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INTERACTIONS OF 200 GEV/C PROTONS WITH EMULSION NUCLEI.
CHARGED PARTICLE MULTIPLICITIES

Alma-Ata - Leningrad - Moscow - Tashkent collaboration

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ABSTRACT

The experimental data on the multiplicity distributions for various kinds of secondaries produced in the proton-nucleus interactions in emulsion at 200 GeV/c and the correlations between them are presented and discussed. All the characteristics of heavy prongs (mean values $\langle n_b \rangle$, $\langle n_g \rangle$, $\langle N_h \rangle$, their distributions and correlations) are independent (or have a very weak dependence) on the collision energy in the range 20 - 200 GeV/c. The data contradict to the cascade-evaporation model and qualitatively agree with the mechanism of particle emission via the long-lived intermediate states.

The observed weak A -dependence ($\sim A^{0.15}$) of shower particle distributions is in agreement with the calculated ones according to the simplified two-step model. It is shown that the n_g - distributions agree well with KNO scaling law in the 67 - 200 GeV/c range, but the form of universal $\psi(n_g/n_g)$ -function has a weak A -dependence.

1. INTRODUCTION

Inelastic hadron-nucleus collisions are the object of the increasing interest since the study of such interactions can clarify the important problems in particle physics such as the choice of the realistic models for hadron-nucleon collisions, the investigation of the space-time structure of multiple production and so on.

This communication is devoted to the inelastic proton-nucleus interactions at incident momentum $p_0 = 200$ GeV/c in nuclear emulsion. We present some data on multiplicities and correlations of the various kinds of charged secondaries. Another characteristics of proton-nucleus collisions will be discussed and published in the nearest future.

Some data on the proton-nucleus interactions at $p_0 = 200$ GeV/c were reported recently in the preliminary works of our collaboration /1/ and in the papers of several authors /2-4/. The present experimental material is based on the higher statistics than in the work /1/. It has the following peculiarities: a) it was obtained entirely by the along-the track scanning ¹⁾ and b) we subdivided carefully the heavy prongs on the "black" and the "grey" tracks (the evaporation and recoil particles, respectively).

1) It should be noted that in the ref. /2/ only the part of experimental material was obtained by the along-the track scanning; in the ref. /4/ all the data based on the area scanning and the events with $N_h = 0,1$ were lost in this experiment.

2. EXPERIMENTAL MATERIAL.

From 9339 inelastic events, which were detected during the scanning, on the total primary length of 3303 m (mean free path for the inelastic scattering $\lambda = 35.4 \pm 0.4$ cm) we selected systematically 1704 events in which all the charged secondaries were classified according to their ionization and range on the shower ($I < 1.4 I_0$, I_0 is the ionization of the primary tracks), the gray ($I \geq 1.4 I_0$, the kinetic energy of protons $T_p > 30$ MeV) and the black ($T_p \leq 30$ MeV) prongs. In these events the emission angles of the shower particles were measured. Additionally in more than 1500 events the total numbers of heavy ($N_h = n_g + n_b$) and shower (n_s) prongs were counted. In this way a total of 3242 events with measured N_h and n_s were recorded. The details of exposure, scanning and measurements were described early in papers devoted to the proton-nucleon and the coherent interactions /5/.

It is obvious /6/ that for the current comparison with models of hadron-nucleus collisions the ensemble of events needs to be purified from the elastic scatterings, the coherent reactions and from the collisions with the hydrogen nuclei (so-called p-free p collisions). Therefore we excluded from the following consideration the next events:

(a) 7 events of the type $N_h + 1$ with $N_h \geq 2$, where the angle of shower particle was $\theta < 2$ mrad (the stars 0 + 0 + 1 and 0 + 1 + 1 with $\theta < 2$ mrad were excluded early /5/ under the analysis of quasimucleon and coherent interactions);

(b) 63 events of the type 0 + 0 + n_s ($n_s = 1, 3, 5, 7$) which were identified /5/ as the coherent production;

(c) 60 events with $n_{ch} = 2, 4, 6, \dots$ which comes from the p-free p interactions. It is easy to obtain their number

from the nuclear composition of the emulsion, if we consider the n_{ch} -distribution in pp-collisions in ref. /7/ at $p_0 = 200$ GeV/c, and the amount of events with $n_s = n_{ch}$ and $n_s = n_{ch} - 1$ (with the slow recoil proton) from our data /5/.

Thus, our sample consists of 1574 events with the measured n_p , n_g and n_s and the emission angles of shower secondaries and of 3007 events with the measured N_h and n_s . The analysis was done mainly for the first 1574 nuclear stars; in all cases where we shall consider the ensemble of 3007 events or the sample of events without excluding p-free p and/or coherent interactions (for the comparison with the data of another works), this will be noted specially.

3. HEAVY TRACKS. THE STATISTICAL SUBDIVISION OF EVENTS ON THE COLLISIONS WITH LIGHT AND HEAVY EMULSION NUCLEI.

Fig.1 presents the integral probability distribution $W(N_h)$ vs. N_h^2 (3007 events without p-free p and coherent interactions). In the agreement with the low energy ($p_0 \leq 25$ GeV/c) data /8/, this distribution is well consistent with the exponential function

$$W(N_h) \sim \exp(-N_h^2/N_0^2), \quad N_0 = 16.1 \quad (1)$$

at $N_h > 8$. It should be noted that the difference between the N_0 values at 200 GeV/c and low energies is small (at $p_0 \leq 25$ GeV/c $N_0 = 14.8$ /8/). The function (1) at the whole of N_h -region describes only 48% of the total proton-nucleus interactions, whereas the amount of such interactions with the heavy emulsion nuclei (Ag, Br) must be about 73.4% ²⁾. This indi-
2). This value was calculated from nuclear composition of the BR-2 emulsion and from values of inelastic proton-nucleus cross-sections computed for the Fermi distribution (9).

states that the function (1) cannot describe the whole N_h -distribution in the interactions of protons with Ag, Br.

On the other hand, the distribution of the rest of data, i.e. of the group of $N_h \leq 8$ events purified from those which describe by Eq.(1), also describes well by another exponent (1) with $N_0 = 4.6$ except the events with $N_h = 0,1$ (Fig.1). The abundance of the last agrees approximately to the number of the quasimucleon interactions in which only one peripheral nucleon from nucleus participate. The similarity of N_h -distributions from interactions with light (C,N,O) nuclei and from part of collisions with heavy nuclei may be understood assuming that the formula (1) describes collisions with the core of heavy nuclei (i.e. with the uniform density region³⁾). Then the rest events can be associated with the region of the decreasing nuclear density which is independent approximately from nuclear sizes. If this picture is correct, then it is easy to subdivide these events into groups associated mainly with the light and the heavy nuclei respectively, using only the composition arguments.

In this way we obtain statistically the number of collisions with C,N,O nuclei at each $N_h \leq 8$ assuming the similarity of the shapes of N_h -distributions for the light nuclei and for the part of interactions with Ag,Br which remains after the subtraction of the distribution (1).

The percentage of interactions with the light nuclei is shown in the Fig.1b and we shall use it under additional as-

3). The part of interactions described by formula (1) corresponds in terms of the impact parameters to the size of this region obtained from the electron scattering experiments /8/.

assumption that any characteristics of the collisions with the fixed N_h are independent of the target nucleus size.

It is obvious that the above described procedure is very rough and is in need of the additional verification. However, it should be noted in this connection that the other experimental procedure (the registration of the short range tracks ($L < 80 \mu$) in the stars with $N_h \leq 6$) used in our preliminary report /1/ for the selection of C,N,O events supports the above described method (of course, this procedure is also crude /6/). In fact, the characteristics of events in two samples selected by these different methods coincide within the experimental errors. The another way to test our method is the comparison of its results with those obtained from the experiments in the emulsion enriched by the light nuclei. Unfortunately, the statistics of such experiments so far is very poor (for example, /9/), however, their results do not contradict to this method.

Fig.2 shows the differential N_h -, n_b - and n_g -distributions from the 200 GeV/c proton interactions with different emulsion nuclei; the mean values $\langle N_h \rangle$, $\langle n_b \rangle$, $\langle n_g \rangle$ and the ratio $\langle n_b \rangle / \langle n_g \rangle$ for different groups are presented in Table 1. Fig.3 shows the energy dependences of the $\langle N_h \rangle$, $\langle n_b \rangle$ and $\langle n_g \rangle$ for proton-nucleus interactions. The data have been taken⁴⁾ from the papers /9-16/ and from this work. In the Table 2 we have presented the data on the ratio

4). We selected only papers in which the experimental material was obtained by the along-the-track scanning and number of stars does exceed a several hundreds events at each $p_0 \geq 10$ GeV/c.

$\langle n_b \rangle / \langle n_g \rangle$ and finally Fig.4 shows integral n_b - and n_g -distributions at different energies.

Let us analyse these data.

1. Clearly, N_h -, n_b - and n_g -distributions shows hardly any energy dependence in the energy interval 20 - 200 GeV/c (see Figs.3,4). The mean values $\langle N_h \rangle$, $\langle n_b \rangle$ and $\langle n_g \rangle$ support the assumption on their constancy in this energy range and contradict to the calculations in the framework of the cascade-evaporation model (CEM) with many-particle interactions /6/ (Fig.3). This contradiction is very large especially for the evaporation particles. When the energy increases, the shape of these distributions (see Figs.3,4 and the data from /8/) remain unchanged except some increasing in the number of events with $N_h = 0$ (Fig.4). It should be noted, however, that the difference in the number of these events at low energies and at 200 GeV/c (see Fig.4 and data of Ref./2/) may be really much smaller because of considerable loss of events (the bulk of which has $N_h = 0$) in /10/. In fact, these data differ from the another investigations (which unfortunately have not subdivision of the number of heavy tracks on n_b and n_g) at neighbouring energies in the values of mean free path for inelastic collisions and $\langle N_h \rangle$. If we compare the data on the mean free path for the quasimucleon interactions in emulsion ($N_h = 0$ or 1 if the "gray" proton is emitted to the forward hemisphere in lab. system) coming from the experiments done at the same conditions at 67 /17/ and 200 GeV/c /5/ it is easy to see that their values practically coincide and equal to 247 ± 7 and 250 ± 7 cm respectively. Therefore we can conclude that the considerable rise in the number of events with $N_h = 0$ noted

in Ref./2/ is associated mainly with the increasing cross-section for the coherent production /5/.

In the very high energy region ($p_0 > 200$ GeV/c) only the cosmic ray data are available /6/. Although these data are very rough they support the energy independence (or very weak dependence) of the heavy prongs distributions up to 10^4 GeV.

2. The portion of black and grey tracks among the heavy prongs remains approximately unchanged up to 200 GeV/c (Table 2). (It is interesting that there is a small dip in this data at ~ 25 GeV/c which qualitatively fits by the GEM). The following circumstances seem to be very important for our understanding of the processes occurring at the collisions of high energy protons with nuclei. At first, the weak energy dependence of $\langle n_g \rangle$ (the bulk of which are the recoil protons) indicates the weak energy dependence of the average number of intranuclear collisions. Secondly, the weak energy dependences of the $\langle n_p \rangle$ and $\langle n_p \rangle / \langle n_g \rangle$ in common with the considerable energy dependence of the $\langle n_g \rangle$ (Section 4) indicate that the excitation of target nucleus is connected mainly with the recoil protons while the created particles give only a small contribution to this process. Finally, it is very interesting that these features of nuclear interactions seem to be independent from the size of the target nucleus (the last column in Table 1). All these features may be explained by the multiple production mechanism via the comparatively long lived intermediate states (clusters).

3. Let us consider in more detail the dependence of heavy prongs multiplicities on the size of target nucleus. If we approximate this dependence by the simple power function A^α

at $A \gg 1$ it is easy to define α from the ratio of mean multiplicities from collisions with Ag, Br and C, N, O :

$$\begin{aligned} \langle n \rangle_{\text{AgBr}} / \langle n \rangle_{\text{CNO}} &= \\ &= \left(\sum_{\text{AgBr}} N_i \sigma_i A_i / \sum_{\text{AgBr}} N_i \sigma_i \right) / \left(\sum_{\text{CNO}} N_i \sigma_i A_i / \sum_{\text{CNO}} N_i \sigma_i \right) \end{aligned} \quad (2)$$

where $n = n_h, n_b, n_g$; N_i is the density of nuclei of i -th type in the emulsion; σ_i is the inelastic cross-section. Using the data from Table 1, we obtained for the black, gray and heavy prongs $\alpha = 0.655 \pm 0.025$, 0.672 ± 0.030 and 0.661 ± 0.025 respectively, i.e.

$$\langle n_h \rangle, \langle n_b \rangle, \langle n_g \rangle \sim A^{2/3}. \quad (3)$$

Since this dependence is considerably stronger than $n_g(A) \sim A^{0.15 - 0.19}$ (see Section 4) this again demonstrates that the connection between shower particle production and emission of heavy tracks is very weak. It should be mentioned that the dependence (3) is more stronger also than the dependence $A^{-1/3}$ suggested by the primitive models in which the incident hadron interacts successively with nucleons inside the nucleus without any cascading of created particles. This circumstance may be considered as an indication that the secondary interactions of the created particles can give some contribution to the nuclear collision products.

4. MULTIPLICITY DISTRIBUTIONS OF SHOWER PARTICLES.

The differential n_g -distributions from the proton-nucleus collisions at our energy are shown in Fig.5 and some moments of these distributions are presented in Table 3. The most reliable data on $\langle n_g \rangle$ are the data from the sam-

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ple of events with measured emission angles of shower particles (the group 2). Taking into account the electrons from Dalitz pairs ($\langle n_{e\pm} \rangle \approx 0.012 \langle n_p \rangle$) we have from the data of Table 3 :

$$\begin{aligned} n_{sp-E\mu} &= 14.0 \pm 0.2, & R &= 1.83 \pm 0.03, \\ n_{sp-CNO} &= 10.9 \pm 0.3, & R &= 1.42 \pm 0.04, \\ n_{sp-AgBr} &= 15.2 \pm 0.3, & R &= 1.98 \pm 0.04. \end{aligned} \quad (4)$$

In order to calculate the popular ratio $R = \langle n_p \rangle / \langle n_{ch} \rangle_{pp}$ we used the value $\langle n_{ch} \rangle_{pp} = 7.68 \pm 0.07$ at $p_0 = 205$ GeV/c /7/. For the full and uncorrected sample of events (including the p-free p and coherent interactions) we have $\langle n_p \rangle = 13.6 \pm 0.2$, $R = 1.77 \pm 0.03$ in agreement with the data of other works : $\langle n_p \rangle = 12.9 \pm 0.2$, $R = 1.68 \pm 0.03$ /2/ and $\langle n_p \rangle = 13.1 \pm 0.3$, $R = 1.70 \pm 0.04$ /3/. The $\langle n_p \rangle$ values for C,N,O and Ag,Br nuclei are consistent also with corresponding data from Ref./2/.

Assuming that $\langle n_p \rangle = \langle n_{ch} \rangle_{pp} A^\alpha$ it is easy to define the parameters α for the quoted three values of R (4) by using the well-known relation

$$R = \frac{\sum_i N_i \epsilon_i A_i^\alpha}{\sum_i N_i \epsilon_i}. \quad (5)$$

They equal to 0.147 ± 0.004 , 0.134 ± 0.010 and 0.150 ± 0.004 respectively. These values do not contradict to the assumed power function and we have as a result a very weak dependence $\langle n_p(A) \rangle$:

$$R \approx A^{0.15} \quad \text{at} \quad p_0 = 200 \text{ GeV/c}. \quad (6)$$

The energy dependences of the $\langle n_p \rangle$ and R are shown in Fig.6 up to 200 GeV/c. In contrast to heavy prongs the mean $\langle n_p \rangle$ values are close to the calculated ones according to the CEM /6/.

As can be seen from Fig.6, the ratio R depends fairly strongly on energy and increases from ~ 1.3 up to ~ 1.8 in the energy range 20 - 200 GeV. In close connection with this rise the increasing of the parameter α (5) from ~ 0 up to 0.13 - 0.15 is also observed in the same energy range /4/. It is easy to show that this growth is partially due to fact that the value of $\langle n_{ch} \rangle$ for pp-collisions contains all secondaries while the $\langle n_g \rangle$ does not include the bulk of secondary protons. In fact, if we consider for example the ratio $R' = \langle n_g \rangle / \langle n_{\pi^\pm} \rangle_{pp}$, where $\langle n_{\pi^\pm} \rangle_{pp} \approx \langle n_{ch} \rangle_{pp} - 1.4$ represent the particles produced at pp-collisions (pions, for simplicity), then we can see that this ratio remains approximately constant in the 20 - 200 GeV/c region and equal to 2.0 - 2.2. The corresponding parameter α' equals to ~ 0.19 , i.e. coincides with the value expected from hydrodynamical model /18/ in which the incident hadron interacts with the tube of nuclear matter. Clearly, the ratio R' is only an upper limit of the coefficient of nuclear multiplication of produced particles. For the correct determination of this coefficient one must measure directly the number of particles produced by nuclei and take into account the proton-neutron collisions.

Thus we can conclude that : (i) the quantity R (and R') is rather crude measure of the ratio of created particles on nuclear and nucleon targets, especially at low energies, (ii) A-dependence of the number of produced particles is very weak ($\alpha = 0.15 - 0.19$ at $p_0 \gg 100$ GeV/c) and contradicts to the class of so-called one-step models, (iii) the two-step models of multiple production /19 - 21/ are favored by the data on the ratio R and its energy independence at high energies.

The obvious next step for the test of particle production models is a comparison of experimental n_g -distribution with theory. For this purpose we have calculated the n_g -distributions for proton-nucleus collisions at 200 GeV/c by the Monte-Carlo method as suggested in Ref. /16/ in framework of some simplified two-step model /20/. The simulation had the following stages :

- a) The target nucleus was chosen randomly in accordance with the BR-2 emulsion composition.
- b) The number of inelastic collisions ν_A within nucleus with atomic number A was chosen according to probability

$$P(\nu, A) = \sigma_A^\nu / \sum_j \sigma_j^\nu \quad (7)$$

where the cross-sections for the exact ν_A collisions are given by

$$\sigma_A^\nu = 2\pi \int_0^\infty b db (\nu!)^{-1} [t(b)]^\nu \exp[-t(b)]$$

and the nuclear density thickness at fixed impact parameter is

$$t(b) = A \sigma_{in} \int_{-\infty}^{\infty} ds \rho(b, s).$$

For the nuclear density we took two popular functions : the Gaussian distribution

$$\rho(b, s) = (\sqrt{\pi} R)^{-2} \exp[-(b^2 + s^2)/R^2] \quad (8)$$

and Fermi (or Baxton - Woods) distribution

$$\rho(b, s) = \rho_0 \left\{ 1 + \exp \left[\frac{(\sqrt{b^2 + s^2} - c)/a}{\pi} \right] \right\}^{-1}, \quad (9)$$

$$\rho_0 = \left[\frac{4\pi e^3/3}{(1 + \pi^2 a^2/c^2)} \right]^{-1},$$

where $R = 0.98 A^{0.85}$, $c = 1.07 A^{1/3}$, $a = 0.545$ and $\sigma_{in} = 32$ mb.

- c) For each intranuclear collision the type of target nucleon (proton or neutron) was chosen in accordance with the

nuclear structure.

d) It was assumed that at each collision two clusters are produced (the multiplicity of each cluster equals to $(n_{ch})_{pN} / 2$). The fast cluster interacts with the next nucleon as the whole whereas the slow one does not interact within nucleus. The multiplicities of each intranuclear collision were chosen randomly in accordance with n_{ch} -distribution from pp-interactions /7/, if target was a proton, or n_{ch} -distribution from pn-interactions which was obtained from our data /5/ taking into account the correction $(\langle n_g \rangle_{pN} / \langle n_g \rangle_{pN})$ from pp-data, if target was a neutron. Finally, the particles from decay of V_A slow and one fast clusters were summed up.

Fig.7 shows the n_g -distributions from proton-nucleus interactions at 200 GeV/c together with the curves approximating the calculated histograms (10^5 simulating events for each model version). From this Figure and from the data on moments of n_g -distributions presented in Table 3 one can see that the model under consideration gives the satisfactory description of experimental distributions at our energy. It should be noted that for heavy nuclei the model version with Fermi distribution (9) is in the best agreement with the data whereas for light nuclei the distribution (8) is more preferable. In Fig.7a we have plotted also the curve for another version of described model in which the ratio of multiplicities from decay of fast and slow clusters equals two (Gottfried's model /21/). The disagreement of this curve with experiment is obvious. In Refs. /2,3/ the agreement of the mean multiplicity with the predicted one by this model was pointed out; in our opinion this agreement is caused by the uniform nuclear density assumed in /21/. In fact, the

mean numbers of intranuclear collisions calculated according to the distributions (8) and (9) (2.6 and 2.7 respectively) are lower than 3.2 obtained by Gottfried /21/.

In conclusion of this Section let us consider the scaling properties of n_s -distribution in proton-nucleus collisions. It is known /22/ that the experimental data for pp-interactions over the large energy range 50 - 300 GeV agree roughly with the KNO scaling /23/, i.e. describe by the universal function

$$\langle n \rangle W(n) = \psi(n/\langle n \rangle). \quad (10)$$

For proton-nucleus interactions this property was studied only in the cosmic rays /24/ for the light nuclei (polyethylene) and it was found that the experimental data are described by the same function as pp-interactions.

It is easy to show that for the mixture of different nuclei such as emulsion the function $\psi(n/\langle n \rangle)$ must be different from one for pp-collisions even in the case when the n -distribution for the any individual nucleus satisfies it. This statement is illustrated by the curve 2 in Fig. 2a which was calculated under assumption that for each A the function ψ has the same form as obtained by Slattery /22/ for pp-interactions and that $\langle n_s \rangle_A = \langle n_{ch} \rangle_{pp} A^{0.15}$. This Figure shows also the experimental data at $p_0 = 200$ and 67 GeV/c (the latter were obtained by summing up of n_s -distributions from Refs. /3,16/, in all about 1200 events), the curve taken from /22/ and our fit to experimental data. One can see that these data at 67 and 200 GeV/c fit well by the common curve ($\chi^2/\text{number of degrees of freedom} \approx 0.2$):

$$\psi(x) = (3.0x + 25x^3 + 4.6x^5 + 0.18x^7) \exp(-4.0x) \quad (11)$$

($s = n_g / \langle n_g \rangle$) which differs both from Slattery's and calculated for photoemulsion curves. In Fig. 8b,c we present separately the data for light (C,N,O) and heavy (Ag,Br) nuclei. For light nuclei the data agree well with the Slattery function ($\chi^2/\text{number of degrees of freedom} \approx 0.8$) whereas for heavy nuclei the data disagree with this form (the agreement probability is less than 0.01) and describe by another function, which nevertheless is not far from Slattery's one.

Thus, the experimental data on the n_g -distributions in proton-nucleus collisions do not contradict to KNO scaling law in the same energy range in which it fulfilled for pp-interactions, but we conclude that the function $\psi(n_g / \langle n_g \rangle)$ has a weak A-dependence. For emulsion nuclei this function has the form defined by the formula (11) in the range 67 - 200 GeV/c. It is easy to show that some regularities observed recently for the moments of n_g -distributions from proton-nucleus interactions (for example, the linear dependence of $[\langle n_g^2 \rangle - \langle n_g \rangle^2]^{1/2}$ on $\langle n_g \rangle$ /3.4/ or the so-called "nuclear multiplicity scaling" /25/) are the direct consequences of the universality of $\psi(n_g / \langle n_g \rangle)$ -function.

5. CORRELATIONS BETWEEN THE DIFFERENT TYPES OF SECONDARIES.

We present our results on correlation dependences of the type $\langle n_i(n_j) \rangle$ (n_i, n_j ($i \neq j$) = K_n, n_p, n_g, n_s) in Fig.9. As follows from this Figure all these dependences are monotonous and fit well by the linear functions with positive slopes :

$$\langle n_i \rangle = a n_j + b \quad (a > 0) \quad (12)$$

on the whole range of n_j variation (except the dependences

from n_g which reach a plateau at $n_g \geq 10$). All the parameters a and b from relation (12) are listed in Table 4 (for the n_g -dependences the fit was carried out up to $n_g = 8$).

The comparison with low energy data (see Ref./10/ and compilation of data in /6/) shows :

(i) Correlations between multiplicities of black and gray tracks are coincide with low energy data. For instance, at $p_0 = 7$ and 22 GeV/c $\langle n_b \rangle = 1.36n_g + 1.59$ (uncorrected data from /10/) and it coincides with the 200 GeV/c data (Table 4). This still emphasizes the remarkable stability of the heavy track characteristics, when the energy changes.

(ii) Correlations between n_g and the numbers of any type of heavy tracks n_b , n_g or N_H depend essentially on the energy. In some papers /1 - 4/ this fact was noted for the $\langle n_g(N_H) \rangle$ -dependence. It is obvious, that a such behaviour reflects the fact that the n_g -distribution depends on p_0 while the N_H -, n_b - and n_g -distributions remain practically unchanged. Therefore, the slopes of straight lines (12) fitted the dependences $\langle n_g(n_j) \rangle$ increase and for the reverse dependences decrease when the energy rises.

In virtue of the monotonous character of $\langle n_g(N_H) \rangle$ -dependence some authors (see for example /3/) used the N_H as a measure of the number of intranuclear collisions and then classified the nuclear interactions by means of N_H . The data from Fig.9 and Table 4 show that the analogical monotony is observed also for n_b and $n_g \leq 8$. Since the $\langle n_g(n_g) \rangle$ -dependence is the most strong, the n_g -value is the most preferable for such classification. However, it should be noted that the mean value of n_g exceeds significantly the number of recoil protons expected from the model considerations (of the

type described in Section 4). It is obvious, that for the more certain and quantitative conclusions it is necessary to have the more detail information on the gray (and black) tracks.

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Table 1.
Mean multiplicities of heavy prongs in the various groups of events.^{x)}

Type of collisions	Group	Number of events	$\langle N_h \rangle$	$\langle n_b \rangle$	$\langle n_c \rangle$	$\langle n_b \rangle / \langle n_c \rangle$
All inelastic	1	3242	7.40 ± 0.13	-	-	-
	2	1697	7.26 ± 0.19	4.79 ± 0.12	2.48 ± 0.08	1.93 ± 0.08
Without coherent	1	3122	7.69 ± 0.14	-	-	-
	2	1634	7.54 ± 0.20	4.97 ± 0.13	2.57 ± 0.08	1.93 ± 0.08
Without coherent and p-free p	1	3007	7.97 ± 0.14	-	-	-
	2	1574	7.82 ± 0.20	5.16 ± 0.13	2.66 ± 0.08	1.94 ± 0.08
Interactions with C, N, O	1	800	2.61 ± 0.08	-	-	-
	2	419	2.70 ± 0.11	1.80 ± 0.08	0.90 ± 0.05	2.00 ± 0.14
Interactions with Ag, Br	1	2207	9.92 ± 0.17	-	-	-
	2	1155	9.66 ± 0.24	6.36 ± 0.16	3.29 ± 0.10	1.93 ± 0.08

x). The first group consist of events with measured N_h and n_c ; in the events from the second group n_b , n_c , n_s and emission angles were measured.

Table 2.

Ratio $\langle n_p \rangle / \langle n_g \rangle$ at different p_0 (all inelastic collisions without coherent)

p_0 GeV/c	Ref.	$\langle n_p \rangle / \langle n_g \rangle$	Calculation from /6/
7.1	/10/	1.80 ± 0.07	2.4 ± 0.2
22.5	/10/	1.71 ± 0.10	2.0 ± 0.2 ^{m)}
25	/16/	1.54 ± 0.10	1.9 ± 0.1
50	/16/	1.66 ± 0.16	2.2 ± 0.2
67	/16/	1.73 ± 0.12	2.3 ± 0.2 ^{m)}
200	this work	1.93 ± 0.08	2.5 ± 0.2 ^{m)}

m). Interpolation of data /6/.

Table 3.

Moments of n_g -distribution in the various groups of events. In brackets - calculation according to the model (see text) with Fermi distribution (9).

Type of collisions	Group	Number of events	$\langle n_g \rangle$	$\langle n_g(n_g-1) \rangle$	$[\langle n_g^2 \rangle - \langle n_g \rangle^2]^{1/2}$	f_2
all inelastic	1	3242	13.9 ± 0.2	253 ± 6	8.7 ± 0.5	61.4 ± 8.2
	2	1697	13.6 ± 0.2	240 ± 7	8.4 ± 0.6	56.5 ± 8.9
Without coherent	1	3122	14.3 ± 0.2	253 ± 6	8.6 ± 0.5	58.8 ± 8.3
	2	1634	14.0 ± 0.2	249 ± 8	8.2 ± 0.6	53.9 ± 9.8
Without coherent and p-free p	1	3097	14.5 ± 0.2	270 ± 6	8.6 ± 0.5	59.0 ± 8.3
	2	1574	14.2 ± 0.2 (14.0)	256 ± 8 (257)	8.5 ± 0.6 (8.7)	54.1 ± 9.2 (61.1)
Interactions with C,N,O	2	419	11.0 ± 0.3	145 ± 8	6.0 ± 0.9	24.7 ± 10.4
			(10.0)	(121)	(5.6)	(21.5)
Interactions with Ag,Br	2	1155	15.4 ± 0.3	297 ± 10	8.7 ± 0.8	59.4 ± 13.6
			(15.4)	(306)	(9.1)	(67.6)

Table 4.

Parameters a (above) and b (below) of the linear dependence $\langle n_i \rangle = an_j + b$ ($n_1, n_j = n_h, n_b, n_g, n_a$).

$\langle n_i \rangle \backslash n_j$	n_h	n_b	$n_g \leq 8$	n_a
$\langle n_h \rangle$	-	1.38 ± 0.01	2.32 ± 0.04	0.48 ± 0.02
	-	0.55 ± 0.01	1.70 ± 0.05	0.86 ± 0.15
$\langle n_b \rangle$	0.69 ± 0.03	-	1.38 ± 0.04	0.32 ± 0.01
	0 ± 0.12	-	1.63 ± 0.05	0.56 ± 0.06
$\langle n_g \rangle$	0.33 ± 0.01	0.37 ± 0.02	-	0.17 ± 0.01
	0.06 ± 0.01	0.56 ± 0.09	-	0.25 ± 0.02
$\langle n_a \rangle$	0.61 ± 0.03	0.85 ± 0.03	1.73 ± 0.08	-
	9.42 ± 0.18	9.75 ± 0.15	10.0 ± 0.2	-

FIGURE CAPTIONS

Fig.1. (a) Integral N_h -distributions for all events (above) and for events remaining after the subtraction of Eq.(1) (below).

(b) Percentage of CNO-events vs. N_h .

Fig.2. Differential N_h - (a), n_g - (b) and n_p - (c) distributions. The histograms are: all events (upper), collisions from Ag,Br (lower) and collisions from C,N,O (pointed). The p-free p events are shaded, the coherent reactions are twice shaded.

Fig.3. Energy dependences of $\langle N_h \rangle$, $\langle n_p \rangle$ and $\langle n_g \rangle$. The curves are according to cascade-evaporation model /6/.

Fig.4. Integral n_p - (above) and n_g - (below) distributions at 7 (full circles), 23 (triangles) and 200 (open circles) GeV/c. Data at 7 and 23 GeV/c from Ref./10/.

Fig.5. Differential n_g -distributions. The designations the same as in Fig.2.

Fig.6. Energy dependences of $\langle n_g \rangle$ and R. The curves are: 1) $\langle n_{ch}(p_0) \rangle$ for pp-collisions, 2) calculation according to cascade-evaporation model /6/, 3) our approximation.

Fig.7. n_g -distributions from all nuclear events (a) and from collisions with C,N,O (b) and Ag,Br (c) in comparison with the model calculations (see text) with the nuclear densities of forms (9) (curves 1) and (8) (curves 2). The dotted curve is according to Gottfried model with the Fermi distribution (9).

Fig.8. Dependence $\langle n_g \rangle \epsilon_{n_g} / \epsilon$ vs. $n_g / \langle n_g \rangle$ for all nuclear interactions in emulsion (a) and for collisions with C,N,O (b) and Ag,Br (c). The circles and crosses are the 200 GeV/c and 67 GeV/c /3,16/ data respectively.

The curves are: 1) Slattery's function /22/, 2) our calculation for the emulsion (see text), 3) empirical fit to experimental data.

Fig.9. Correlations between n_i and n_j ($n_i, n_j = n_g, n_g, n_p, N_n$) for the proton-nucleus interactions at 200 GeV/c in emulsion.

500
 N_n^2
400
300
200
 $W(>N_i) \%$

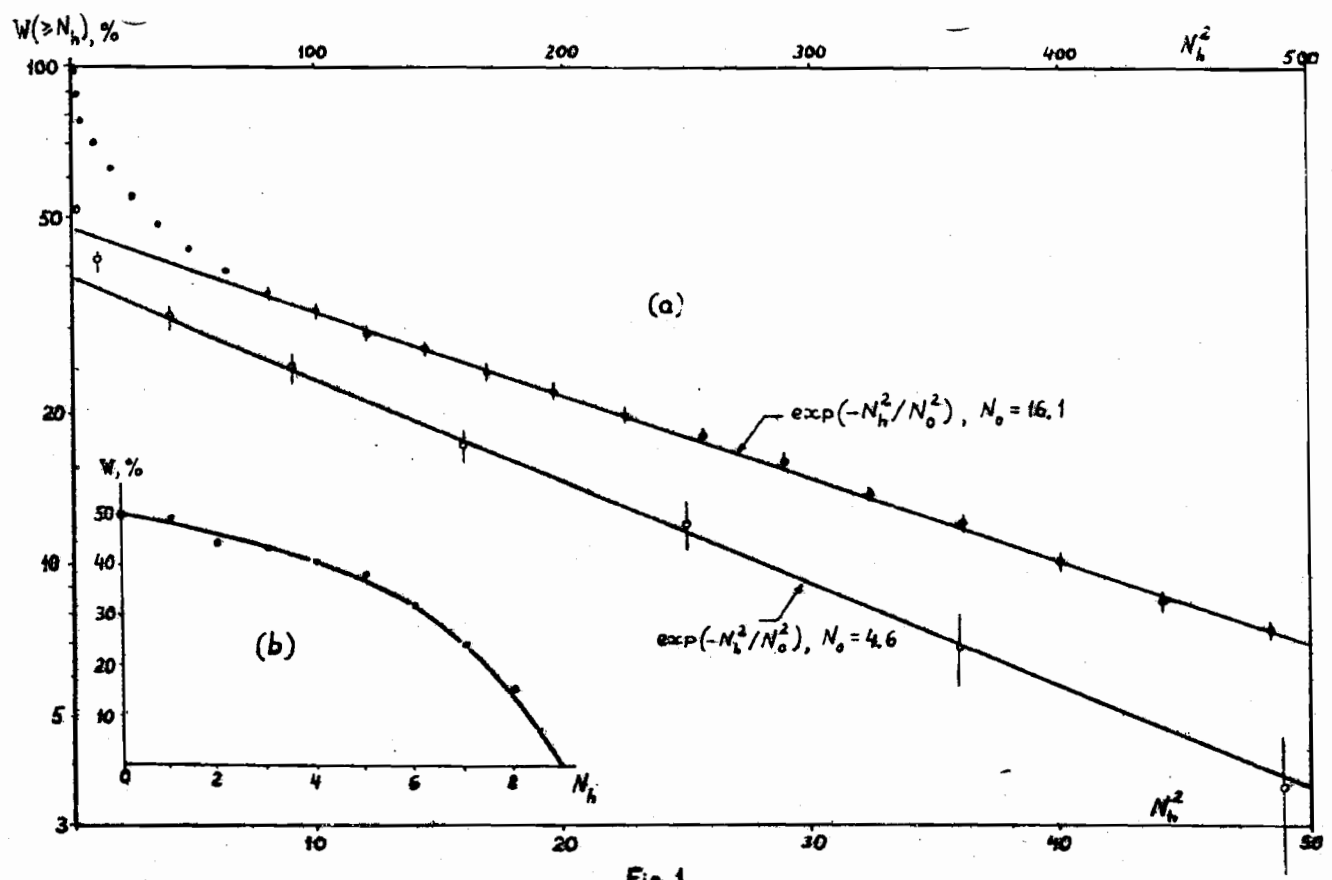


Fig. 1

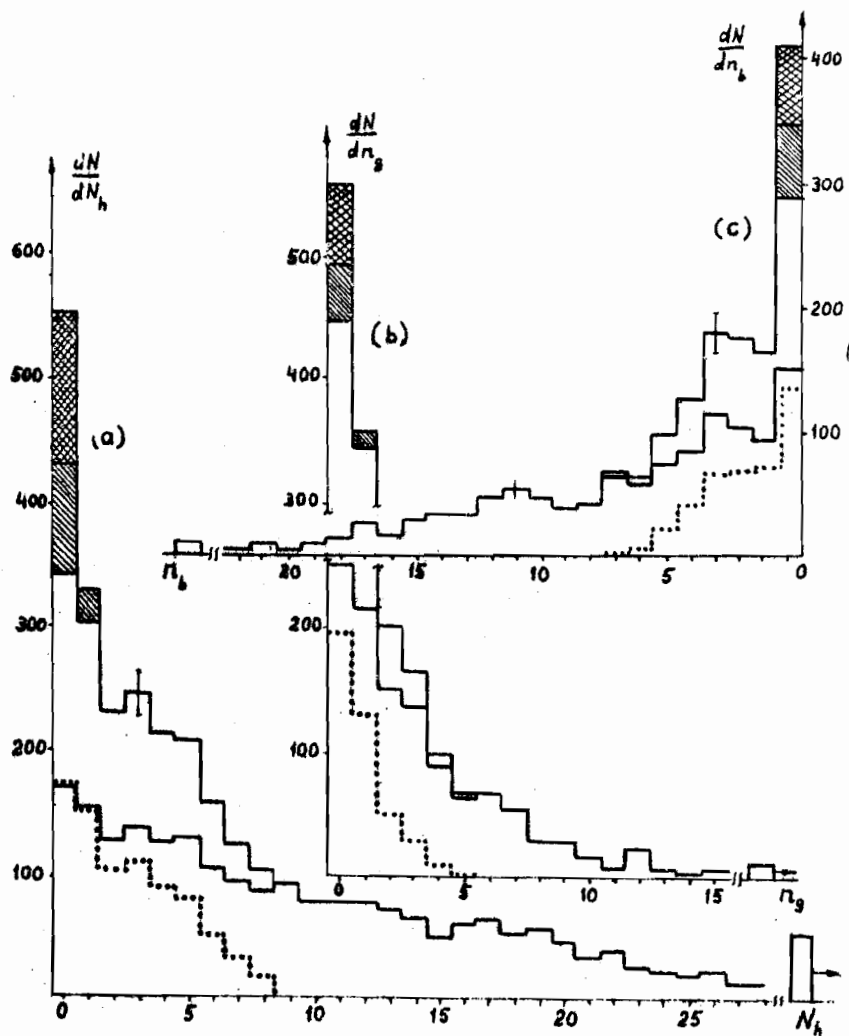


Fig. 2

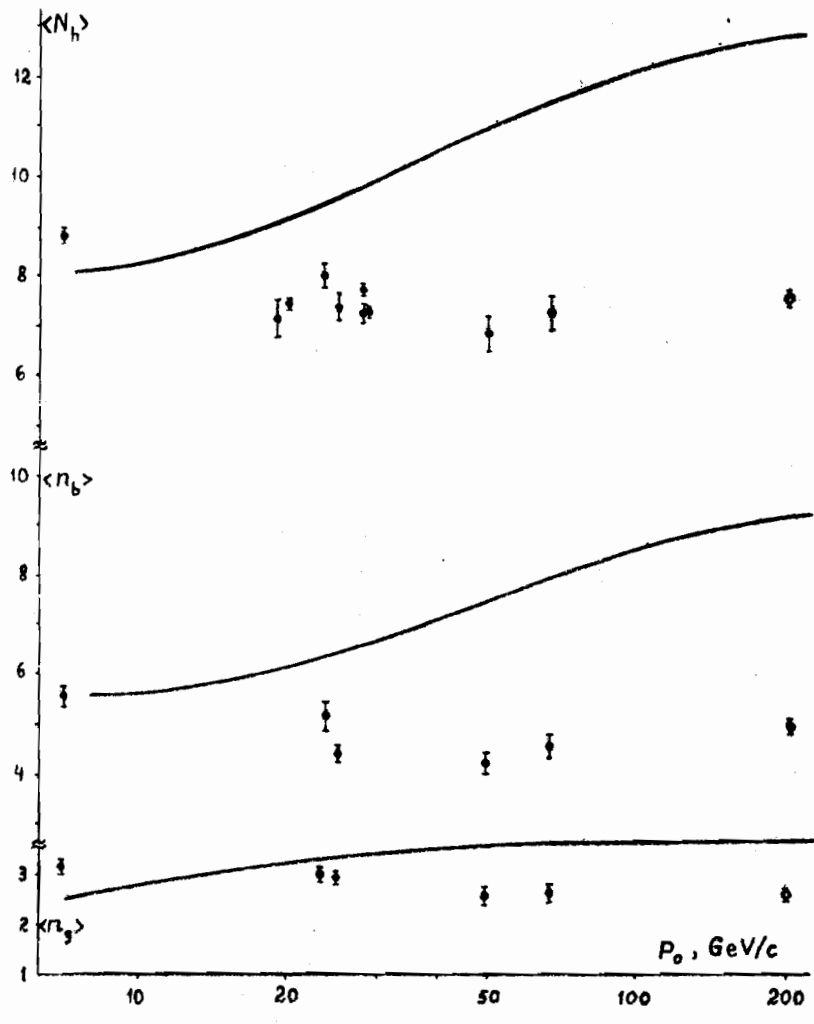


Fig. 3

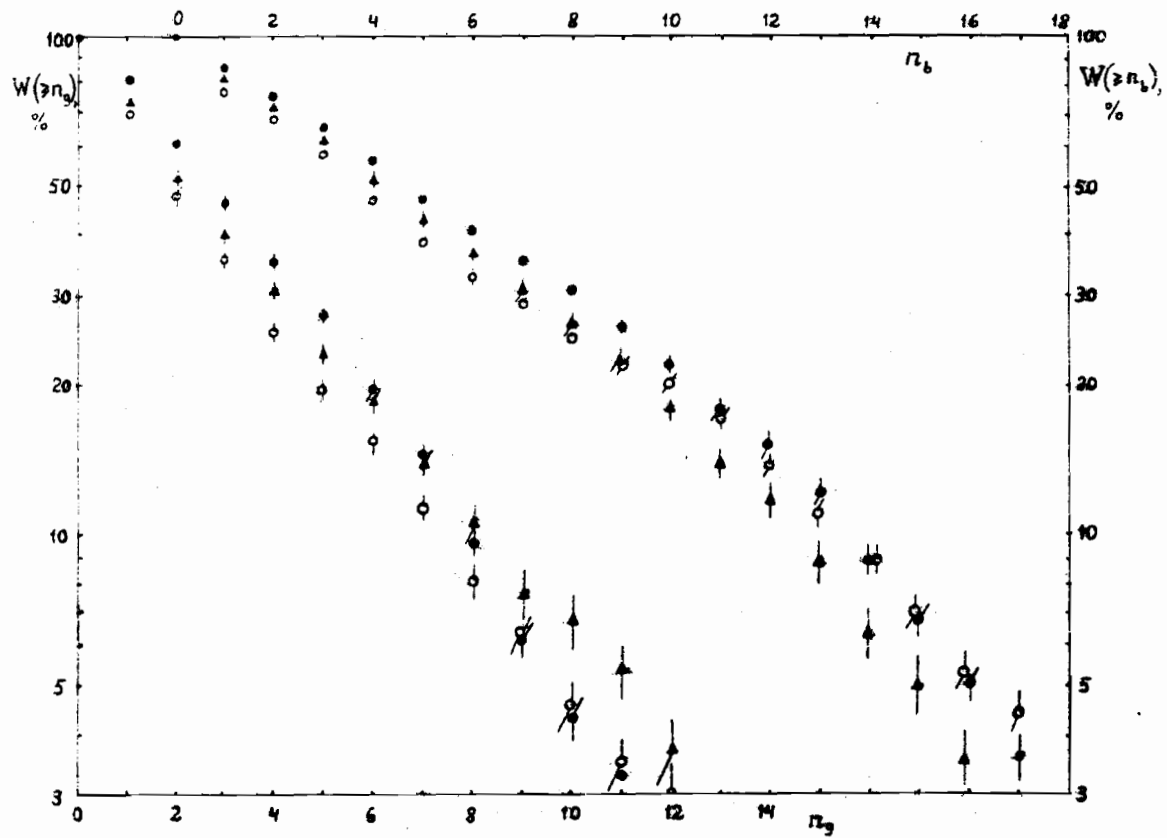


Fig. 4

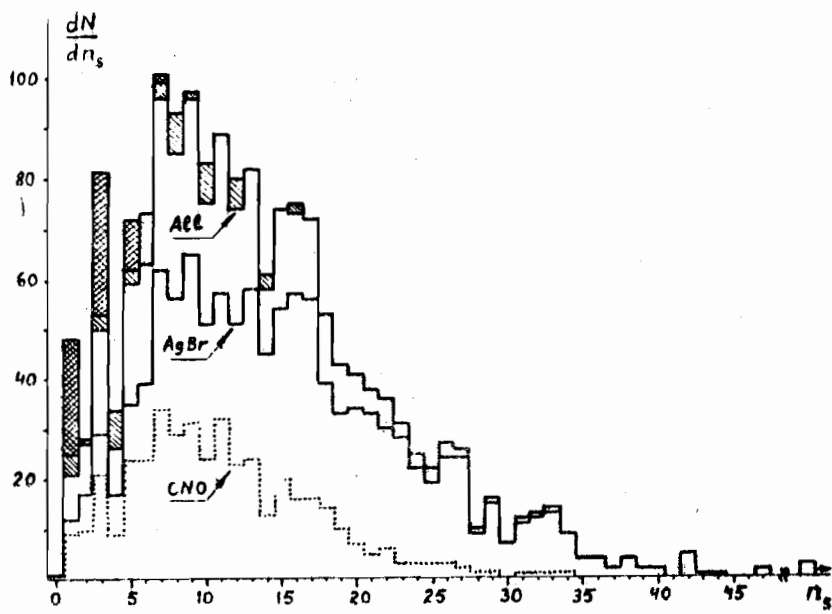


Fig. 5

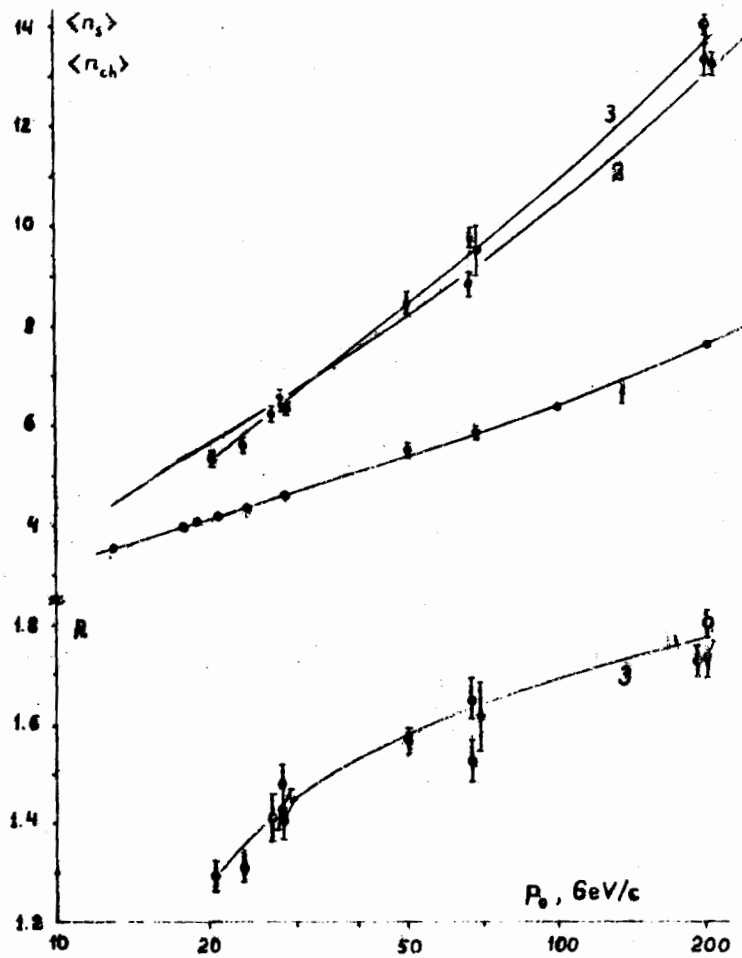


Fig. 6

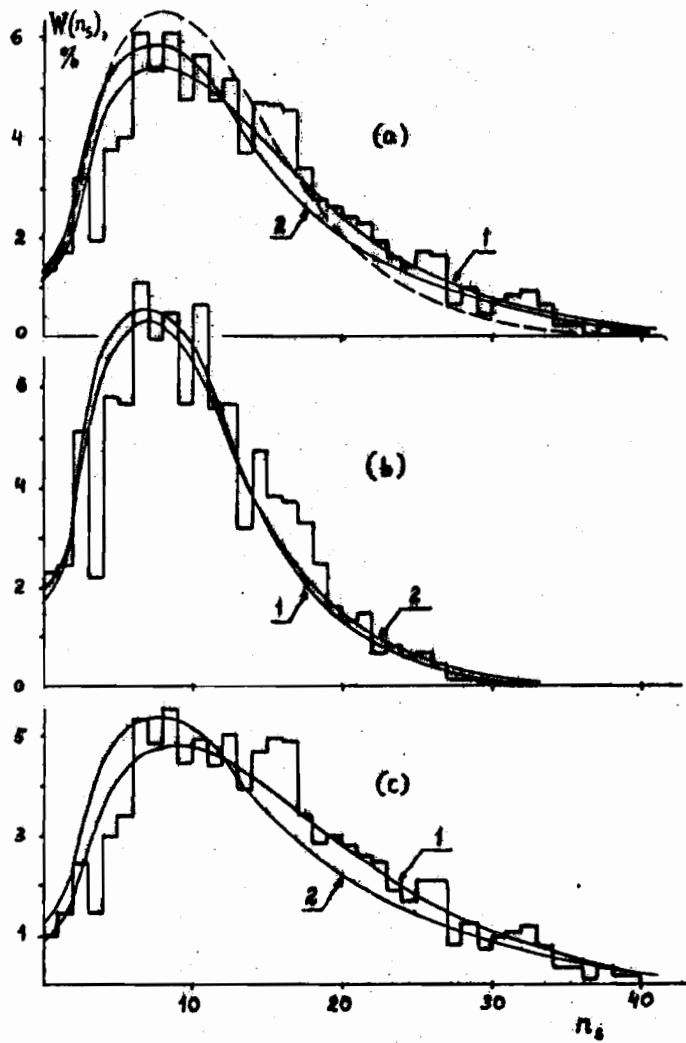


Fig. 7

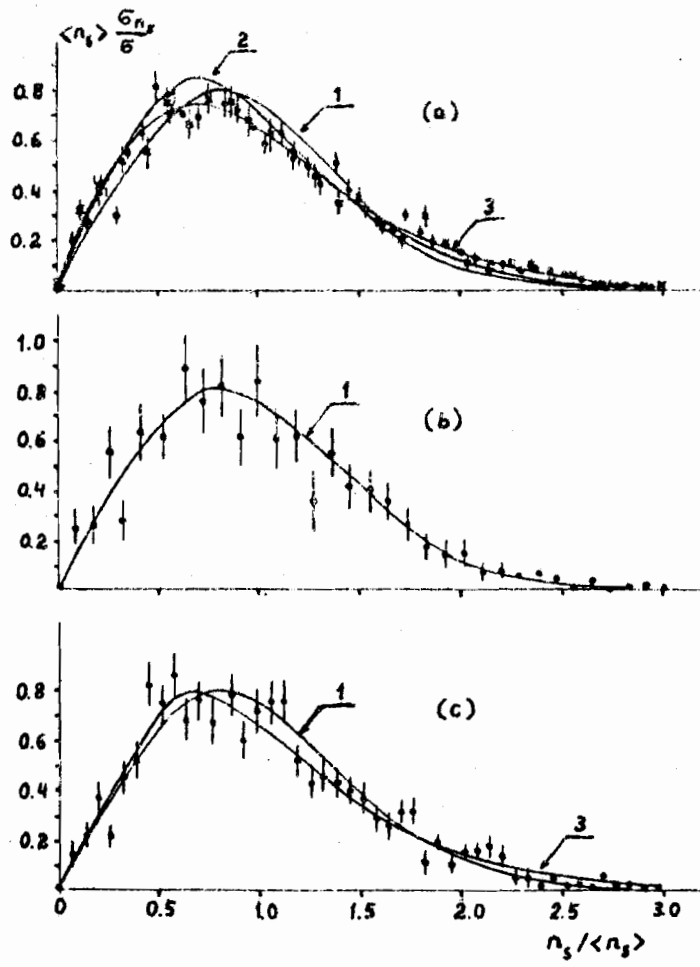


Fig. 8

20
18
16
14
12
10
8
6
4
2
0
20
25
20
15
10
5
0

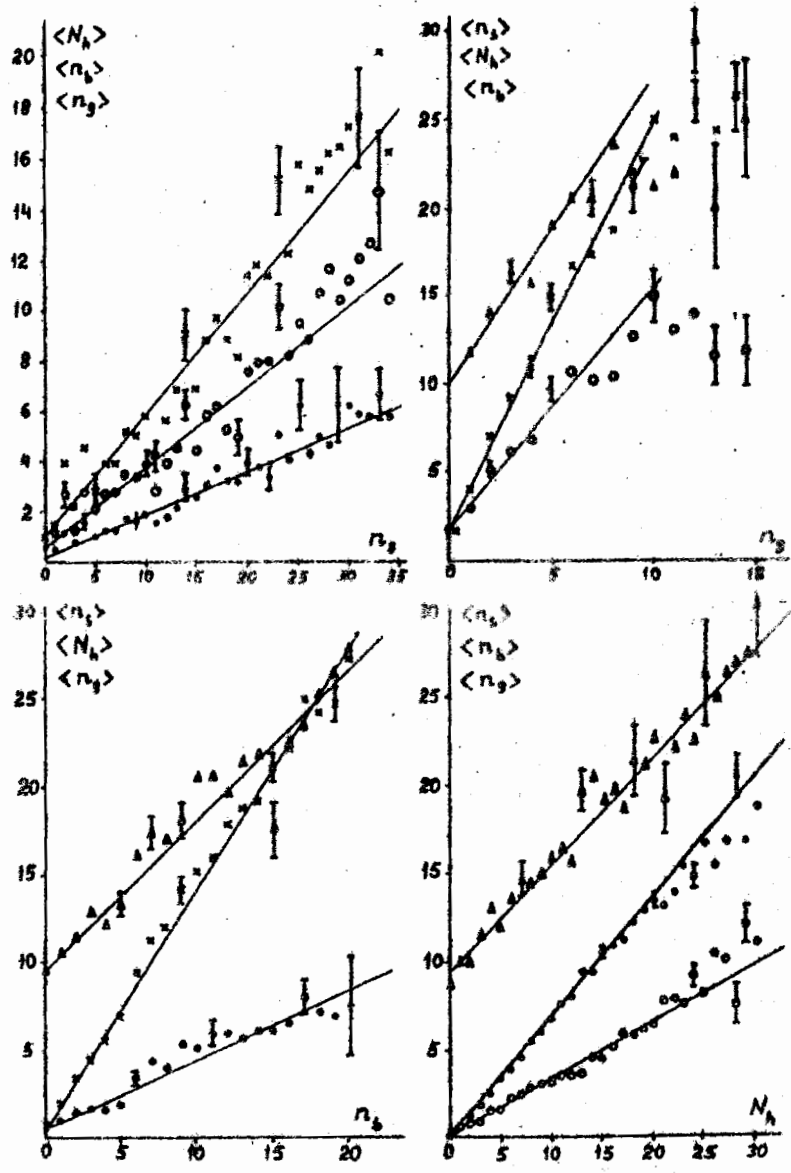


Fig. 9