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# PHYSICS

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MISHAKOVA,

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**Abstract**

**Full Text**

*PHYSICS*

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**STUDY OF EXPLOSIVE SHOWERS PRODUCED BY COSMIC PARTICLES OF HIGH ENERGY**

*(Presented by Academician A. I. Alikhanov, 28 VIII 1956)*

This paper gives preliminary results on the study of explosive showers caused by cosmic particles of high energy, obtained in processing 29 showers by the nuclear-emulsion chamber method. The nuclear-emulsion chamber consisted of 100 layers, each 10 cm in diameter and 450  $\mu$  thick. NIKFI emulsion of type "R" was used. The chamber was exposed in the stratosphere at an altitude of 27 km for 7 hours, in May 1955.

The emulsion layers were examined systematically over the area with a magnification of  $10 \times 15 \times 1.5$  on MBI-2 microscopes. During the examination, explosive showers with a number of relativistic tracks  $n_s > 5$ , located in a sufficiently narrow cone (no discrimination was made according to the number of black and gray tracks), were recorded, as were jets containing a number of relativistic tracks  $n_s > 3$ .

As a result of examining 26.5 cm<sup>3</sup> of photographic emulsion, 27 explosive showers and 29 jets were found. On further tracing the jets through the emulsion chamber, it was found that 2 of them originate from stars, while the remaining 27 jets proved to be electron-photon showers.

**Table 1**

Nos. of plates	Primary particle	$\Omega$ , deg.	$n_h + n_g$	$n_s$	$\theta_l$ , deg.	$P$ for $k = 12$	$P$ for $k = 6$
1	—		9+14	22	20	0.7	0.54
2	$\alpha$	0	12+12	50	20	0.97	0.99
3	—		1+1	31	35	0.53	0.95
4	$\alpha$	3	10+10	26	10	0.12	0.52
5	—		13+13	39	25	0.65	0.8
6*	Z	12.5	14+8	52	15	0.001	0.00001
7*	p	9.5	10+7	25	10	0.09	0.02
8	—		12+7	16	20	0.4	0.8

Nos. of plates	Primary particle	$\Omega$ , deg.	$n_h + n_g$	$n_s$	$\theta_l$ , deg.	$P$ for $k = 12$	$P$ for $k = 6$
9	Z	12	12+4	90	27	0.8	0.85
10	n		6+9	22	10	0.85	0.8
11*	Z	2	6+16	78	22	0.037	0.09
12	—		3+2	7	7.5	0.25	0.67
13*	p	0	5+3	23	20	0.1	0.09
14	p	9	3+0	8	5	0.8	0.98
15	p	12	5+2	10	2.5	0.4	0.42
16	—		11+8	12	7.5	0.45	0.12
17	—		9+13	13	10	0.3	0.54
18*	p	1.5	2+4	24	4	0.0028	0.09
19	—		4+7	10	15	0.86	0.95
20	—		10+10	17	9	0.25	0.54
21	—		13+12	22	15	0.02	0.54
22	n		6+2	15	15	0.53	0.08
23	—		13+8	20	25	0.61	0.67
24*	Z	11.5	1+7	93	13	0.05	0.06
25	n		6+2	7	5	0.85	0.91
26	p	0	8+8	26	15	0.12	0.67
27	Z	0	8+9	18	20	0.4	0.9
28	—		7+12	13	32	0.44	0.54
29	—		11+13	13	1	—	—

The 29 explosive showers found in this way were processed under a microscope with a magnification of  $90 \times 15 \times 1.5$ . During processing, the primary particle that caused the shower was determined, the number of relativistic particles in the shower was counted, and the angular distribution of the shower particles relative to the shower axis was measured. The angles in the plane of the emulsion  $\alpha$  and the dip angle  $\beta$  were measured with an accuracy of up to  $1^\circ$ . The angular distribution of the shower particles relative to the shower axis was determined with the aid of an instrument specially designed by V. V. Alpers. Each shower particle was plotted on an aluminum

sphere, the angles  $\alpha$  and  $\beta$  being read off with the aid of two special verniers. The spatial angles of the shower particles plotted on the sphere were determined with the aid of an attachable hemisphere made of Plexiglas, on which latitude ( $\vartheta$ ) and longitude ( $\varphi$ ) angles had been marked. With the aid of the sphere, for each shower the angle  $\vartheta_{1/2}$  was determined, within which half of the shower particles are contained, as well as the distributions over the angles  $\vartheta$  and  $\varphi$ . In addition, the angle  $\Omega$  between the axis of symmetry of the shower and the direction of the particle that caused the shower was determined for those cases in which the latter could be reliably established.

Fig. 1

Figure 1: Fig. 1

Fig. 1. Dependence of  $n_s$  on  $\vartheta_{1/2}$  for the observed showers: *a*–showers caused by a neutron or proton; *b*–showers caused by an  $\alpha$ -particle; *v*–showers caused by heavy particles; *g*–showers for which the nature of the primary particle was not determined (nucleon or  $\alpha$ -particle). The solid curve is the dependence between  $n_s$  and  $\vartheta_{1/2}$  according to Fermi' s theory (4).

A summary of the experimental results is presented in Table 1, where  $n_s$  is the number of relativistic tracks in the shower, and  $n_h$  and  $n_g$  are, respectively, the numbers of black and gray tracks in the star.

Figure 1 shows a plot of the dependence of  $n_s$  on  $\vartheta_{1/2}$ . Each shower is represented by a point. In the figure the points are specially distinguished in cases where the nature of the particle that caused the shower is reliably known. In Fig. 1 the showers caused by heavy particles form a special region and are characterized by a significantly larger number of shower particles.

If it is assumed that the observed showers are formed as a result of nucleon–nucleon collisions, then one should expect that in the center-of-inertia system of the two colliding particles the angular distributions of the shower particles will be symmetric with respect to the angle  $\theta_{c.i.} = \pi/2$ . Under this assumption, the experimentally measured angle  $\vartheta_{1/2}$  corresponds in the center-of-inertia system of the two colliding particles to the angle  $\theta_{c.i.} = \pi/2$ .

The transformation formulas thereby obtained for passing to the center-of-inertia system for the case of limiting relativistic shower particles will then have the form:

$$\operatorname{ctg} \vartheta = \gamma_c \frac{\cos \theta + 1}{\sin \theta}, \quad (1)$$

$$\gamma_c = \operatorname{ctg} \vartheta_{1/2}, \quad (2)$$

where  $\vartheta$  is the angle of the shower particle in the laboratory coordinate system;  $\theta$  is the angle in the center-of-inertia system;  $\gamma_c = \frac{1}{\sqrt{1 - \beta^2}}$ , and  $\beta$  is the velocity of motion of the center of inertia.

On the other hand, according to Fermi' s thermodynamic theory, the number of shower particles is related to the energy of the colliding nucleons in the center-of-inertia system by the formula

$$n_s = k \left( \frac{E}{2mc^2} \right)^{1/4} = k\gamma_c^{1/2}, \quad (3)$$

Fig. 2. Angular distributions of shower particles: a –showers caused by heavy particles; b –caused by nucleons; c –caused by nucleons and  $\alpha$ -particles; d –showers which, according to relation (4), may be assigned to nucleon-nucleon interactions (see Fig. 1)

Figure 2: Fig. 2. Angular distributions of shower particles: a –showers caused by heavy particles; b –caused by nucleons; c –caused by nucleons and  $\alpha$ -particles; d –showers which, according to relation (4), may be assigned to nucleon-nucleon interactions (see Fig. 1)

where  $E$  is the energy in the laboratory system,  $k = 1 \div 2$ .

Thus, under the assumption of a nucleon-nucleon mechanism of shower formation, one can write the following dependence between  $n_s$  and  $\vartheta_{1/2}$ :

$$n_s = k\sqrt{\text{ctg } \vartheta_{1/2}}. \quad (4)$$

Figure 1 shows the dependence of  $n_s$  on  $\vartheta_{1/2}$  under the assumption that  $k = 2$ .

It is seen from Fig. 1 that some showers satisfy relation (4) and thus may be assigned to cases of nucleon-nucleon interactions. However, as will be seen below, the angular distributions of shower particles contradict such a conclusion.

Fig. 2. Angular distributions of shower particles: *a*–showers caused by heavy particles; *b*–caused by nucleons; *c*–caused by nucleons and  $\alpha$ -particles; *d*–showers which, according to relation (4), may be assigned to nucleon-nucleon interactions (see Fig. 1).

Using formulas (1) and (2), the values of  $\gamma_c$  and the corresponding angular distributions in the center-of-inertia system  $f(\theta)$  were found for each shower. Figure 2 shows the total angular distributions obtained in this way. It is seen from the figure that all showers caused by nucleons and  $\alpha$ -particles are characterized by a noticeable asymmetry with respect to the angle  $\theta = \pi/2$ , which contradicts the model of shower production in nucleon-nucleon collisions. It should be noted here that the angular distribution  $f(\theta)$  for showers caused by heavy particles turned out to be symmetric with respect to  $\theta = \pi/2$ , although this conclusion is not sufficiently definite because of the small number of observed cases.

In studying the distribution of shower particles with respect to the azimuthal angle  $\varphi$ , a noticeable asymmetry of the angular distribution  $f(\varphi)$  was found for several showers.

The values of  $P$  given in Table 1 are Pearson probabilities of observing the given magnitude of asymmetry in the distribution  $f(\varphi)$  for each shower, under the assumption that the observed cases of asymmetry are a consequence of statistical fluctuations. The Pearson probabilities  $P(\chi^2)$  were determined from tables for values of  $\chi^2$ , which were not calculated by the formula

$$\chi^2 = \frac{k}{N} \left( \sum_{i=1}^k n_i^2 \right) - N,$$

where  $N$  is the total number of shower particles in the shower;  $k$  is the number of intervals of division in the angle  $\varphi$ ;  $n_i$  is the number of shower particles in the  $i$ -th interval  $\Delta\varphi$ .

It should be noted that in a number of cases the values of  $P$  for  $k = 6$  and  $k = 12$  differ substantially from one another (see showers 6, 7, 18, 21, 22). This is...

is a consequence of the comparatively small number of particles in the observed showers and indicates insufficient accuracy in determining the value of  $P$ . In 6 cases the observed asymmetry corresponds to a value  $P \leq 0.1$  for cases  $k = 6$  and  $k = 12$  (such showers are marked in Table 1 with an asterisk). Of course, in order to settle definitively the question of the existence of showers with azimuthal asymmetry of relativistic particles, a substantial increase in the number of observed cases is required, and the data of Table 1 should be regarded only as preliminary results.

It should be noted that large asymmetry is observed both in showers caused by heavy particles and in showers caused by nucleons. It is also evident from Table 1 that in a number of cases appreciable angles are observed between the direction of motion of the particle that produced the shower and the axis of symmetry of the shower (angle  $\Omega$ ).

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*Note: Figure translations are in progress. See original paper for figures.*

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