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Multiplicity Characteristics of Emitted Particles in Heavy-Ion Interactions with Emulsion at 4.5A GeV/c

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Abstract

A systematic study has been carried out for the multiplicity characteristics of the emitted particles in the interactions of ^{2}H, ^{3}He, ^{4}He, ^{6}Li, ^{12}C, ^{22}Ne, ^{24}Mg, ^{28}Si and ^{32}S with emulsion at momentum (4.1-4.5)A GeV/c. The average multiplicities of the emitted particles have been studied as functions of the incident nucleus mass number and of the number of the interacting projectile nucleons. A strong correlation between the average value of the emitted charged shower particles and the incident nucleus mass number has been observed and a universal empirical relation has been deduced. The correlations between the different types of the emitted charged particles have been investigated and a strong dependence of the shower particles on the number of grey ones has been shown. The multiplicity distributions and the average values of the emitted charged particles have been compared with the corresponding values calculated according to a modified cascade evaporation model which implies a superposition of the nucleon-nucleon interactions and a formation time for the produced particles. An agreement between the experimental and theoretically calculated data has been observed.

1 Introduction:

Heavy ion interactions with nuclei provide a suitable technique for studying the multiparticle production and the nuclear fragmentation processes and for investigating the correlations between these two processes(EL Naghy et al .,1994 and all references therein). They can also give valuable information on the space-time development of the considered reactions(EL Naghy et al.,1982). The nuclear emulsion, as a 4π-detector, is a convenient tool for detecting all the charged particles emitted in the whole space(Khan,Khushnood,\& Ansari,1996). In the interaction of a high-energy hadron or nucleus with a target nucleus,the multiparticle production is considered as a two-step process, in which intermediate systems are firstly created. After a short time, these systems decay and finally hadrons emerge. Thus, the creation of a hadron is not instantaneous but takes a certain time called the formation time. The systems, firstly created, may collide with one or more nucleons from the target nucleus before decaying. The struck nucleon recoils and may leave the target nucleus. Thus, the hadron- nucleus or nucleus-nucleus interaction may be considered as a cascade of hadron-nucleon collisions. In emulsion physics, the fast charged particles of velocity $\beta \geq 0.7$ are called ``shower'' particles or ``s-particles''. The charged recoil nucleons (or particles) emitted from the target nucleus with $0.3 < \beta < 0.7$ are referred to as the ``grey'' particles or ``g-particles''. At the end of the cascade step, the residual target nucleus is left in a highly excited state of high temperature. Then ,during a period of time, relatively long with respect to the interaction time, the excited residual nucleus attains a thermal equilibrium and loses its excitation energy by evaporation, i.e., by emitting slow nucleons and nuclear fragments . The emitted charged slow particles are called ``black'' particles or ``b-particles''. The classification scheme of the emitted particles, according to emulsion physics, is given explicitly in the following section. This paper presents a study of the multiplicity characteristics of the shower, the grey and the black particles emitted in the interactions of (4.1- 4.5)A GeV/c ^{2}H, ^{3}He, ^{4}He, ^{6}Li, ^{12}C, ^{22}Ne, ^{24}Mg, ^{28}Si and ^{32}S with emulsion nuclei .The obtained data have been compared with the interactions simulated according to a modified cascade evaporation model which implies a superposition of the nucleon-nucleon interactions and a formation time for the produced particles(Ranft,1989).

2 Experimental Techniques:

Nuclear emulsions of the type Br-2 were exposed to (4.1-4.5)A GeV/c beams at the Dubna Synchrophasotron. The pellicles of emulsion have the dimensions of 20cm x 10cm x 600ìm (undeveloped) emulsion. The intensity of the beam was about 10^4 particles/cm^2 and the beam diameter was approximately 1cm . Along the track, a double scanning has been carried out fast in the forward direction and slow in the backward one. The scanned beam tracks have been further examined by measuring the delta-electron density (Powell,Fowler,\& Perkins,1959) on each of them to exclude any track having a charge less than the beam particle charge. The scanning has been performed using Leitz-Laborlux-S microscope. According to the range L in the emulsion and the relative ionization $I^*=I/I_o$, where I is the particle track ionization and I_o is the ionization of a relativistic shower track in the narrow forward cone of an opening angle $\theta = 3^o$. All the charged secondary particles, in these interactions, have been classified into the following groups:

- Shower tracks producing particles ``s-particles" having a relative ionization $I_o<1.4$. Such tracks, having an emission angle $\theta<3^o$ have been further subjected to multiple scattering measurements for momentum determination(Barkas,1963), in order to separate the produced pions from the non-interacting singly charged projectile fragments and to differentiate them into protons, deuterons and tritons .
- Grey tracks producing particles ``g-particles" having a relative ionization $I^*> 1.4$ and L>3mm.
- Black tracks producing particles ``b-particles" having L<3mm.

The g- particles emitted within $\theta< 3^o$ and having L>2cm are considered to be projectile fragments having Z=2. The b-particles of $\theta< 3^o$ and L>1cm are due to projectile fragments having $Z\geq 3$.

The number of delta-electrons has been measured for each of these particles in order to determine the corresponding charge $Z=3,......,Z_b$.

Thus, all the particles have been adequately divided into: projectile fragment with Z varying from 1 to Z_b ; target fragments ,i.e., h-particles(sum of g- and b-particles); and the generated shower particles. The polar angle θ of each track ,i.e. , the space angle between the direction of the beam and that of the given track has been measured.

3 The Modified Cascade Evaporation Model:

The modified cascade evaporation model (MCEM) views the collision between two nuclei as a collision between two clouds of a Fermi gas. The interaction between two nucleons, one from the projectile and the other from the target, was followed in time by the Monte-Carlo technique. When the cascade stage is finished, the residual nucleus is treated statistically and the evaporation process is considered.

Projectile	$<n_s>$	$<n_g>$	$<n_b>$
^2H	2.5± 0.1 (1.8 ± 0.0)	3.9± 0.1 (1.9 ± 0.1)	4.6± 0.2 (2.9 ± 0.1)
^3He	3.6 ± 0.1 (2.7 ± 0.1)	3.0 ± 0.1 (2.5 ± 0.1)	5.3 ± 0.2 (3.6 ± 0.1)
^4He	3.8 ± 0.1 (3.3 ± 0.1)	4.4 ± 0.1 (2.8 ± 0.1)	4.2 ± 0.1 (3.5 ± 0.2)
^6Li	5.7 ± 0.3	4.2 ± 0.2	4.9 ± 0.3
^{12}C	7.6 ± 0.2 (7.0 ± 0.2)	5.9 ± 0.3 (5.2 ± 0.2)	4.4 ± 0.2 (4.8 ± 0.2)
^{22}Ne	10.5 ± 0.1 (10.1 ± 0.3)	6.3 ± 0.1 (6.8 ± 0.3)	4.2 ± 0.1 (5.1± 0.2)
^{24}Mg	11.0 ± 0.4 (11.6 ± 0.3)	7.9 ± 0.4 (6.9 ± 0.3)	5.1± 0.2 (5.2 ± 0.2)
^{28}Si	11.8 ± 0.3 (12.6 ± 0.4)	6.4 ± 0.2 (7.0 ± 0.3)	4.8 ± 1.0 (5.2 ± 0.2)
^{32}S	13.4 ± 0.6 (14.1 ± 0.4)	7.9 ± 0.5 (7.9 ± 0.4)	5.9 ± 0.3 (5.3 ± 0.2)

4 Results and Discussion:

The average values of the multiplicity of the different charged secondary particles, emitted from the interactions of heavy ions with the emulsion at (4.1-4.5) GeV/c per nucleon ,are given in the Table. The Table shows that the values of the average multiplicities $<n_s>$,$<n_g>$ and $<n_b>$, calculated according to MCEM, written between parenthesis, are in fair agreement with the corresponding experimental values. From the comparison of the experimental data for the average multiplicities of the different charged particles, emitted in the nucleus-nucleus interactions, with the corresponding values for the MCEM, it can be seen that the

MCEM describes qualitatively the average values of the emitted charged particles and their dependences on the projectile mass number A_b. The quantitative comparison shows that the model overestimates systematically the average multiplicities for ^{24}Mg , ^{28}Si and ^{32}S. It can be seen that both $<n_s>$ and $<n_g>$ increase with the projectile mass number. This result is in agreement with that previously obtained (EL Naghy et al.,1982), in which it has been found that $<n_s>/\nu \cong <n_s>_{pp}$, where ν is the average number of the projectile nucleons participating directly in the interaction and $< n_s >_{pp}$ is the average multiplicity of shower particles for proton-proton collision. The increase of the values of $<n_g>$ with the mass number of the beam nucleus is less pronounced than the corresponding one for the shower particles. From previous studies, $< n_g>$ has been found to be a measure of the number of the interacting projectile nucleons and of the corresponding number of the intranuclear collisions (Khrasznouszky,1998). The value of $<n_b>$ is almost independent of the projectile mass number, in the given energy range , which shows that the excitation of the target nucleus together with the subsequent evaporation of the particles and the fragments, seem to be independent of the first stage of the collision. Accordingly, the nucleus-nucleus collision may be considered as a superposition of the hadron-nucleon collisions.

It is interesting to investigate the relation between the number of produced shower particles and the mass number of the projectile nucleus, A_b .Figure 1 shows $<n_s>$ versus A_b. The experimental data have been fitted to a power law of the form $<n_s> = \alpha A_b^{\beta}$. From the fitting ,it has been found that $\alpha = 1.79 \pm 0.05$ and $\beta = 0.57 \pm 0.01$. It is to be noticed that the value of β is approximately two thirds ,i.e., $<n_s>$ is almost directly proportional to the geometrical cross-sectional area of the beam nucleus. Figure 2 shows the relation between $<n_g>$ and A_b , the experimental points were found to fit the relation $<n_g> = \alpha A_b^{\beta}$ where $\alpha = 2.87 \pm 0.08$ and $\beta = 0.27 \pm 0.01$.

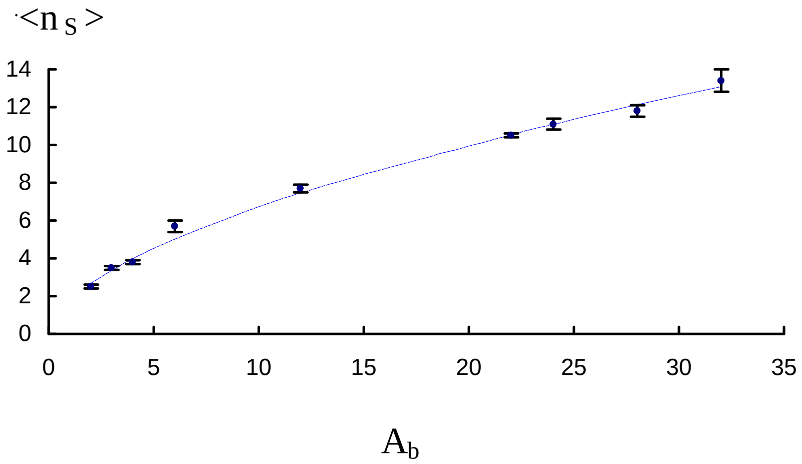

Figure 1 Average number of the shower particles $< n_s >$ as function of the projectile mass number A_b at (4.1 - 4.5) A GeV/c.
The curve is given by :
$< n_s > = 1.79 A_b^{0.57}$

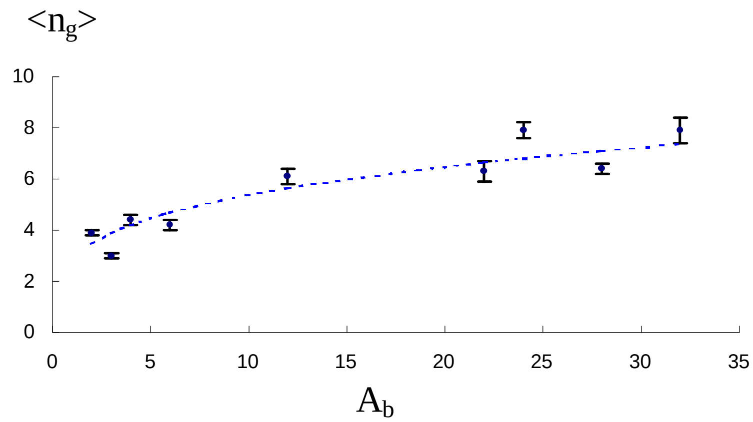

Figure 2 Average number of the grey particles $< n_g >$ as function of the projectile mass number A_b at (4.1 4.5) A GeV/c.
The curve is given by :
$< n_g > = 2.87 A_b^{0.27}$

The relation between the average number of shower particles and the average number of intranuclear collisions, ν, has been studied. Figure 3 shows $<n_s>$ versus ν . The experimental data have been fitted by a straight line. It has been found that $<n_s>$ increases linearly with ν according to the relation , $<n_s> = (0.54 \pm 0.08) + (0.98 \pm 0.01)\ \nu$. It may be noticed that $<n_s>$ for $\nu = 1$ approximately equals the average multiplicity for a nucleon-nucleon collision. Moreover, this result confirms the idea of considering the nucleus-nucleus collision as a superposition of the hadron-nucleon collisions. Figure 4 shows the relation between $<n_g>$ and ν , the experimental points were found to fit the relation $<n_g> = (2.60 \pm 0.10) + (0.37 \pm 0.02)\ \nu$ ·

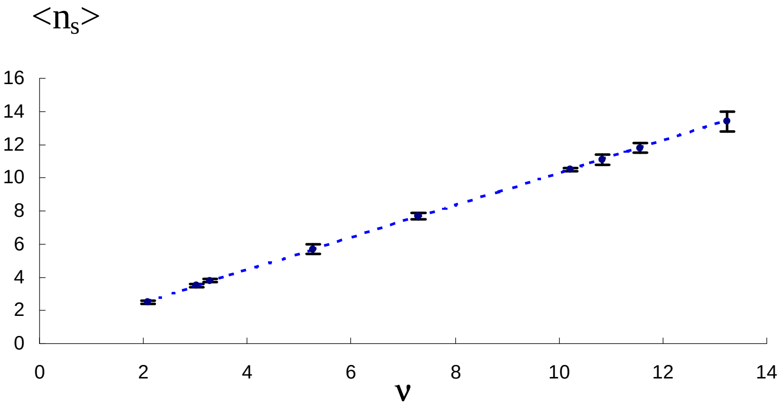

Figure 3 Average number of the shower particles $< n_s >$ versus the average number of the intranuclear collisions ν . The straight line is given by: $< n_s> = 0.54 + 0.98\ \nu$

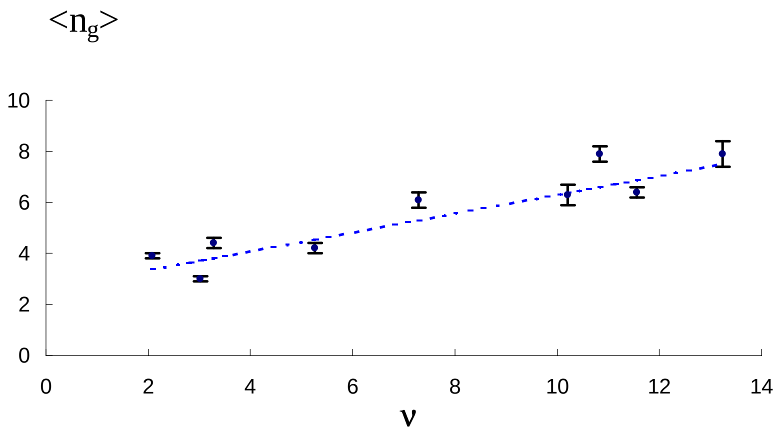

Figure 4 Average number of the grey particles $< n_g >$ versus the average number of the intranuclear collisions. The straight line is given by : $< n_g > = 2.60 + 0.37\ \nu$

5 Conclusions

From the present study , it may be concluded that the average multiplicities $<n_s>$,$<n_g>$ and $<n_b>$ agree qualitatively with those calculated from the modified cascade evaporation model. The $<n_s>$ and the $<n_g>$ values increase with the projectile mass number while the $<n_b>$ values are independent of the projectile mass number. The dependences of $<n_s>$ and $<n_g>$ on the projectile mass number, A_b , are described by the empirical relations $< n_s > = (1.79 \pm 0.05)\ A_b^{0.57}$ and $<n_g > = (2.87 \pm 0.08)\ A_b^{0.27}$, respectively.

The relations of $< n_s >$ and $< n_g >$ with the average number of the intranuclear collisions ν are given by: $< n_s > = (0.54 \pm 0.08) + (0.98 \pm 0.01)\ \nu$ and $< n_g > = (2.60 \pm 0.10) + (0.37 \pm 0.02)\ \nu$, respectively.

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