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STUDY OF ELECTRON-PHOTON SHOWERS IN IRON

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The shape of electron-photon showers in iron was measured with an ionization calorimeter for primary electron and photon energies of about 2×10^{11} eV. The shape found agrees with the theoretical one if the shower length is taken as 14.1 g/cm^2.

THEORETICAL calculation of the shape of electron-photon showers in materials of medium and high atomic number is a difficult problem which is complicated by the necessity of taking into account electron scattering and the energy dependence of the photon absorption cross section. For primary photon energies of 10^{11} to 10^{12} eV this calculation has been carried out for copper by Ivanenko and Samosudov[1] by the method of moments. The authors estimate the accuracy of their results as 10% near the peak of the shower development (the calculation was limited to consideration of the first two moments). In view of the special interest attached to the shape of the electron-photon shower in connection with interpretation of experiments on high energy nuclear interactions (see, for example, Grigorov et al.[2]), we undertook to determine it experimentally.

Our investigation was made with an ionization calorimeter[3]. Figure 1 shows the main features of the apparatus. The experimental data were obtained in 1957 at an elevation of 3860 meters in the Pamirs. We recorded the distribution of ionization in 49 ionization chambers arranged in six horizontal rows. Only those events were recorded in which ionization pulses arising simultaneously in at least three rows corresponded to the passage of at least 250 relativistic charged particles through each row. This guaranteed efficient counting of electron-photon showers with energy E $\gtrsim 10^{11}$ eV.

Further selection of events from those recorded

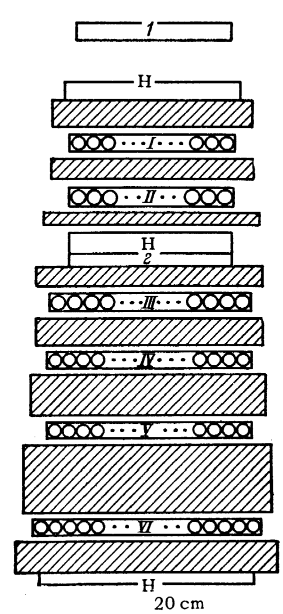

FIG. 1. Main features of the apparatus. 1, 2 — rows of Geiger counters operating in coincidence and determining the solid angle of the apparatus; H — rows of hodoscopic counters; I–VI — rows of pulse ionization chambers.

was made in order to separate the electron-photon component in a background of nuclear-interacting particles. The nuclear processes accompanying the passage of nuclear-interacting particles through the calorimeter (the greater part of the nuclear collisions occur at a considerable depth in the calorimeter) lead, as a rule, to a broader depth distribution of ionization in the calorimeter, which often possesses several peaks. This gives a basis for selecting as electron-photon showers those events for which the ionization distribution has minimum width, one peak, and starts within the first few shower lengths of the calorimeter iron absorber. It was also necessary to select only those cases in which only one or a few electrons or photons simultaneously hit the apparatus from the atmosphere. For this reason we selected cases in which most of the ionization produced in one row (more than 75%) was concentrated in a single ionization detector (of width 12 cm), and excluded from consideration cases of uniform distribution of ionization along a row.

The stringency of the selection is illustrated by the following figures. Out of 80 recorded events, in 16 cases the core of the shower left the calorimeter through a side wall, in 9 the ionization was uniformly distributed along the row of chambers, in 19 the ionization did not form a distinct core, and in 4 events two cores were observed. These events were excluded from consideration. The remaining 38 events are plotted in Fig. 2 as a function of the parameter n_{max}/E_0, which was taken as a measure of the width of the ionization depth distribution in the calorimeter (the narrower the distribution, the greater the ratio n_{max}/E_0; n_{max} is the number of particles at the peak of the curve; E_0 is the primary particle energy, which is proportional to the area under the ionization distribution curve). In the histogram shown in Fig. 2 we can distinguish the group of events marked by smaller width of the ionization distribution. This group was obtained after excluding events with several peaks in the distribution and events in which the shower originated at a depth greater than 40 g/cm^2 (about 3 shower lengths). It is shown in Fig. 2 by the dashed line. In the 14 cases remaining at this stage, there is some contamination N_0' of nuclear-interacting particles, which we can estimate from the expression

$$N_0' = \frac{1}{3} N_0 \{1 - \exp(-40/L_{\text{int}})\},$$

where N_0 is the number of nuclear-interacting particles included in the 38 events mentioned above and has the value $N_0' + (38-14)$, L_{int} is the range of interaction for the nuclear-interacting particles, which has been determined from data obtained in the same apparatus (without correction) as L_{int} = 80 g/cm^2 [2]; the coefficient $1/3$ expresses the relative number of nuclear cascade curves having one peak [4]. N_0' was determined in this way to be equal to 4. This contamination was excluded from the distribution shown by the dashed line in Fig. 2, by subtraction of the similar distribution observed for events arising in the interior of the calorimeter and normalized to N_0' = 4. The remaining 10 events were interpreted as electron-photon showers.

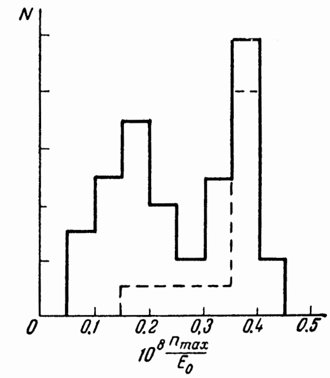

FIG. 2. The solid line is the distribution of 38 events dissipating energy in the calorimeter, as a function of the ratio n_{max}/E_0 which characterizes the width of the ionization depth distribution in the calorimeter. The dashed line is the same distribution after exclusion of events with several ionization peaks and events arising deep in the calorimeter.

For these 10 events we constructed an averaged ionization distribution as a function of depth in the absorber. It is shown in Fig. 3, where the ionization is expressed as the number of relativistic particles passing through the chambers. The average energy of the events selected is E = 2.2 $\times 10^{11}$ eV. In the averaging, each of the individual curves was normalized to an energy of 10^{11} eV. The angle between the shower direction and the vertical axis of the apparatus was also taken into account.

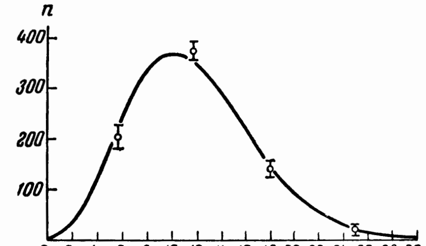

FIG. 3. Averaged electron-photon shower curve. o – experimental data (a shower length is taken as 14.1 g/cm^2); the solid line is a theoretical curve corresponding to the average of the experimentally recorded energies, based on the calculations of Ivanenko and Samosudov. The area under the curve has been normalized to a primary energy of 10^{11} eV.

$E_0 \cdot 10^{11}$, eV	I_1	I_2	I_3	I_4	I_5	I_6	
	80 g/cm²	145 g/cm²	240 g/cm²	330 g/cm²	450 g/cm²	645 g/cm²	θ_x°
1.8	67	369	177	45	27	—	13
1.0	125	403	174	6	8	5	17
1.9	130	425	136	15	5	—	5
2.8	187	386	180	13	—	—	25
3.4	218	372	95	24	21	—	13
3.3	230	333	200	27	—	—	0
2.5	241	380	107	5	—	—	27
1.4	275	395	92	12	—	—	0
2.3	275	360	105	22	—	—	10
1.5	308	365	130	5	4	5	0

E_0 – particle energy; I_i – number of relativistic particles in the i-th row; θ_x – projection of the angle between the particle trajectory and the vertical.

In Fig. 3 we have shown for comparison with the experimental data a theoretical shower curve obtained by averaging 10 calculated curves [1] for the same energies as the experimental data. Here the shower length for iron was taken as 14.1 g/cm², rather than 12.6 g/cm² as assumed by Ivanenko and Samosudov [1]. We can see from Fig. 3 that under these conditions the experimental data agree satisfactorily with the theoretical curve over the range from 6 to 25 shower lengths.

The experimental errors indicated in Fig. 3 for the average shower curve are due to the limited statistics and result from fluctuations in the development of the individual electron-photon showers. Some indication of the magnitude of these fluctuations at different absorber depths is given by the table, in which we have listed data on the number of particles observed at the different levels of the calorimeter in each of the 10 events. These data are normalized to a primary particle energy of 10^{11} eV.

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[3] Grigorov, Murzin, and Rapoport, JETP **34**, 506 (1958), Soviet Phys. JETP **7**, 348 (1958).

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Translated by C. S. Robinson
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