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Features of compound multiplicity in heavy-ion interactions at 4.5 A GeV/c

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This paper mainly deals with some important features of compound multiplicity in the inelastic nuclear reactions induced by 4.5 A GeV/c carbon and silicon ions in nuclear emulsion. The characteristics of this parameter observed in the present study are compared with the corresponding values obtained for proton-emulsion interactions at the same incident momentum per nucleon. The average compound multiplicity is found to vary linearly with black and heavy particle multiplicities. Finally, the compound multiplicity distributions for carbon- and silicon-emulsion interactions are observed to obey a Koba-Nielsen-Olesen (KNO) type of scaling law.

I. INTRODUCTION

During recent years most of the experiments on hadron-nucleus [1–5] and nucleus-nucleus [6–8] collisions have been carried out primarily to investigate the characteristics of relativistic ($\beta \geq 0.7$) charged particles and very little attention has been spent [9,10] on the study of the gross features of gray ($0.3 \leq \beta < 0.7$) particles envisaged to arise from the target. It is interesting to mention that the study of the emission characteristics of gray particles is of special significance because these particles are visualized to be produced during or shortly after the passage of the leading particle and hence are expected to remember a part of the history of these reactions [9,10]. Jurak *et al.* [11] and Ghosh *et al.* [12] have investigated the interesting features of shower and gray particles, taking them together per event, without making any distinction between them, for the case of hadron-nucleus interactions; the number of gray and shower particles taken together in an interaction is termed the compound multiplicity N_c ($=N_s+N_g$).

Since the existing knowledge on the behavior of compound multiplicity for the case of heavy-ion collisions is quite meager, we have carried out a detailed study of the characteristics of compound multiplicity for proton ($p-$), carbon- (^{12}C$-$), and silicon- (^{28}Si$-$) emulsion interactions at 4.5 A GeV/c, in order to glean some useful and important information on the mechanism of nucleus-nucleus interactions.

II. EXPERIMENTAL DETAILS

Two stacks composed of NIFKI-BR$_2$ emulsion pellicles of dimensions $18.6\times9.5\times0.06$ and $16.9\times9.6\times0.06$ cm^3, exposed to 4.5 A GeV/c ^{12}C and ^{28}Si beams at Dubna Synchrophasotron, have been used in the present investigation. Along-the-track scanning was performed to select the data samples consisting of 852 and 1024 inelastic ^{12}C- and ^{28}Si-emulsion interactions, respectively. Other relevant details, about the method of measurements, selection criteria, etc., may be found in our earlier publication [13].

The tracks arising from each interaction are classified according to the emulsion experiment terminology, based upon their appearances in the microscope, as follows: *s*, shower tracks; *g*, gray tracks; and *b*, black tracks. The shower tracks correspond to the singly charged, relativistic particles, whereas gray and black tracks are produced by comparatively slower particles emitted from the target nucleus. Gray tracks are mostly recoil protons with momenta lying in the interval 0.2–1.0 GeV/c, with less than a few-percent admixture of low-momenta pions. The black tracks are due to slow particles and evaporated fragments. The number of shower, gray, and black particles produced in an interaction are denoted by N_s, N_g, and N_b, respectively.

Gray and black tracks taken together are referred to as the heavy tracks, and their number in an interaction is designated by N_h ($=N_g+N_b$). It may be noted that the gray and black tracks having dip angles $\theta_d \leq 30°$ are considered in the present study. To account for the loss of gray and black tracks having dip angles $\theta_d > 30°$, a statistical weight factor K, defined below is assigned to each gray and black track having $\theta_d \leq 30°$:

$$K=\frac{\pi/2}{\arcsin(\sin 30°/\sin\theta)} . \quad (1)$$

$K=1$ for the space angles lying in the interval $150° \leq \theta \leq 30°$.

III. EXPERIMENTAL RESULTS

The probability distributions of the compound multiplicity for p-, ^{12}C-, and ^{28}Si-emulsion interactions are shown in Fig. 1. It is seen from the figure that the shape of the compound multiplicity distribution changes appreciably with increasing projectile mass; the distribution tends to become broader with increasing projectile mass. Furthermore, the number of events with comparatively lower values of N_c decreases with increasing projectile mass. This observation may be explained in terms of the predictions of the fireball model.

The values of the mean compound multiplicities obtained for ^{12}C- and ^{28}Si-emulsion collisions and other projectiles are plotted as a function of the projectile mass at 4.5 A GeV in Fig. 2. The solid line in this figure can be

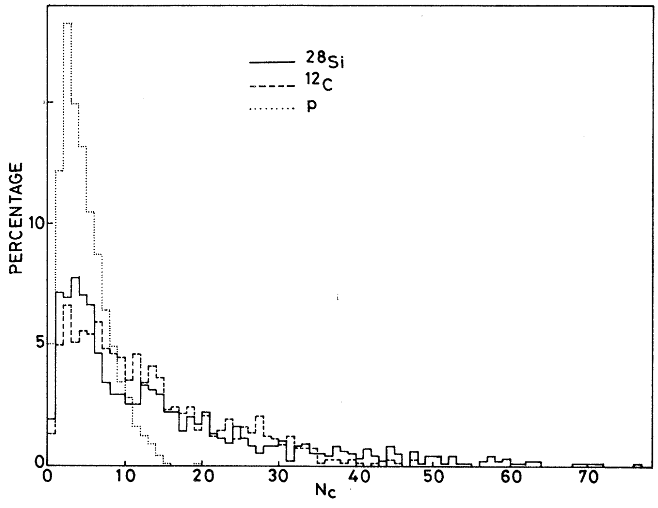

FIG. 1. Compound multiplicity distributions for p-, ^{12}C-, and ^{28}Si-emulsion interactions.

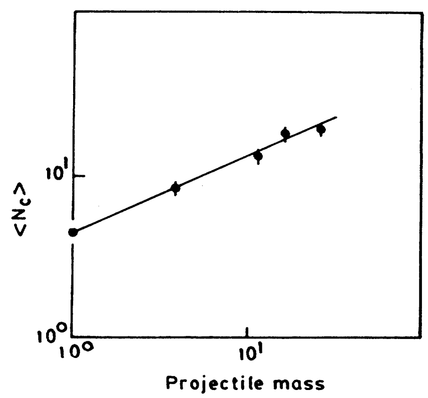

FIG. 2. Dependence of the average compound multiplicity on the projectile mass.

TABLE I. Values of the slope coefficient in compound multiplicity correlations in proton-, carbon-, and silicon-emulsion interactions.

Correlations	Proton	Carbon	Silicon
$\langle N_c \rangle - N_b$	0.44±0.02	0.87±0.14	1.23±0.14
$\langle N_c \rangle - N_h$	0.36±0.01	0.76±0.02	1.21±0.06

represented by the following equation:

$$\langle N_c \rangle = (4.50 \pm 1.07) A^{0.46 \pm 0.03} . \quad (2)$$

Several workers [13–15] have attempted to investigate the multiplicity correlations of the type $\langle N_i(N_j) \rangle$, where $N_i, N_j = N_g, N_b, N_h, N_s$ and $i \neq j$, over widely different incident energies using different projectiles. But no serious attempt has been made so far to examine the behavior of compound multiplicity correlation with various secondary particle multiplicities. Therefore, an attempt is made to investigate the compound multiplicity correlations in both proton-nucleus and nucleus-nucleus collisions; these correlations are nicely fitted by a linear relation of the type

$$\langle N_c \rangle = a + bN_j . \quad (3)$$

Here j stands for the heavy or black particles.

Correlations among the average compound multiplicity and N_b and N_h are plotted in Figs. 3 and 4. From these figures it is quite clear that the dependence of $\langle N_c \rangle$ on N_b and N_h in the case of proton-emulsion interactions is comparatively weak in comparison to the corresponding

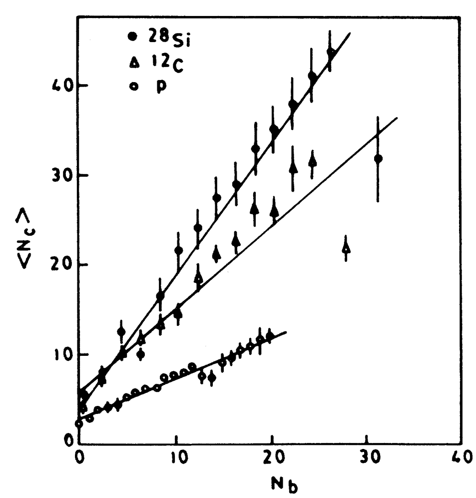

FIG. 3. Compound multiplicity correlation of $\langle N_c \rangle$ with N_b.

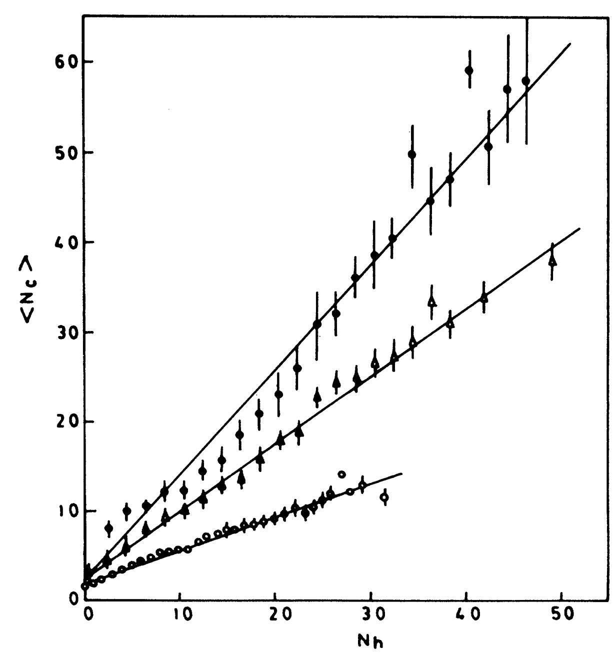

FIG. 4. Compound multiplicity correlation of $\langle N_c \rangle$ with N_h.

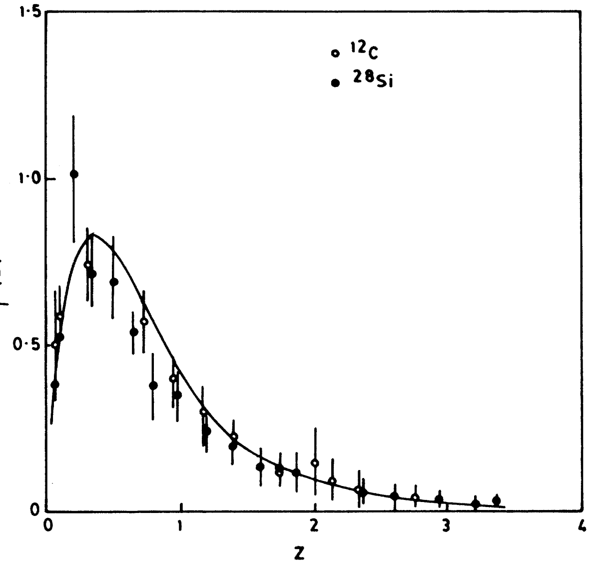

FIG. 5. $\psi(Z)$ vs the scaling function Z. The solid curve represents the KNO-type scaling function.

dependence in the case of heavy-ion collisions, demonstrating thereby that the projectile mass does not play any vital role in the correlation behavior. The values of the slope parameter occurring in Eq. (3) for p-, ^{12}C-, and ^{28}Si-emulsion interactions are listed in Table I.

It has been pointed out by Ghosh *et al.* [12] that the compound multiplicity distributions in the case of hadron-nucleus collisions at different projectile energies obey a Koba-Nielsen-Olesen (KNO)-type scaling [16]. We have, therefore, tried to check whether the compound multiplicity distributions in the case of carbon- and silicon-emulsion interactions show a KNO-type scaling behavior. For this study we exclude the gray tracks which do not arise from the target nuclei, i.e., the projectile fragments. Only those gray tracks are considered for the present study which have emission angles greater than 5°.

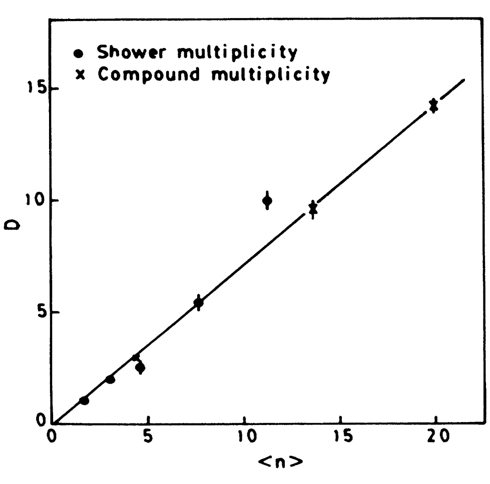

FIG. 6. Variation of dispersion with average compound multiplicity.

TABLE II. Central moments of the compound multiplicity distributions of proton-, carbon-, and silicon-emulsion interactions.

Projectile	$2\sqrt{\mu_2}$	$3\sqrt{\mu_3}$	$4\sqrt{\mu_4}$
Proton	2.89±0.04	2.87±0.04	3.89±0.06
Carbon	9.52±0.23	9.54±0.23	13.01±0.32
Silicon	14.20±0.31	16.59±0.37	21.56±0.48

A $\psi(Z)$-vs-Z $(=N_c/\langle N_c\rangle)$ plot for carbon- and silicon-nucleus interactions is shown in Fig. 5. The solid curve in the figure is fitted with the following KNO-type scaling function:

$$\psi(Z)=(7.43Z+15.64Z^3-4.54Z^5+2.04Z^7)\times\exp(-3.92Z)\ . \quad (4)$$

The values of χ^2 per degree of freedom $(=0.04)$ is very small, implying that the experimental points are close to the corresponding points obtained using the above equation.

In order to investigate these features in more detail, we have plotted the dispersion against the average compound multiplicity in Fig. 6. A linear relationship between the dispersion and the average compound multiplicity is observed which leads to a KNO type of scaling.

The central moments of the compound multiplicity distributions are defined as

$$q\sqrt{\mu_q}=q\sqrt{\langle(N_c-\langle N_c\rangle)^q\rangle}\ , \quad (5)$$

where $q=2,3,4$. The values of the central moments of the compound multiplicity distributions for p-, ^{12}C-, and ^{28}Si-emulsion interactions are given in Table II. It is noted from the table that the values of the central moments $(2\sqrt{\mu_2}$, $3\sqrt{\mu_3}$, and $4\sqrt{\mu_4})$ depend strongly on the projectile mass. These results support the coherent tube model [17] of multiparticle production.

IV. CONCLUSION

The following important conclusions may be arrived at on the basis of the results of the present investigation: (1) Compound multiplicity distribution changes appreciably with increasing projectile mass and the mean compound multiplicities vary linearly with the projectile mass. (2) Dependence of the average compound multiplicity $\langle N_c\rangle$ on N_b and N_h in the case of p-emulsion interactions is relatively weaker as compared to the corresponding dependence for heavy-ion collisions. (3) Compound multiplicity distributions in carbon- and silicon-emulsion collisions are observed to obey a KNO-type scaling law. (4) Central moments of the compound multiplicity distributions increase linearly with increase in projectile mass.

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