Transverse momenta of α fragments from interactions of neon-22 with emulsion nuclei at a momentum of 4.1A GeV/c

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Analysis of a statistical base of 4156 interactions of neon-22 nuclei with an emulsion at 4.1A GeV/c reveals that the yield of α particles is higher than that of other fragments (0.8 α particle and 0.5 $z \geqslant 3$ per star). The transverse-momentum distribution of the α particles has an excess at large values. This excess depends on the nature of the impinging nucleus, the nature of the target, and the nature of the interaction.

1. Stacks of a nuclear emulsion, GOSNIIKhIMFOTOPOEKT type BR-2, consisting of sheets $10 \times 20 \times 0.06$ cm^3 in size, were bombarded with neon-22 nuclei at the synchrophasotron of the high-energy laboratory of the Joint Institute for Nuclear Research. The search for the interaction was carried out by scanning along a track; this approach made it possible to obtain an ensemble of events without discrimination. The experiment is described in Ref. 1.

Relativistic α particles were distinguished up to angles $\theta \leqslant 15°$ from the primary projectile nucleus: a) They were distinguished from nuclei with $z = 3$ on the basis of measurements of the number of breaks with a length greater than a specified value. b) It was required that the initial ionization satisfy $J/J_{\min} = 4$ and that it remain constant over a distance $l > 2$ cm (for protons with $J/J_{\min} = 4$, we would have $p\beta c = 200$ MeV, and over a distance $l = 2$ cm the ionization would change from four to eight times the minimum ionization).

The transverse momentum of the α fragments was determined from the formula $P_\perp = 2zP_0 \sin\theta$, where P_0 is the primary momentum per nucleon, and $\beta = 0.97$. Measurements of the momentum on the basis of multiple Coulomb scattering for some of the α tracks revealed that their momenta agree within the errors with the primary momenta, specifically, a) $\langle p\beta c\rangle = 15.6 \pm 0.8$ GeV for fragments with $\theta < 0.6°$ (on the basis of eight tracks each with $l = 50$) and b) $\langle p\beta c\rangle = 15.3 \pm 0.6$ GeV, which is an average over 23 tracks of α fragments with $\theta = 3$–$15°$.

For all the singly charged relativistic particles with $\theta \leqslant 3°$, we measured the momentum on the basis of the multiple scattering, and we determined the multiplicities of protons, deuterons, and tritons statistically.[2] Working from part of the statistical base, we measured the momentum of all singly charged relativistic particles with angle up to 5°. In some of the laboratories, the momentum of the relativistic particles was measured for arbitrary θ at a depth angle up to 5°, and geometric corrections were made.[3]

2. Table I shows the distribution of events in the multiplicity of relativistic fragments for NeEm interactions for various $N_h = n_b + n_g$ groups and for various groups in terms of the resultant charge of the fragments of the projectile nucleus, $Q = \Sigma z_f$.

The multiplicity of α fragments is 0.8 per star, significantly greater than the yield of all fragments with $z_f \geqslant 3$ ($\langle n_{z_f} \geqslant 3\rangle = 0.48$) and considerably greater than the yield of tritons[2] ($\langle n_t\rangle = 0.14$). The multiplicity of α fragments decreases with increasing N_h and decreases by a factor of about two as we go from $Q \geqslant 5$ to $Q = 2$–4, i.e., as the impact parameter of the nucleus-nucleus interaction decreases. The fragment with $z = 2$ is a special case: The frequency at which α particles appear is 10–15 times that for any other fragment with $z_f = 3$–10. It was also shown in our previous studies[4,5] that channels involving the emission of α particles are also distinguished by their frequency during the fragmentation of neon-22. A comparison of the experimental

TABLE I.

N_h, Q \ n_α	0	1	2	3	4	5	N_{ev}	N_α/N_{ev}
$N_h \geqslant 0$	2057	1262	509	240	78	10	4156	0.81 ± 0.02
$N_h = 0$–1	457	343	109	66	40	7	1022	0.93 ± 0.04
$N_h = 2$–6	568	425	200	96	26	1	1316	0.93 ± 0.03
$N_h \geqslant 7$	1032	494	200	78	12	2	1818	0.65 ± 0.02
$N_h \geqslant 28$	381	80	10	2	1	0	474	0.23 ± 0.03
$Q = 2$–4	405	318	44	0	0	0	767	0.53 ± 0.03
$Q = 5$–7	312	320	272	107	0	0	1011	1.17 ± 0.05
$Q = 8$–10	848	574	177	131	74	9	1808	0.92 ± 0.03

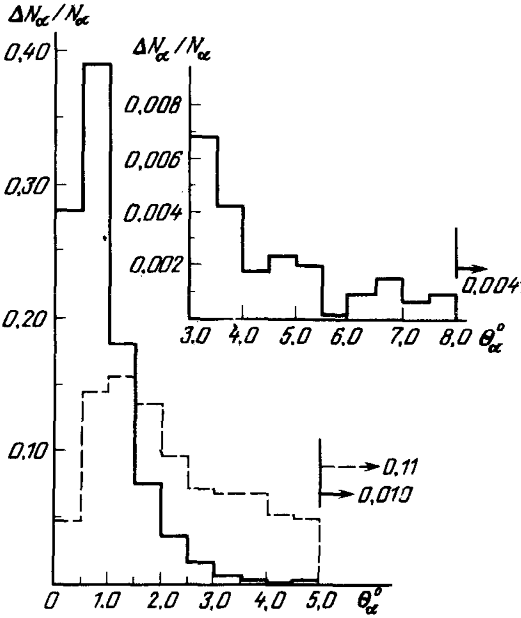

FIG. 1. Angular distributions of relativistic α particles and protons which are fragments from ^{22}NeEm interactions. Solid histogram—α particles ($N_{\rm int} = 4156$, $N_\alpha = 3381$); dashed histogram—protons ($N_{\rm int} = 1180$, $N_p = 1208$).

data with the cascade-evaporation model shows that channels with $n_\alpha \geqslant 2$ and $n_\alpha \geqslant 3$, respectively, are either too low or absent from the model.

3. The transverse momenta of the α fragments were determined on the basis of their emission angle $P_\perp = 4P_0 \sin\theta$. Figure 1 shows angular distributions of relativistic

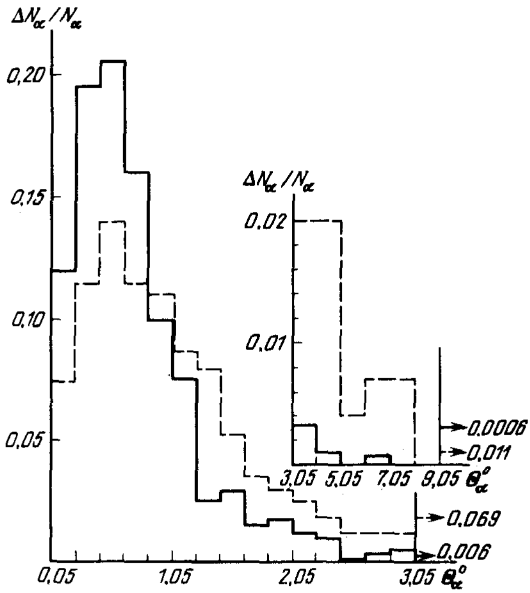

FIG. 2. Angular distributions of α fragments from ^{22}NeEm interactions for various Q groups. Solid histogram—$Q = 8$–10 ($N_{\rm int} = 1649$, $N_\alpha = 1595$); dashed histogram—A = 2–4 ($N_{\rm int} = 778$, $N_\alpha = 449$).

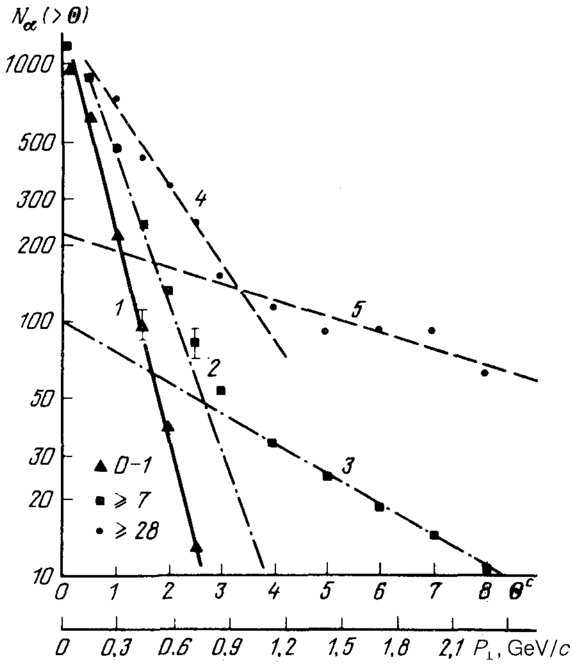

FIG. 3. Integral distributions in $P_\perp$ of the α fragments from $^{22}NeEm$ interactions for various N_h groups (the labels on the points). For scales 4 and 5: $N_\alpha(>\theta)(N_h \geqslant 28) = N_\alpha(>\theta):10$.

α particles for all interactions. Shown for comparison in the same figure, up to angles $\theta \leqslant 5°$, are the angular distributions of relativistic fragments: protons. The protons were distinguished from part of the statistical base by working from the errors in the measurements of the momenta of individual particles. It can be seen from this figure that for angles $\theta < 1.5°$ the fraction of α particles is significantly greater than the fraction of protons, while for angles $\theta > 1.5°$ we find the opposite situation. As the angel θ increases from 2° to 5°, the fraction of protons decreases by a factor of about two, while the fraction of α particles decreases by about an order of magnitude. Figure 2 shows angular distributions of α fragments for different Q groups. We see that the angular distributions become substantially wider as Q decreases. Some of the results of a detailed analysis of the $P_\perp$ distribution of the α fragments were given in Refs. 2, 5, and 6–8. Figure 3 shows integral angular and, respectively, $P_\perp$ distributions of relativistic α fragments for various groups of interactions in terms of N_h. We see that these distributions can be described by exponential functions $N(>\theta) \sim \exp(-\theta/\theta_0)$, where the slope of the exponential depends on N_h. Table II shows values of the angle θ_0 along with $\langle P_\perp \rangle$ for the α particles. It follows from an analysis of the data in Figs. 2 and 3 and Table II that for all interactions and also for groups of interactions with $N_h \geqslant 7$ and $N_h \geqslant 28$ the angular distributions of the α particles are described by two exponential functions, with slopes differing by a factor of four or five. For events with $N_h \geqslant 7$ and $N_h \geqslant 28$, the fractions of α particles in the second exponential function are about 10% and 20%, respectively.

The average value $\langle P_\perp \rangle_\alpha$ increases with increasing N_h and with decreasing Q.

TABLE II.

N_h	θ_0, deg	$\langle\theta\rangle$, deg	$\langle P_\perp\rangle$, GeV/c	N_α
Ne + Em, P_0 = 4,1 GeV/c per nucleon				
0–1	0,50	0,77 ± 0,02	0,217 ± 0,007	954
2–6	0,60; 2,5	0,91 ± 0,02	0,261 ± 0,005	1222
⩾ 7	0,80; 3,5	1,16 ± 0,04	0,332 ± 0,013	1186
⩾ 28	1,5; 6,5	2,19 ± 0,03	0,63 ± 0,09	110
⩾ 0	0,65; 3,5	0,955 ± 0,016	0,273 ± 0,004	3362
C + Em [9], P_0 = 4,5 GeV/c per nucleon				
⩾ 0	0,50	0,76 ± 0,03	0,241 ± 0,008	1128
Fe + Em [10], E_0 = 1.7 GeV per nucleon				
⩾ 0			0,370 ± 0,010	–

The angular distributions of α fragments in Fe + Em interactions at $E_0 = 1.7$–1.9 GeV per nucleon were studied in Refs. 11–13 as a sum of two independent distributions with temperatures $\sigma_1 \approx 10$ MeV/c and $\sigma_2 \approx 40$–50 MeV/c. The fraction of α particles from the second source was about a third of the total number of α particles. Kolybasov and Sokol'skikh[14] have offered a theoretical explanation of the α-particle tail with large transverse momenta ($P_\perp > 0.8$ GeV/c, $\theta_\alpha > 2.8°$) on the basis of an "adhesion" model.

Analysis of the data in Table II and Refs. 8–13 shows that the angular distributions of the α fragments become broader, while $\langle P_\perp \rangle_\alpha$ and the fraction of α particles with large $P_\perp$ increase with increasing atomic number of the projectile nucleus. The relation $\langle P_\perp \rangle_\alpha \sim A^{0.25}$ holds.

4. Conclusion. The multiplicity and angular distributions of the α fragments in nucleus-nucleus interactions depend on the atomic number of the projectile nucleus, the degree of excitation of the target nucleus, and the impact parameter. The statistical mechanism alone is incapable of explaining the nature of the $P_\perp$ distributions of the α particles. The entire set of experimental data on the characteristics of the α fragments can be linked with the appearance of short-lived α-cluster structures in the course of the nuclear interaction as a result of the fragmentation of the projectile nucleus and their scattering by nucleons or clusters of the target nucleus.

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