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Features Study on Target Fragmentation in the Collisions Of ^{24}Mg and ^{28}Si with Emulsion Nuclei at 3.7A GeV

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Abstract: Problem statement: The process of nuclear fragmentation in interactions of 3.7A GeV ^{24}Mg and ^{28}Si nuclei with the different target nuclei in a nuclear emulsion have been investigated. **Approach:** The probability of interactions without any projectile fragment with charge $Z \geq 2$ is zero for hydrogen target, but increases by increasing the mass of the target. **Results:** The disruption of a projectile nucleus is more save in interactions with the heavy target nuclei than with the light ones. The nuclear fragmentation mechanism was investigated for shower and slow particles at Dubna energy. Several correlations between these particles are studied and analyzed. The variation of $<n_g>/<n_s>$ with N_h behaves a straight line up to $N_h = 14$ in the collision of ^{24}Mg and ^{28}Si with emulsion nuclei, it reaches to constant value. These results are contradicted with that obtained from the light projectile nuclei such as p, d, ^{4}He and ^{7}Li with emulsion nuclei at the same energy. **Conclusion:** The behavior of the scale shower ($<n_s>P(n_s/<n_s>)$) and compound ($<n_c>P(n_c/<n_c>)$ where ($n_c = n_s+n_g$) particles are the same, also for both the collisions of ^{24}Mg and ^{28}Si with nuclei give the same behavior.

Key words: ^{24}Mg, ^{28}Si, nuclear fragmentation, emulsion nuclei, gray production

INTRODUCTION

The study of projectile and target fragmentation processes for the relativistic heavy ion interactions has become a subject of great important. It gives an indication of being a rich source of information on nuclear structure and may reveal new phenomena (Buguta, 1982) relate to phase transition of hadron gas to quark glone plasma. These studies can provide information about the fragmentation mechanism and liquid gas phase transition process in hot nuclei and help to trace the reaction mechanism of nucleus. Nucleus interactions (Hufner, 1985; Jilany, 2003; 2004). It is well known from the nucleus- nucleus collisions that, the over lapping region of nuclear volume is called participant region where multiple productions of new particles occur and the nuclear matter breaks up into nucleons. The remaining parts of nuclei which do not participant in the disintegration process are called the spectator regions of the projectile and target. The projectile fragments corresponding to the spectator part are being in narrow forward cone. The angle of this cone in θ lab$\leq 3^o$, while the produced particle and rescattering protons have a much broader distribution. Extensive investigation of the target fragmentation through nucleon-nucleon or nucleus-nucleus interaction at high energy has greatly increased for over three decades (Abdelsalam *et al*., 2002; Solite and Abd El-Daiem, 2007; Nour El Din and Solite, 2008; Abdelsalam *et al*., 2007; Bogdanov *et al*., 1983; Abd El-Daiem, 2009).The aim of the present study is to investigate the breakup of relativistic ^{24}Mg and ^{28}Si nuclei in nuclear emulsion at 3.7A GeV. On the other hand we have through a spotlight on the investigation of the production mechanism of nucleus- nucleus ^{24}Mg and ^{28}Si with emulsion investigations.

MATERIALS AND METHODS

Experimental details: NIKFI BR-2 stacks of nuclear emulsions, 10×10×2 cm in volume, were exposed to the 3.7A GeV ^{24}Mg and ^{28}Si beams at the JINR Synchrophastion in Dubna. The flux intensity was 10^3 particles cm^{-2}. Emulsion plates, 600 μm in thickness, were 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 from two samples ^{24}Mg and ^{28}Si. A total of 1000 interactions of each two samples with the nuclei of the emulsion were observed by following, a primary track length of 5954 and 8712 cm which led to a mean free path of $\lambda = (10.2\pm0.6)$ cm $\lambda = (8.71\pm0.3)$ cm from ^{24}Mg and ^{28}Si.

Interactions which were within 30 μm from the top or bottom surface of the emulsion were not taken into consideration for the final analysis. For each detected interaction, the following characteristic features were recorded: n_s, the number ionizing shower tracks with kinetic energy E>400 MeV and very light velocity $\beta = v/c \geq 0.7$ (most n_s tracks are π-mesons); n_g, the number of grey tracks (recoil protons with $40<E<400$MeV, $0.3<\beta<0.7$ and range >3 mm) and n_b, the number of black tracks due to evaporated target fragments with E<40 MeV, $\beta \leq 0.3$, $R \leq 3$ mm. (n_g+n_b) is the sum of heavily ionizing charged particles,denoted by N_h. The percentages given for each element are the reaction percentage of their ^{24}Mg and ^{28}Si induced reaction. The number N_h emitted in an interaction is an important parameter and greatly helps in separating events due to target types, i.e., all events due to H interactions have $N_h = 0.1$. The interactions having $N_h \geq 8$ almost definitely belong to AgBr collisions, while events with $2 \leq N_h \leq 7$ are due to interactions with CNO and peripheral AgBr. It was found that the events due to H, CNO and AgBr were estimated to be 37 (7.3%), 147 (29%) and 323 (63.7%) for ^{24}Mg and 53 (10.2%), 155 (29.8%) and 315 (60%) for ^{28}Si respectively.

In each event, the charge $Z \geq 2$ of individual projectile fragments were determined by the combination of several method, which include grain and δ-ray densities projectile fragments essentially travel with the same speed as that of the parent beam nucleus, so the energy of the produced projectile fragments is high enough to distinguish them easily from the target fragments.

RESULTS AND DISCUSSION

A-selected correlations: The complete charge distributions of projectile fragments with $Z \geq 2$ emitted from minimum-bias events in ^{24}Mg and ^{28}Si with interactions emulsion shown in Fig. 1. This distribution are characterized by a strong peak with Z = 2 projectile fragments constituting almost of the total population. One can also observe from Fig. 1 is a distinct structure in the shape of this histogram, a sharp dip at Z = 3,6 followed by a gradual rise and then the second peak with Z = 4,6 followed by a gradual drop. Table 1 shows that the mean multiplicities of the different charged projectile fragments in interactions of ^{24}Mg and ^{28}Si projectiles with different components (different ranges of N_h, i.e., H,CNO, Em and AgBr nuclei) of emulsion nuclei are in a similar trend with those obtained previously for ^{16}O and ^{22}N beam interactions with groups of emulsion nuclei at Dubna energy. The dependence of average projectile fragment numbers on the target mass is clear in the case of charge $Z \geq 3$. As the target mass increases, the mean multiplicities of fragments $\langle n_f \rangle$ with charges $Z \geq 3$ decrease substantially. The mean number of helium target nuclei (AgBr) is smaller than that stripped in the collisions with hydrogen target nuclei. No target mass dependence is, however, seen in the emission of fast singly charged projectile fragments.

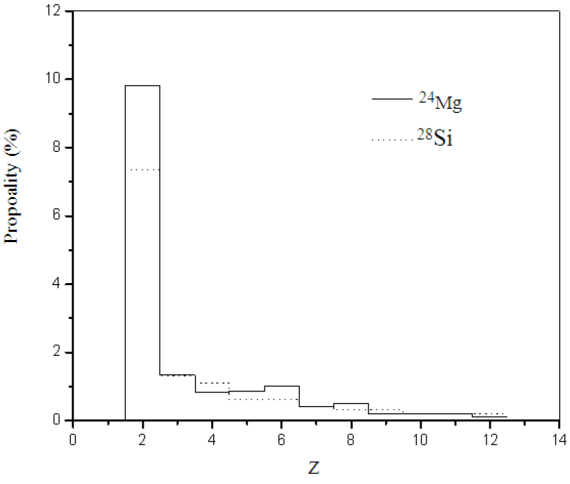


Fig. 1: Charge distribution for doubly (Z = 2) and multiplicity ($Z \geq 2$) charged projectile fragments

Table 1: The average multiplicity of the different charge (Z) PFS stripped in ^{16}O (Meng and Zhang, 2006), ^{22}N (Andreeva *et al*., 1988), ^{24}Mg and ^{28}Si beams interactions with the various emulsion groups of nuclei 3.7A GeV

Fragment charge Z	Projectile nucleus	H	CNO	Em.	AgBr	References
1	^{16}O	1.42±0.07	1.47±0.05	1.36±0.03	1.22±0.04	Meng and Zhang (2006)
	^{22}N	1.17±0.02	1.47±0.05	1.36±0.02	1.37±0.03	Andreeva *et al*. (1988)
	^{24}Mg	1.42±0.09	1.64±0.07	1.50±0.05	1.39±0.06	Present study
	^{28}Si	1.39±0.14	1.62±0.07	1.63±0.06	1.48±0.08	Present study
2	^{16}O	1.19±0.06	0.88±0.04	0.75±0.02	0.48±0.03	Meng and Zhang (2006)
	^{22}N	1.02±0.04	0.92±0.03	0.82±0.02	0.63±0.02	Andreeva *et al*. (1988)
	^{24}Mg	1.14±0.02	1.10±0.13	0.89±0.03	0.73±0.04	Present study
	^{28}Si	1.37±0.11	1.23±0.06	1.03±0.03	0.86±0.04	Present study
≥3	^{16}O	0.52±0.03	0.36±0.02	0.29±0.01	0.14±0.01	Meng and Zhang (2006)
	^{22}N	0.79±0.03	0.57±0.02	0.48±0.01	0.21±0.01	Andreeva *et al*. (1988)
	^{24}Mg	0.89±0.06	0.66±0.03	0.50±0.02	0.32±0.02	Present study
	^{28}Si	0.85±0.08	0.68±0.04	0.47±0.02	0.28±0.02	Present study

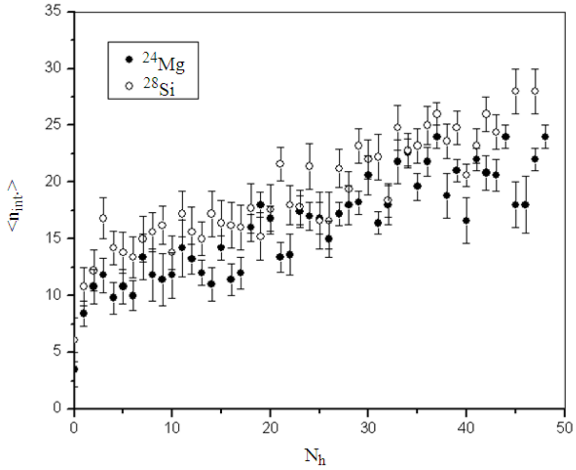


Fig. 2: Variation of < n_{int}.> with N_h from ^{24}Mg and ^{28}Si

To find the degree of centrality of an event, from the geometrical point of view information about the impact parameter is necessary. However, one cannot directly measure the impact parameter in individual collisions. Hence we introduce an alternate parameter, n_{int} (the number of interacting nucleons), which can be estimated on an event basis from the following relation:

$$n_{int} = Ap-(Ap/Zp)\ Q$$

where, Ap and Zp are the mass and charge number, respectively, of the projectile nucleus and Q is the total charge of the projectile fragments in an event. In order to see the dependence of the average number of interacting projectile nucleus $<n_{int}>$ on the degree of disintegration of the target nuclei (collision geometry, i.e., different impact parameter) in ^{24}Mg and ^{28}Si with emulsion interactions are represented in Fig. 2. Figure 2 indicates that even in collision where no or very little excitation of target occurs (i.e., N_h = 0.1). Some of the projectile nucleons take part in the interaction.

As expected, the average number of interacting projectile nucleons increases substantially as nh increases from peripheral to central collision but attains a more or less constant value for extreme central collisions. The average lightest value of $<n_{int}>$ in this experiment are and impaling the participation of nearly and of projectile nucleons in the collision process these events, representing almost and of the total samples of extreme central collisions where it is expected that almost all nucleons of projectile and the majority nucleons of the heavy Ag Br target nuclei take part in the collision (Singh and Tuli, 1996; 1999; Sherif *et al.*, 1995). These events are potentially useful for seeking evidence for the formation of quark-gluon plasma.

Table 2: The percentage probability of the interactions for P, d, ^{4}He and ^{7}Li, ^{24}Mg and ^{28}Si-with emulsion nuclei with no $n_s = 0$

Projectile	P(n_s = 0) %	References
P	9.85±0.61	Nour El Din and Solite (2008)
d	2.60±0.40	Bogdanov *et al*. (1983); Admovich (1977) Bogdanov (1972)
^{4}He	7.120±0.59	Nour El Din and Solite (2008)
^{7}Li	10.37±1.02	Nour El Din and Solite (2008)
^{24}Mg	6.60±0.27	Present study
^{28}Si	7.50±0.23	Present study

Table 3: The fitting parameters characterizing the dependence of $<n_s>$ on N_h through the interaction of different projectiles with emulsion nuclei

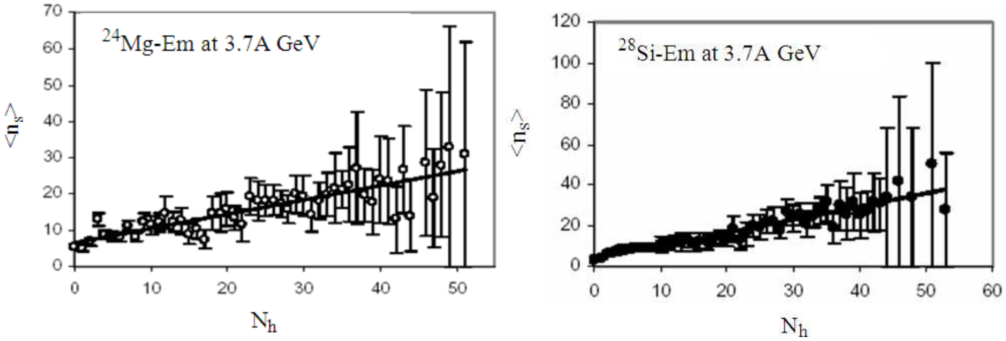
Projectile	a	b	References
P	-0.01	1.64	Nour El Din and Solite (2008)
D	0.07	2.44	Nour El Din and Solite (2008)
^{4}He	0.17	2.38	Nour El Din and Solite (2008)
^{24}Mg	0.39	6.40	Present study
^{28}Si	0.65	3.35	Present study

It is well known that the most of the shower particles are mainly pions emitted due to the fragmentation of the projectile. Therefore, to investigate the target fragmentation process, it is nice to choose events with no relativistic charged particles (shower), (i.e., with no n_s = 0) as an indicator of the target effect in the fragmentation process in this study. Table 2 summarizes the percentage probability of the interaction for our experimental data for ^{24}Mg and ^{28}Si with emulsion nuclei at 3.7A GeV (with no n_s = 0) compared with another experimental data for P, d, ^{4}He and ^{7}Li with emulsion.

Except for the percentage of the probability of P (n_s = 0) % for P with emulsion and ^{7}Li with emulsion; the Probability is increased with increasing the mass of the projectile at constant energy. We notice also that both P with emulsion and ^{7}Li with emulsion are more high Values of pionization than others. This may be due to the structure of the two projectiles where they have an odd number of particles which may be played an important rule in the value of ionization. From Fig. 3, we can show the dependence of the average shower particle which represents the projectile indicator (Nour El Din and Solite, 2008) on N_h. The best fit can be followed by the linear relation as:

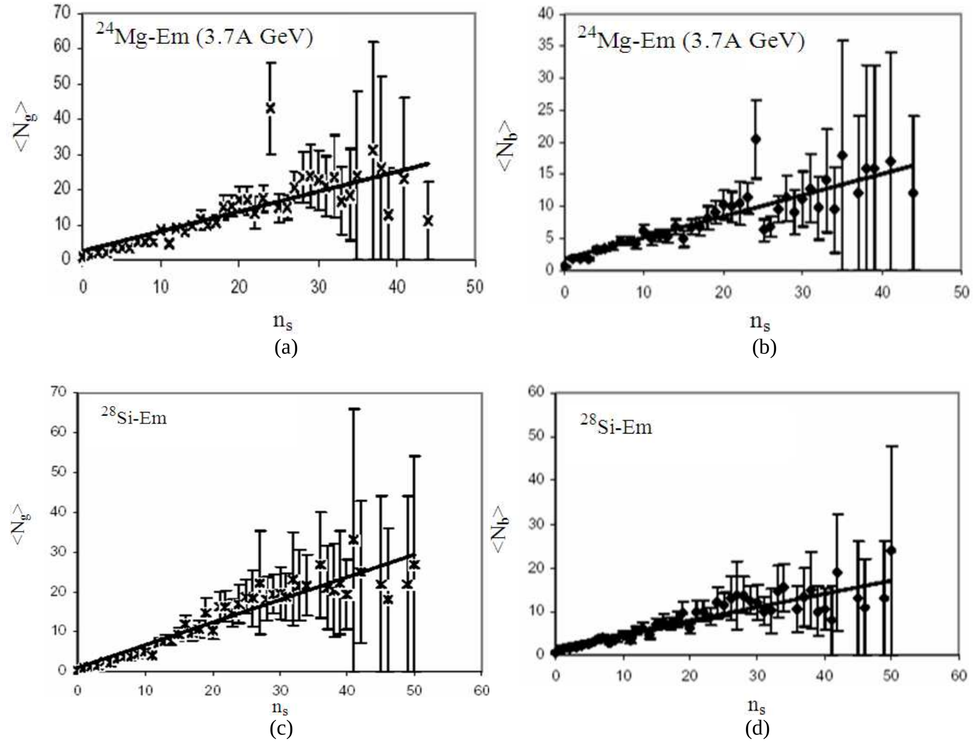
$$<n_s> = a\ N_h + b$$

Hence, Table 3 shows the fitting parameters for different projectiles at 3.7A GeV. From Fig. 3 and Table 3, we can notice that; the slope parameter increases as the mass number of the projectile increases, which indicates the strong dependence of the shower particles on the projectile mass except for proton with emulsion collision which is weak and its slope is negative.



(a) (b)

Fig. 3: (a) The experimental points for $<n_s>$ against N_h for the collision of ^{24}Mg (3.7A GeV), the straight line is obtained by the best fit; (b) The same as Fig. 3a but for the projectile ^{28}Si (3.7A GeV)



(a) (b)

(c) (d)

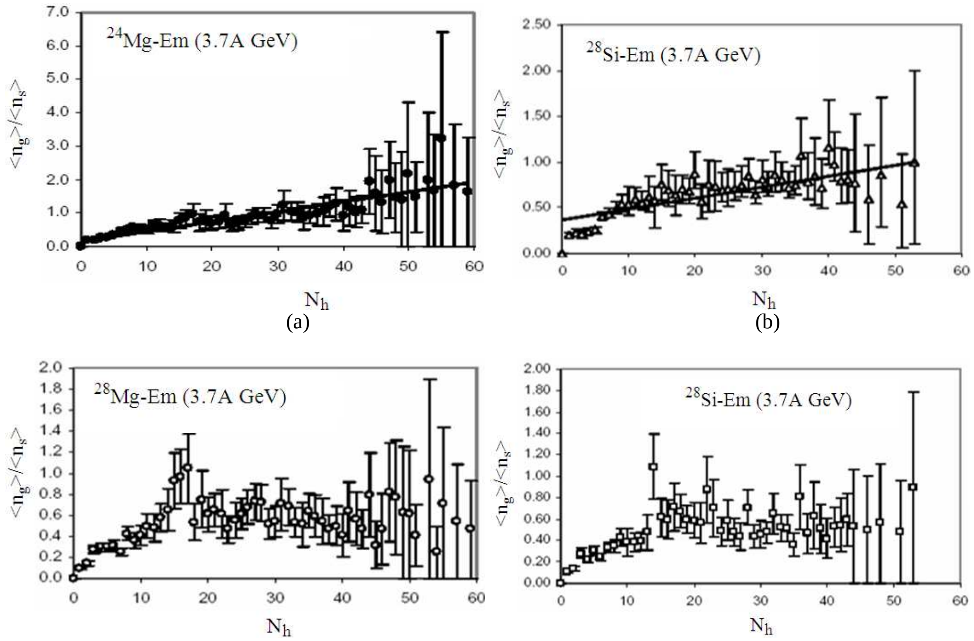
Fig. 4: The dependence of $<N_g>$ and $<N_b>$ on ns for the collisions of ^{24}Mg (a, c) and ^{28}Si (b, d) with emulsion at 3.7A GeV

Table 4: The fitting parameters characterizing the correlations between $<n_{g,b}>$ and n_s for the interaction of P (3.7 GeV), ^{4}He (2.1A GeV), ^{24}Mg (3.7A GeV) and ^{28}Si (3.7A GeV) with emulsion nuclei

	$<n_s>$versus n_s		$<n_b>$ versus n_s		
Projectile	Cg	Dg	C_b	D_b	References
P	0.006	1.64	0.29	6.30	Nour El Din and Solite (2008)
^{4}He	0.53	0.61	1.13	1.13	Nour El Din and Solite (2008)
^{24}Mg	0.57	2.38	0.33	1.74	Present study
^{28}Si	0.56	1.11	0.31	1.90	Present study

To show the dependence of the target fragmentation on the shower particle, we draw a relation between the mean number of grey and black particle multiplicities with the number of shower particles as shown in Fig. 4 for the interactions of ^{24}Mg (a, c) and ^{28}Si (b, d) with emulsion nuclei at 3.7A GeV.

From Fig. 4 the best fit can follow the linear relation of the form, $<n_{g,b}> = C_{g,b}n_s+D_{g,b}$. The fitting parameters are given in Table 4. From Fig. 4 and the slope.



(a) (b)

(c) (d)

Fig. 5: The relation between $\langle n_g\rangle/\langle n_s\rangle$ and$\langle n_b\rangle/\langle n_s\rangle$ with N_h in the collisions of ^{24}Mg (a, c) and ^{28}Si (b, d) with emulsion nuclei

Table 5: The best fit parameters for the relations between $\langle N_g\rangle/\langle n_s\rangle$and $\langle n_b\rangle/\langle n_s\rangle$ and the target size indicator N_h in the reactions of proton, ^{4}He and ^{7}Li-with emulsion nuclei produced from (Nour El Din and Solite, 2008)

	$\langle n_b\rangle/\langle n_s\rangle$versus N_h		$\langle n_b\rangle/\langle n_s\rangle$versus N_h		
	-----------------------		-----------------------		
Projectile	α_g	β_g	α_b	β_b	References
P	0.10	1.64	0.40	-0.21	Nour El Din and Solite (2008)
^{4}He	0.04	0.61	0.09	0.56	Nour El Din and Solite (2008)
^{7}Li	0.03	2.38	0.05	0.64	Nour El Din and Solite (2008)

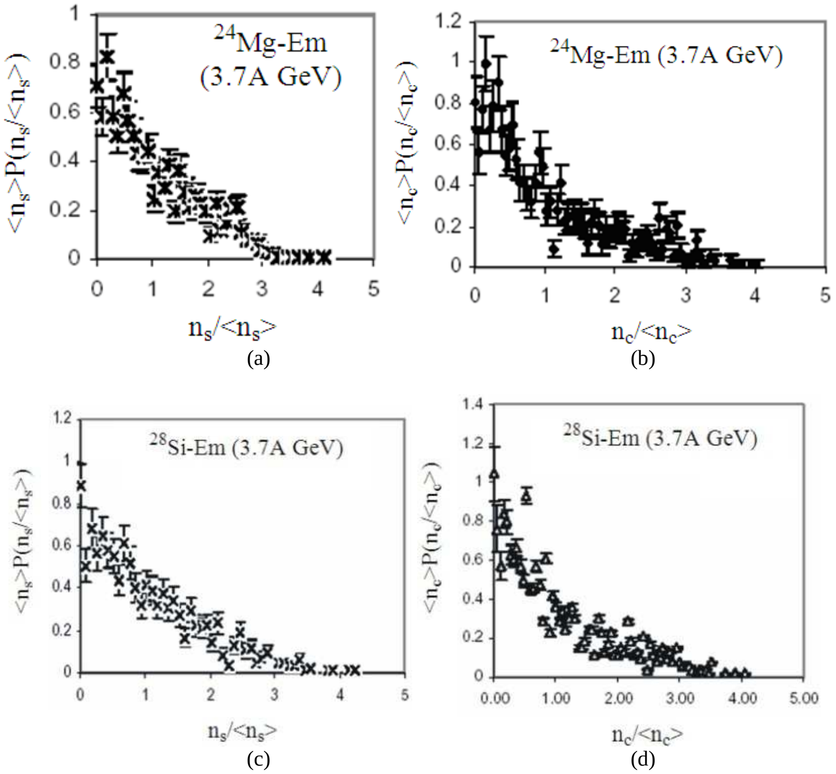
Parameters in Table 4, we can say that, the dependence of $\langle n_g\rangle$ and $\langle n_b\rangle$ on n_s incase of P with emulsion collision is weak, but for the other projectiles, it is stronger. The difference for the dependence between the interaction of P with emulsion and the collision of the other projectiles may be due to the excess of the number of particles for the heavier projectiles. Hence the result is excess in the rescattering process between the colliding nuclei which may reduce the number of particles produced in the energy interval of pionizetion more sensitive characteristic for nucleus-nucleus interaction is the correlation between the multiplicities of different types of the emitted particles. Therefore, it is convenient to study the ratio between the average multiplicities of the recoil target protons (grey particles) and the average multiplicity of the evaporated target fragments(black particles) and the projectile parameter $\langle n_s\rangle$, (i.e., $\langle n_g\rangle/\langle n_s\rangle$ and$\langle n_b\rangle/\langle_{ns}\rangle$) and ($N_h$) at energy 3.7A GeV as shown in Fig. 5a-d. The best fit parameters are takes the form : $\langle n_{g,b}\rangle/\langle n_s\rangle = \alpha$ g, b N_h+ ß$_g$, b for light projectiles obtained by the authors of ref (Nour El Din and Solite, 2008) and summarized in Table 5.

Figure 5 a-c shows the heavier nuclei as in our data for the collision of ^{24}Mg (a,c) and ^{28}Si (b,d) with emulsion nuclei at 3.7A GeV we see that:

The behavior of the relation for $\langle n_g\rangle/\langle n_s\rangle$ and $\langle n_b\rangle/\langle n_s\rangle$ with N_h stays straight line up to N_h =14 and these relations are:

$\langle n_g\rangle/\langle n_s\rangle = 0.04N_h+0.14$
$\langle n_b\rangle/\langle n_s\rangle = 0.038\ N_h+0.007$ for ^{24}Mg with emulsion
$\langle n_g\rangle/\langle n_s\rangle = 0.04\ N_h+0.11$
$\langle n_b\rangle/\langle n_s\rangle = 0.044\ N_h+0.034$ for ^{28}Si with emulsion

From the parameters in Table 5 and the corresponding parameters obtained from our data, we notice that, the collision of the heavier nuclei with emulsion in the interval of the target size, N_h = 0-14, behaves as the light one. At N_h>14, the relations became merely constant. This constancy leads to a limiting fragmentation in this interval of the target sizes.



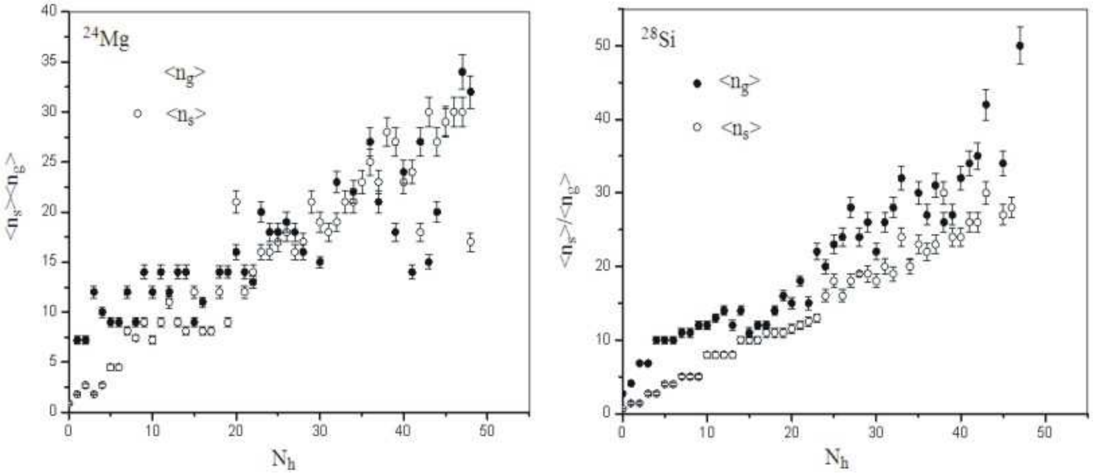
(a) (b)

(c) (d)

Fig. 6: The comparison between $<n_i>P(n_i / <n_i>)$; i = s,c versus the scaling function $n_i / <n_i>$ for; (a, b) ^{24}Mg with emulsion at 3.7 A GeV and (c, d) ^{28}Si with emulsion at 3.7A GeV

B-compound multiplicity: (1) Although the process responsible for the production the grey particles is not fully known, it is generally believed that these are the low energy part of the inter nuclear cascade and that they leave the target nucleus on the same time scale as the secondary of the interactions. (2) It has been felt quite recently that the study of grey track particles should of special interest, because they are emitted during or shortly after the passage of leading hadrons; hence to incorporate the rule of grey particles, available termed the compound multiplicity, $n_c = n_s + n_g$, was introduced by Judrack and Linscheid (1977) and Ahmed and Irfan (1991; 1993). The main motivation for studying the compound multiplicity in high energy heavy ion collisions is that these investigations may helpin refining the models of multiparticle production of the final state particles produced in hadrons-nucleus and nucleus nucleus collisions. In Fig. 6a-d, we have plotted a comparison between $<n_s>P(n_s/<n_s>)$ versus$<n_s>$and $<n_c>P(n_c/<n_c>)$ versus $n_c/<n_c>$ for both ^{24}Mg and ^{28}Si collisions with emulsion nuclei.

Here, ($<n_s>$ and $<n_c>$) are denoted the average multiplicity of relativistic shower and average of compound multiplicity, respectively also, when we draw a relation between $<n_s>$ and $<n_g>$ with the target size (N_h) we shall obtain Fig. 7. It is noticed from the Fig. 6 and 7 and the conclusions of sections 1 and 2 are the behaviors of the two kinds of particles (shower and grey) are resembled. This may be encouraged us to say that the object emitting shower or grey particles keep little or no memory of the formation or excitation mechanism which produced it and it is different from that source emitting black particles. This conclusion was confirmed by Hegab *et al*. (1987). He was shown that, the angular distribution of grey particles, peaks in forward direction and they are emitted during or shortly after the passage of the leading particle. The grey particles are therefore close to the primary sequence (pre-equilibrium stage) of the interaction and are thus expected to bear important information about the interaction mechanism. The same author in ref (Hegab and Hufner, 1981; 1982), when was considered the energy degenerate between successive generations, he has shown that grey particles should not result from generation greater than the second, i.e., 11 during the inter a nuclear cascade only primaries and secondary contribute to the grey particles production.



(a) (b)

Fig. 7: The relation between $<n_s>$, $<n_g>$ and N_h in the collisions of: (a) ^{24}Mg with emulsion at 3.7A GeV, (b) ^{28}Si with emulsion at 3.7A GeV

Higher generations, they considered to contribute to the slow particle emission (black particles with energy ≤30 MeV). Thus, the energy of the projectile nucleon will in the mean be divided among several nucleons in cascade in the target nuclei, specially the heavy nuclei will be probable that some of the cascade nucleons will have an energy low enough for the nucleon to fall in the interval defined for the grey tracks. The corresponding cascade in light target nuclei will include fewer nucleons with the correspondingly of higher mean energy and smaller probability for them to fall in the energy interval of the grey tracks.

CONCLUSION

From the present study, it may conclude that:

- The complete charge distribution of projectile fragments with Z≥2 emitted from the minimum-bias events in ^{24}Mg and ^{28}Si with emulsion interactions are show in Fig. 1
- The fragmentation of the projectile nucleus depends strongly on the target mass
- It is clear that the percentage of the probability of events having P ($n_s = 0$) % for the projectiles with odd mass number (P and ^{7}Li with emulsion) are higher values of pionization than the even one. The structure of these projectiles may play an effective rule for its higher of pionization
- There is a strong dependence of the shower particle on the target mass number
- The dependence of $<n_g>$ and $<n_b>$ on ns in case of P with emulsion collision is weak, but forth other projectiles, it is stronger. The difference for the dependence between the interaction of P with emulsion and the collision of the other projectiles may be due to the excess of the number of particles for the heavier projectiles
- The relation between $<n_g>/<n_s>$, $<n_b>/<n_s>$ and N_h is linear up to $N_h = 14$, for the collisions of ^{24}Mg and ^{28}Si with emulsion nuclei. For $N_h>14$, there is constant behavior which leads limiting fragmentation
- At all interval of N_h for the collisions of P, d' ^{4}Heand ^{7}Li with emulsion nuclei 8-The source emitting shower and grey particles may be the same and it is different from that source emitting black particles. This proposing was based on the following:
  - The scaling behavior for the shower and grey particles are almost the same
  - The relation between the shower and grey particles with respect to the target fragmentation is linear and stronger dependence

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