 ± 0.02	1.74 ± 0.12	0.12 ± 0.12
Fe	2.88 ± 0.03	-	-
Cu	3.11 ± 0.16	2.64 ± 0.19	0.47 ± 0.25
Ag	4.42 ± 0.15	3.04 ± 0.12	1.38 ± 0.19
Pb	8.28 ± 0.09	5.26 ± 0.46	3.02 ± 0.47

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FIGURE CAPTIONS

- Fig. 1 Number of events as a function of pulse height from the silicon detector BT (a) and the Cerenkov counter FC (b). Number of events versus the number of reconstructed clusters in the calorimeter IGD. (C).
- Fig. 2 Square root of charge changing cross section for 200 GeV/c/A ^{32}S with Al, Fe, Cu, Ag, and Pb as a function of $A_p^{1/3} + A_T^{1/3}$. Data from refs. [4,10] are included.
- Fig. 3 Square root of production cross section for 200 GeV/c/A ^{32}S with Al, Fe, Cu, Ag, and Pb as a function of $A_p^{1/3} + A_T^{1/3}$. Data of lower energies [5] and with an oxygen beam [1,2] are also shown. The line represents a fit to the sulfur data of the expression $\sigma_{\text{prod}} = \sigma_0 (A_T^{1/3} + A_p^{1/3} - \delta)^2$, with $\sigma_0 = (75 \pm 15) \text{ mb}$, $\delta = 1.4 \pm 0.7$
- Fig. 4 Difference between the charge changing and the production cross sections (σ_{dif}) as function of the target atomic mass.

FIG. 1

FIG. 2

FIG. 3

FIG. 4