Physics International 1 (1): 31-37, 2010
ISSN 1948-9803

Characteristics of Compound Multiplicity in ^{24}Mg with Emulsion at 4.5 A GeV/c

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Abstract: Problem statement: The interactions of ^{24}Mg at 4.5A GeV/c with an emulsion can reveal some compound multiplicity characteristics. **Approach:** Furthermore, the number of grey and shower particles taken together a termed the compound multiplicity. **Results:** The results revealed that the compound multiplicity distributions become wider with increasing the size of the struck nucleus and the value of the $<n_c>$ increases with increasing mass of the projectile and target. Moreover, the average compound multiplicity is found to vary linearly with shower, grey, black and heavily ionized particles. On the other hand, the mean multiplicities of shower, grey, black and heavily ionized particles increase with an increase in the number of compound multiplicity. Meanwhile, the dependence of shower, grey and black particles emitted in the forward and backward hemispheres on the number of compound particles emitted in the forward and backward hemispheres is also investigated. **Conclusion:** Finally, the n_s distributions obey the KNO scaling (i.e., the multiplicity distribution has a universal behavior when it is rescaled to the $<n_s>$.

Key words: Compound multiplicity, forward and backward hemispheres

INTRODUCTION

In recent years most of the experiments on high energy hadrons-nucleus and nucleus-nucleus collisions have been carried out to investigate the characteristics of shower particles. The study of characteristics of grey particles produced in such collisions has also increased recently (Anderson *et al*., 1978; Stenland and Otterland, 1982; Jain *et al*., 1991; EL-Nadi *et al*., 1995). As already explained the grey particles are emitted shortly after the passage of the leading hadrons. Therefore one may expect that it is worthy to use the compound multiplicity of grey and shower particles. Let us define the variable n_c which equal the sum of n_s and n_g, i.e., n_c ($= n_s+n_g$) was introduced by the authors (Ghosh *et al*., 2009) in the case of hadrons-nucleus interactions and then some interesting characteristics of compound particles produced in hadrons-nucleus and nucleus-nucleus collisions were investigated by several authors (Ghash *et al*., 1987; Basova *et al*., 1978; Nasr and Khushnood, 1994; Khan *et al*., 1997; Abdelsalam *et al*., 2002; Ahmed and Irfan, 1991). The production of particles emitted in the backward hemispheres in the laboratory system, was extensively studied in hadrons-nucleus collisions at high energies. The target nucleus, being an extended object gives a unique opportunity for studying the space time development of the multiparticle production process. It has been shown that the internuclear cascade plays a significant role the production of particles, in the backward direction in high energy hadrons-nucleus and nucleus-nucleus collisions (El-Nadi *et al*., 2001) became a subject of considerable interest. This interest may be attributed to the fact the backward emission of particles, produced in high energy hadrons-nucleon collisions is restricted due to kinematics such emission of particles allows the possibility of considering some of the theoretical cluster models.

MATERIALS AND METHODS

Experiment details: A stack of nikfi-BR-2 nuclear emulsion was exposed to 4.5 A GeV/c ^{24}Mg beam at Dubna Synchrophastron. The stacks have dimensions of $20\times10\times0.06$ cm^3. The intensity of irradiation was 10^4 particle cm^{-3}. Each of the stacks particle was scanned by the along the track method, in the fast forward direction and slow in the backward direction. The scanned beam tracks were further, examined by measuring δ-ray density on each of them to exclude the tracks having charge less than the beam particle charge. Along the track scanning was performed to select the data samples, consisting of 2300 inelastic ^{24}Mg with emulation interactions. In the measured events, the secondary particles are classified as follows:

- Shower particles (s-particles) having $I^*(= I/I_0)$ <1.4(tracks of such type with an emission angle of $\theta<3°$ were further subjected to rigorous multiple scattering measurement for momentum determination and consequently, for separating the produced pions and singly charged projectile fragments (protons, deuterons, tritons)

- Grey particles (g-particles) relative ionization I* (= I/I_0)> 1.4 and L>3 mm which correspond to a proton kinetic energy of 26-400 MeV, where I is the particle track ionization and I_0 is the ionization of shower track in the narrow forward cone of an opening angle of $\theta<3°$
- Black particle (b-particle) having a range L<3 mm in emulsion which corresponds to a proton kinetic energy of <26 MeV, (the g and b particle are called heavy ionizing particle tracks (h)

RESULTS AND DISCUSSION

Compound multiplicity: Figure 1 presents the compound multiplicity distributions for 4.5 A GeV/c, in case ^{24}Mg with emulsion interactions for different ensembles of n_h. It can be seen that the multiplicity distributions become wider with increasing target size. The average value of the compound multiplicity $<n_c>$, its dispersion D (n_c) = $\sqrt{<n_c^2>-<n_c>^2}$ and the ratio $<n_c>/D(n_c)$ are presented in Table 1.

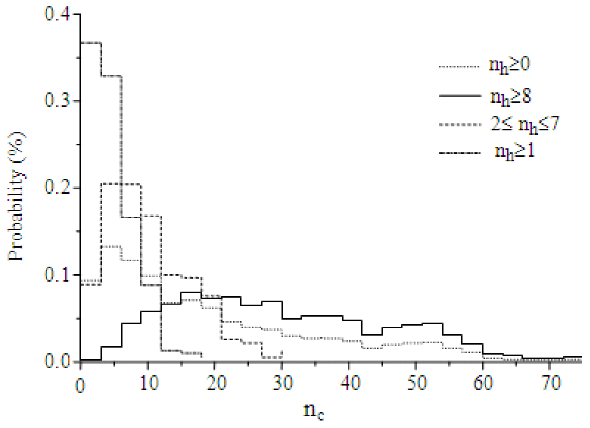

Fig. 1: Compound multiplicity distributions for different groups of n_h in $^{24}M_g$ with emulsion collisions at 4.5 A GeV/c

Table 1: The value of average compound multiplicity $<n_c>$, the dispersion D (n_c) and the ratio $<n_c>/D(n_c)$ in $^{24}M_g$ with emulsion interactions at 4.5 A GeV/c

Target	$<n_c>$	$D(n_c)$	$<n_c>/D(n_c)$
H	4.23±0.17	3.40±0.26	1.65±0.16
CNO	10.00±0.24	6.65±0.16	1.50±0.08
Emulsion	19.00±0.34	16.00±0.34	1.16±0.70
AgBr	29.72±0.47	15.89±0.18	1.80±0.50

Furthermore, to study the dependence of the behavior of the compound multiplicity distributions on the projectile mass at the same incident momentum, we have plotted the compound multiplicity distributions in Fig. 2 for the ^{24}Mg, ^{28}Si and ^{32}S with emulsion interactions at 4.5 A GeV/c. It can be seen that the distributions become wider and the peak of the distributions shifts toward higher values of n_c with increasing projectile mass, which further confirms the results of (Khan *et al*., 1995; 1997). Figure 3 shows the dependence of the average compound multiplicity $<n_c>$ on the mass number of the beam nucleus A_B. It may be observed from the Fig. 3 that $<n_c>$ increase rapidly with increasing mass of the beam. The points are the experimental data while the continuous line is the result of fitting by the relation $<n_c> = K\, A^{\alpha}_B$. The result of fitting gave that k = 4.40±0.43 and α = 0.44±0.03. This result agreement with the results in reported in Ref. (Khan *et al*., 1997).

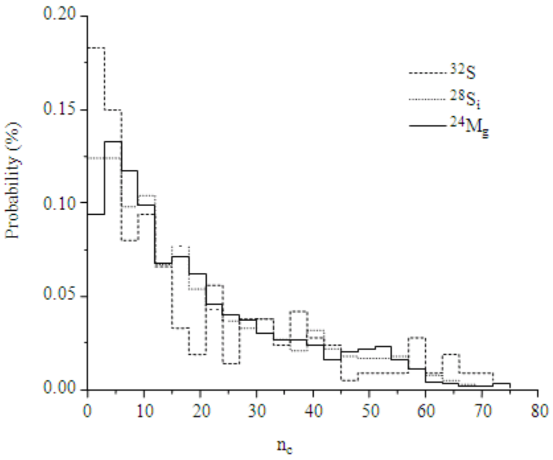

Fig. 2: Compound multiplicity distributions in nucleus-nucleus collisions at 4.5 A GeV/c

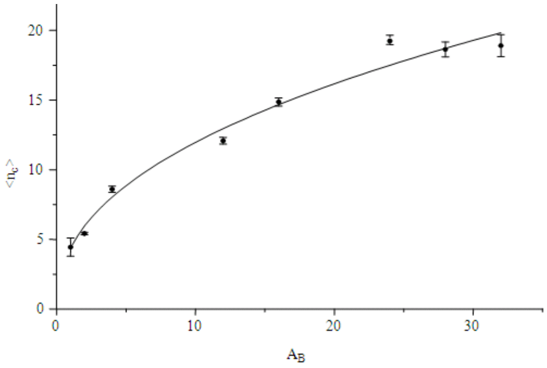

Fig. 3: Dependence of $<n_c>$ on the mass of the projectile in nucleus-nucleus collisions at 4.5 A GeV/c

Table 2: A compilation of the compound multiplicity for different projectile induced emulsion reactions at 4.5 A GeV/c

Projectile	$<n_c>$	$D(n_c)$	Reference
^{1}H	4.44±0.66		Aabddklmtu (1981)
^{2}H	5.42±0.09		Basova *et al.* (1978)
$^{4}H_e$	8.60±0.22		Khan *et al.* (1997)
^{12}C	12.08±0.24	7.50±0.24	Ghash *et al.* (1989)
^{16}O	14.87±0.30	13.72±0.23	Cai and Zang (2006)
$^{24}M_g$	19.00±0.34	16.00±0.24	Present study
$^{28}S_i$	18.64±0.54	16.71±0.28	Present study
^{32}S	18.91±1.33	16.65±0.33	Present study

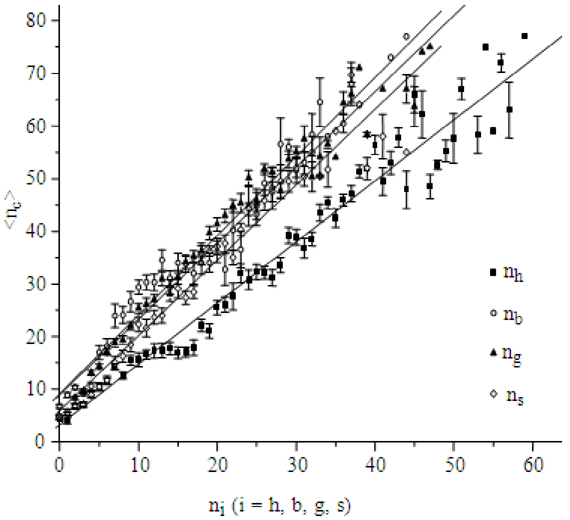

Fig. 4: Dependence of $<n_c>$, on n_s, n_g, n_b and n_h for $^{24}M_g$ with emulsion at 4.5 A GeV/c

The study of the compound multiplicity correlation in high energy heavy ion collisions has been carried out in some experiment (Ghash *et al*., 1987; 1989; Khan *et al*., 1997), but it was limited to a few projectiles. So the detailed results from different projectiles are needed. In Fig. 4 we present the average compound multiplicity $<n_c>$ versus shower, grey, and black and heavy ion particles n_s, n_g, n_b and, n_h for ^{24}Mg with emulsion at 4.5 A GeV/c. It can be seen that $<n_c>$ increase linearly with increasing n_s, n_g, n_b and, n_h. The experimental point are fitted by the relation $<n_c> = a+bn_i$, where i indicate to s, g, b and h respectively. The best fit parameter b is listed in Table 3 for comparison the corresponding results from the ^{1}H, ^{12}C and ^{16}O with emulsion interactions at the same energy are also listed in the Table 3. It is observed that the value of the inclination coefficients in the case of the $<n_c$ and n_h correlation are almost of the same order for heavy ion proton -nucleus collision. It can be seen from Table 3 that the inclination coefficients for the dependence of $<n_c>$ on n_g and n_h increases with increasing projectile mass, but for the dependence of $<n_c>$ on ns, the inclination coefficients decreases with increasing projectile mass, which can be explained by the impact geometry.

Table 3: Values of inclination coefficients for compound multiplicity correlation in nucleus emulsion interactions at 4.5 A GeV/c

Projectile	n_i	$<n_c>$	Reference
^{1}H	n_b	0.32±0.04	Ghash *et al.* (1989)
^{12}C		2.49±0.10	Khan *et al.* (1997)
^{16}O		1.73±0.05	Cai and Zang (2006)
$^{24}M_g$		1.51±0.05	Present study
^{12}C	n_g	1.51±0.07	Khan *et al.* (1997)
^{16}O		2.19±0.03	Cai and Zang (2006)
$^{24}M_g$		1.43±0.04	Present study
^{1}H	n_h	0.32±0.03	Ghash *et al.* (1989)
^{12}C		0.94±0.04	Khan *et al.* (1997)
^{16}O		1.05±0.02	Cai and Zang (2006)
$^{24}M_g$		1.16±0.03	Present study
^{12}C	n_s	1.70±0.07	Khan *et al.* (1997)
^{16}O		1.45±0.10	Cai and Zang (2006)
$^{24}M_g$		1.43±0.05	Present study

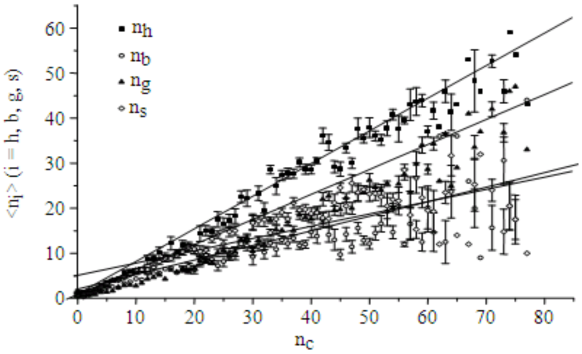

Fig. 5: Dependence of $<n_s>$, $<n_g>$, $<n_b>$ and $<n_h>$ on n_c for $^{24}M_g$ with emulsion at 4.5 A GeV/c

Figure 5 present the dependence of the average particles $<n_s>$, $<n_g>$, $<n_b>$ and $<n_h>$ on the number of compound particles n_c. We find that $<n_s>$, $<n_g>$, $<n_b>$ and $<n_h>$ increase linearly with n_c. The experimental points are fitting by the above relation and the relations representing these fits are:

$$<n_s> = (5.21\pm1.10)+(0.27\pm0.03)n_c$$
$$<n_g> = (-2.92\pm0.69)+(0.55\pm0.02)n_c$$
$$<n_b> = (0.79\pm1.08)+(0.32\pm0.03)n_c$$
$$<n_h> = (0.15\pm0.67)+(0.70\pm0.02)n_c$$

Forward-backward correlations in nucleus-nucleus collisions: The correlations between the multiplicities of the difference types of particles emitted in the forward particles and backward particles are one of the most sensitive sources of information about the mechanism of particles production in both forward and backward hemisphere. It has been mentioned in Ref. (Abdelsalam *et al*., 2002; EL-Nadi *et al*., 1994; 1996; 1998a; 1998b) that the numbers of shower and grey particles emitted in the backward hemisphere are mainly dependent on the projectile size. Therefore, it is also reliable to use the sum of the numbers of shower and grey particles emitted per event in the backward hemisphere (compound particles emitted in backward hemisphere), n^{b}_{c}, as a sensitive experimental parameter for the production mechanism.

In Fig. 6 and 7 we present the average multiplicities of shower, grey and black particles emitted in the forward and backward hemisphere as a function of the number of compound particles produced in the backward hemisphere n^{b}_{c}. Found that, the average multiplicity of shower, grey and black particles emitted in the forward and backward hemisphere increases with the number of compound particle produced in the backward hemisphere. The experiment of points is also fitted by a linear relation and the fitting parameters are presented in Table 4.

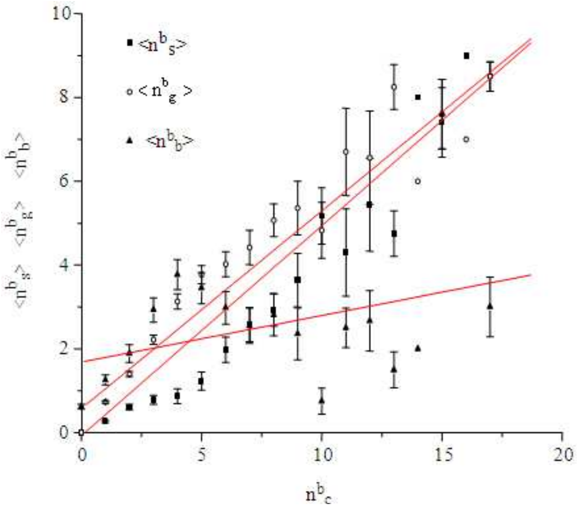

Fig. 6: The depend of $\langle n^{b}_{s}\rangle$, $\langle n^{b}_{g}\rangle$ and $\langle n^{b}_{b}\rangle$ on n^{b}_{c} for $^{24}M_{g}$ with emulsion at 4.5 A GeV/c

Table 4: The fitting parameters for the dependence of the average multiplicities of shower, grey and black particle emitted in the forward and backward hemisphere on the number of compound particles produced in the forward and backward hemisphere. From $^{24}M_{g}$ with emulsion at 4.5 A GeV/c

Correlations	Stop	Intercept
$\langle n^{f}_{s}\rangle$-n^{b}_{c}	0.55±0.03	-0.88±0.33
$\langle n^{f}_{g}\rangle$-n^{b}_{c}	4.55±0.03	0.88±0.33
$\langle n^{f}_{b}\rangle$-n^{b}_{c}	0.11±0.07	1.67±0.69
$\langle n^{b}s\rangle$-n^{b}_{c}	0.50±0.28	7.39±2.76
$\langle n^{b}_{g}\rangle$-n^{b}_{c}	0.73±0.10	4.21±1.04
$\langle n^{b}_{b}\rangle$-$n^{b}c$	0.13±0.10	2.29±0.92
$\langle n^{f}_{s}\rangle$-n^{f}_{c}	0.03±0.01	0.40±0.25
$\langle n^{f}_{g}\rangle$-n^{f}_{c}	0.13±0.01	-0.52±0.23
$\langle n^{f}_{b}\rangle$-n^{f}_{c}	0.07±0.01	0.71±0.24
$\langle n^{b}_{s}\rangle$-n^{f}_{c}	0.40±0.03	1.90±1.04
$\langle n^{b}_{g}\rangle$-n^{f}_{c}	0.56±0.03	-2.43±1.02
$\langle n^{b}_{b}\rangle$-n^{f}_{c}	0.83±0.01	1.03±0.30

In Fig. 8 and 9 shows the dependence of the average multiplicities of shower, grey, black particles emitted in the forward and backward hemisphere on the numbs of forward compound particles n^{f}_{c}.

A linear correlation is observed and the linear fitting parameters are presented in Table 4. It also should be pointed out that the value of $\langle n^{f}_{b}\rangle$ increases with the increasing of n^{f}_{c} up to 40 and then becomes constant, because of limit target.

Multiplicity characteristics: The average values of the multiplicity of the different charged secondary particles emitted from the interactions of heavy ions with the emulsion at a few GeV/c per nucleon are given in Table 5.

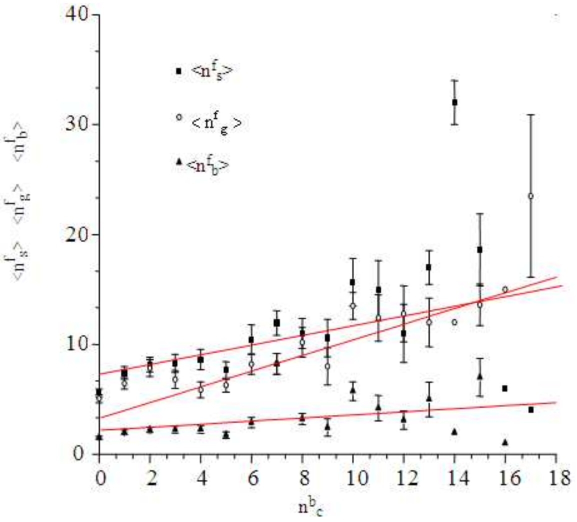

Fig. 7: The depend of $\langle n^{f}_{s}\rangle$, $\langle n^{f}_{g}\rangle$ and $\langle n^{f}_{b}\rangle$ on n^{b}_{c} for $^{24}M_{g}$ with emulsion at 4.5 A GeV/c

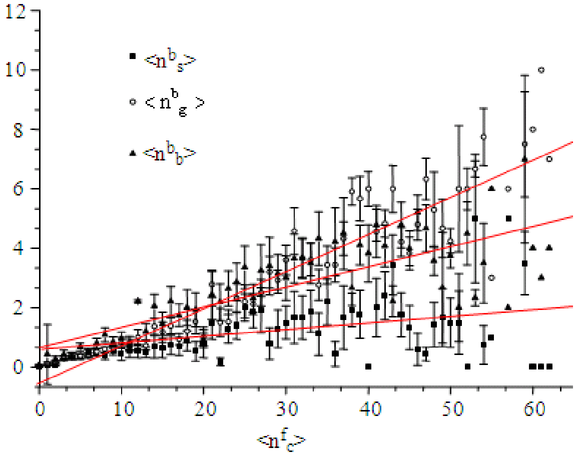

Fig. 8: The depend of $\langle n^{b}_{s}\rangle$, $\langle n^{b}_{g}\rangle$ and $\langle n^{b}_{b}\rangle$ on n^{f}_{c} for $^{24}M_{g}$ with emulsion at 4.5 A GeV/c

Table 5: Experimental values of the average multiplicities of the different projectiles

Projectiles	<n$_s$>	<n$_g$>	<n$_b$>	Reference
^{1}H	1.6±0.2	2.8±0.1	3.8±0.1	Aabddklmtu (1981)
^{2}H	2.5±0.1	3.9±0.1	4.6±0.2	Bogdanov *et al.* (1983)
^{4}H$_e$	3.8±0.1	4.4±0.2	4.3±0.3	Admovich *et al.* (1977)
^{12}C	77.0±0.2	6.1±0.3	4.4±0.2	EL-Naghy and Toneev (1980)
^{16}O	10.5±0.6	7.6±0.6	4.9±0.3	Antonchik *et al.* (1984)
^{22}N$_e$	10.5±0.1	6.3±0.4	4.2±0.3	Andreeva *et al.* (1987)
^{24}M$_g$	09.6±0.2	8.1±0.2	6.7±0.1	Present study
^{28}S$_i$	11.9±0.5	7.3±0.3	5.2±0.2	Present study

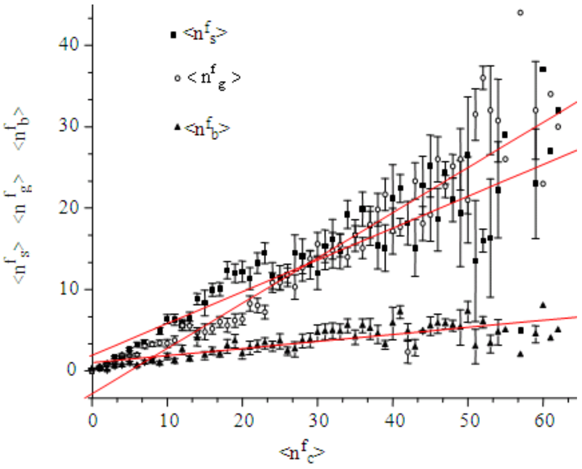

Fig. 9: The depend of <n^f_s >, <n^f_g> and <n^f_b>on n^f_c for ^{24}M$_g$ with emulsion at 4.5 A GeV/c

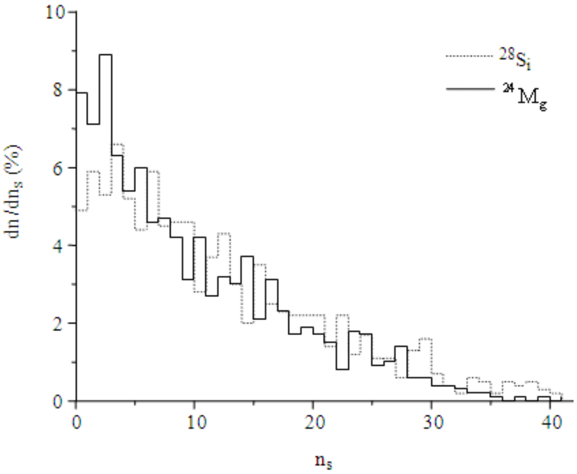

Fig. 10: Multiplicity distributions (a) of shower particles; (b) of grey particles and (c) of black particles emitted from 4.5 A GeV/c, ^{28}S$_i$ and ^{24}M$_g$ with emulsion

It can be seen that <n$_s$> increase with the projectile mass number while <n$_g$> shows a tendency to increase with the projectiles mass number.

This result is agreement with that previously obtained (El-Naghy *et al*., 1982) in which it has been found that the ratio between <n$_s$> and the number of the projectiles nucleons participating directly in the interaction is approximately equal to the average multiplicity for the harden nucleon interaction. Moreover, <n$_g$> has been found to be measure of the number of interanuclear collisions (Anderson *et al*., 1978; Hegab and Hufner, 1981). The value of <n$_b$> is almost independent of the projectile mass number in the given energy range which shows that the excitations of the target nucleus together with the subsequent evaporation of the particles and the fragments seems to be independent of the first stage of the collision.

Figure 10 shows the n$_s$-distributions for the ^{24}M$_g$ with emulsion interactions at 4.5 A GeV/c. It can be seen that the n$_s$-distributions change with mass number of the projectiles. For further investigation, the n$_s$-distributions have been plotted according to the KNO scaling (Koba *et al*., 1972).

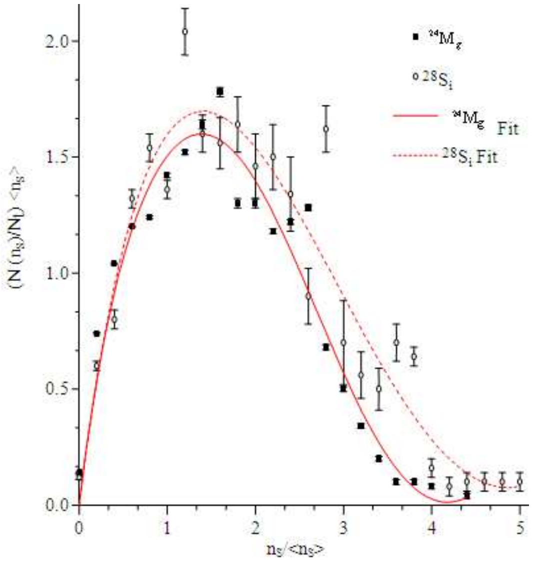

Fig. 11: Dependence of (N (n$_s$)/N$_t$) <n$_s$> on n$_s$ / <n$_s$> for 4.5 A GeV/c, ^{28}S$_i$ and ^{24}M$_g$, interactions with emulsion. The curve is the result of fitting of experiment data by the KNO scaling formula

Figure 11 shows the relation between $(N(n_s)/N_t)$ $<n_s>$ and $n_s/<n_s>$.The experimental values obey the KNO scaling and may be fitted by the formula:

$$\Psi (Z) = (2.52Z+3.09Z^3-0.9Z^5+1.04Z^7)\ e^{-4.08z}$$

where, $Z = n_s/<n_s>$. In the present study we use the following formula two times:

$$\Psi (Z) = (a1+a2Z^3-a3Z^5+a4Z^7)\ e^{-a5z}$$

Where the fit parameters are given by:
a1 = 3.2005
a2 = 0.67782
a3 = -0.10856
a4 = 0.00034
a5 = 0.91931

In case of $^{24}M_g$ (the triangles and solid curve), while:
a1 = 3.03668,
a2 = 0.05573,
a3 = -0.01045,
a4 = 0.00034
a5 = 0.6208

In case of $^{28}S_i$ (the triangles and solid curve).

CONCLUSION

From the present study, it may concluded that:

- The compound multiplicity distribution depends strongly not only on the impact parameter $<n_h>$ but also on the projectile mass
- Generally, the average multiplicities of shower, grey, beak and heavy particles increases linearly with the number of compound particles, but for $<n_b>$ and the average a saturation at $n_c = 50$ is observed and the average compound multiplicity also increases with the increasing of shower, grey, black and heavily charged particles
- The average multiplicities of shower, grey and black particles emitted in the forward and backward hemispheres depend linearly on the compound particles produced in the backward hemispheres, but because of the limitation of target size a saturation in the correlation of $<n^b_b>$ on n^b_c, $<n^f_b>$ and n^b_c is also observed
- The n_s-distribution change with the projectiles mass number while the n_g and n_b distributions are independent of the projectile mass number
- The n_s distributions obey the KNO scaling (i.e., the multiplicity distribution has a universal behavior when it is rescaled to the $<n_s>$

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