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SECONDARY PARTICLE MULTIPLICITY AND THE NUMBER OF INTERACTING NUCLEONS IN THE COLLISIONS OF p,d,He AND C WITH TANTALUM NUCLEI AT 4.2 GeV/c PER NUCLEON

Alma-Ata-Budapest-Bucharest-Cracow-Dubna-Moscow-Prague-Sofia-Tashkent-Tbilisi-UlanBator-Varna-Warsaw-Yerevan Collaboration

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Множественность вторичных частиц и число взаимодействующих нуклонов в столкновениях p , d , He и C с ядрами тантала при импульсе P_0 = 4,2 ГэВ/нукл.

В рабочем объеме двухметровой пропановой камеры размещена мишень, состоящая из трех танталовых (A=181) пластин толщиной 1 мм. Камера экспонировалась в пучках ядер p , d , He и C при импульсах на нуклон P_0 = (2-5) ГэВ/с. Получены сечения неупругих взаимодействий p , d , He и C с ядрами углерода и тантала при P_0 = = 4,2 ГэВ/с. Экспериментальные величины сечений находятся в удовлетворительном согласии с расчетами по моделям, основанным на геометрических представлениях. Исследована зависимость множественностей вторичных частиц от числа провзаимодействовавших нуклонов ядра-снаряда $\langle\nu_i\rangle$. Множественности π^--мезонов и быстрых протонов ($P_p \gtrsim$ 700 МэВ/с) растут примерно пропорционально числу $\langle\nu_i\rangle$, тогда как изменение множественности g -частиц замедляется с увеличением числа $\langle\nu_i\rangle$.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Angelov N. et al.

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Secondary Particle Multiplicity and the Number of Interacting Nucleons in the Collisions of p , d , He and C with Tantalum Nuclei at 4.2 GeV/c per Nucleon

A target consisting of three tantalum (A=181) plates 1 mm thick was placed in the working volume of the 2 m propane bubble chamber. The chamber was exposed to p , d , He and C beams at momenta of (2-5) GeV/c per nucleon. The inelastic cross sections of the interactions of p , d , He and C with carbon and tantalum nuclei at P_0= 4.2 GeV/c were obtained. The experimental cross sections are in satisfactory agreement with calculations by geometric models. The dependence of secondary particle multiplicities on the number of interacting nucleons of the projectile nucleus $\langle\nu_i\rangle$ was investigated. The multiplicities of π^- -mesons and fast protons ($P_p \gtrsim$ 700 MeV/c) grow approximately proportional to the number $\langle\nu_i\rangle$ while the change of the g -particle multiplicity becomes slower with increasing the number $\langle\nu_i\rangle$.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1978

1. INTRODUCTION

At present experimental and theoretical studies of the inelastic interactions of relativistic nuclei with the heavy nucleus are of great interest [1,2]. In inelastic nuclei collisions not all nucleons of the incident nucleus interact. Some nucleons remain spectators. Nucleon-spectators are often called stripped ones. Determining experimentally the number of stripped nucleons ν_s, one can know the number of interacting nucleons in each inelastic collision. However, the detection of neutrons is connected with certain methodical difficulties. Knowing the number of proton-spectators, the average number of interacting nucleons can be obtained by the formula

$$\langle\nu_i\rangle = 2(Z - \langle z_s\rangle), \qquad (1)$$

where Z is the incident nucleus charge and $\langle z_s\rangle$ is the average charge of stripped particles. To define $\langle z_s\rangle$, it is not important whether a proton-spectator is a part of any stripped particle (d , t , ^{3}He , ^{4}He etc.) or it is in the free state.

For correct comparison of secondary particle multiplicities in the collision of relativistic nuclei with the heavy nucleus, it is necessary to select events of the incoherent type. Experimental material has to correspond to inelastic interactions

$$\sigma_{in} = \sigma_{tot} - \sigma_{coh}. \qquad (2)$$

Elastic scattering on the nucleus as a whole and nucleus diffraction break-down are attributed to coherent processes. The contribution of coherent particle production processes at our energies is negligible.

2. *THE METHOD OF OBTAINING EXPERIMENTAL MATERIAL*

A target consisting of three tungsten (A=184) plates 0.8 *mm* thick was placed in the working volume of the 2 *m* propane bubble chamber (High Energy Laboratory, JINR[3]). The distance between neighbouring plates was equal to 93 *mm*. The target plates were located in the first part of the chamber parallel to the photographic system stereobase. Afterwards, for technical reasons tungsten plates were replaced by tantalum (A=181) ones 1 *mm* thick. The chamber was exposed to p, d, He and C beams at the following momenta per nucleon: $P_0 =$ (2.2; 4.2; 5.6; 9.9) *GeV/c* for protons: $P_0 =$ (2.2; 4.2; 5.15) *GeV/c* for deuterons, He -particles and carbon nuclei. In this report we present the experimental material obtained at $P_0 = 4.2$ *GeV/c*. Practically all heavy hadrons with a kinetic energy of $T \lesssim 25$ *MeV/nucl.*, b - particles in emulsion terminology, were stopped in their passage through the plate and ~ 3 *mm* propane. Nonrelativistic tracks with a high ionization of $I \geq 2I_{min}$ are considered to be g -tracks. The ionization density $I \sim 2I_{min}$ corresponds to the protons with $P_p \simeq$ 700 *MeV/c*. In our definition the contamination of b -particles to g -tracks is equal to ~ 3%. The contamination of nonidentified short tracks from π -mesons is negligible.

3. *INELASTIC CROSS SECTIONS OF THE INTERACTIONS OF* p, d, He *AND* C *WITH CARBON AND TANTALUM NUCLEI*

The cross sections in barns are presented in *Table 1*. The inelastic cross sections σ_{in} correspond to formula (2). The cross sections of inelastic interactions on the carbon target were obtained from the relation

$$\sigma_{C_3H_8} = 3\sigma_c + 8\sigma_p \quad . \qquad (3)$$

Table 1

A_t \ A_i	p	d	He	C
C	0,250±0,015	0,38±0,02	0,44±0,02	0,79±0,05
Ta	1,67 ±0,11	1,94±0,11	2,34±0,12	3,67±0,22

Here $\sigma_{C_3H_8}$ is the cross section on the propane molecule found in the experiment: σ_c the cross section on the propane carbon; σ_p the cross section on the propane proton. The cross sections of pp, dp, Hep and Cp interactions were taken from the literature [4,5]. *Figure 1* shows the dependence of the inelastic cross sections on the atomic weight of projectile nucleus A_i and target nucleus A_t. The solid line corresponds to the calculation by the model of hard spheres with overlapping

$$\sigma_{in} = \pi R_0^2 (A_i^{1/3} + A_t^{1/3} - b)^2 \; , \qquad (4)$$

where $R_0 = 1.45$ *fm* and $b = 1.25$.

The available inelastic cross sections obtained by the track method are satisfactorily described by the dependence (4). The calculations by the soft sphere model [9] are marked by crosses (fig. 1). The experimental values of the nuclei radii were taken from ref.[10]. One can see that the experimental cross sections of inelastic interactions, within errors, are in satisfactory agreement with theoretical calculations [6,9]. However, the inelastic cross sections for the interactions of light nuclei with tantalum show that the dependence on the projectile nucleus atomic weight differs from that calculated by the geometric model [6].

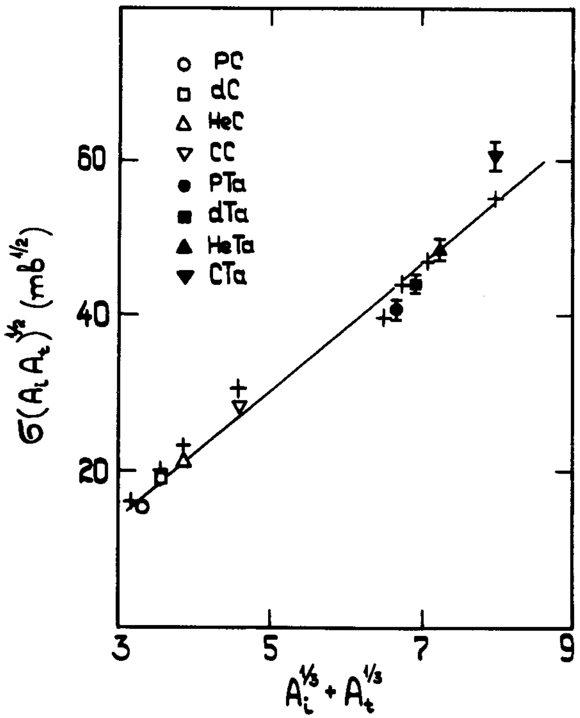

Fig. 1. The inelastic cross sections versus the atomic weight of projectile nucleus A_i *and target nucleus* A_t .

4. *AVERAGE MULTIPLICITIES OF SECONDARY PARTICLES*

Table 2 presents the experimental average characteristics of the inelastic interactions of incident nuclei p, d, He, C with the tantalum nucleus. Here $\langle n_- \rangle$, $\langle n_+ \rangle$, $\langle n_g \rangle$ are the multiplicities of negative particles (π^--mesons), positive particles and g-tracks; $\langle n_{\pi\mu e} \rangle$ is the multiplicity of slow π^+-mesons with a kinetic energy of ~ (10-60) *MeV* decayed into $\pi^+ \to \mu^+ \to e^+$; $\langle n_{S1} \rangle$ is the number of single-charged stripped particles; $\langle n_{S2} \rangle$ is the number of stripped particles with charge $Z \geq 2$;

Table 2

Average numbers \ A_i	P	d	He	C
$\langle n_- \rangle$	0.45± 0.02	0.88 ± 0.06	1.36 ± 0.04	3.10 ± 0.25
$\langle n_+ \rangle$	4.28± 0.17	6.80 ± 0.40	9.52 ± 0.30	14.90 ± 1.20
$\langle n_g \rangle$	2.77± 0.12	4.00 ± 0.25	5.30 ± 0.16	6.70 ± 0.50
$\langle n_{\pi\mu e} \rangle$	0.06± 0.01	0.10 ± 0.02	0.15 ± 0.01	0.33 ± 0.04
$\langle n_{s1} \rangle$	-	0.20 ± 0.02	0.45 ± 0.03	1.10 ± 0.10
$\langle n_{s2} \rangle$	-	—	0.09 ± 0.01	0.65 ± 0.06
$\langle n_p \rangle$	0.88± 0.05	1.92 ± 0.13	2.86 ± 0.12	5.10 ± 0.50
$\langle \nu_i \rangle$	1.0	1.60 ± 0.05	2.74 ± 0.10	6.00 ± 0.60
F/B	3.11 ± 0.13	2.85 ± 0.20	3.22 ± 0.10	3.60 ± 0.30
N_{tot}	862	347	1460	215

$\langle n_p \rangle$ is the number of fast protons with $P_p \gtrsim 700$ *MeV/c*; $\langle \nu_i \rangle$ is the number of interacting nucleons of the incident nucleus; F/B is the forward-backward relation for g-tracks in the laboratory system; N_{tot} is the number of inelastic interaction events. The average multiplicity $\langle n_+ \rangle$ is equal to the sum of average multiplicities $\langle n_g \rangle$, $\langle n_p \rangle$, $\langle n_{\pi^+} \rangle$. Stripped particles do not enter into the given numbers $\langle n_+ \rangle$. The total number of positive particles is equal to the sum of numbers $\langle n_+ \rangle$, $\langle n_{S1} \rangle$, $\langle n_{S2} \rangle$.

As a result of analysis of possible distortions and of making corrections, the average multiplicites of positive, negative and nonrelativistic particles differ from the scanning multiplicity by no more than ~ 5%.

The number of stripped particles was determined by counting positive tracks with a momentum of $P_+ \gtrsim 3$ *GeV/c* and an angle of $\phi \lesssim 4°$. For single charged particles a definite part of contaminated events was subtracted using the experimental pTa data. The average charge of stripped particles was defined by the formula

$$\langle z_s \rangle = \frac{\Sigma n_{si} q_i}{N_{tot}}, \qquad (5)$$

where n_{si} is the number of stripped particles with charge q_i . In the stars of CTa collisions the charge of many-charged particles was identified by the δ - electron density and the secondary interaction of carbon fragments in propane /11/. The number of interacting nucleons was obtained by formula (1).

The average multiplicity of fast protons with a momentum of $P_p \geq$ 700 *MeV/c* was determined in the following way. For proton irradiation the number of g - tracks and the calculated number of π^+ -mesons (see *table 3* and below) are subtracted from the total number of positive particles

$$n_p = n_+ - n_g - n_{\pi^+} . \qquad (6)$$

Table 3

$\langle n\rangle$ \ NN	pN	nN
$\langle n_{\pi^-}\rangle$	0.32 ± 0.01	0.46 ± 0.03
$\langle n_{\pi^+}\rangle$	0.45 ± 0.02	0.27 ± 0.01

For d , He and C irradiations the number of g - tracks, π^- -mesons and stripped particles are subtracted from the total number of positive particles

$$n_p = N_+ - n_g - n_{\pi^-} - n_s \qquad (7)$$

In d , He and C interactions the average numbers $\langle n_{\pi^-}\rangle$ and $\langle n_{\pi^+}\rangle$ must practically coincide. A negligible difference appears due to various numbers of neutrons and protons in the tantalum nucleus, $\langle n_{\pi^-}\rangle \gtrsim \langle n_{\pi^+}\rangle$.

Figure 2 presents the average multiplicities versus A_i. The solid lines connecting the experimental points are drawn by hand. One can see that the average multiplicities grow over the whole interval of A_i values. A rise in the number $\langle n_g\rangle$ becomes slower in the region $A_i \sim 4$. *Table 2* shows that increasing the multiplicity of slow π^+ -mesons is proportional to the growth of the average

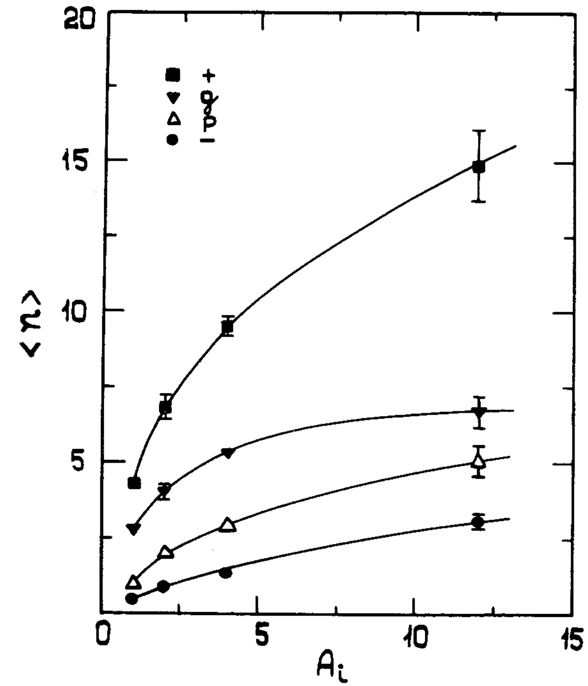

Fig. 2. The average multiplicities of positive particles, g -tracks, fast protons with $P_p \gtrsim$ 700 MeV/c and negative hadrons versus the projectile nucleus atomic weight.

multiplicity $\langle n_{\pi^-}\rangle$. i.e., in the region of kinetic energies ~ (10-60) *MeV there is no anomalous increase of* π - meson production with growing atomic weight A_i . The ratio F/B within experimental errors, is independent of A_i .

For correct comparison of nucleon-nucleus NA and nucleus-nucleus AA collisions in our energy region (2-5) *GeV/nucleon* we need experimental data on neutron-nucleus nA interactions. Unfortunately, experimental data on nTa interactions are not available. This is the reason why the average multiplicities of π^- -mesons, g -tracks and fast protons are compared under the following assumptions:

1) Using the data for the average multiplicity of $\pi^\pm$ - mesons in pp and np -interactions, the average multi-

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