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SHOWER EFFICIENCY OF SPARK CHAMBER

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The counting efficiency for shower particles passing through a spark chamber with a large electrode gap was measured. The dependence of the efficiency on the number of particles in the shower, on the angle of entrance into the chamber, and for different chamber energizing conditions are given.

A spark chamber with metallic electrodes has many advantages over other charged-particle detectors. The clarity of display, the short dead time, and principally the large transmission ratio and the simple construction have attracted the interest of physicists working with cosmic radiation at high energies to this instrument. In chambers with metal electrodes, as in discharge chambers [1], if the front of the supply pulse is sufficiently steep and the distance between electrodes if 50—100 mm, single tracks as well as showers of charged particles can be observed [2,3]. The spark discharge develops in this case along the particle trajectory, provided the angle between the direction of motion of the particle and the direction of the pulsed electric field does not exceed approximately 40°. On the other hand, if the particle crosses the working volume of the chamber parallel to the electrodes, the discharge occurs over a large number of spark channels directed along the electric field. Finally, if the duration of the pulse applied to the chamber is limited with the aid of a special discharge gap [4], then a series of glowing segments is observed along the particle trajectory; each segment is the initial stage of a streamer. It is assumed that when a single particle passes through a spark chamber with a large gap, any one of the modes is realized with an efficiency of 100%. When it comes to the registration efficiency, for example, when photography on film is used, the first mode entails no difficulties but it is much more difficult to register the tracks in the second mode, and particularly in the streamer mode.

When the spark chamber is crossed by many particles simultaneously, all the discharge-development modes are realized in the chamber, depending on the angle α between the direction of the electric field and the trajectory of the shower particle. In the present investigation we studied the shower efficiency Q of the spark chamber, i.e., the probability of registering an individual particle of a shower passing through the working volume of the spark chamber, and also the efficiency q of shower registration and the influence of the angle α on the discharge development.

The installation used to investigate shower registration consisted of two or three spark chambers measuring $600 \times 600 \times 100$ mm each, placed on one another, and separated by aluminum electrodes 1.5 mm thick. Lead or aluminum targets were placed over the chambers, and showers were generated in them by electrons and photons from cosmic radiation. Under the chambers were installed a plastic scintillator with an FÉU-33 photomultiplier. Whenever a shower with more than three particles passed through the scintillator, a pulse of amplitude from 100 to 200 kV with a 0.3 μsec delay and a leading front ≤ 10 nsec was applied to the chambers. The chambers were filled with pure neon to atmospheric pressure. Connected in parallel with each chamber was a resistance R, the magnitude of which determined the duration of the trailing front of the pulse. Photography was by means of a stereoscopic pair of objectives with relative apertures 6 and 3.5. The installation was already described by us in detail earlier [5].

The shower efficiency can be defined as the ratio of the number of registered particles to the total number of charged particles passing through the chamber:

$$Q = n / N, \tag{1}$$

where n —number of spark tracks and N —number of particles passing through the working volume of the spark chamber.

In the first part of the experiment, the showers were registered simultaneously in two chambers (Fig. 1). It was assumed that the discharges in the

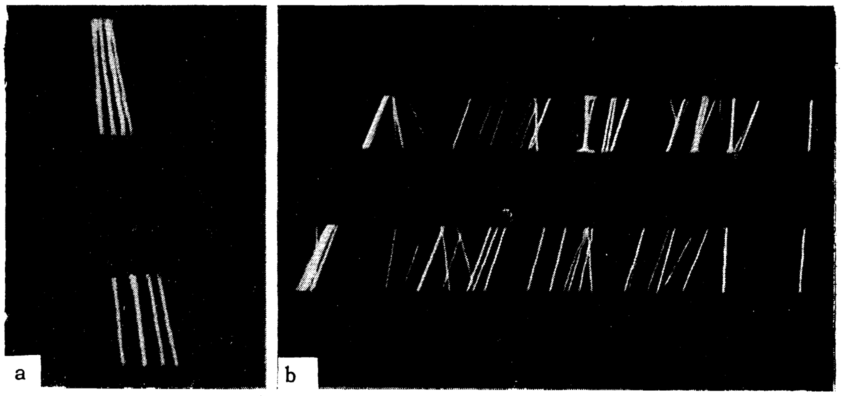

FIG. 1. Electron shower generated in aluminum (a), and a portion of an extensive air shower registered in two spark chambers (b).

two chambers developed independently of each other. The shower efficiency was estimated in this case from the ratio

$$Q_u = n_{u,l} / n_l, \qquad (2)$$

where Q_u —shower efficiency of the upper chamber[1)], $n_{u,l}$ —number of pairs of tracks in the upper and lower chambers for particles passing through both chambers ("joined" tracks), n_l —number of tracks in the lower chamber, produced by particles passing through both chambers (the number of tracks belonging to particles produced in 1.5 mm of aluminum or entering into the lower chamber from the side was determined experimentally).

In the investigation of the shower efficiency with the aid of Eq. (2) it was observed that the efficiency did not depend (or depended very little) on the number of particles in the shower N, but depended noticeably on the form of the shower. Thus, for showers generated in the aluminun target (two t-units), where the particles have in the mean a high energy and are scattered through smaller angles than the particles of showers produced in lead, the shower efficiency turned out to be $Q_{Al} = 0.91 \pm 0.01$. For showers generated in the lead target (four t-units) $Q_{Pb} = 0.82 \pm 0.01$ at an average $\bar{N} = 18$ particles in the shower.

It turns out that the brightness of the tracks depends on the angle α between the trajectories of the particle and the direction of the electric field. Figure 2 shows the angular distributions for tracks of different brightness, and also for tracks in the transition mode, when the discharge develops both along the particle trajectory and along the set of channels in the direction of the electric field. It is seen that the brightness of the sparks decreases with increasing α, and that particles with angle

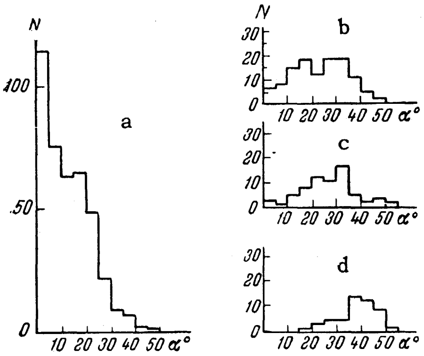

FIG. 2. Angular distribution of sparks of different brightness and in the transition made: a — bright sparks, b — medium bright sparks, c — pale sparks, d — sparks in the transition mode.

$\alpha > 50°$ are not registered at all (in spite of the presence of such particles, since the stack of chambers was placed at angles up to 20° to the horizontal). By virtue of this it can be assumed that there is a maximum angle between the particle trajectory and the direction of the electric field, α_{max}, above which no registration of particles takes place. Then the value of Q_u obtained by the two-chamber method is the lower limit of the shower efficiency of the spark chamber. Indeed, some shower particles passing through the upper spark chamber at an angle greater than α_{max} are not registered. After some of these particles are scattered in the central electrode, the angle with the direction of the magnetic field becomes less than α_{max}, as a result of which they are registered only in the lower chamber. Thus, n_l increases and Q_u decreases. Such an effect is more important for showers under lead, so that Q_{Pb} is smaller than Q_{Al}. In order to make more precise the shower efficiency and its dependence on α, an experiment was performed with a set-up consisting of three spark chambers (Fig. 3), in which Q was determined from the relation

[1)]We note that the quantity Q_u determined from this equation will exactly correspond to the shower efficiency if the latter is independent of the angle of inclination α and the number of particles N in the shower.

$$Q_c = n_{u,\,c,\,l} \,/\, n_{u,\,l},$$

where Q_c —shower efficiency of the central chamber, $n_{u,l}$ —number of tracks produced in the upper and lower chambers by particles passing through all three chambers without scattering, while $n_{u,c,l}$ —number of tracks in all three chambers for the same particles (''joined'' tracks).

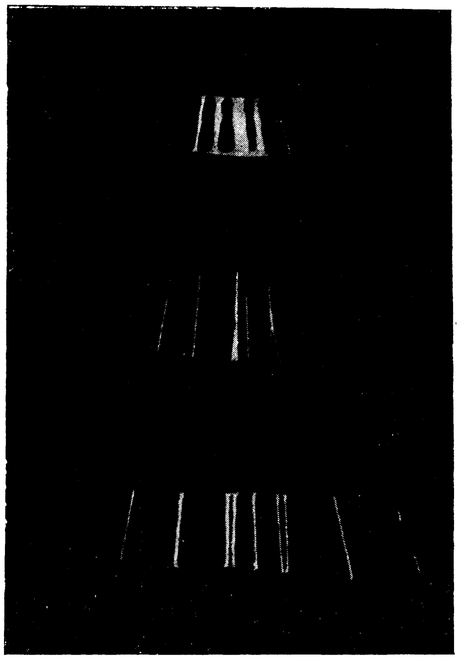

FIG. 3. Electron shower registered in three spark chambers.

Figure 4 shows the dependence of the shower efficiency on the number of particles that pass simultaneously through the spark chambers. The points indicate the shower efficiency values obtained with the spark chambers connected in series to the power supply, and the circles—for parallel connection. It is seen that this number remains constant up to N = 50.

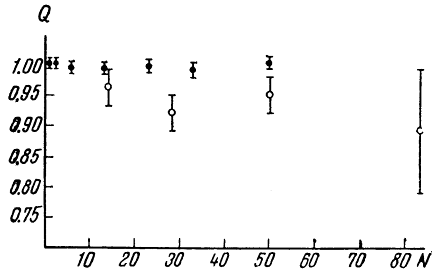

FIG. 4. Dependence of the shower efficiency on the number of particles which crossed the working volume of the spark chamber. The points indicate the values of Q for chambers connected in series, the circles indicate those for chambers connected in parallel.

The table lists the values of the shower efficiency for different methods of energizing the spark chambers, obtained by investigation of 400 showers (R —resistance connected in parallel with the spark chamber, E —intensity of the pulsed electric field).

E, kV/cm	R, kΩ						
	∞	15	5	3	1	0.1	10^{-5}
	Chambers connected in series						
2.6	0.53	0.98	0	0			
2.8	0.99	1	1	1	0		
3.3	0.99		1	1	0.95		
6.5						1	0
	Chambers connected in parallel						
7,8	0.87			0.94	0.90	0.84	0
8.4					0,97	0.92	0.59

On the basis of this table we can draw the following conclusions.

1. A broad region of high-efficiency shower registration exists in the presence of a finite resistance R when the chambers are connected in series.

2. Q decreases to zero abruptly on the boundary of this region (when the intensity of the pulsed electric field E decreases, as well as when R decreases).

3. The absence of resistance (R = ∞) decreases the shower efficiency of the spark chamber. It is interesting to note that at R = ∞ and E = 2.6 kV/cm the value of the shower efficiency also changes abruptly from event to event. In this mode, the shower efficiency, determined from 47 frames, turned out to be $\bar{Q} = 0.53 \pm 0.03$, with Q = 1 for 21 frames, Q = 0 for 20 frames, and $Q \approx 0.5$ for only 6 frames.

4. The spark chamber shower efficiency is larger in the case of series connection than for parallel connection. In the latter connection the track brightness varies from chamber to chamber, since the discharge develops in the different chambers under unequal conditions (different concentrations of impurities in the neon, differences in the interelectrode gaps, etc.).

In the region of high shower registration efficiency, which was determined by the amplitude and duration of the pulse applied to three series-connected chambers, we analyzed approximately 120 showers with an average $\bar{N} = 15$ particles. For this region, $q = 0.995 \pm 0.05$, and $Q = 0.990 \pm 0.008$. The error in the latter quantity consists of the statistical error and the error connected with the choice of the criterion for the scattering of particles in the thin electrodes separating the chambers. The shower efficiency at the optimal supply mode, with the chambers in parallel, was $Q = 0.94 \pm 0.01$.

The dependence of the shower efficiency Q on the angle of track inclination has a step-like character. For the optimal mode of series-connected chambers, Q is close to unity up to angles on the order of 40°, and is equal to zero for angles above this value.

On the basis of the experimental data given above we can draw the following picture of spark-discharge development when a large number of particles pass simultaneously through the chamber and cross its working volume at different angles. The spark channel along the track develops more rapidly than the spark channels along the electric field, and the rate of development of the former increases with decreasing angle α. A large number of such channels in the shower shortens the supply pulse. For particles which pass at large angles ($> 40°$), the discharges which develop only along the field direction have no time to go over into the spark stage and are not registered, owing to the weak luminosity of the streamers. Thus, for tracks with $\alpha > 40°$ the sparks of the shower are similar to the shunting discharge gap in the streamer chamber[4]. Fluctuations in the development of each spark channel for particles traveling at small angles are so small, that the sparks can be regarded as independent of one another. In this respect chambers with large interelectrode gaps are more convenient for the registration of several particles than chambers with a small gap (on the order of 10 mm). Bayukov et al.[6] have shown that the efficiency of registration of several particles in one spark gap (d = 10 mm) decreases even following the passage of three particles.

Spark chambers with metallic electrodes and with large interelectrode gaps (on the order of 100 mm) have high efficiency for the registration of showers and individual particles in the showers, up to angles on the order of 40°, for simultaneous passage of several dozen particles through the chamber. The shower particles crossing the working volume of the chamber at an angle more than 40° to the direction of the pulsed electric field are not registered.

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