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Analysis Slow Particle Emitted ^{24}Mg with Emulsion Interactions at Relativistic Energies

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Abstract In this work has been made to study the general characteristics of slow particles produced in the interactions of ^{24}Mg with emulsion at 4.5 A GeV/c to extract the information about the mechanism of particle production. The results have been compared with the experimental results obtained by other workers. The multiplicity distributions of the slow target associated particles (grey, black and heavy tracks) produced by ^{24}Mg- incident with different targets have been studied. Also several types of correlations between them have been investigated. The variation of the produced particles with projectile mass number and target size has been studied.

Keywords Multiplicity distributions, Correlations between multiplicities of slow particles

1. Introduction

The study of the characteristics of secondary charged particles produced in nucleus- nucleus interactions at relativistic energies has received considerable necessary during the recent years [1-6]. Our objective in this work is to employ the interactions of ^{24}Mg in nuclear emulsion. The emulsion has the unique property of acting simultaneously as the target as well as the detector, for registering all the charged particles in 4π geometry with the highest spatial resolution as compared to the electronic. We have reported some results based on the general characteristics of slow particles produced in the interactions of ^{24}Mg with emulsion at 4.5 A GeV/ c to extract the information about the mechanism of particle production. The multiplicity distributions of the slow target associated particles (grey, black and heavy tracks) produced by ^{24}Mg projectile with different targets have been studied. Also several types of correlations between them have been investigated. The variation of the emitted particles with incident mass number and target size has been studied.

2. Experimental Techniques

Nuclear emulsions of the type BR-2 were exposed to 4.5 AGeV/c ^{24}Mg beam at the Dubna synchrophastron. The pellicles of emulsion have the dimensions of 20 cm x 10 cm x 600 mm. The intensity of the beam was 10^{24} particles/ cm^2 and the beam diameter was approximately 1 cm. Along the track, a double scanning has been carried out fast in the forward direction and slow in the backward one. The multiplicity of charged particles in high energy nucleus-nucleus interactions is an important parameter which indicates how many particles are produced in that interaction. The multiplicity distributions of produced particles or emitted particles help in learning the interaction mechanism. Generally, it is accepted that in high energy nucleus- nucleus collision, the emission of slow target- associated particles (i.e. black tracks) and other heavier fragment takes place at a still later stage with range $L \leq 3$ mm, relative velocity $\beta < 0.3$ and energies less than 30 MeV. The emission of fast target associated particles mostly the knocked out protons known as grey particles, takes place at a relatively latter stage of the collision. These fast protons with range $L \geq 3$ mm and relative velocity $0.3 \leq \beta \leq 0.7$ lie in the energy range 30 to 400 MeV. Moreover, these target – associated particles are mostly slow and fast protons and grey particles are often assumed to be the measure of the number of encounters made by the incident hadron inside the target nucleus [7] and believed to be produced as a result of process of re-scattering in the target spectator region. The black and grey tracks together are known as heavily ionizing tracks denoted by N_h.

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3. Results and Discussion

3.1. Multiplicity Distributions of Grey, Black, Heavily Particles Production

The investigation of the experimental data in terms of multiplicity distributions for different emitted secondaries is one of the main sources of information about the mechanism of particle production. Figures 1 (a)-(c) presents the multiplicity distributions of grey, black and heavily ionizing particles from ^{24}Mg with emulsion interactions at 4.5 GeV/c along with the distribution obtained from ^{32}S with emission [8] and ^{28}Si with emulsion [9] interactions at 200 A GeV and 14.6 A GeV respectively for comparison. It is seen that from the figures that the distributions appear in the lower values of N_g, N_b and N_h. These distributions seem to be independent of incident energy as well as projectile mass within statistical errors up to lower value of N_g, N_b, and N_h. It may also notice that from the figures that the percentage of events with large value of N_g, N_b and N_h increases with projectile mass. Finally, it may be arranged from the multiplicity distributions of slow and fast protons produced in nucleus- nucleus interactions that no significant differences are observed regarding the mechanism of their production with energy. Figures 2(a)-(c) and figures 3(a)-(c) presents the N_g, N_b, and N_h multiplicity distributions from ^{24}Mg with CNO and ^{24}Mg with AgBr interactions at 4.5AGeV/c. The results obtained by other workers for ^{32}S and ^{28}Si at 200 A GeV and 14.6 A GeV [8.9] respectively are collection in the same figure for comparison. For the figures 2(a)-(c) and 3(a)-(c) we see that the characteristics features of the distribution is same in shape for all targets, but the multiplicity range or decay tail increases with target size. It has also been found that the distributions for ^{24}Mg with AgBr are broader than those for ^{24}Mg with CNO interactions.

3.2. Scaling of Grey Particles

At this part from the work, the events with $N_g = 0$ neglected because the stick processes may be also share to such events. Figure 4(a) displays the $N_g/ <N_g>$ distribution from ^{24}Mg with emulsion at 4.5 A GeV/c. A straight line of the form:

$$\mathrm{Ln}\,(N_{ev}) = A\,(N_g / < N_g >) + B \qquad (1)$$

is found to represent the present data, N_{ev} denotes the number of events in the given bin and A and B are constants. The best fit to the data is given as $\ln (N_{ev}) = -(0.760.04\pm)\ N_g/< N_g> +$ (4.35 ±0.13).

For comparison the $N_g/ <N_g>$ distributions from ^{32}S with emulsion at 200 A GeV [8] and ^{28}Si with emulsion at 14.6 A GeV and 4.5 A GeV [10] are also plotted in figures 4 (b)-(d). The values of the slopes for ^{32}S with emulsion at 200 A GeV and ^{28}Si with emulsion at 14.6 A GeV and 4.5 A GeV are found to be – 0.97 ± 0.07, - 0.88 ± 0.04 and -0.89 ± 0.08 respectively. The slope parameters are ~ - 0.90, which are very much consistent with the value obtained for ^{24}Mg with emulsion at 4.5 A GeV/c. The constancy in the value of slopes for nucleus- nucleus collisions at different energies may be interpreted as existence of some kind of scaling for the emission of grey tracks.

3.3. Average Multiplicity of Charged Particles

Multiplicity of different charged particles is helpful in understanding the mechanism of multiparticle production. The average value of number of grey, black and heavily ionizing particles emission in ^{24}Mg with emulsion interactions at 4.5 A GeV/c are presented in Table 1. It can be observed from the results presented in the table that the value of $<N_g>$ depends weakly with increasing mass of the projectile as well as energy of the projectile, whereas the value of $<N_g>$ do not exhibit any such trends. The increasing trend is missing in the value of $<N_b>$ because slow particles are produced due to evaporation of excited residual nucleus.

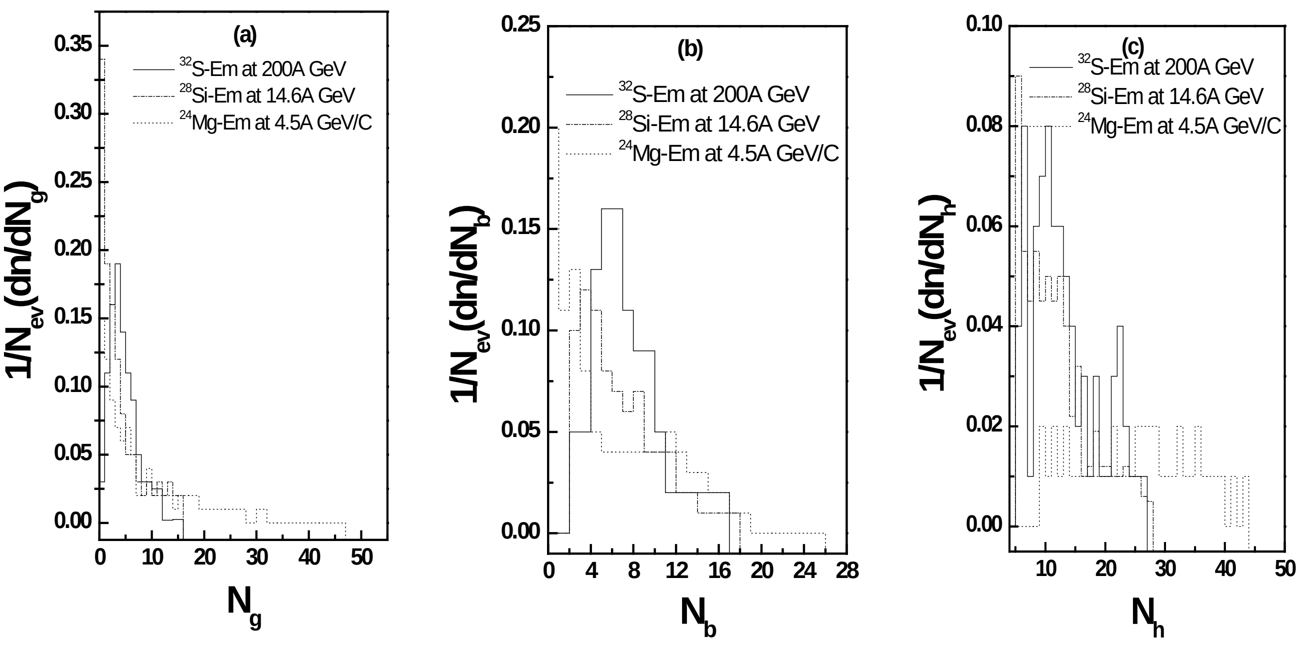

Figure 1. Multiplicity distributions of charged particles emitted in collisions of projectiles with emulsion for (a) grey particles (b) black particles and (c) heavily ionizing particles

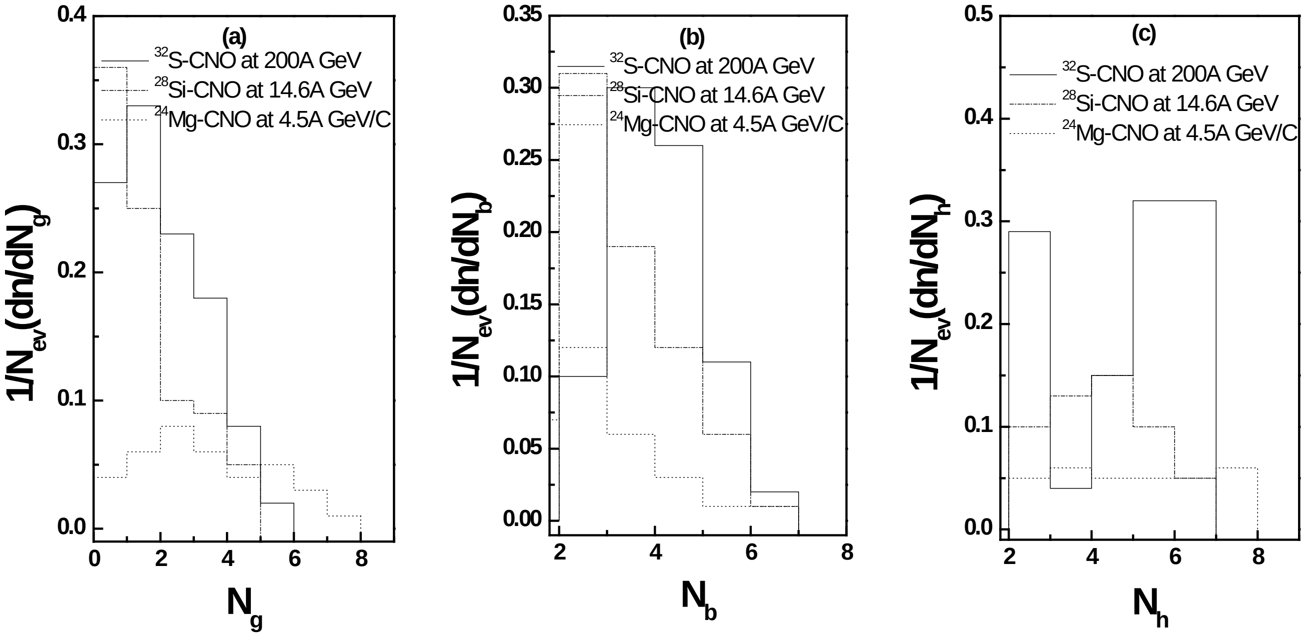

Figure 2. Multiplicity distributions of charged particles emitted collisions of different projectiles with CNO for (a) grey particles (b) black particles and (c) heavily ionizing particles

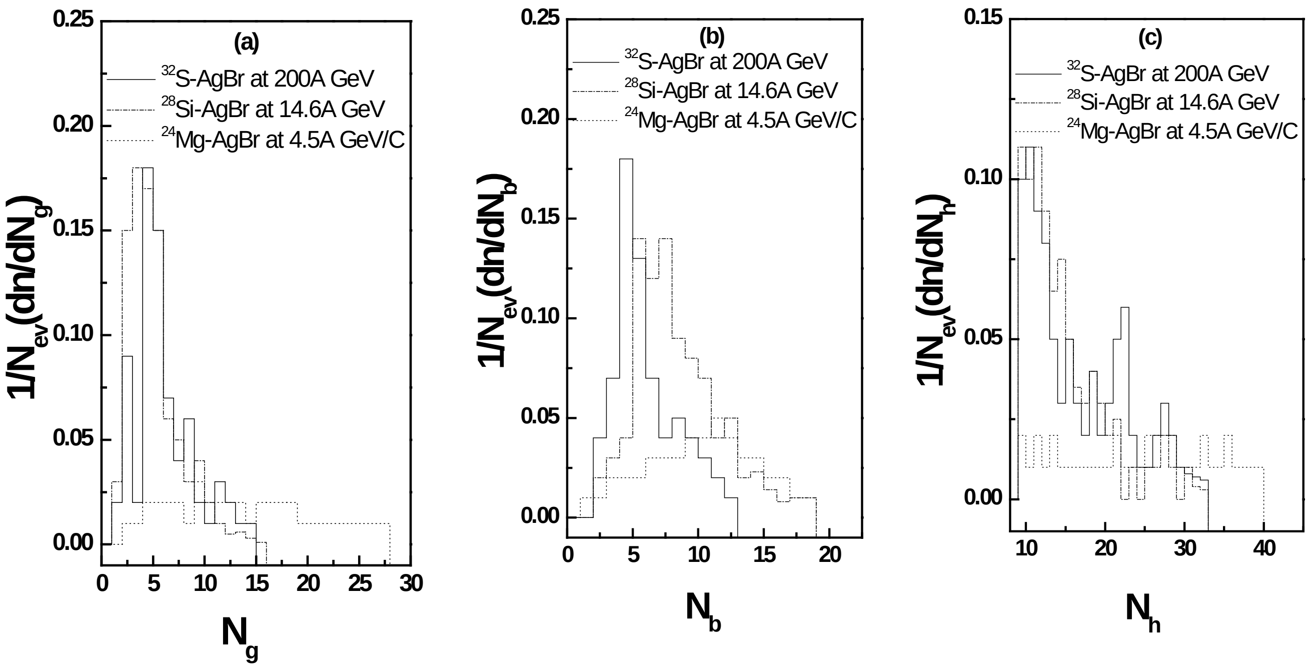

Figure 3. Multiplicity distributions of charged particles emitted collisions of different projectiles with AgBr for (a) grey particles (b) black particles and (c) heavily ionizing particles

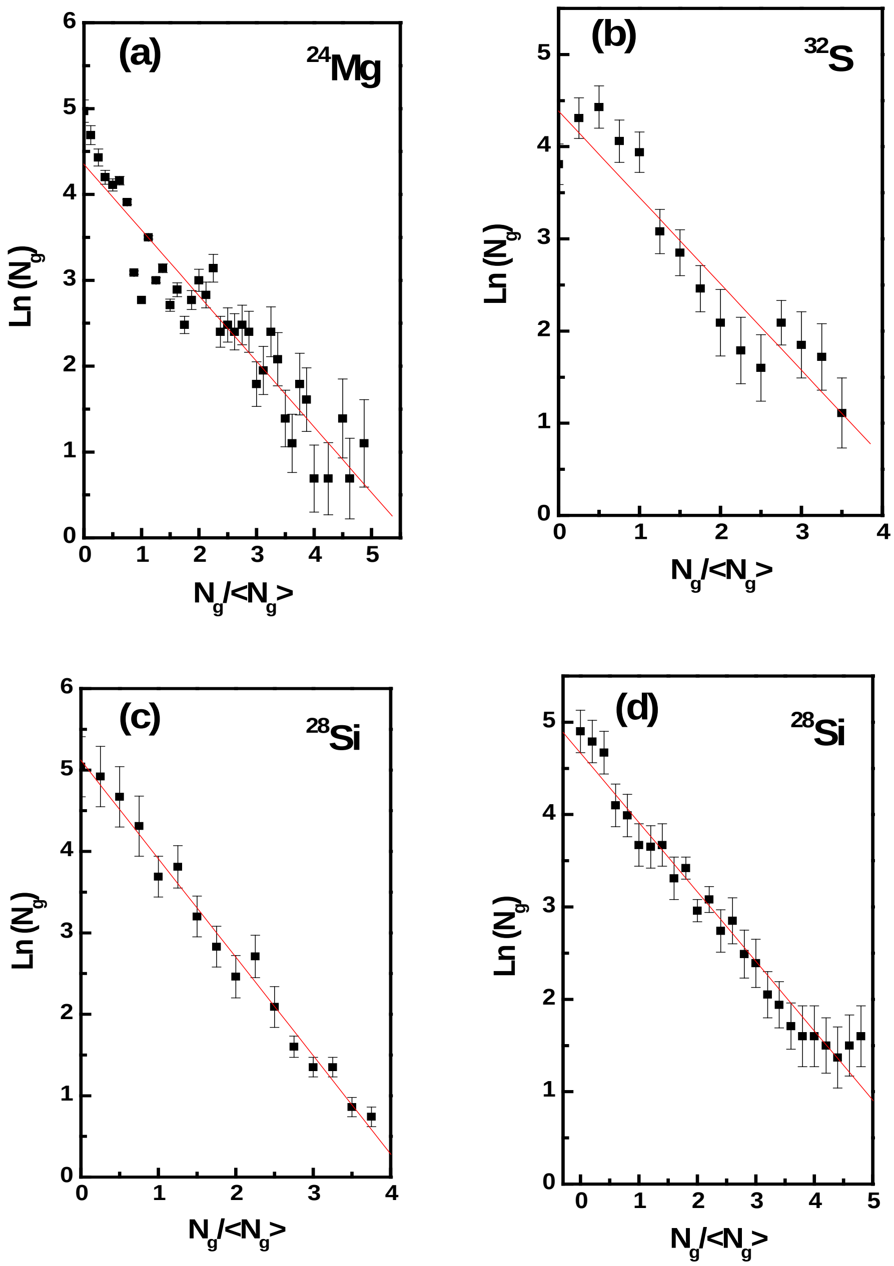

Figure 4. Draw of Ln(Nev) against N_g /< N_g > for different collision at different energies (a) ^{24}Mg – Em at 4.5 AGeV. (b) ^{32}S – Em at 200 AGeV. (c) ^{28}Si – Em at 14.6 AGeV. (d) ^{28}Si –Em at 4.5 AGeV

Table 1. Average multiplicity of various particles produced in heavy ion collisions at high energies

Energy/nucleon GeV	Collision type	$< N_b >$	$< N_g >$	$< N_h >$	Ref
4.5	P – Em	3.77±0.08	2.81±0.06	6.51±0.10	11
4.5	^{4}He – Em	4.70±0.20	4.70±0.20	9.40±0.23	12
4.5	^{7}Li – Em	5.37±0.18	3.80±0.12	9.14±0.29	13
4.5	^{12}C – Em	4.51±0.10	5.75±0.11	10.26±0.37	9
2.1	^{14}N – Em	4.57±0.21	5.29±0.31	9.86±0.25	14
14.6	^{28}Si - Em	5. 5±0.08	2.85±0.06	8.40±0.09	9
200	^{16}O - Em	5.39±0.29	2.03±0.11	7.42±0.33	15
200	^{32}S - Em	6.67±0.14	3.14±0.20	9.81±0.17	8
4.5	^{24}Mg – Em				Presen work

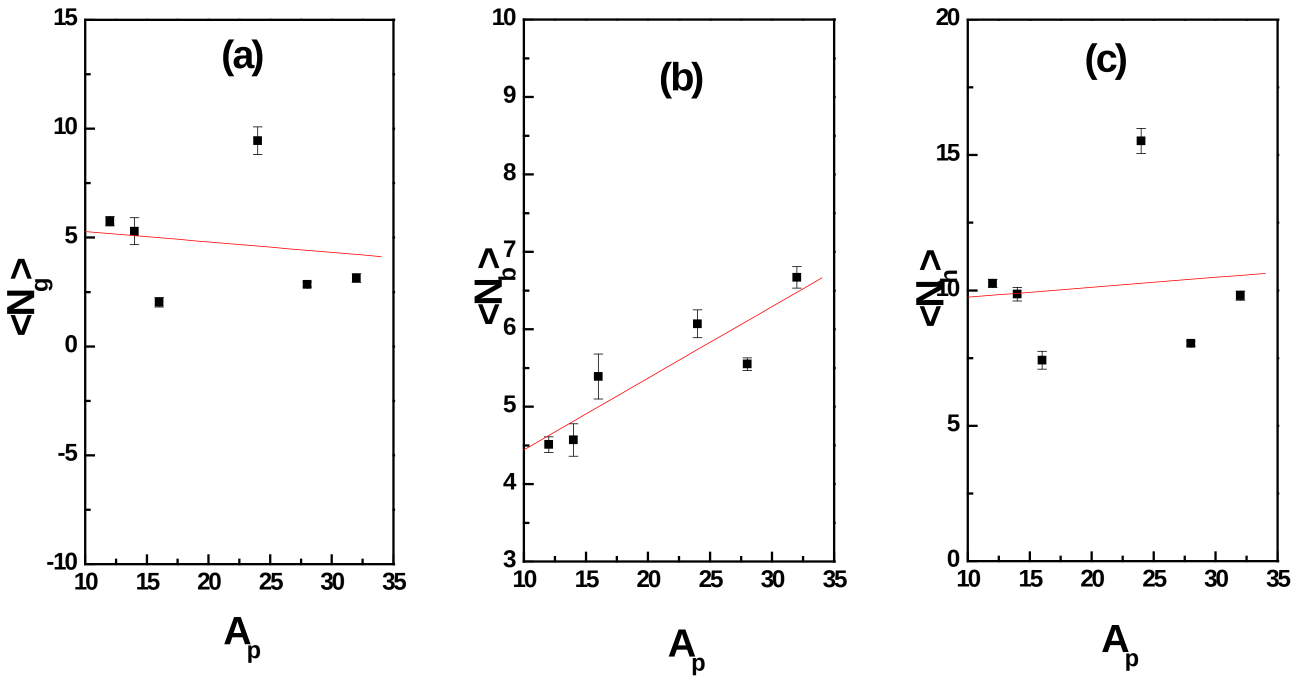

Figure 5. Deviation of $<N_g>$, $<N_b>$ and $<N_h>$ as a function of projectile mass number (A_p) at different energies

Table 2. Average values of $<N_g>$, $<N_b>$, $<N_h>$ in ^{24}Mg with emulsion interactions along with different N_h intervals at 4.5 A GeV/c

Interval group of evens	$< N_g >$	$< N_b >$	$< N_h >$	$< N_b >/D$
All-Em	9.45±0.34	6.07±.18	15.52±0.46	0.64±0.06
$2\leq N_h \leq 7$	3.99±0.08	3.43±0.13	7.40±0.39	0.86±0.10
$8 \leq N_h \leq 20$	13.44±0.24	9.99±0.31	23.43±0.45	0.74±0.10
$N_h \geq 8$	18.23±0.44	10.56±0.24	28.79±0.52	0.58±0.05
$N_h > 20$	27.54±0.61	10.95±0.34	38.49±0.66	0.40±0.06

Table 3. Values of D(Ng) and $< N_b > / < N_h >$

Group of events	$D(N_g)$	$< N_b >/< N_h >$	$D/< N_g >$	$< N_g >/D$
^{24}Mg-Em	8.79±0.02	0.39±0.04	0.95±0.i0	1.05±0.02
$22 \leq N_h \leq 7$	1.58±0.02	0.46±0.03	0.40±0.03	2.52±0.04
$8 \leq N_h \leq 20$	3.72±0.09	0.43±0.07	0.28±0.04	3.62±0.03
$N_h \geq 8$	7.86±0.10	0.37±0.05	0.43±0.02	2.32±0.04
$N_h > 20$	6.19±0.27	0.28±0.05	0.22±0.05	4.45±0.02

Also we study the dependence of the average multiplicities on projectile mass A_p, using the following power law:

$$<N_i> = \alpha_i (A_p)^{\beta j} \quad (2)$$

where i= g, b, h and $<N_i>$ represents the mean multiplicity. The values of the slope (β) for grey, black and heavy tracks obtained from the least square fits are given as (-0.05 ± 0.016) (0.04 ± 0.02) and (0.04 ± 0.02) respectively. The dependence of $<N_g>$, $<N_b>$ and $<N_h>$ on the projectile mass number A_p, is presented in figure 5 (a) – (c). The deviation of $<N_b>$ with A_p is shown in figure 5 (a), which is almost independent of the projectile mass number and its energy. This constancy of $<N_b>$ indicates that the average excitation of the residual target nucleus has reached its saturation at present incident energy. The strong dependence of the charged secondary particles on the masses of colliding nucleus are due to the increase in the overlapping region of the two interacting nuclei. Table 2 presents the average multiplicities of grey, black and heavily ionizing particles for ^{24}Mg with emulsion inelastic interactions at 4.5 A GeV/c for different N_h-intervals. It is seen that the average multiplicities of slow particles increases with increase of centrality collisions. A regular pattern in the values of the ratio $<N_b>/<N_g>$ has been recorded from the table except for interval ($2 \le N_h \le 7$) events which is slightly higher.

The average values of dispersion $D(N_g)$, $<N_b>/<N_h>$ and $D/<N_g>$ for different N_h groups of ^{24}Mg with emulsion interactions at 4.5 A GeV/c are given in Table 3. From the table it may be clearly noticed that the as the degree of disintegration of the target nuclei increases, the ratio of the number of slow evaporated particles (N_b) to heavily ionizing particles (N_h) i.e. the $<N_b>/<N_h>$ is nearly constant. The result contradicts the results obtained by Antonchilk et al. [16] for $7 \le N_h \le 27$ and $N_h \ge 28$ respectively.

3.4. Correlations between Multiplicities of Slow Particles

Multiplicity correlations between the heavily ionizing particles produced in nucleus- nucleus collisions have been widely studied which help to investigate the mechanism of particle production. In order to examine the behavior of multiplicity correlations of secondary particles produced in nucleus- nucleus collisions, we have studied the correlations in the interactions of ^{24}Mg with emulsion at A GeV/c. The experimental data have been analyzed by using linear fits of the type:

$$<N_i (N_j)> = a_{ij} N_j + b_{ij} \quad (3)$$

Where N_i, N_j = N_g, N_b and N_h with $i \ne j$. The values of inclination coefficients, a_{ij}, and intercepts, b_{ij} are given in Table 4. The behaviour of multiplicity correlations of secondary particles produced in ^{24}Mg with emulsion interactions at 4.5 A GeV/c is presented in figures 6 (a)- (c) along with their linear fits least square method. From these plots following conclusions may be drawn.

i) variation of $<N_g>$ with N_b is similar to that of $<N_b>$ with N_g. However, the saturations are not statistically significant. Also $<N_b>$ shows a linear dependence on N_h in the whole range of N_h.

ii) A clear saturation in the values of $<N_b>$ is observed in $<N_b>$ vs N_g plot for values of N_g beyond ~ 10. This means correlation does not depend on mass of the projectiles and the contribution of the recoiling nucleons towards the excitation energy of the residual nucleus is approximately the same for proton- nucleus and nucleus- nucleus interactions.

iii) The values of $<N_h>$ increases with increase of in the hole range of N_g and N_b in nucleus- nucleus interactions.

Table 4. Values of deviation coefficients a_{ij}, and intercepts b_{ij}, in multiplicity correlation in ^{24}Mg with emulsion at 4.5 A GeV/c

N_j	a_{ij}			b_{ij}		
	$<N_g>$	$<N_b>$	$<N_h>$	$<N_g>$	$<N_b>$	$<N_h>$
N_g	**0000000**	0.21+0.05	1.22+0.04	**00000000**	5.40±1.03	4.92±0.86
N_b	0.98±0.10	**0000000**	1.98±0.10	3.43±1.111	**00000000**	3.42±1.11
N_h	0.75±0.02	0.26±0.02	**0000000**	2.08±0.59	2.43±0.59	**00000000**

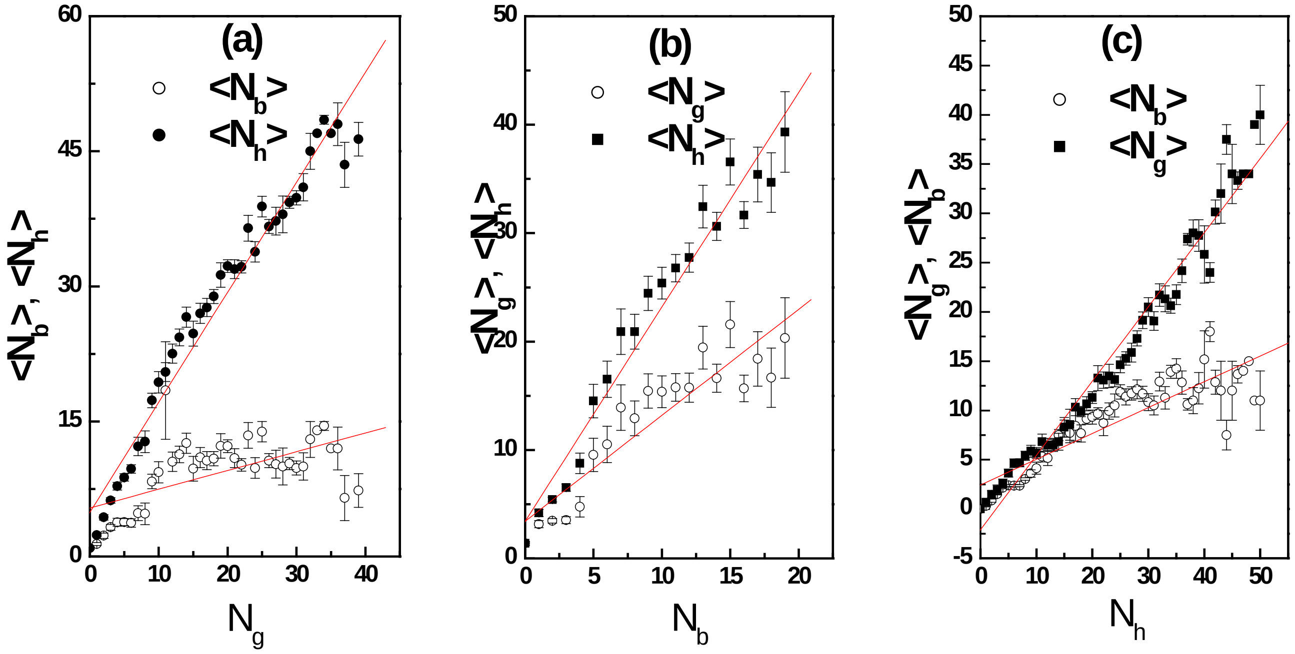

Figure 6. Correlations multiplicity of various charged particles, emitted in the collisions of ^{24}Mg with emulsion at 4.5 AGeV

3.5. Target Size Dependence of <N_g>, <N_b> and <N_h>

In order to see the dependence of the average multiplicities on the mass numbers of the nuclei, the following relation has been used as:

$$< N_j > = KA^{\alpha} \quad (4)$$

Where j stands for grey, black and heavy particles respectively. The variation of average multiplicities on masses of the target nuclei is display in figure 7. The coefficients K and α, are determined from the least- square fit using the experimental data of the present study. The values of these coefficients are given in table 5. The results show that the multiplicities of grey particles are characterized by extremely weak target size dependence. The multiplicities of black particles are nearly proportional to linear dimensions of target nuclei.

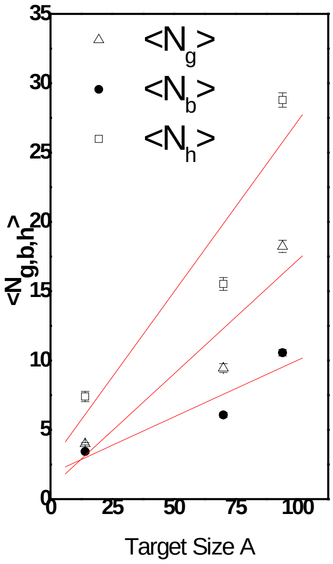

Figure 7. Deviation of <N_g>, <N_b> and <N_h> with the size of the target

Table 5. Values of coefficients K and α

N_j	K	α
< N_g>	4.21±0. 84	0.16±0.06
< N_b>	2.20±0.18	0.08±0.03
< N_h>	6.40±0.27	0.25±0.10

4. Conclusions

From the analysis of slow particles emitted from ^{24}Mg with emulsion collision, we can make the following conclusion:

i) It is seen that the peaks N_g, N_b and N_h of multiplicity distributions appear in the lower values of N_g, N_b and N_h and all the distributions are essentially independent of incident energy and the projectile masses. It is also notice that the target combination particles have a weak dependence on the projectile mass number A_p.

ii) It is seen that average multiplicity of slow particles increases of centrality collisions. A regular pattern in the values of the <N_b>/<N_g> has been observed except for CNO ($2 \leq N_h \leq 7$) events.

iii) It can be seen that the value of<Ng> depends weakly with increasing mass of the projectiles as well as energy of the projectiles. The values of <N_b> do not exhibit any such trends.

iv) It may be seen that the impact parameter decreases, the ratio of the number of slow particles (N_b) to heavily ionizing particles (N_h) i.e <N_b>/<N_h> is approximately constant.

v) It has been found that multiplicities of black particles are nearly proportional to linear dimension of target nuclei whereas the multiplicities of grey particles are characterized by extremely weak target size dependence.

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