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A MEASUREMENT OF CROSS SECTIONS FOR ^{16}OAl AND ^{16}OPb INTERACTIONS
at 60 and 200 GeV/c per NUCLEON

NA36 Collaboration

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ABSTRACT

Cross sections are measured for ^{16}O collision with Al and Pb.
Dependences on beam momentum and atomic number are compared with data obtained
at much lower beam momenta.

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INTRODUCTION

Recent acceleration of ^{16}O at the SPS opened up a new energy range for the exploration of ion collisions with stationary targets. Cross sections contain the most basic information of these interactions.

For beam momenta up to 4.5 GeV/c/N inelastic nuclear cross sections σ_{in} were found [1] to depend on the atomic numbers A_p and A_T of the projectile and target nucleus in the following way [2]:

$$\sigma_{\text{in}} = \pi r_0^2 (A_p^{1/3} + A_T^{1/3} - \delta)^2. \quad (1)$$

This reflects the fact that colliding nuclei efficiently interact within a distance $R = r_0 (A_p^{1/3} + A_T^{1/3} - \delta)$. This distance is effectively the sum of the radii of the interacting ($r_0 \approx 1.2$ fm) nuclei with the exception of the parameter δ (≈ 1.3) which provides a correction due to the more transparent surface layers.

This dependence on atomic number as well as a potential energy dependence of σ_{in} are the subjects of the present analysis.

EXPERIMENTAL SET-UP

The previous European Hybrid Spectrometer [3] was modified for the present experiment. Only the detectors relevant for the measurement of cross sections are described here. Oxygen ions in the incident beam were tracked by multi-wire proportional chambers [3] and identified by a scintillator counter T_0 (5 mm thick) and/or by a Quartz glass Cerenkov counter BT (3 mm thick). These counters were positioned at distances of 17 m and 2.5 m from the target. The beam traverses most of this distance in a vacuum beam pipe. Downstream of single Al or Pb targets with a thickness of about 3% and 5% of one interaction length λ_I and after passing through a multiplane track chamber system, oxygen ions are again identified by a scintillator counter BV (1 cm thick) at 6m from the target. The transverse dimensions of BV are $2 \times 1 \text{ cm}^2$, large enough to cover the size of the beam and the angular range of beam fragments [4].

The matter traversed by the beam between two charge measurements corresponds to $8\% \div 12\%$ of λ_I (including the targets) depending on the combination of counters used.

EXPERIMENTAL PROCEDURE

The subsequent analysis is based upon 124 000 (29 000) identified oxygen ions at 200 GeV/c/N (60 GeV/c/N) for Pb targets and on 7500 identified oxygen ions at 200 GeV/c/N for Al targets. Cross sections σ_m for a given target nucleus are extracted from ratios $P_i = N_i^{\text{out}}/N_i^{\text{in}}$ of the numbers $N_i^{\text{out}}(N_i^{\text{in}})$ of outgoing (incoming) oxygen ions identified by the counters BV (T_o or BT); here $i=1(2)$ stands for the target 1(2) of a thickness of about 3% (5%) of λ_I . Typical measured pulse height distributions from the scintillator counter T_o and the Quartz Cerenkov counter BT are displayed in fig. 1a,b. The numbers N_i^{in} of identified incoming oxygen ions correspond to the numbers of particles with pulse heights within ± 1.5 rms standard deviations about the peak position. In fig. 1c a pulse height distribution is shown from the scintillator counter BV. The numbers N_i^{out} of identified outgoing oxygen ions is given by the number of incident oxygen ions (identified by T_o or BT) with pulse heights in BV exceeding a certain threshold which is adjusted such that the contribution of nitrogen ions is less than a few percent. The low pulse height oxygen ions thus removed were corrected for using the Gaussian fit shown in fig. 1c. None of the subsequent results exhibit any significant variation if the selection criteria are modified within reasonable limits.

Of course, the ratios P_i contain a background factor BG due to the contributions from oxygen interactions outside the target. This factor cancels in the ratio $Q = P_1/P_2 = e^{-n\sigma_m \Delta L}$ which tends to minimize potential systematic biases, and which yields the measured cross section σ_m for oxygen interactions in the target:

$$\sigma_m = - \frac{A_T}{N_A \rho} \frac{\ln Q}{\Delta L}$$

Here, $n = N_A \rho / A_T$ was used, where ρ is the target density, ΔL is the difference of the thicknesses of targets 1 and 2 and N_A is Avagadro's number.

In this way the cross section $\sigma_m(^{16}\text{OPb})$ was determined at 200 GeV/c/N. With a known cross section the background contribution BG to the ratios P_i can be calculated. With this background $\sigma_m(^{16}\text{OAl})$ was derived at 200 GeV/c/N. Assuming that the background is independent of the beam momentum (see below) $\sigma_m(^{16}\text{OPb})$ was evaluated from P_1 at 60 GeV/c/N, where only a Pb target of 3% λ_I was used. All cross sections were determined using both T_o and BT.

Averages over results obtained from both counters are given in table I together with statistical errors. Systematic uncertainties of about 2% were estimated from a comparison of the individual results.

The measured cross section σ_m is the sum of the production cross section σ_{prod} (corresponding to secondary particle production), of the cross section σ_F for removing k protons and l neutrons ($k \geq 1, l \geq 0$) by pure nuclear projectile fragmentation (i.e. no production of secondary particles) and of the cross section σ_{em} for removing k protons and l neutrons by electromagnetic projectile dissociation: $\sigma_m = \sigma_F + \sigma_{\text{em}} + \sigma_{\text{prod}}$.

The cross sections σ_{em} are dominated, and therefore approximated, by the cross sections σ_{em} for single proton removal ($k = 1, l = 0$) [5]. These cross sections σ_{em} for Al and Pb targets were calculated according to ref.[5] and are given in Table I for both incident momenta [6a]. Preliminary results on electromagnetic target dissociation induced by ^{16}O beams at 60 and 200 GeV/c/N [6b] seem to suggest that the measured cross sections exceed expectations by 0(30%).

Measurements in refs. [7,8,9] indicate that pure nuclear projectile fragmentation in ^{16}O interactions in emulsions (Em) does not strongly decrease in the range of beam momenta between 1.7 and 200 GeV/c/N. A value of $\sigma_F(^{16}\text{OEm}) = 153\text{mb}$ at 60 GeV/c was measured in ref.[7], a potential contribution from el. magnetic dissociation is negligible due to the small effective charge of an average emulsion nucleus. One should note that the cross section for nuclear target fragmentation may decrease by about a factor 2 between 60 and 200 GeV/c/N[9].

Application of the concept of strong factorization [10] yields $\sigma_F(^{16}\text{OPb}) = \sigma_F(^{16}\text{OEm})\gamma_{\text{Pb}}/\gamma_{\text{Em}}$; the parametrization of the γ factors is given in ref. [10]. The evaluation of γ_{Em} incorporates a weighted average over all emulsion components. The calculated values of σ_F , assumed to be independent of energy [7,8], are listed in table I; it should be noted that these cross sections σ_F do not contain contributions from single proton and/or neutron stripping processes which cannot be measured efficiently in an emulsion experiment [4]. Based on ref. [4] these contributions were estimated to be negligible at the present level of precision.

RESULTS AND DISCUSSIONS

Subtraction of the cross sections σ'_{em} ($\sigma'_{em} + \sigma_F$) from the measured cross in sections σ_m yields the values of inelastic nuclear (production) cross sections in Table I. In principle, one should add to the inelastic nuclear cross section σ_{in} defined in this way the contribution from pure target fragmentation. Based on ref. [4] this cross section may be on the order of $0.5 \cdot \sigma_F$. It appears that not all of the previous experiments have considered this process.

Systematic uncertainties are in the order of 5% ; they are dominated by the subtraction procedure. The square roots of the inelastic cross sections are displayed in fig. 2 as function of $A_T^{1/3} + A_P^{1/3}$. The high energy data exhibit the familiar dependence on atomic number. At 200 GeV/c/N one finds $r(A) = \sigma_m(^{16}OAl)/\sigma_m(^{16}OPb) = 0.34 \pm 0.06$. From equation (1) one expects, with $\delta = 1.32$ [1a], $r(A) = 0.35$.

There is no indication for a strong energy dependence. For the ratio $r(P_{beam})$ of inelastic cross sections for ^{16}O collisions with Pb at 200 and 60 GeV/c/N one finds $r(P_{beam}) = 1.03 \pm 0.13$. Since $r(P_{beam}) \approx 1$, it is justified to assume (see above) that also background contributions are independent of beam energy. A rather constant value of cross sections for ^{16}O collisions with Pb is in good agreement with the energy independence of $\sigma_{in}(pp)$ (corresponding to σ_{prod} for nuclear collisions) measured in pp collisions for $P_{beam} \approx 60 \div 200$ GeV/c [11]. The cross sections presented here tend to be larger than expected from a fit of (1) to the low energy ($P_{beam} \leq 4.5$ GeV/c/N) ion data in fig. 2. This may be both connected to the fact that the inelastic cross section for pp collisions increases by about $(10 \pm 10)\%$ between $P_{beam} \approx 4.5$ and 60 GeV/c [11] and to systematic uncertainties in all measurements.

The cross sections σ_{in} determined here are rather close to, but exceeding the cross sections σ_{prod} predicted by the IRIS Monte Carlo program (fig. 2, [12]). Preliminary cross sections obtained by the NA35 collaboration [13] tend to be smaller than those presented here.

In conclusion, cross sections for ^{16}O collisions with Al and Pb at SPS energies have been measured. They exhibit the expected dependence on atomic number. While no energy dependence is found between $P_{beam} = 60$ GeV/c and 200 GeV/c, the cross sections tend to be larger than those obtained at much lower energies.

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TABLE I

Cross sections in barns and statistical errors

	σ_m	σ'_{em}	σ_F	$\sigma_{in} = \sigma_m - \sigma'_{em}$	$\sigma_{prod} = \sigma_{in} - \sigma_F$
$^{160}\text{Pb}, 60 \text{ GeV}/c/N$	4.97 ± 0.46	0.39	0.27	4.58 ± 0.42	4.31 ± 0.40
$^{160}\text{Pb}, 200 \text{ GeV}/c/N$	5.22 ± 0.43	0.50	0.27	4.72 ± 0.39	4.45 ± 0.37
$^{160}\text{Al}, 200 \text{ GeV}/c/N$	1.63 ± 0.27	0.02	0.15	1.61 ± 0.27	1.46 ± 0.24

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FIGURE CAPTIONS

Fig. 1 Number of events as function of pulse height from the scintillator T_0 (a), the Cerenkov beam tag BT(b) and the scintillator BV(c).
 The solid line in (c) corresponds to a Gaussian fit.

Fig. 2 Square root of inelastic cross sections for ^{16}O collisions with Pb (60 and 200 GeV/c/N) and Al (200 GeV/c/N) as function $A_p^{1/3} + A_T^{1/3}$.
 Also shown are data from ref. [1] at lower energies.

FIG. 1

FIG. 2