National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

ST – CR – NP – 10656

DETERMINATION OF THE FRAGMENTATION PARAMETERS OF THE MULTI-CHARGE COMPONENT OF PRIMARY COSMIC RAYS

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13 OCTOBER 1967

ST — CR — NP — 10656

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Kosmicheskiye Issledovaniya
Tom 5, vypusk 3, 450 - 455,
Izdatel'stvo "NAUKA", 1967.

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SUMMARY

The fragmentation parameters of heavy nuclei have been obtained on the "hydrogen" emulsion by utilizing nuclear emulsions exposed at 300 km altitude, and sorting the interactions of heavy nuclei of cosmic rays with a number $\leqslant 1$ of black and gray rays related to target nucleus.

The possibilities of transition (fragmentation parameters) of nickel nuclei to groups H ($Z > 10$); H_1 ($Z = 20 \div 28$); H_2 ($Z = 16 \div 19$); H_3 ($Z = 10 \div 15$); M ($Z = 6 \div 9$) and L ($Z = 3 \div 5$) were obtained by studying the interactions of protons with energy 10 Bev with nuclei of nickel, introduced into the emulsion in the form of spherical particles of $\sim$ 9 mkm diameter.

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One of the fundamental problem of theory of cosmic ray origin is the interpretation of data on the charge composition of cosmic rays near Earth. At the same time, the most essential moment is accoutning of the transformation of cosmic radiation's charge composition during transit through interstellar gas. Such an accounting requires an as precise a knoweldge of fragmentation parameters P_{ik} as possible (P_{ik} being determined as the number of nuclei of kind k forming, as an average, during one interaction of the primary nucleus i on interstellar hydrogen).

The values of these parameters P_{ik} determine to a significant degree the choice of the model of cosmic ray propagation: the quantity of matter traversed by cosmic radiation to Earth; the charge spectrum of cosmic rays after emergence from the source and others [1].

Data on fragmentation parameters are very scarce in literature [2 — 6]. Particularly small are the statistics for the group H ($Z \geqslant 20$). For the group H ($Z \geqslant 10$) the total number of cases brought out in literature is less than 100.

(*) OPREDELENIYE PARAMETROV FRAGMENTATSII MNOGOZARYADNOY KOMPONENTY PERVICHNYKH KOSMICHESKIKH LUCHEY

Besides, there exist considerable discrepancies in the values of certain P_{ik} in the works of different authors.

The fragmentation parameters in the hydrogen nuclei may be obtained by two methods: a) from analysis of interactions of multi-charge particles of cosmic radiation in an emulsion exposed at great height; b) in a mirror system, when the various targets ($Z = 6 \div 28$) are irradiated by protons of high energy on accelerators. Nearly all the data available in literature have been obtained by the first method. Some of the data may be obtained by the second method from the work [7] (for carbon) and computed from radiochemical data [2, 8].

The determination of the parameters P_{ik} appeared to us as being appropriate by both the first and the second methods. In the latter case values of P_{ik} might be obtained for the heaviest nuclei of cosmic radiation (VH), whose determination by the first method with sufficient precision is difficult.

DETERMINATION OF P_{ik} IN AN EMULSION IRRADIATED BY COSMIC RAYS

A pellicle stack of 10 x 10 x 10 cm^3 dimension, consisting of a type-NIKFI-BR relativistic emulsion layers was irradiated during 72 hours at the altitude of 300 km (Kosmos-4). The interactions were investigated of multi-charged particles of primary cosmic radiation with nuclei of the emulsion and up to 401 such interactions were detected.

All primary multi-charge particles inducing interaction were traced in the emulsion prior to entry into the pellicle stack , and all secondary ones with $Z \geqslant 3$ — after egress, taking into account all secondary interactions.

The charge of multi-charge cosmic particles with $E \geqslant 2$ Bev/nucleon was determined by the number of δ-electrons (n_δ) corresponding to 100 mkm of the path. Utilized to that effect was graduated curve of n_δ dependence on Z, obtained for the same emulsion.

Of all the cases investigated 74 interactions could be ascribed to those of interest to us, on "hydrogen", inasmuch as the number of gray and black rays related to the target-nucleus was respectively 0 and 1.

Analysis of these cases allowed us to obtain data on fragmentation parameters P_{ik} of groups $H(Z \geqslant 10)$ and $M(Z = 6 \div 9)$ of cosmic radiation compiled in Table 1. The statistics relative to the group L so far is small, and data relative to this group will be presented later.

Data of other authors were also brought out for the sake of comparison. It may be seen that for the group H, the parameters P_{HH}, P_{HM}, AND $P_{H\alpha}$ obtained by us coincide sufficiently well with the parameters computed from the combined data of [2 - 6] (presented in [2]). However, there is a considerable discrepancy as regards the data on P_{HL}. Note at the same time that the Friedlander data [9], obtained by the difference method on teflon and polyethylene with small statistics depart rather strongly from our own results and from those of the work [2].

For the group M and within the limits of experimental erros, parameters P_{MM} and P_{ML} agree with the data of [2] and may be coordinated with the experimental results by Frienlander [9]. According to our data, P_M exceeds to some extent the value brought out in [2].

In the following a further refinement of all these parameters is anticipated as statistics increase.

The results of calculations [9, 2], obtained with the utilization of some radiochemical data, are compiled in the last two lines of Table 1.

TABLE 1

Author	Group H (Z > 10)				Group M (Z = 6 ÷ 9)		
	p_{HH}	p_{HM}	p_{HL}	p_{Hx}	p_{MM}	p_{ML}	p_{Mx}
Present work............	0,29±0,09	0,35±0,11	0,35±0,11	1,5±0,2	0,10±0,05	0,43±0,12	2,06±0,27
Aizu, Fujimoto, Hasegava et al [2]. Combined results of [2-6]	0,31±0,07	0,36±0,07	0,12±0,04	1,35±0,18	0,11±0,02	0,28±0,04	1,3±0,11
Friedlander et al [9]	0,41±0,15	0,02±0,13	0,59±0,18		0,04±0,07	0,41±0,12	
Calculation of Friedlander et al [9]	0,39	0,28	0,28		0,25	0,48	
Calcul. of Aizu et al [2]	0,50	0,30	0,15		0,15	0,40	

DETERMINATION OF FRAGMENTATION PARAMETERS FOR THE SEVENTH GROUP OF COSMIC RAYS WITH THE UTILIZATION OF ACCELERATING PARTICLES

As already noted above, the fragmentation parameters for a specific initial nucleus may be obtained during the study of interactions of high energy protons with a specific nucleus. The results must not depend on which of the colliding partners rests.

We were interested in target-nuclei close in their charge to iron, inasmuch as there are very few parameters P_{ik} of the heaviest component of cosmic rays.

The methods of introduction into the emulsion of specific elements in the form of solutions of salts (during the preparation of the emulsion [10-11] or by way of saturation of ready layers) may not be utilized, for they are most effective for the elements of the end of the periodical system. In the last case the fission of nuclei, attending most probably the nuclear reaction, permits a good indentification of the target-nucleus and the detailed investigation of the interaction of various particles on these elements [12 - 14].

During the introduction into the emulsion of specific elements in the form of suspension, one may observe the complete pattern of interaction for any elements. The possibility of introducing suspensions into the emulsion has been indicated in a series of works [15 - 21]. However, data on parameters P_{ik} can be obtained only from the work by Zhdanov and Fedotov [7].

When charging the emulsion by various elements a series of conditions must be fulfilled, of which two are most essential.

1. The element introduced must not desensitize the emulsion and react with revealing and fixing solutions.

2. A reliable identification of the interaction on the nuclei of the element introduced must be guaranteed.

The second condition defines the requirements relative to the configuration and the optical properties of the particles introduced. Because of the presence of a zone of indiscernibility around a particle linked with emulsion settling, the identification of interactions on opaque particles with irregular shape is very unreliable. (The probability of identification of the interaction is less than 50 percent for particles of 9 mkm transverse dimensions and it decreases rapidly as the size of particles decreases). A more reliable identification is possible only when the element's particles introduced have a regular shape, the spherical one being the optimum case.

The first condition diminishes significantly the number of elements that may be introduced into the emulsion in the region of interest to us, $Z(3 \div 28)$.

We investigated the influence on the emulsion of elements introduced in it, namely, iron, sulphur and nickel. The introduction of iron disrupts even the mechanical properties of the emulsion, without speaking about the sensitivity. The introduction into the emulsion of sulphur in the form of balls (spheres) leads to the disappearance of relativistic sensitivity in the neighborhood of the sphere at a distance of 20 — 30 mkm. Good results have been obtained with nickel, whose introduction does not disrupt the basic properties of the emulsion. (It should be noted that for the study of the fragmentation parameters P_{ik} of heavy nuclei of group VH($Z \geq 20$)'s cosmic rays, it is possible to introduce into the emulsion certain brands of stainless steel, of which the composition is very near the observed composition of cosmic rays of the group indicated).

a) Method of Preparation of Layers with Nickel and Identification of Interactions. The nickel balls were prepared by the method of "electric spark sputtering"(?) [17, 18] in distilled water(*). The mean diameter of balls introduced into the emulsion is 9.2 mkm. The scattering by diameter is from 5 to 13 mkm. Layers with nickel were so prepared that practically all the nickel introduced is found to be in one plane in the middle of the layer 400 mkm thick. This facilitates significantly the survey of the emulsion. The amount of nickel introduced in the layer is 0.2 mg/cm^2.

(*) The purity of nickel utilized for sputtering in 99.7% by weight. In connection with water electrolysis during sputtering and the formation of atomic oxygen the formation of oxides is possible. Chemical analysis of the powder prepared has shown an insignificant admixture of oxygen (less than 0.1% by weight).

The pellicle stack (chamber) made of 30 layers with nickel NIKFI BR-2 emulsion (layer dimensions: 10 by 10 cm^2, thickenss 400 mkm) was irradiated in the internal beam of the synchro-phasitron of the United Institute of Nuclear Investigations by protons with energy of 10 Bev in the form of a single impulse. The direction of proton flux was parallel to the emulsion plane. The variation of flux along the thickness of the pile was $(2.5 \div 0.8) \cdot 10^6\ cm^{-2}$.

The mean diameter of the ball (9.2 mkm) chosen for the introduction into the emulsion, is optimum. The losses of short-range tracks on account of absorption in the ball are comparatively small, (< 3%). On the other hand, the number of interactions in the effective volume of the ball is sharply decreases as the ball's diamter decreases. We understand here by effective volume the sphere's volume in the ball, in which the interaction of the incident particle may be identified with a probability of 100 percent. The radius of the effective sphere is by one micron less than the observed (1 mkm is the measurement precision of the vertical coordinate in the microscope).

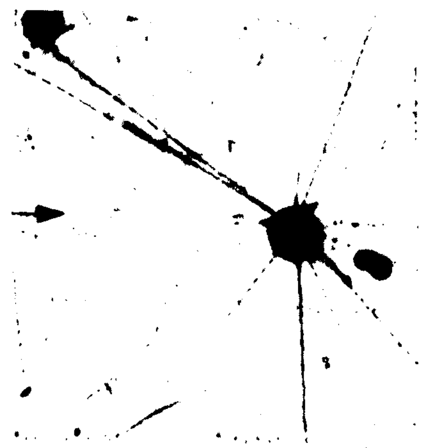

Fig.1

Interaction of the proton with energy of 10 Bev with the nickel ball

The ingressing proton is indicated by the arrow. The diameter of the ball is 8.5 mkm

It was estimated that the nickel nucleus' splitting is induced by a proton with 10 Bev energy only in the case when it takes place in the effective volume of the ball and when the entering relativistic track of the proton is not continuing (the angle with the primary direction is greater than 30 min). The observation of the entering proton track, lying in the emulsion plane, and the geometry of splitting particles allow us to determine precisely the point of interaction in the given ball.

A microphotograph of interaction on the nickel ball, induced by a proton of 10 Bev energy, is shown in Fig.1. The ingressing proton is shown by the arrow. Of the total number of found interactions on nickel balls ($\sim$ 700 cases) thirty-five percent (35%) of events satisfy the chosen criterion. In the remaining cases the interaction took place either in the superficial layer 1 mkm thick or was not attended by the entering relativistic track, or still the entering relativistic track did not change its direction. The last two groups of interactions were apparently induced by secondary particles (π^0, $\pi^\pm$, p, n), arising from interactions of primary protons with the nuclei of the emulsion.

From the numbers brought out it is clear that for the study of splittings on suspension particles and at specific energy of incident particles it is necessary to utilize only the relativistic emulsion. (Follows Table 2).

TABLE 2

Parent nucleus	Reference	Residual nucleus					
		H $(Z \geq 10)$	H_1 $20 \leq Z \leq 28$	H_2 $16 \leq Z \leq 19$	H_3 $10 \leq Z \leq 15$	M $6 \leq Z \leq 9$	L $3 \leq Z \leq 5$
Ni, Z = 28	present work	0,86±0,05 [0,91±0,04]	0,38±0,04 [0,48±0,03]	0,27±0,03 [0,24±0,02]	0,21±0,03 [0,19±0,02]	0,10±0,02 [0,07±0,01]	0,12±0,02 [0,08±0,02]
Fe, Z = 26	calc. by [8]	0,75	0,45	0,15	0,15	0,10	0,14
	calc. by [2]	0,55	0,40			0,05	0

ANNOTATION . The values in parentheses were obtained after introduction of corrections for the effectiveness of detection of interactions on nickel with different number of black and gray rays.

b) Results of Measurements. The review of plates was conducted by areas. After careful analysis 255 cases were referred to interactions on nickel nuclei. The entering primary proton was registered in each interaction and the number of black, gray and thin tracks was determined. Among black tracks all fragments with $Z \geq 3$ were separated and investigated. Considering that black and gray rays are related to the target-nucleus, and taking into account, according to theory of evaporation, the percentage of α-particles among the evaporative or black particles, it was possible to compute for each case the charge of the residual nucleus and, consequently, have all the data for the derermination of P_{ik} for the given parent nucleus.

When determining P_{ik} corrections were introduced, taking into account the omission of interactions with small number of gray and black rays (≤ 2) and the difficulty of identification of gragments escaping at angles > 60° to the emulsion plane.

We compiled in Table 2 all the fragmentation parameters measured by us-and characterizing the transition of the parent nucleus Z = 28 into the group H ($Z > 10$), M ($Z = 6 \div 9$) and L ($Z = 3 \div 5$). The group H may be divided into sub-groups: H_1 ($Z = 20 \div 28$), H_2 ($Z = 16 \div 19$) and H_3 ($Z = 10 \div 15$), for which data can also be obtained.

There is no information in literature on the experimental data on P_{ik} parameters for very heavy nuclei ($Z > 20$). This is why our own data may be only compared with the results of calculations by Badhwar et al [8] and Aizu et al [2], based upon available radiochemical data. Note the satisfactory agreement wuth the Badhwar results [8], though the latter are quite approximate and they utilize the arbitrary assumption on the constance of P_{ik}, beginning with energy of 300 Mev/nucleon.

In the following works the values of P_{ik} will be utilized at consideration of charged spectrum of cosmic rays' transformation.

In conclusion the authors express their gratitude to N. L. Grigorov, I. A. Savenko and D. A. Zhuravlev for their cooperation during the arrangement of the experiment. They also acknowledge the cooperation of S. I. Lyubomilov and V. I. Baranov in processing the emulsion piles. Their gratitude goes also to I. G. Khilyuto, N. N. Kotlov, Z. G. Laptev and L. A. Stekol'shchikov for their participation in the cumbersome work of surveying the emulsion.

THE END

Manuscript received on
5 September 1966

CONTRACT No.NAS-5-12487
VOLT TECHNICAL COOPERATION
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Translated by ANDRE L. BRICHANT

on 12 - 13 October 1967

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