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The characteristics of SecondaryCharged Particlesproduced in 4.5 A GeV/c ^{28}Si-Nucleus Interactions.

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Abstract: *To study the characteristics of secondary charged particles produced in 4.5GeV/c ^{28}Si-nucleus interactions a lot of rigorous attempts have been made. The results reveal that the multiplicity correlations are not linear. The findings do not agree with those reported by several earlier workers. However, these correlations may be reproduced quite well by second order polynomial. It is also observed that the dependence of mean normalized, R_A and reduced multiplicity, R_S on the multiplicity of different charged secondaries is linear up to a certain value and then acquire almost a constant value. Results also reveal that the K^{th} root of central moment increases with the increase of $\langle Ns \rangle$ and the values of normalized moments do not depend on the nature and the energy of the projectiles. Finally, it is observed that the integral multiplicity distribution of heavily ionizing tracks provide a method for selecting the disintegrations caused by the projectile due to different target nuclei of nuclear emulsion.*

I. Introduction

In1935 Japanese Physicist Hideki Yukawa proposed the existence of one type of mesonic particle inside the Nucleus which might be sole responsible for binding together the nucleons (protons & neutrons) in the Nucleus. In 1947 British Physicist Cecil Frank Powell of Bristol University of London with the help of High Energy Nuclear Emulsion technique discovered exactly the same mesonic particle which was proposed by Yukawa and it was named as pion in the name of Powell. So in 1949 Yukawa was awarded the Nobel Prize for the theoretical prediction of pion and in 1950 Cecil Frank Powell was awarded the Nobel Prize for its experimental verification. In the present work the samples of high energy emulsion plates were imported from Joint Institute of Nuclear Research (JINR), DUBNA, MOSCOW.

II. Experimental Results And Discussions

The integral multiplicity distributions of heavily ionizing particles, N_h, produced in 4.5 A GeV/c ^{28}Si-nucleus interactions is plotted in Fig.1. It is interesting to note in the figure that the distribution has two different slopes with breaks approximately corresponding to CNO and Ag Br constituents of the emulsion nuclei.
It is reported that the multiplicity correlations between $\langle N_s \rangle$ - N_b, $\langle N_S \rangle$ - N_h and $\langle N_b \rangle$ - N_g acquire almost constant value beyond $N_b \sim 9$ and $N_h \sim 31$ and $N_g \sim 20$ in both hadron-nucleus and nucleus-nucleus collisions [1,2,5]. In order to understand the nature of the multiplicity correlations, an attempt has been made to investigate the multiplicity correlations between $\langle N_s \rangle$ - N_b, $\langle N_S \rangle$ -N_h and $\langle N_b \rangle$ - N_g. For this purpose the regression of the type $\langle Ni(Nj) \rangle$, where Ni, Nj = N_b, N_g, N_s and N_h and $i \neq j$. In the present work regression $\langle N_s(N_h) \rangle$, $\langle N_s(N_b) \rangle$ and $\langle N_b(N_g) \rangle$ for ^{28}Si-nucleus reactions at 4.5 A GeV/c and their dependence on the nature of the projectile are studied. The dependence of $\langle N_s \rangle$ with N_b, N_g and N_h and $\langle N_b \rangle$ on N_g are displayed in Figs.2-4.
The multiplicity correlations obtained in ^{28}Si-nucleus collisions may be represented by the following second order polynomial quite well.

$$\langle N_s \rangle = (5.47 \pm 3.11) + (0.41 \pm 0.35) N_h + (0.002 \pm 0.008) N_h^2 \quad (1)$$
$$\langle N_s \rangle = (6.85 \pm 1.82) + (0.69 \pm 0.56) N_b + (0.008 \pm 0.03) N_b^2 \quad (2)$$
$$\langle N_b \rangle = (0.92 \pm 0.02) + (1.41 \pm 0.38) N_g - (0.03 \pm 0.02) N_g^2 \quad (3)$$

The continuous curve shown in figures corresponds to equations. (1-3) for 4.5 A GeV/c ^{28}Si-nucleus interactions. It is reported that the multiplicity correlations between $\langle N_s \rangle$ - N_h and$\langle N_S \rangle$ -N_g in case of hadron-nucleus collisions in the energy range ~ (24-400) GeV [2] and in 4.5 A GeV/c ^{12}C-nucleus reactions [7] may be represented by the second order polynomial. This indicates that the nature of the correlation $\langle N_s \rangle$ - N_h is almost similar in both hadron-nucleus and nucleus-nucleus collisions.
The **mean normalized multiplicity R_A** defined as the ratio of average number of relativistic charged particles produced in hadron-nucleus and hadron-hadron collisions at the same projectile energy is one of the most

important parameter to test the predictions of various theoretical models put forward for explaining the mechanism of hadronization of final stage charged particles produced in hadron-nucleus collisions. The study of R_A and its dependence on the nature and energy of the impinging hadron has been investigated by several workers in hadron-nucleus collisions at high energies [1]. However, a little attention has been paid to study this parameter in nucleus-nucleus interactions [6]. Thus, an attempt has been made to investigate the dependence of the mean normalized multiplicity, on the mass of the projectile and target nucleus. Mathematically, R_A may be given as;

$$R_A = \langle N_s \rangle_{AA} / \langle N_{ch} \rangle_{PP} \qquad (4)$$

Here $\langle N_s \rangle_{AA}$ refers to to the average number of relativistic charged particles produced in nucleus-nucleus interactions and $\langle N_{ch} \rangle_{PP}$ is the average number of charged particles emitted in Proton-Proton collisions at the same projectile energy.
The **reduced multiplicity, R_S** is defined as the ratio of the average number of relativistic charged particles produced in nucleus-nucleus reactions, $\langle N_s \rangle_{AA}$ and Proton-nucleus reactions $\langle N_{ch} \rangle_{PP}$ at the same projectile energy,

$$R_S = \langle N_s \rangle_{AA} / \langle N_s \rangle_{PA} \qquad (5)$$

It may be pointed out that the values of $\langle N_s \rangle_{AA}$ have been calculated using the following relations [6].

$$\langle N_s \rangle_{AA} = 2.34 \langle N_{ch} \rangle_{PP} - 4.12 \qquad (6)$$

The values of R_A and R_S are estimated and their dependence with the number of black tracks, N_b produced in 4.5 A GeV/c ^{28}Si-nucleus interactions is shown in Fig.5.

It is noticed in the figure that both R_A and R_S increase linearly with increasing the value of N_b up to N_b ~ 10. The experimental values of R_A and R_S are found to satisfy the following relationship, obtained by the method of least squares;

$$R_A = (0.219 \pm 0.07)\, N_b + (3.519 \pm 1.15) \qquad (7)$$
$$R_S = (0.330 \pm 0.114)\, N_b + (5.368 \pm 1.73) \qquad (8)$$

A similar behaviour of dependence of R_A and R_S with N_b is also observed in case of ^{12}C-nucleus reactions at 4.5 A GeV/c [6].Fig.6 deals with the dependence of parameters R_A and R_S with the multiplicity of grey particles, N_g. It may be noted from the figure that the values of R_A and R_S increases with increasing value of N_g up to N_g ~ 9.

The following relations obtained by the method of least square fit are found to satisfy the experimental data quite well;

$$R_A = (0.276 \pm 0.009)\, N_g + (3.321 \pm 1.32) \qquad (9)$$
$$R_S = (0.437 \pm 0.148)\, N_g + (4.860 \pm 2.08) \qquad (10)$$

A similar result has also been reported by Saleem et al [6] in the study of ^{12}C-nucleus collisions at 4.5 A GeV/c. An attempt has also been made to study the dependence of the parameters R_A and R_S with the multiplicity of heavily ionizing tracks, N_h. The variation of R_A and R_S with N_h for ^{28}Si-nucleus collisions is shown in Fig.7.
It is clear from the figure that R_A and R_S increase linearly with increasing value of N_h up to N_h ~ 28. The experimental value of R_A and R_S are found to satisfy the following fits obtained by the method of least squares.

$$R_A = (0.221 \pm 0.033)\, N_h + (1.721 \pm 0.762) \qquad (11)$$
$$R_S = (0.334 \pm 0.050)\, N_h + (2.601 \pm 1.149) \qquad (12)$$

The normalized moments of the multiplicity distributions of relativistic charged particles produced in high energy hadron-nucleus collisions has been investigated by several workers in the energy range ~ (50-400) GeV [4]. However, a little attention has been paid to study the normalized moments of the multiplicity distributions of relativistic charged particles produced in nucleus-nucleus interactions [3, 6]. Thus, it was considered worthwhile to investigate the normalized moments of the distributions and their dependence on the mass of the projectile and struck nucleus.

The **normalized moments** of the multiplicity distributions of relativistic charged particles is defined as;

$$C_K = \langle N_S^K \rangle / \langle N_S \rangle^K \quad (13)$$

where K is a constant and can have different values 2, 3, 4 etc. For studying the dependence of C_K on the size of the target nucleus, the values of C_2, C_3 and C_4 are calculated for different groups of emulsion nuclei in 4.5 A GeV/c ^{28}Si-nucleus interactions. The values of C_K obtained in 4.5 GeV/c ^{28}Si-nucleus reactions are listed in Table-1 along with the results obtained in ^{12}C-nucleus reactions [3,6] at the same projectile energy.

It is interesting to note that the values of C_K in 4.5 A GeV/c ^{12}C-nucleus reactions and ^{28}Si-nucleus collisions are almost consistent with constant with the statistical limits. It may be further noted in the Table-1 that, the value of this parameter is observed to increase with increasing value of k. On comparing the findings of the present work with those obtained in 50 GeV and 400 GeV hadron-nucleus collisions [4], it may be observed that the value of C_K are very similar in both type of interactions. The kth root of the central moment, μ_K of the multiplicity distribution is also studied in 4.5 A GeV/c ^{28}Si-nucleus collisions.

The parameter μ_K is defined as:

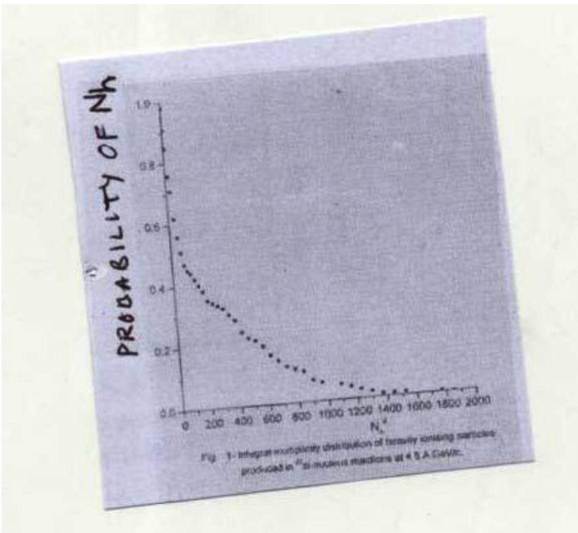
$$(\mu_K)^{1/2} = (\langle (N_S - \langle N_S \rangle)^K \rangle)^{1/2} \quad (14)$$

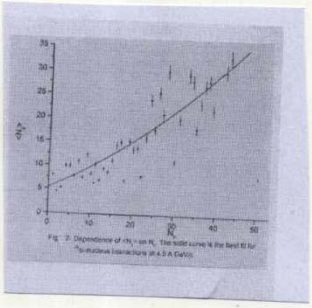
In Fig.7 we have plotted $(\mu_2)^{1/2}$, $(\mu_3)^{1/2}$, $(\mu_4)^{1/2}$ as a function of $\langle N_S \rangle$ for ^{28}Si-nucleus interactions at 4.5 A GeV/c. It may be seen in the figure that the solid line which represent the variation of the moments with $\langle N_S \rangle$ fits the experimental data quite well. On comparing these observation with those obtained in high energy hadron-nucleus collisions, it may be concluded that there is at least a qualitative similarity in the mechanism of hadronization in the final stage of high energy hadron-nucleus as well as nucleus-nucleus reactions.

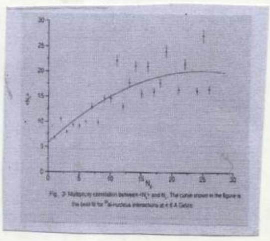
III. Figures And Table

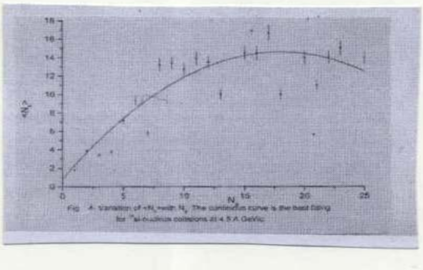
Table.1- Values of normalized moments C_2, C_3 and C_4in nucleus -nucleus reactions at 4.5 A GeV/c.

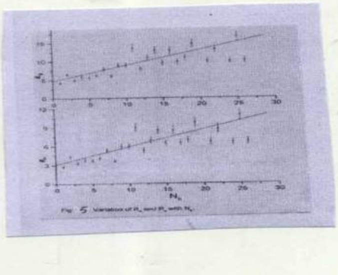
Type of Interactions	C_2	C_3	C_4	References
^{12}C-CNO	1.41 ±0.10	2.42 ±0.23	4.73 ±0.58	6
^{28}Si-CNO	1.41±0.01	2.44±0.007	4.41±0.003	Present work
^{12}C-Em	1.43±0.05	2.51±0.12	5.15±0.33	6
^{12}C-Em	1.58±0.07	2.67±0.13	-	3
^{28}Si-Em	1.53±0.01	3.06±0.013	7.19±0.01	Present work
^{12}C-AgBr	1.27±0.06	2.20±0.13	3.09±0.24	6
^{12}C-AgBr	1.29±0.26	2.48±0.08	-	3
^{12}Si-AgBr	1.31±0.007	4.56±0.004	3.55±0.35	Present work

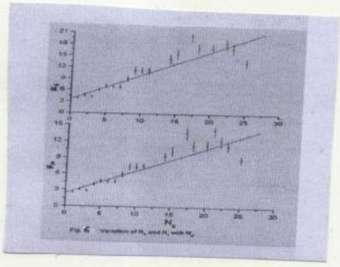


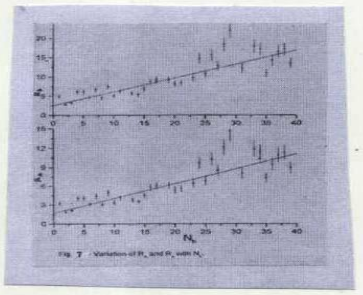












IV. Conclusions

On the basis of the study of the present work we draw some important conclusions which are summarized as follows:

(i).The multiplicity correlations amongst $\langle N_S \rangle$ - N_b, $\langle N_b \rangle$ - N_g, $\langle N_S \rangle$ - N_h are non-linear and may be represented quite well by the second order polynomial. Thus, our findings are in marked disagreement with those reported by other workers in both hadron-nucleus and nucleus-nucleus interactions.

(ii).The experimental values of R_A and R_S are found to increase linearly with increasing value of N_b, N_g and N_h, N_b up to $N_b \sim 10$, N_g up to $N_g \sim 9$, and N_h up to $N_h \sim 28$.

(iii).The values of normalized moments are found to remain almost constant. However, the value of this parameter increases with increasing value of k.

(iv).The results reveal that the k^{th} root of the central moment increases with increasing value of $\langle N_S \rangle$.

(v).On comparing the results obtained in 4.5 A GeV/c nucleus-nucleus interactions with those obtained in high energy hadron-nucleus collisions, we conclude that the results both in hadron-nucleus and nucleus-nucleus interactions are almost similar and the mechanism of hadronization of final stage charged particles operating in these reactions is perhaps the same.

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