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INELASTIC INTERACTIONS OF 16.5 GeV/c α-PARTICLES WITH LIGHT (H, C, O) AND HEAVY (Br, Ag) NUCLEI

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The inelastic interactions of 16.5 GeV/c α-particles with light (H, C, O) and heavy (Br, Ag) tagret nuclei were studied. Nuclear emulsions with different atomic compositions were used both as targets and detectors.

The interactions corresponding to the processes of fragmentation of the primary α-particles were selected out of the main sample of inelastic evants. The cross-section values, multiplicity, angular and momentum distributions of secondary particles were obtained and analysed.

Nuclear reactions on light (H,C,O) and heavy (Br,Ag) nuclei (α,X), p=16.5 GeV/c. Analysed cross sections, multiplicity, angular and momentum distributions.

НЕУПРУГИЕ ВЗАИМОДЕЙСТВИЯ α-ЧАСТИЦ С ИМПУЛЬСОМ 16,5 Гэв/с НА ЛЁГКИХ (H, C, O) И ТЯЖЁЛЫХ (Br, Ag) ЯДРАХ

В работе изучаются неупругие взаимодействия α-частиц с импульсом 16,5 Гэв/с с мишенью, представляющей собой лёгкое (H, C, O) или тяжёлое (Br, Ag) ядро. Ядерные эмульсии с различным атомным составом были использованы как в качестве мишеней, так и в качестве детекторов. Из основного количества неупругих случаев были исключены взаимодействия, соответствующие процессам фрагментации первычных α-частиц. Проведён также анализ полученных поперечных сечений, множественности, углового распределения и распределения по импульсам вторичных частиц.

Ядерные реакции типа (α, X) на лёгких (H, C, O) и тяжёлых (Br, Ag) ядрах при p = 16,5 Гэв/с. Анализ поперечных сечений, множественности, угловых распределений и распределений по импульсам.

I. INTRODUCTION

This experiments is a part of a complex programme of investigations in the domain of relativistic nuclear physics undertaken in the Joint Institute for Nuclear Research in Dubna [1]. The programme is based on the facilities at JINR — high intensity beams of deuterons and α—particles of a 4.5 GeV/c momentum per incident nucleon. These beams have been used in the present experiment (see also [2, 3]) and in the previous one [4, 5], in which the nuclear emulsion techniques were used.

Then aim of the present experiment is:

a) an analysis of inelastic interactions of relativistic particles with light and heavy target nuclei,

b) an analysis of projectile fragmentation processes, accompanying the collisions of α particles with light and heavy target nuclei.

II. EXPERIMENTAL

The use of the nuclear emulsion both as a target and a detector yields the possibility of an analysis of separate interaction events (e.g.: multiplicity, angular and momentum characteristics of secondary particles). The well-known drawback of the nuclear emulsion techniques, namely the necessity of dealing with a variety of target nuclei with a wide range of atomic mass values, has been partly removed in this experiment by use of two types of nuclear emulsions: the "standard" (S.E) and the "light", (L.E.); the latter has been obtained by addition of a glycerine (or glucose) solution to a standard emulsion (see Appendix and Table 1).

The experimental data such as mean free path values, multiplicity and angular distributions, obtained in S. E. and in L. E. allow to determine these characteristics separately for interactions with light and heavy target nuclei. The procedures used for this purpose are described in the Appendix.

The inelastic interactions of α particles (A-events) have been found by means of the well known method of "along the track" scanning.

The interactions, in which at least one relativistic secondary particle with a single ($Z=1$) or double ($Z=2$) charge was emitted at an angle $\Theta \leq 3°$, with respect to

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Table 1

Emulsion type	Number of atoms (10^{22}/cm^3) H	C	N	O	Br	Ag
I — "standard emulsion"	3.15	1.41	0.395	0.956	1.031	1.036
II — "light" emulsion with glucose	5.23	1.29	0.147	2.38	0.385	0.387
III — "light" emulsion with glycerine	5.12	1.51	0.172	1.99	0.45	0.450
Glucose solution	6.46	1.2	—	3.22	—	—
Glycerine solution	6.63	1.6	—	2.78	—	—

Table 2

Emulsion type	Number of A — events	λ (cm)	Number of A1 — events*)	Number of A2 — events*)
I S. E.	4028	19.5 ± 0.3	1468 (4028)	299 (4028)
II L. E. with glucose	1028	28.0 ± 0.9	192 (522)	58 (565)
III L. E. with glycerine	1763	26.3 ± 0.6	679 (1580)	112 (1580)

*) In brackets: numbers of A-events out of which A1 or A2 were selected

the primary direction, have been selected out of the main sample of inelastic interactions. They are further on referred to as A1 and A2 events, respectively[9]).

The number of events in each group, found in S. E. and L. E., is given in Table 2, together with the corresponding mean free path values, λ, corrected for the scanning efficiency.

For a part of the total sample of A-events both in S. E. and L. E. the multiplicity characteristics were determined (number of heavily ionising (N_h) and shower (n_s) particles, according to the well-known criteria used in the emulsion techniques) and the emission angles of "*h*" and "*s*" secondaries were measured.

For all events belonging to the A1 and A2 samples both in S. E. and L. E. the multiplicity characteristics were determined and emission angles of relativistic $Z=1$ and $Z=2$ secondaries ($\Theta \leqq 3°$) were measured. Whenever technically possible, the $p\beta$ values of $Z=1$ and $Z=2$ relativistic secondaries in S. E. were determined by the multiple Coulomb scattering method. Unfortunately, the $p\beta$ measurements in L. E. were not reliable enough.

III. RESULTS AND DISCUSSION

III.1. Cross-section

The mean free path values (Table 2) for the A-events found in S. E. and L. E. and the value of the relative increase of the emulsion volume due to the addition of a glucose (or glycerine) solution allow to determine the mean free path value, λ^{sol}, for inelastic interactions of α particles in the solution (see Appendix). The λ^{sol} values and the known concentrations of various atoms (n_i^{sol}) in each solution are further used in the formula

$$1/\lambda^{sol} = \sigma_H n_H^{sol} + \sigma_c n_c^{sol} + \sigma_o n_o^{sol} , \qquad (1)$$

where $\sigma_{H'}$, $\sigma_{C'}$, σ_O are cross-section values for α interactions with H, C, O nuclei, respectively.

Taking the σ_H value (100 mb) from [6] and assuming the form of $\sigma(A)$ dependence to hold within a rather narrow interval of atomic mass values, A, between C and O, one obtains σ_C, σ_N and σ_O values. These values, the atomic concentrations (n_i) in S. E. and the mean free path value, $\lambda^{S.E.}$ are further used in the formula

$$1/\lambda^{S.E.} = \sum_i n_i \sigma_i ,$$

containing σ_{Br} and σ_{Ag} as unknown values. Assuming the same form of $\sigma(A)$ dependence within the interval of mass numbers between Br and Ag, one obtains the cross section values σ_{Br} and σ_{Ag}.

The obtained cross sections for heavy target nuclei can be compared with those derived from the σ_C value and the assumption that the same form of $\sigma(A)$ dependence holds for the whole interval of A values between C and Ag.

Two forms of the $\sigma(A)$ dependence have been used: a) $\sigma \sim A^{2/3}$ and b) $\sigma \sim (r_\alpha + r_0 A^{1/3})^2$, where $r_\alpha = 1.2$ fm and $r_0 = 1.2$ fm.

The cross section values for inelastic α-nucles interactions are given in Table 3.

Table 3

Assumed form of $\sigma(A)$ dependence	(a) $\sigma \sim A^{2/3}$		(b) $\sigma \sim (r_+ + r_0 A^{1/3})^2$	
cross-section values in mb target nuclei	values obtained (assumption: a holds for $12 \leqslant A \leqslant 16$ and $80 \leqslant A \leqslant 108$, separately)	values expected if (a) holds for $12 \leqslant A \leqslant 108$	values obtained (assumption: (b) holds for $12 \leqslant A \leqslant 16$ and $80 \leqslant A \leqslant 108$, separately)	values expected if (b) holds for $12 \leqslant A \leqslant 108$
C	410 ± 30	—	430 ± 30	—
N	450 ± 30	—	460 ± 30	—
C	500 ± 30	—	490 ± 30	—
Br	1570 ± 60	1453	1590 ± 50	1115
Ag	1910 ± 70	1774	1880 ± 60	1314

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[9]) One prong events with a single $Z=2$ secondary emitted at an angle $\Theta \leqslant 3°$ with respect to the primary direction were not included into the A1 and A2 samples.

The errors in the Table are statistical errors only. The main source of systematical errors is due to the unknown error in the σ_H value. If a (± 10 %) error of this value is assumed; then the corresponding systematical errors of σ_C, σ_H, σ_O, σ_{Br} and σ_{Ag} are: -14, -15, -16, $+20$ and $+24$ mb, respectively.

It can be seen that the thus obtained cross-section values are rather insensitive to the assumed form of the $\sigma(A)$ dependence for the A intervals between 12 and 16 and between 80 and 108, separately. The cross section values for heavy target nuclei, expected under the assumption that the $\sigma(A) \sim (r_\alpha + r_0 A^{1/3})^2$ dependence holds for the wide interval of A between 12 and 108, are inconsistent with the experimental values, while the $\alpha(A) \sim A^{2/3}$ dependence seems to work for the whole range of the target mass numbers.

III.2. Multiplicities

The multiplicity tables $N_h - n_s$ were obtained for the inelastic interactions found in S. E. and L. E. [2, 3]. The differential procedure, described in the Appendix, allows, in principle, to obtain multiplicity tables for interactions with light (H, C, O) and heavy (Br, Ag) target nuclei. However, since the number of events for fixed pairs of N_h and n_s values was in most cases rather small, the differential procedure has been applied only to the N_h *and* n_s projections of the tables.

The N_h and n_s distributions for the inelastic interactions with light and heavy nuclei are shown in Figs. 1a and 1b. The N_h distribution for interactions with light nuclei falls rapidly at $N_h = 6$ and fluctuates around zero for $N_h \geq 7$. This observation shows that the $N_h \geq 8$ criterion traditionally used in the nuclear emulsion techniques for the selection of interactions with heavy nuclei is too "weak". Similar effects at $N_h = 6$ have been observed in all the N_h distributions for light target nuclei obtained in the experiment. A cutt-off at $N_h = 6$ was therefore applied in the analysis of these distributions.

The N_h distributions in case of both light and heavy target nuclei show a certain structure in the region of small N_h values. This effect may be tentatively ascribed to the contribution of "peripheral" (mainly $N_h < 3$) and "central" (mainly $N_h \geq 3$) collisions of α particles with target nuclei (see III.5).

The n_s distribution for α interactions with heavy target nuclei is much broader than that for light target nuclei and the corresponding average $\langle n_s \rangle$ values are significantly different. This effect indicates the essential role of the target mass in the process of secondary particle production.

III.3. Angular distributions of secondary particles

The angular distributions of s-particles emitted from the α interactions with light (H, C, O) and heavy (Br, Ag) target nuclei are shown in Fig. 2. It can be seen that the shower particle emission from interactions with light target nuclei is practically limited to cos $\Theta > 0.4$. For larger emission angles the distribution fluctuates around zero, while in the case of interactions with heavy target nuclei there are about 20 % of s-particles with cos $\Theta > 0.4$. The tentative interpretation of this effect is that α

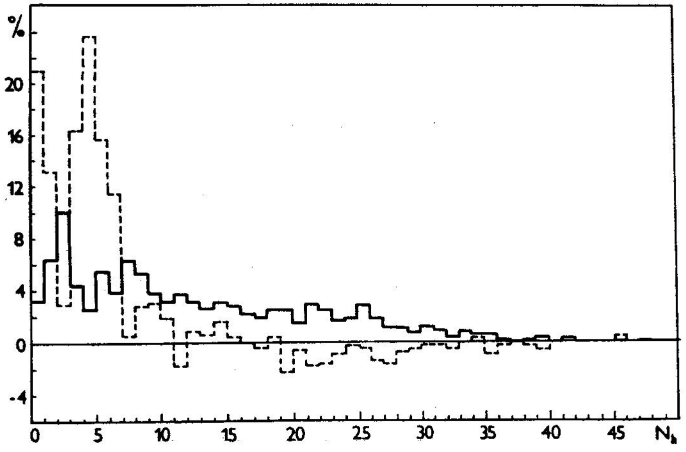

Fig. 1a. N_h distributions for α interactions with light (C, O) and heavy (Br, Ag) target nuclei. The N_h distribution for light target nuclei has been corrected for interactions with free hydrogen nuclei (see Appendix). —— heavy target nuclei (Ag, Br); $\langle N_h \rangle = 11.66 \pm 0.26$; $\Sigma = 1305$; --- light target nuclei (C, O); $\langle N_h \rangle = 2.97 \pm 0.13$; $\Sigma = 246$.

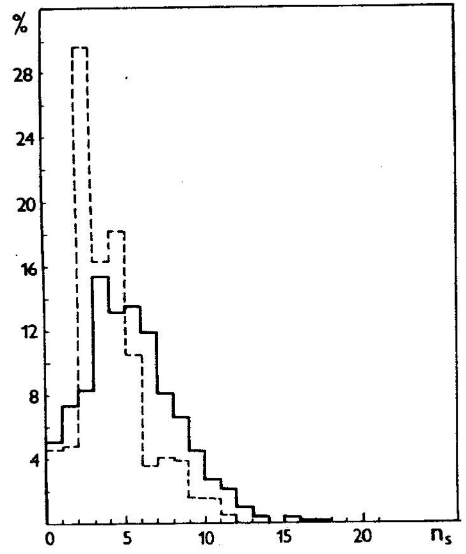

Fig. 1b. n_s distribution for α interactions with light (H, C, O) and heavy (Br, Ag) target nuclei. —— heavy target nuclei $\langle n_s \rangle = 4.80 \pm 0.08$; $\Sigma = 1317$; --- light target nuclei $\langle n_s \rangle = 3.59 \pm 0.12$; $\Sigma = 322$.

collisions with heavy target nuclei contain an essential contribution of "central" or/and multiple interactions (see III.4 and 5), responsible for the broadening of the angular distribution.

The angular distributions of h-particles emitted from the interactions with light and heavy target nuclei yield statistically unreliable number of tracks in single angular intervals. However, a quantitative feature of this distribution, the F/B (ratio of the number of particles emitted in the forward and the backward hemisphere) value is statistically significant for both distributions, and the corresponding values are: 7.2 ± 1.8 and 1.70 ± 0.07 for light and heavy target nuclei, respectively. The strong anisotropy of the h-particle emission from interactions with light target nuclei cannot be explained by the well-known anisotropy of "gray" tracks or by the velocity of the residual nucleus, emitting h-particles after the first stage of the collision process. A similar effect of the "black" track anisotropy has been observed in the case of deuteron interactions with light nuclei [7], while for proton nucleus interactions such effects have not been observed. These observations seem to be the result of the mechanism of the nucleus-nucleus interaction process.

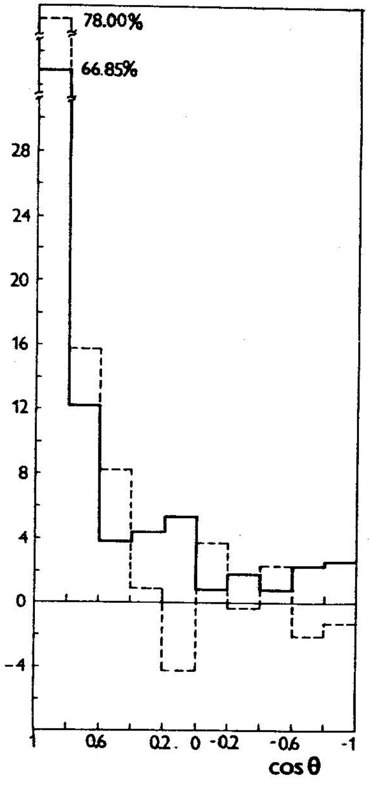

Fig. 2. Angular distributions of shower particles emitted from interactions with light and heavy target nuclei. ——heavy target nuclei $\Sigma = 1446$; – – – light target nuclei $\Sigma = 360$.

III.4. α-fragmentation reactions

The inelastic interactions in which at least one $Z=1$ or $Z=2$ relativistic secondary particle has been emitted at an angle $\Theta \leqslant 3°$ (A1 and A2 events, respectively) have been further analysed.

No direct identification of forward emitted $Z=1$, or $Z=2$ particles has been performed. Nevertheless, whenever possible, (675 tracks from A1 events and 311 tracks from A2 events) the $p\beta$ values for these particles were determined by means of the multiple Coulomb scattering method. Thus obtained $p\beta$ spectra are shown in Figs. 3 and 4. This distributions have been corrected for the geometrical criteria used for the selection of measurable tracks. The relative errors in the values for the single tracks were about 20—25 %. The reliability of the determination of the $p\beta$ values and their errors have been confirmed by the analysis of the $p\beta$ distribution obtained by the same method for about 200 primary α-particles.

The $p\beta$ distribution of $Z=1$ particles ($\Theta \leqslant 3°$) from A1 events is consistent with a superposition of three gaussian-like distributions with a) mean values equal to those expected for p, d, t particles resulting from the fragmentation of primary α

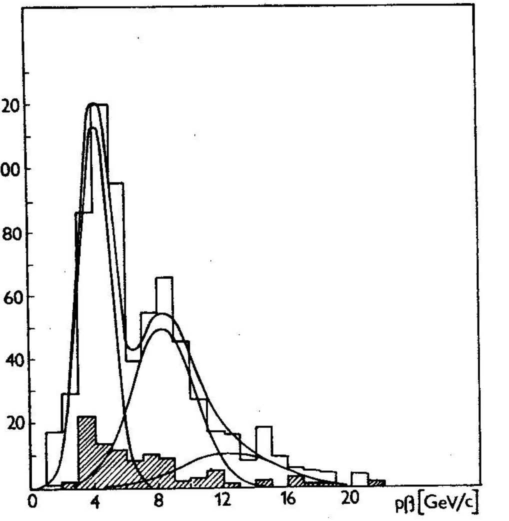

Fig. 3. $p\beta$ spectrum of $Z=1$ forward emitted secondaries from A1 events (standard emulsion). The curve is a best fit superposition of three guassian functions (see text). The shaded area corresponds to the group of 0-0-2 events — with no geometrical corrections. ▨ 0-0-2 events (99 events); $\Sigma = 675$.

particles and b) dispersion equal to the average errors of $p\beta$ values for the corresponding $p\beta$ intervals. The best fit of the three distributions to the experimental $p\beta$ spectrum leads to a rough estimation of relative yields of fragmentation p, d and t particles: $(3.6 \pm 0.6) : (3.0 \pm 0.6) : 1$[10]).

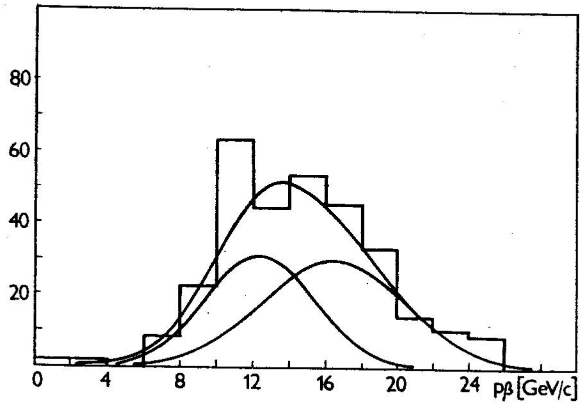

Fig. 4. $p\beta$ spectrum of $Z=2$ forward emitted secondaries from A2 events (standard emulsion). The curve is a best fit superposition of two gaussian functions (see text); $\Sigma = 311$.

The $p\beta$ spectrum of $Z=2$ particles ($\Theta \leqslant 3°$) from A2 events (Fig. 4) is consistent with the superposition of two gaussian distributions with average values and dispersions equal to those expected for ^{3}He and ^{4}He secondaries of the fragmentation processes and with approximately equal yields of ^{3}He and ^{4}He ($(0.8 \pm 0.2) : 1$).

Accepting the tentative interpretation that the secondary $Z=1$ and $Z=2$ ($\Theta \leqslant 3°$)[11]) particles are the result of the fragmentation processes of primary α particles one can consider A1 and A2 events as being due to the inclusive reaction:

$$\alpha + \text{nucleus} \rightarrow \left.\begin{matrix} {}^1\mathrm{H} \\ {}^2\mathrm{H} \\ {}^3\mathrm{H} \end{matrix}\right\} + \text{anything}$$

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[10]) An excess of events in the region of small $p\beta$ values can be ascribed to the contamination of the sample by pions and "nonfragmentation" protons; however, the best fit procedure applied to the total sample and the sample limited to particles with $p\beta > 2$ *GeV/c* leads to indistinguishable results.

[11]) The choice of the cut-off emission angle at 3° may sem to be arbitrary. However, since the angular distributions (see below) rapidly drop, the main characteristics, including cross-section values, are fairly insensitive to the angular cut-off value. On the other hand, the results of other experiments concerning stripping and fragmentation reactions (8) show that the $\Theta \leqslant 3°$ interval includes practically all fragmentation secondaries.

and

$$\alpha + \text{nucleus} \rightarrow \left.\begin{matrix} {}^3\mathrm{He} \\ {}^4\mathrm{He} \end{matrix}\right\} + \text{anything}\,.$$

The transverse momenta ($(p\beta)_\perp \approx p_\perp$) of the hydrogen and helium fragments have been determined and the corresponding distributions are shown in Figs. 5a and 5b.

The angular distributions of secondary $Z=1$ and $Z=2$ particles emitted at angles $\Theta \leqslant 3°$ from the α-fragmentation reactions on light and heavy target nuclei are given in Fig. 6a, b. All these distributions show a strong forward collimation, the affect being more marked for A2 events. The shapes of the distributions of light and heavy target nuclei in each group (A1 and A2) of events are almost identical within statistical fluctuations. This observation suggests that fragmentation reactions are mainly of the peripheral type both for light and heavy target nuclei.

The multiplicity distributions for A1 and A2 events are shown in Figs. 7a, b and 8a, b[12]).

The N_h distribution for heavy target nuclei is broader and the average $\langle N_h \rangle$ value is much higher for A1 events than in the case of A2 events. This observation is consistent with the assumption that the effective number of nucleons of the primary α-particle is — on the average — lower in the latter (A2) case.

The N_h distributions and $\langle N_h \rangle$ values for light target nuclei are close to each other for A1 and A2 samples (remembering the shift in N_h values for A2 events (see footnote. p ... .). Indeed, in the case of light target nuclei the effective number of interacting nucleons of the α-primary may lead to an increase of the number of shower particles (n_s distributions are broader for a) heavy target nuclei and b) A1 events (see Fig. 7. 8), while the number of h-tracks is limited by the mass of the light target nucleus.

The closs-section values for the fragmentation processes on light (C, O) and heavy (Br, Ag) target nuclei have been determined from the corresponding cross-section values for inelastic interactions (A-events) and the values of ratios of the number of events A1/A and A2/A (being approximately equal for interactions found in all three types of the nuclear emulsion used in this experiment (see Table 2)). The obtained cross-section values are:

$$\sigma^{\mathrm{A1}}_{\mathrm{C,O}} = (203 \pm 52)\ \mathrm{mb}; \quad \sigma^{\mathrm{A1}}_{\mathrm{Br,Ag}} = (570 \pm 160)\ \mathrm{mb}\ ;^{13)}$$

$$\sigma^{\mathrm{A2}}_{\mathrm{C,O}} = (37 \pm 12)\ \mathrm{mb}; \quad \sigma^{\mathrm{A2}}_{\mathrm{Br,Ag}} = (130 \pm 54)\ \mathrm{mb}\,.$$

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[12]) In the case of A1 events the fragmentation particle has been included into the n_s value, while in the case of A2 events into the N_h value.

[13]) The contamination of the A1 sample by non-fragmentation events (secondary pions or recoil protons) among $Z=1$ forward secondaries with low momenta has been subtracted.

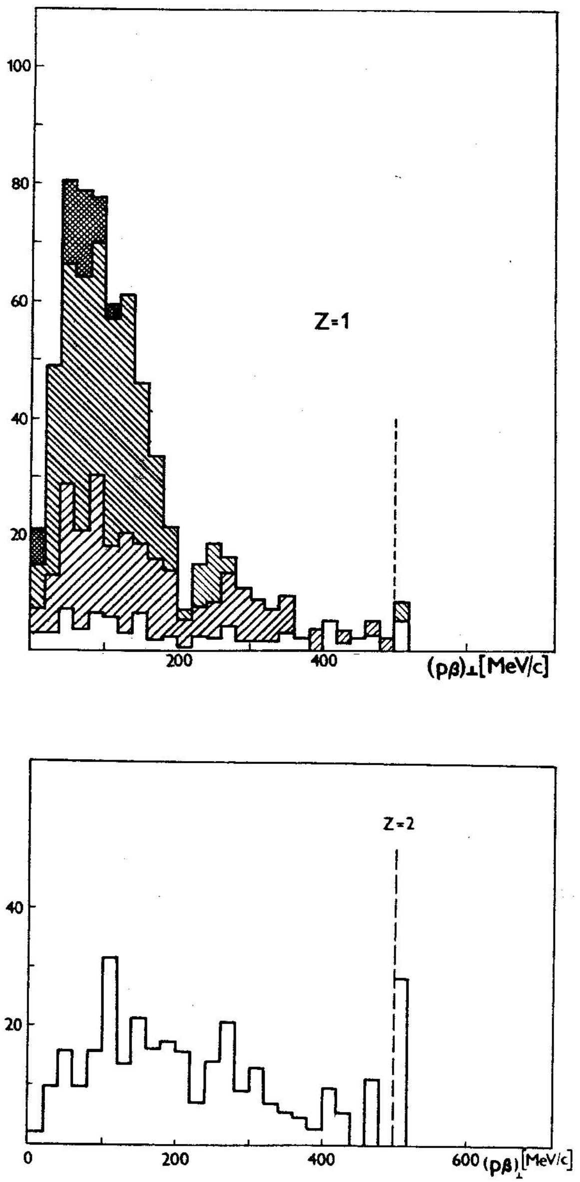

Fig. 5a,b. $(p\beta)_\perp$ distributions for (a) $Z=1$ and (b) $Z=2$ secondaries from A1 and A2 events. The shaded area in Fig. 5a correspond to different momentum intervals of the secondaries. ▨ $p\beta > 10.5$ GeV/c; ▨ 6.0 GeV/c $< p\beta < 10.5$ GeV/c; ▨ 2.5 GeV/c $< p\beta < 6.0$ GeV/c; ▨ $p\beta < 2.5$ GeV/c.

The quoted errors are only statistical. It should be noted that no assumption concerning the σ^{A1} or σ^{A2} dependence on the atomic mass number of the target nucleus was used in the determination of the fragmentation cross sections.

Multiplicity and angular characteristic of the fragmentation events corresponding to various intervals of secondary momenta are given in Table 4. The chosen intervals correspond roughly to ^{1,2,3}H and ^{3,4}He fragment momenta. In spite of the evident overlaping of the momentum distributions (see Figs. 3, 4) of the secondary fragments with different masses, it can be accepted that the samples of particles belonging to various momentum intervals are strongly enriched in the corresponding nuclei. One can see that the heavier the emitted fragments, the smaller their emission angles and the lower average multiplicity values. This observation can be

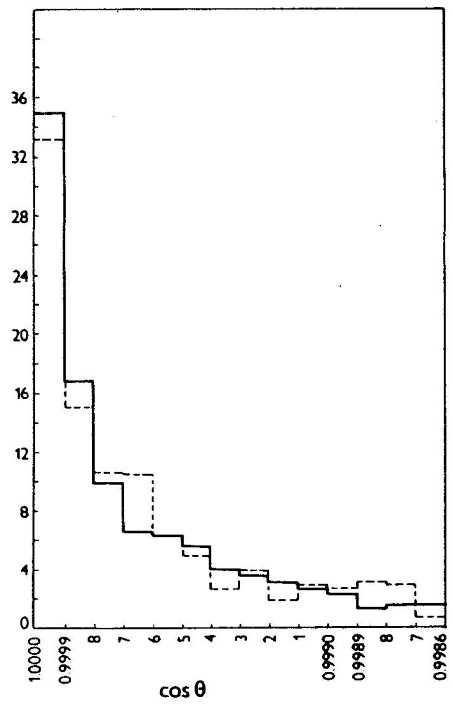

Fig. 6a. Angular distributions of $Z=1$ secondaries emitted from interactions with light and heavy target nuclei. —— heavy target nuclei, $\Sigma = 1764$; - - - light target nuclei, $\Sigma = 540$.

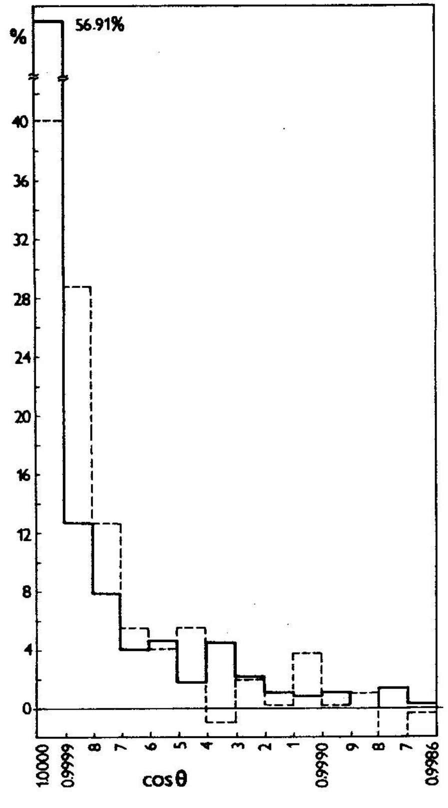

Fig. 6b. Angular distribution of $Z=2$ secondaries emitted from interactions with light and heavy target nuclei. —— heavy target nuclei, $\Sigma = 309$; - - - light target nuclei, $\Sigma = 76$.

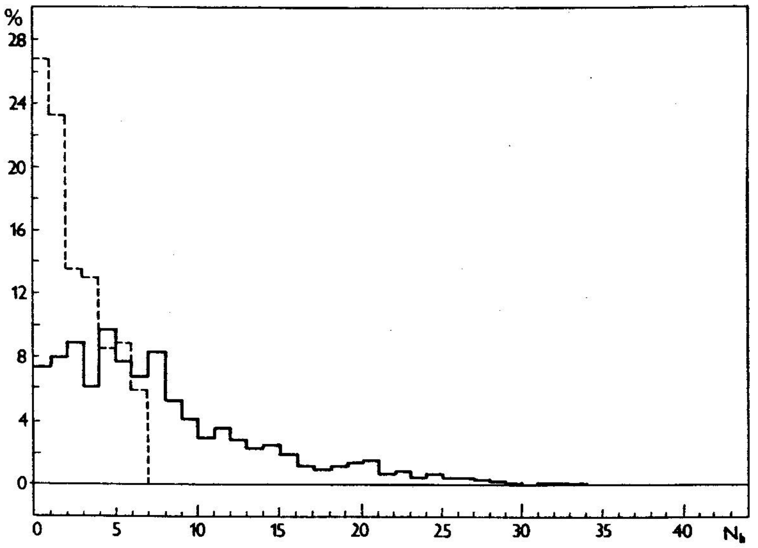

Fig. 7a. N_h distributions for A1 interactions with light and heavy target nuclei. —— heavy target nuclei, $\Sigma = 1163$, $\langle N_h \rangle = 7.40 \pm 0.19$; - - - light target nuclei, Σ $(N_h < 7) = 408$, $\langle N_h \rangle = 2.04 \pm 0.09$.

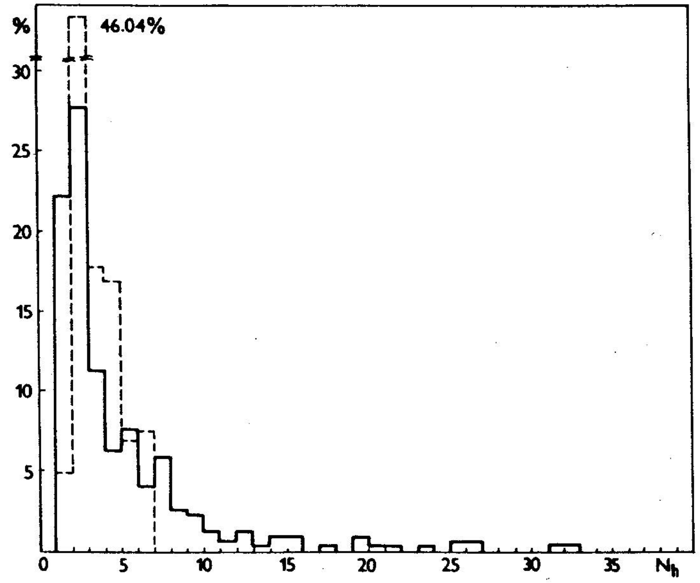

Fig. 7b. N_h distributions for A2 interactions with light and heavy target nuclei. —— heavy target nuclei, $\Sigma = 305$, $\langle N_h \rangle = 4.51 \pm 0.29$; - - - light target nuclei, Σ $(N_h < 7) = 72$; $\langle N_h \rangle = 2.97 \pm 0.16$.

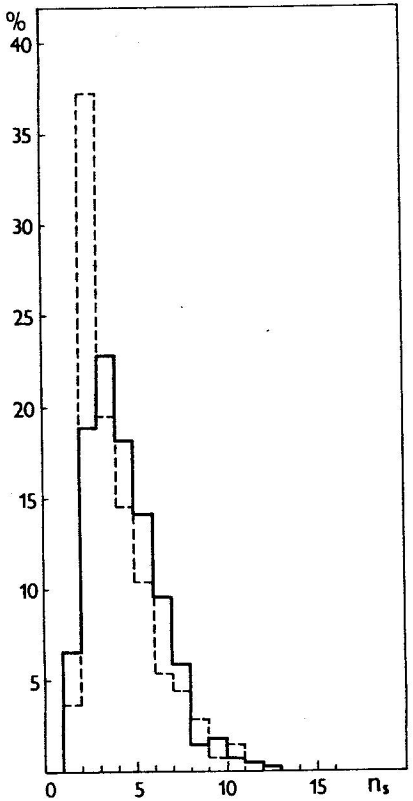

Fig. 8a. n_s distributions for A1 A2 interactions with light and heavy target nuclei. —— heavy target nuclei, Σ 1155, $\langle n_s \rangle = 3.94 \pm 0.06$; - - - light target nuclei, $\Sigma = 408$, $\langle n_s \rangle = 3.55 \pm 0.10$.

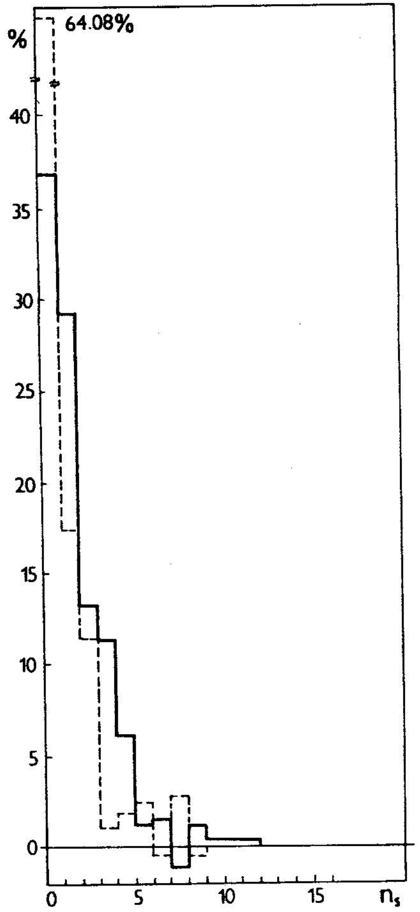

Fig. 8b. n_s distributions for A2 interactions with light and heavy target nuclei. —— heavy target nuclei, $\Sigma = 289$, $\langle n_s \rangle = 1.38 \pm 0.10$, - - - light target nuclei, $\Sigma = 72$, $\langle n_s \rangle = 0.75 \pm 0.16$.

Table 4

Z	momentum interval (GeV/c)	$\langle N_h\rangle$	$\langle n_s\rangle$	$\langle\Theta\rangle$ (degrees)
1	$2.5 \leqslant p < 6.0$	6.1 ± 0.5	4.1 ± 0.2	1.4 ± 0.1
	$6.0 \leqslant p < 10.5$	4.2 ± 0.4	3.3 ± 0.2	1.2 ± 0.1
	$10.5 \leqslant p$	2.9 ± 0.4	2.9 ± 0.2	1.0 ± 0.1
2	$p < 14$	4.0 ± 0.3	1.3 ± 0.1	1.1 ± 0.1
	$14 \leqslant p$	3.3 ± 0.3	0.6 ± 0.1	0.9 ± 0.1

interpreted as a result of an increase of the effective number of interacting nucleons of the incident α-particle.

Out of the total sample of A1 events there was selected a group of events characterized by the emission of two relativistic $Z = 1$ particles at angles $\Theta \leqslant 3°$ with no other secondaries (0-0-2 events). These events may be interpreted as due to the dissociation of primary α-particles in the field of the target nuclei:

$$\left.\begin{array}{lll} \alpha + \text{nucleus} & \rightarrow & p + {}^3\text{H} \\ & \rightarrow & d + d \\ & \rightarrow & p + d + n \text{ (unregistered)} \\ & \rightarrow & p + p + 2n \text{ (unregistered)} \end{array}\right\} + \text{nucleus}$$

61 events of the 0-0-2 type have been found in S. E. and 18 events in L. E.

The angular and $p\beta$ (Fig. 3. hatched area) distributions of the secondaries omitted from the 0-0-2 events are consistent (within their — rather poor — statistical significance) with these for the main sample of A1 events, which supports the interpretation of 0-0-2 events as due to the dissociative fragmentation of primary α-particles in the field of the target nucleus.

The mean free path values for 0-0-2 events are 12.9 ± 1.7 m and 23.3 ± 5.5 m in S. E. and L. E., respectively. These values suggest that the cross-section for dissociative fragmentation on heavy target nuclei is much higher than for the case of light target nuclei. However, due to the poor statistics no significant conclusions concerning the cross-section values on groups of light and heavy target nuclei separately can be obtained. We can state only that, since the ratios of the number of 0-0-2 events to the number of A1 events are 4.5 ± 0.6 % in S. E. and 2.9 ± 0.7 % in L. E., the cross-section dependence on the target mass (or charge) is probably stronger for dissociative processes than that for fragmentation reactions.

III.5. "Peripheral" and "central" collisions of α-particles with nuclei

All the characteristics of fragmentation reactions analysed in this experiment indicate that these processes correspond to "peripheral" interactions. Once this interpretation has been accepted, it is possible to obtain the multiplicity characteristics for the "peripheral" (A1 and A2 events) and "central" collisions, the latter by subtraction of N_h on n_s distributions for the (A1 + A2) sample for those for the A sample. Thus obtained multiplicity spectra are shown in Figs. 9 and 10.

One should note that the sample of "central" collisions, obtained in this way, is contaminated with the fragmentation reactions: α + nucleus → n + anything (a

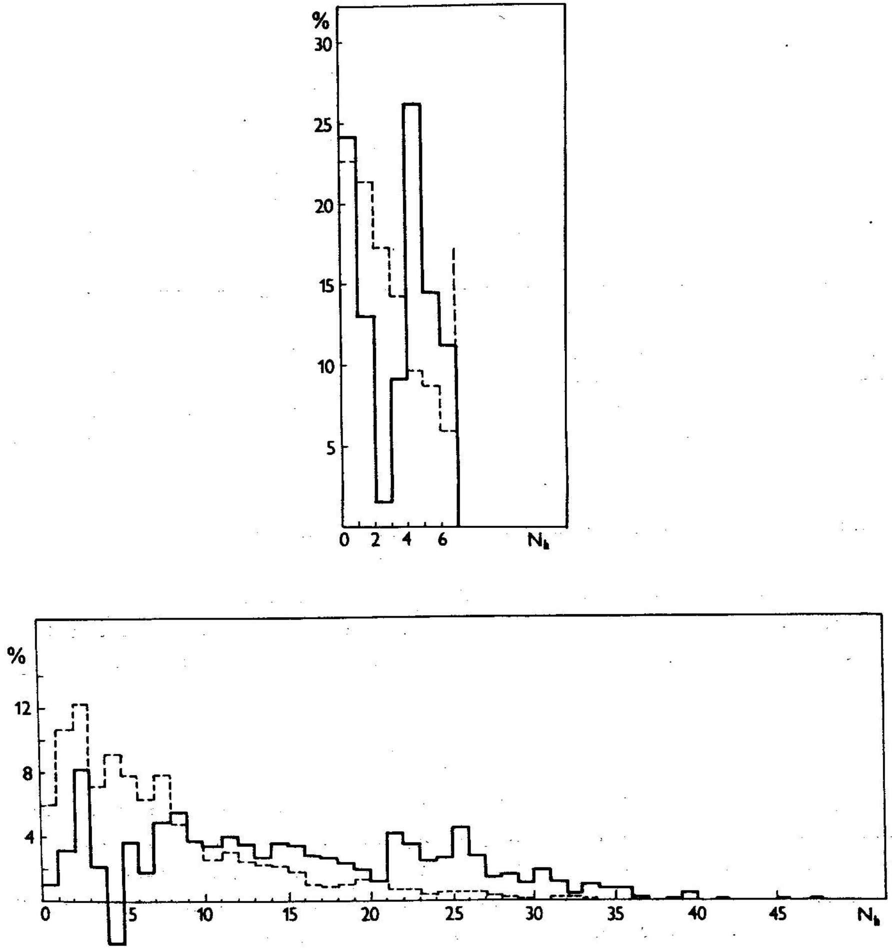

Fig. 9a, b. N_h distributions for "fragmentation" and "central" interactions with (a) light and (b) heavy target nuclei. a) —— "central" events on light nuclei, $\Sigma = 147$, $\langle N_h\rangle = 2.89 \pm 0.18$, - - - "fragmentation" events on light nuclei, $\Sigma = 177$, $\langle N_h\rangle = 2.17 \pm 0.14$; b) —— "central" events on heavy nuclei, $\Sigma = 739$, $\langle N_h\rangle = 15.32 \pm 0.35$, - - - "fragmentation" events on heavy nuclei, $\Sigma = 566$, $\langle N_h\rangle = 6.88 \pm 0.26$.

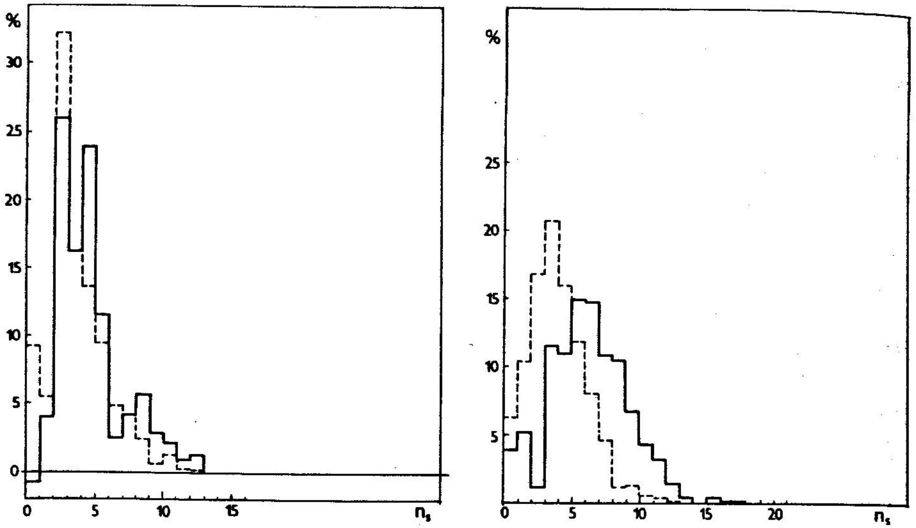

Fig. 10a, b. n_s distributions for "fragmentation" and "central" interactions with (a) light and (b) heavy target nuclei. a) —— "central" events on light nuclei, $\Sigma = 148$, $\langle n_s \rangle = 4.17 \pm 0.19$, – – – "fragmentation" events on light nuclei, $\Sigma = 177$, $\langle n_s \rangle = 3.20 \pm 0.16$; b) —— "central" events on heavy nuclei, $\Sigma = 757$, $\langle n_s \rangle = 5.78 \pm 0.10$, – – – "fragmentation" events on heavy nuclei, $\Sigma = 557$, $\langle n_s \rangle = 3.50 \pm \pm 0.09$.

rough estimation of this contamination, based on the ratio of $p/(p+d+t)$ for secondary $Z = 1$ particles from A1, leads to the value of 33 %).

The N_h and n_s distributions are broader for "central" collisions and the corresponding $\langle N_h \rangle$ and $\langle n_s \rangle$ values are higher (see Table 5). These effects are more marked for interactions with heavy target nuclei than for those with light ones.

IV. CONCLUSIONS

1. A method of the statistical separation of interactions with light and heavy target nuclei has been worked out, proving that the essential drawback of the nuclear emulsion techniques (inhomogeneous target) can be partly removed by use of nuclear emulsions of two types with different atomic compositions (the relative contents of heavy nuclei differing by a factor of about 3).

2. The cross-section values for inelastic interactions of 16.5 GeV/c α-particles with various nuclei (C, O, Br, Ag) have been obtained.

3. The cross-section values for α-nucleus collisions, accompanied by the fragmentation of the primary α-particle have been obtained for interactions with light (C, O) and heavy (Br, Ag) nuclei.

Table 5

Events	A — events			A1 — events		A2 — events		"fragmentation" collisions		"central" collisions	
Target nuclei	H, C, O	C, O	Br, Ag	H, C, O	Br, Ag	H, C, O	Br, Ag	H, C, O	Br, Ag	H, C, O	Br, Ag
$\langle N_h \rangle$	2.5±0.1	3.0±0.1	11.7±0.3	2.0±0.1	7.4±0.2	3.0±0.2	4.5±0.3	2.2±0.2	6.9±0.3	2.9±0.2	15.3±0.4
$\langle n_s \rangle$	3.6±0.1	—	4.8±0.1	3.6±0.1	3.9±0.1	0.8±0.2	1.4±0.1	3.2±0.2	3.5±0.1	4.2±0.2	5.8±0.1

4. The multiplicity and angular distributions of secondaries emitted from the inelastic and fragmentation interactions of α-particles with light and heavy nuclei have been obtained and analysed.

5. The momentum and transverse momentum distributions for the fragmentation secondaries have been studied.

6. The sample of inelastic α-nucleus interactions has been divided into two samples, corresponding to "peripheral" and "central" collisions. The multiplicity characteristics of the two types of collisions with light and heavy targets have been obtained.

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APPENDIX

The differential procedure used for the statistical separation of interactions with light and heavy emulsion nuclei consists of the following steps:

1. For any type of the analysed events the following experimental data are considered:

a) The mean free path values for the "standard" and "light" emulsion S. E. and L. E. (in the latter a glycerine (or glucose) solution has been added — see Table 1): $\lambda^{\text{S.E.}}$ and $\lambda^{\text{L.E.}}$.

b) the coefficient K^{sol} — the ratio of the emulsion volume with the solution added to the emulsion volume before the solution had been introduced,

c) the number of events of the considered type found in S. E. ($N^{\text{S.E.}}$) and in L. E. ($N^{\text{L.E.}}$).

2. The mean free path for the considered type of interactions in the glycerine (or glucose) solution is obtained from the rather obvious formula:

$$\frac{1}{\lambda^{\text{L.E.}}} = \frac{1}{\lambda^{sol}} \frac{K^{sol}-1}{K^{sol}} + \frac{1}{\lambda^{\text{S.E.}}} \frac{1}{K^{sol}}\,.$$

3. Multiplicity or angular distributions for interactions with light nuclei of the solution (H, C, O) are obtained by subtraction:

$$Ni^{sol} = Ni^{\text{L.E.}} - \frac{1}{K} Ni^{\text{S.E.}},$$

where Ni is the number of events (tracks) with given characteristics (e.g. multiplicity of shower particles — n_s, multiplicity of h-particles — N_h, emission angle Θ_i), $K = K^{sol} \frac{\lambda^{\text{S.E.}} N^{\text{S.E.}}}{\lambda^{\text{L.E.}} N^{\text{L.E.}}}$. Note: In the case of the N_h distribution for inelastic interactions with light target nuclei (H, C, O) the N_h spectrum for interactions with free protons has been subtracted from the total distribution by the following procedure. The fraction of interactions with free hydrogen among all the interactions with the nuclei of the solution is 24% or $\sigma_H n_H^{sol} / (\sigma_H n_H^{sol} + \sigma_O n_O^{sol} + \sigma_C n_C^{sol})$. The N_h spectrum for α-H interactions is obviously limited to the N_h values: 0, 1, 2. Since the shape of this spectrum is not known, it has been assumed that the three N_h values are represented in the spectrum with equal probabilities. The resulting N_h spectrum for inelastic interactions with C and O nuclei is shown in Fig. 1a. The average N_h values and the shape of the N_h distribution for interactions with heavy target nuclei (see procedure step 4, described below) are fairly insensitive to the arbitrarily assumed shape of the N_h spectrum for α-H interactions.

4. Multiplicity and angular distributions for interactions with heavy target nuclei (Br, Ag) are obtained by an analogous subtraction procedure, according to the formula:

$$Ni^{\text{Br, Ag}} = \left(Ni^{\text{S.E.}} - \frac{1}{K'} Ni^{sol}\right) + \left(Ni^{\text{L.E.}} - \frac{1}{K''} Ni^{sol}\right).$$

In this case a rather reasonable assumption was made, namely that the angular and multiplicity characteristics for interactions with light nuclei of the solution (H, C, O) are the same as those for interactions with light nuclei of the emulsion (H, C, N, O).

The coefficients K' and K'' are obtained from:

$$K' = \frac{1}{f'} \frac{\Sigma Ni^{sol}}{\Sigma Ni^{\text{S.E.}}}, \qquad K'' = \frac{1}{f''} \frac{\Sigma Ni^{sol}}{\Sigma Ni^{\text{S.E.}}},$$

where f' and f'' — the fractions of interactions with light nuclei in S. E. and L. E., respectively — are derived from the known atomic compositions of both types of the nuclear emulsions used in the experiment.

5. In the case of the distributions characterizing A1 and A2 events similar procedures are applied with an assumption that the ratios of the numbers of these interactions with an assumption that the ratios of the numbers of these interactions with the gelatine nuclei to those with glycerine (or glucose) nuclei are the same as in the case of all inelastic interactions (A events).

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