Energy Spectrum of π^--Mesons Produced by Cosmic Rays in Photographic Emulsions

A. A. VARFOLOMEEV, R. I. GERASIMOVA, E. A. ZAMCHALOVA, M. I. PODGORETSKII AND M. N. SHCHERBAKOVA
Academy of Sciences, USSR

(Submitted to JETP editor March 28, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 1164-1166 (June, 1956)

1. IN the research we investigated the energy spectrum of π^--mesons (with energies < 70 mev) produced in the interaction of cosmic rays with the nuclei of photographic emulsions. We made use of two piles of emulsion layers of diameter 10 cm of emulsion type P, irradiated in the stratosphere (56 layers of 330μ each and 60 layers of 450μ). In the exposure the piles were assumed to be vertical so that the mean direction of the primary cosmic particles was directed into the plane of the emulsion. The processing of the plates was carried out according to the method described in Ref. 1. In the systematic examination of the plates under a microscope, all the tracks of stopped π-mesons were observed and then traced to the point of meson creation or of its entry into the plate. In the determination of the energy of the π-mesons from their total range, use was made of the tables[2] of the dependence of the range-energy for the emulsion Ilford G-5, inasmuch as the stopping action of the emulsion actually used differed insignificantly from the Ilford emulsion.

2. In all, about 1000 tracks of stopped π-mesons were traced, of which 195 π^+- and 328 π^--mesons were formed in the emulsions. Their energy spectra are shown in Figs. 1 and 2 (dashed line histograms). In view of the fact that the π-mesons of different energies formed in the emulsion have different probabilities of stopping in the plate, appropriate geometrical corrections were introduced to take account of the finite size of the emulsion volume.

The correction coefficients were computed in the following way. First, for each track of a π-meson which makes an angle θ with respect to the vertical the total interval $\Delta\varphi$ was determined of those angles φ (φ is the azimuth angle) for which the track of a π-meson with range R will end within the emulsion chamber. The first correction coefficient $K_\varphi = 2\pi/\Delta\varphi$ determines the ratio of the number of all π-mesons which leave the given point with angle θ and with energy $E(R)$ to the number of those of them which stop in the emulsion. Second, that part of the layer ΔS on which the π-mesons created in the plate could be stopped if they emerge from different parts of the chamber with energy E at the given angle θ and at different φ. It was determined (Fig. 3) as the area of the intersection of the circle O_1 of diameter 10 cm with one of the similar circles O_2 or O_3, whose centers, together with the center of O_1, form an isosceles triangle with legs R and apex angle 2θ (shaded part of Fig. 3). The second correction coefficient K_s was computed as the ratio of the area of the entire layer to the size of ΔS.

As a result of the introduction of the correction coefficients $K = K_\varphi K_s$ for each case, we obtained energy spectra for the π^-- and π^+-mesons, formed in the emulsion (which are shown in Figs.

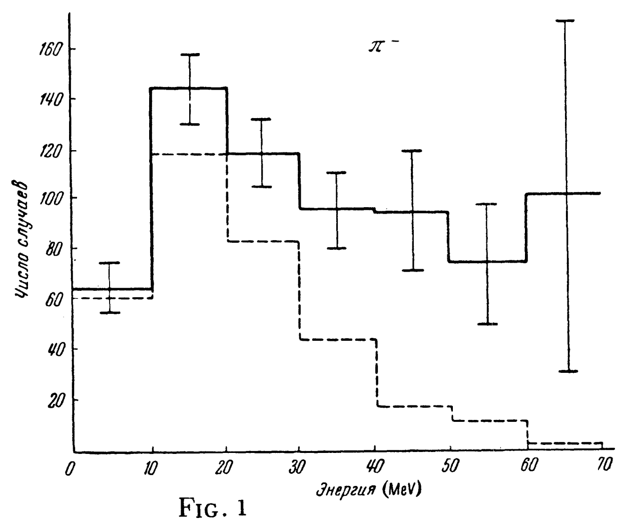

FIG. 1

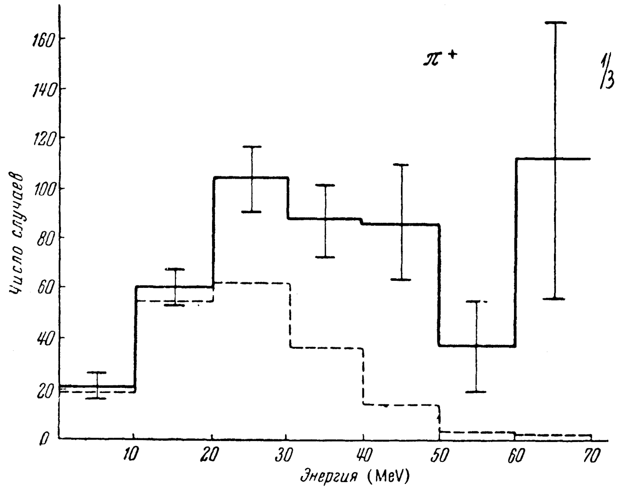

FIG. 2

1 and 2, respectively by the solid line histograms). It appears that the statistical sampling is too small to make a definitive judgement on the spectra; however, it seems possible to us to note a certain observed difference in the spectra of π^-- and π^+-mesons.

First, the initial part of the π^--meson spectrum is displaced to the left, relative to the corresponding part of the π^+-meson spectrum, by ~ 10 mev. This shift can be explained by the Coulomb interaction of π-mesons with the nuclei from which they emerge, in the case of the magnitude of the mean Coulomb barrier of the the nuclei being of the order of several mev.

Second, the spectrum of the π^--mesons, in contrast to that of the π^+-mesons, is evidently not monotonic: in the region 10-30 mev a small maximum is observed. If this maximum actually exists, then it is possible to explain it by the decay of Λ^0-particles, absorbed by the same nuclei in which they are formed. The position of the maximum does not contradict this hypothesis. Actually, for π-meson decay of a Λ^0-particle connected with the original nucleus, an energy

$$Q = 37 \text{ mev} - (B_{\Lambda^0} - B_n) - (m_n - m_p) - (M_2 - M_1),$$

will be produced, where M_1, m_n and m_p are the masses (in mev) corresponding to the original stable Λ^0-nucleus, neutron and proton, M_2 is the total mass of all the products of the decay of the Λ^0-nucleus, other than the π-meson, B_{Λ^0} is the binding energy of the Λ^0-particle in the Λ^0 nucleus, and B_n is the binding energy of the neutron in the corresponding stable nucleus.

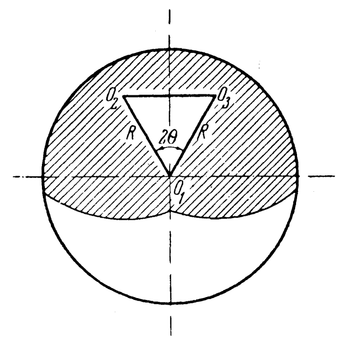

FIG. 3

As the distribution of primary stars according to the number of "black" or "gray" rays (the average number of "black" and "gray" rays is equal to 10) shows, the π-mesons are formed principally on the heavy nuclei of the photographic emulsion--Ag and Br. In such nuclei, the Λ^0-particle can appear to be at an energy level that is much lower than the lowest bound neutron, since its levels are all free. As a consequence, the quantity $(B_{\Lambda^0} - B_n)$ is greater than zero, the latter leading to a reduction of Q. Moreover, the π^--meson, in leaving the nucleus, will be retarded by the Coulomb field and lose several million electron volts. All this could lead to a shift of the maximum in the interval from 30 to 10 mev. The size of the maximum does not contradict (with accuracy of one order) data on the quantity of excited fragments which decay with the emission of π^--mesons.

In conclusion the authors express their thanks to V. V. Alpers and I. I. Gurevich for the help in the research and for criticism of the results, and also to A. A. Barkhudarov, L. V. Kruglov, L. A. Karpov,

V. M. Kutukov, A. P. Mishakov, A. S. Romantsev, A. I. Ryzhov, L. V. Surkov and S. A. Chuev for taking part in measurements on the microscope.

[1] V. V. Alpers and A. A. Varfolomeev, PTE, 1, 1956.

[2] Fay, Gottstein and Hain, Nuovo Cimento 2, Suppl. 2, 234 (1954).

Translated by R. T. Beyer
246

Disintegration of Beryllium and Carbon Nuclei as a Result of π^-–Meson Capture

A. A. VARFOLOMEEV AND R. I. GERASIMOVA
Academy of Sciences, USSR
(Submitted to JETP editor, March 28, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 1167-1167 (June, 1956)

TO obtain information on the disintegration of light nuclei in stopping π^-–mesons, an investigation was carried out on σ-stars in beryllium and carbon. Powdered beryllium and carbon (crystal size $5-10\,\mu$) were introduced into the emulsion to the amount $4\,\mu$ gm per cm.^{3} The method developed for introducing the powders guaranteed a uniform distribution of the crystals over the emulsion layer. A plate of total thickness 2– 2.5 mm was prepared from emulsion layers of diameter 42 mm,

The powder of the material under investigation was contained in only 3–4 layers out of 10. The plates were exposed to a beam of slow π^-–mesons in the synchrocyclotron of the Institute for Nuclear Problems of the Academy of Sciences, USSR. The method of processing the layers[1] differed little from the procedures used previously for the processing of emulsions in layers.[2] (The work was completed in 1953.[3]) A layer with beryllium was fixed at low temperature $\beta \sim 5°$) to preserve the blackening.

Each fixed case which resembled the nuclear absorption of a pion in the crystal was subjected to processing under a microscope. After all the necessary measurements had been completed, the tracks were again subjected to examination. For improvement of the visibility of the layer, the emulsion below the crystal was removed with chamois and wetted in a solution of methyl alcohol in ethyl. We succeeded in reducing the layer to several microns thickness. The emulsion was soaked in water at the place under investigation and was examined (in swollen condition) under the microscope. Only by means of such careful testing could it be reliably established whether the pion was absorbed in the crystal.

As a result of the investigation of 4 cm^3 of the emulsion, 7 cases of pion absorption in carbon and 12 in beryllium were observed. In the analysis of the tracks, we used a method of counting the grains on some plates and the δ-electrons on the others as functions of the remaining range of the particles. Singly-charged particles differed from doubly-charged ones in the remaining range by more than 50-100 μ. Information on the particles which arise in the nuclear disintegrations of carbon and beryllium are shown in Tables 1 and 2, respectively. The symbols H, p, d, T, α and f denote, respectively, singly-charged particles, protons, deuterons, tritons, doubly-charged particles and particles with short tracks, which could not be identified.

The average number of prongs in the stars in beryllium amounted to 1.15 ± 0.23. In nearly one fourth the cases (28 ± 12 %), the absorption of the pion did not lead to the release of charged particles. In each disintegration of a Be

TABLE 1

Number of prongs in the star	Nature of particles	Energy of particles in mev (range in μ)
0	—	—
1	p	14
1	f	(46)
2	p, α	10,10
2	α, f	12, (14)
3	p, f, f	19, (70), (12)
4	H. H. f. f	5.5. 4.7, (24), (37)