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TRANSITION EFFECT OF STARS PRODUCED BY COSMIC RAYS IN LEAD AND GRAPHITE ABSORBERS

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Results of an investigation of the transition effect of stars produced in lead and graphite absorbers at an altitude of 3100 m above sea level are presented. Photographic emulsions were used in the experiments. The effect amounts to 30% and 10% in lead and in graphite, respectively. A hypothesis is proposed concerning the properties of the particles producing the effects.

CONTRADICTORY results have been obtained by various authors in the study of the transition effect of the stars in dense absorbers. It has been shown[1] that the reason for this might lie in the low efficiency of a single scanning, and in the small depth at which the maximum of the transition curve occurs. It would therefore be of interest to set up an experiment which would enable us to carry out these measurements more accurately. For this purpose, the transition effect of stars in lead and graphite absorbers has been measured on Mount Terskol (3100 m above sea level). The experimental arrangement was placed in a wooden hut with dimensions 1.6 × 2.8 m, and having walls and roof of 1 cm thickness. The hut was set up on an open plateau. (A single-story building was also situated on the same plateau at a distance of 100 m from the hut.)

Emulsion layers of the type NIKFI-BR-400, 5 cm in diameter, were used in the experiments. The emulsion layer was wrapped in black paper and placed in a rubber case (thickness 10^{-2} g/cm^2). A getinax (paper-laminated bakelite) plate 6 cm in diameter and of 1 mm thickness was placed under the emulsion layer to prevent curling.

Stars with a number of prongs ≥ 3 were selected. To increase the efficiency of scanning, each layer was scanned three times, since, as has been mentioned in reference 1, the observed value of the effect is decreased, owing to the low scanning efficiency. All values of the relative number of stars that are presented correspond to the same weight of undeveloped emulsion layer.

The experimental arrangement with the lead absorber (Fig. 1) consisted of nine layers of lead placed one above the other. The dimensions of each layer were 40 × 60 cm. A frame 40 × 60 cm, made of a 25 × 25 mm steel angle 3 mm in thickness, was placed under each lead layer. To prevent the buckling of the lead layers, two duraluminum angles 15 × 15 mm, 1.5 mm thick, were placed on the frame in two places. Each was placed 15 cm from the edge of the longer side of the frame. The position and thickness of the layers are shown in Fig. 1. Instead of additional duraluminum angles, 25 × 25 mm steel angles were placed under the layers of 25 mm and 42 mm thickness, which consisted of separate lead bars. Above these, 1.5 mm thick getinax plates were placed. The remaining lead layers were solid, and were placed on the frames directly. On top of the array and below each lead layer, a single emulsion layer was placed horizontally in the center.

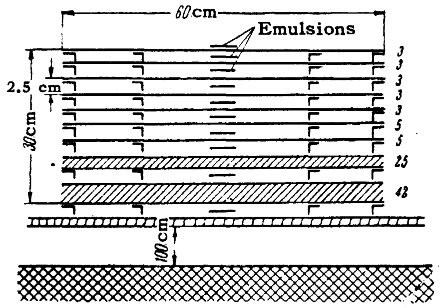

FIG. 1. Diagram of the experimental arrangement for measurements with lead absorber. The numbers on the right denote the thickness of the lead layers in mm.

Results of the scanning are shown in Fig. 2. It can be seen that the intensity curve of the stars attains a maximum at the depth of 5 — 6 mm of lead. The value of the transition effect is 30%. At the depth of the order of 2.5 — 3 cm of lead, the transition effect almost completely disappears, and the slope of the curve beyond this point corresponds to the absorption of the N component in lead.

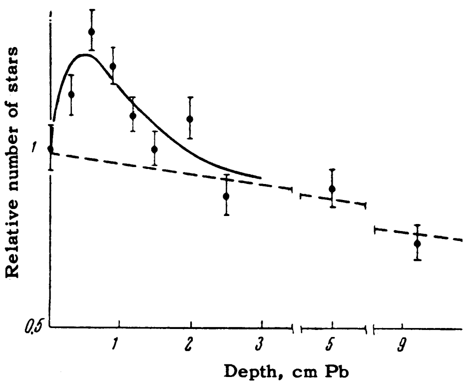

FIG. 2. Variation of the number of stars with the thickness of the lead absorber. Solid curve – the observed number of stars, according to Eq. (1). Dashed curve – the number of stars produced by the N component.

The existence of a transition effect of stars in graphite[2] indicates that the photon component is not the cause of the transition effect of stars. In the experiments of Rössle and Schopper, the value of this effect in graphite was calculated by subtracting from the total number of stars those which were produced by the N component. The latter were obtained by calculation. The purpose of our experiment with the graphite absorber was the measurement at each depth both of the total number of stars and the number of stars produced by the N component.

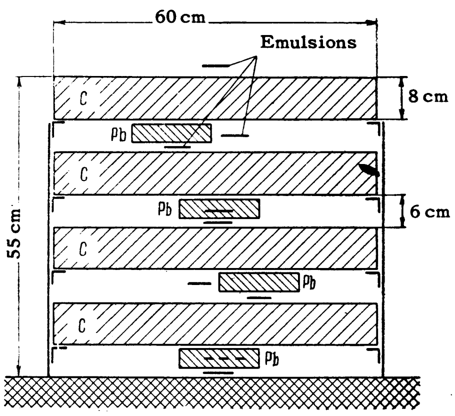

FIG. 3. Schematic diagram of the experimental arrangement with the graphite absorber.

The array consisted of four graphite blocks (Fig. 3), the dimensions of each being 60 × 60 cm. The blocks were placed one above the other, and were supported by steel frames held in a steel shell. A 25 × 25 mm steel angle was used.

Under each graphite block and in its center, two emulsions were placed horizontally. One of these was shielded from above by a 3 cm lead plate of 15 × 15 cm size. In order to decrease the shielding by the lead plates above the higher-placed emulsions, the lower-placed emulsions were turned with respect to the upper emulsions by 90°.

From the experimental data it follows that, at a depth of 3 cm of lead, the transition effect of the stars almost completely disappears, and the shielded emulsion recorded, therefore, only those stars produced by the N components at a given depth. The difference between the number of stars recorded in the unshielded layers, taking the absorption of the N component in 3 cm of lead into account, gives directly the number of stars of the transition effect.

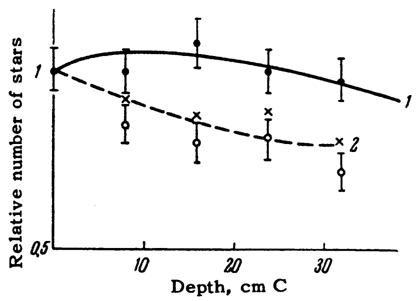

FIG. 4. Variation of the number of stars with the thickness of the graphite absorber. ● – number of stars under graphite absorber (curve 1), ○ – number of stars under the lead plate, × – number of stars under graphite absorber obtained by counting the number of stars detected under the lead plates (curve 2). In calculating this curve, the geometry of the arrangement has been taken into account.

The results of the experiment are shown in Fig. 4. From the figure, it can be seen that the intensity of stars under the graphite absorber (curve 1) is greater than the intensity of stars produced by the N component (curve 2). It is thus evident that there exists a transition effect of stars in graphite. Its value is 10 – 15%. From the existence of the transition effect of stars in graphite it follows that the star-producing particles of this effect are unstable. The presence of a maximum in the intensity curve of stars in lead indicates that these particles are produced in the absorber and, consequently, are secondary ones. According to Rössle and Schopper,[2] they are neutral. It has been shown earlier by the authors[3] that the "primary" particle incident on the absorber and responsible for the production of "secondary" particles cannot be charged.

In order to obtain a good agreement with the experimental data, it is necessary to assume that the mean free path for the production of "secondary" particles by the "primary" ones is approximately equal to the mean free path for star production by "secondary" particles. If, for simplicity, we consider a one-dimensional picture, we obtain the following expression for the intensity of stars at various depths in lead:

$$A \exp\left(-\frac{x}{L}\right) + B \frac{x}{\lambda} \exp\left(-\frac{x}{\lambda}\right) \qquad (1)$$

(solid curve in Fig. 2). The first term gives the intensity of stars produced by the N component (dashed curve in Fig. 2), while the second term gives the intensity of stars of the transition effect (difference between the solid and the dashed curve).

From our experimental data, we obtain: $A \approx 1$, $B \approx 0.8$, $\lambda \approx 0.5$ cm, and $L \approx 33.5$ cm. The value λ is markedly smaller than the mean free path corresponding to the geometrical cross section for nuclear interactions. No known particle possesses such a small mean free path for star production. Knowing A, B, λ, and L we can determine the intensity of the "primary" particles. This was found to be of the order of 4% of the intensity of the star-producing component at the observation altitude.

The expression (1) has been obtained under the assumption that the "primary" particles fall on the absorber from the air. This corresponds to the steep slope of the star-intensity curve after it has passed through its maximum in lead, indicating that the production of "primary" particles in lead is insignificant as compared with air.

From an analysis of experimental data at other altitudes,[4] it follows that these particles are in equilibrium with the N component. In view of the fact that the atomic weights of air and graphite are approximately equal, one can expect that the N component will also produce "primary" particles in graphite. To check this, a graphite array similar to the one described above was surrounded from all sides, except on the bottom, by a 4 cm lead layer. This lead layer shielded the side of the array from the air, both from "primary" and "secondary" particles. The diagram of the position of the experimental arrays in the wooden hut is given in Fig. 5.

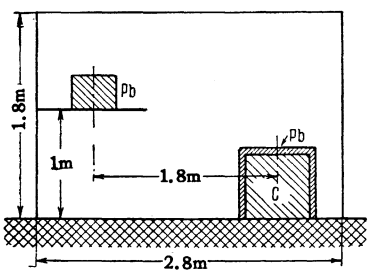

FIG. 5. Schematic diagram of the position of the experimental arrays.

The experiments were carried out in two series. First, the arrays with plane lead absorbers and with a graphite absorber shielded by lead were simultaneously exposed. Then, the graphite array took the place of the lead-shielded graphite array. The time of exposure of each series amounted to about two months. The results of the experiments are shown in Fig. 6.

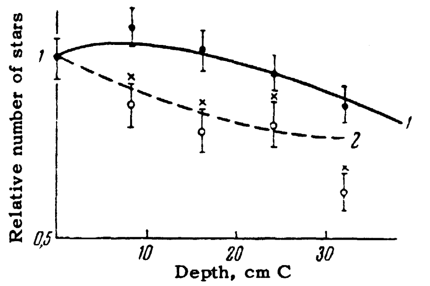

FIG. 6. Variation of the number of stars with the thickness of the graphite absorber in the experiment with the graphite absorber shielded by lead. Notation as in Fig. 4.

The existence of the transition effect in the described array confirms that the particles responsible for this effect are also produced in graphite. Thus, in graphite not shielded by lead, one should observe a total transition effect from "primary" particles produced both in air and in graphite. As a result, the slope of the intensity curve beyond the maximum should correspond to the absorption of the N component in graphite. As can be seen from Fig. 4, the experimental data up to the depth of 32 cm of graphite do not contradict our conclusions.

It should be mentioned that the production of "secondary" particles, as a result of a spontaneous decay of the "primary" ones, is excluded. In fact, in such a case the mean free path of the "primary" particles for the production of the "secondary" ones should be equal to ~ 0.5 cm. Consequently, the transition effect in lead can be produced only by those "primary" particles which were produced in the 0.5 cm of air directly above the lead array. By calculating the number of interactions of the N components with the air nuclei in this layer of air we find that for each such interaction there are 10^3 stars of the transition effect with ≥ 3 prongs. Since one three-prong star has, on the average, an energy of 150-Mev, then the energy lost in a single act of interaction by one particle of the N component to the production of the "primary" particles should be greater than 150 Bev, which contradicts well-known data.

It should be concluded that the "secondary" particles are produced as a result of the interaction of the "primary" particles with nuclei. The energy transferred to the nucleus should, moreover, be insufficient for the production of a visible star. Such a picture does not contradict the energy which is available in the star-producing component of cosmic rays.

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[1] T. V. Varsimashvili, Тр. Института физики АН ГрузССР (Proceedings of the Physics Institute, Academy of Sciences, Georgian S.S.R.) **7**, (1959), in press.

[2] E. Rössle and E. Schopper, Z. Naturforsch. **9a**, 836 (1954).

[3] T. V. Varsimashvili, loc. cit. ref. 1.

[4] J. J. Lord and M. Schein, Phys. Rev. **75**, 195 (1949).

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