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The Ionization Spectrum of Cosmic Rays 3250 m above Sea Level

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Using a previously described method,[1] we measured the ionization spectra produced by the soft and hard components of cosmic rays of various ranges at 3250 m above sea level. The proton momentum spectrum was obtained in the interval 0.36–1.0 bev/c.

IN an earlier paper,[1] we described in detail a method for measuring the ionization spectrum of cosmic rays. The basic idea of the method is to select the minimum ionization produced by a particle as it passes through several scintillation crystals; experiments at sea level showed that quantitative information about the proton component of cosmic rays with ranges 2 to 15 cm of lead could be obtained.

It was interesting to apply this method to the ionization spectra of cosmic rays at mountain altitudes, especially as the resolving power of our system was considerably better than that available to previous authors.[2,3] With this in mind, the apparatus was transported to the Alagez high altitude (3250 m above sea level) station of the Academy of Sciences of the Armenian SSR.

Two series of measurements were made. In the first series, lasting 407 hours, we measured the ionization spectrum of particles having ranges 2–3, 3–5, 5–9 and 9–15 cm of lead. In the second series, which lasted 270 hours, the lead filters were replaced by carbon ones equivalent to 1–1.5, 1.5–2, and 2–3 cm of lead. During both series, the ionization spectrum of particles with ranges in excess of 15 cm of lead was also measured.

The amount of material above the apparatus was kept to a minimum and consisted of a single layer of iron roofing plus 0.5 cm plywood. During both series of measurements (i.e., for ranges 2 to 15 cm of lead) we counted the number of times two or more particles went through the system together (multiple traversals). In analyzing the data, these multiple traversals were discarded, so that our results for the soft component refer to single particles only. Multiple traversals in the hard component were not registered.

Figure 1 shows the ionization spectrum obtained for the hard component (particles with ranges of more than 15 cm of lead); from it we can obtain the resolving power of our system. Ionization in arbitrary units is plotted along the abscissa, and the relative intensity in some ionization interval along the ordinate. Our method[1] is such that the ionization spectrum shown in Fig. 1, together with all the other spectra presented in this paper, is the product of the differential distribution of ionization and the fourth power of the integral distribution. The curve in the figure is almost symmetric and has one sharp maximum. The relative width at half maximum is 18%.

Seven ionization spectra for particles of various ranges in the soft component were taken. As an example of these, Fig. 2 gives the spectrum corresponding to 1–1.5 cm of lead. The insert shows the right-hand side of the spectrum on an enlarged scale. In this graph ionization is measured in units of the minimal ionization, which is taken to be the ionization at the maximum in the spectrum corresponding to the hard component. The arrows show the most probable ionization Δ_0 for μ-mesons, protons and mesons of masses 550 and 965 electron masses. The other 6 ionization spectra for the

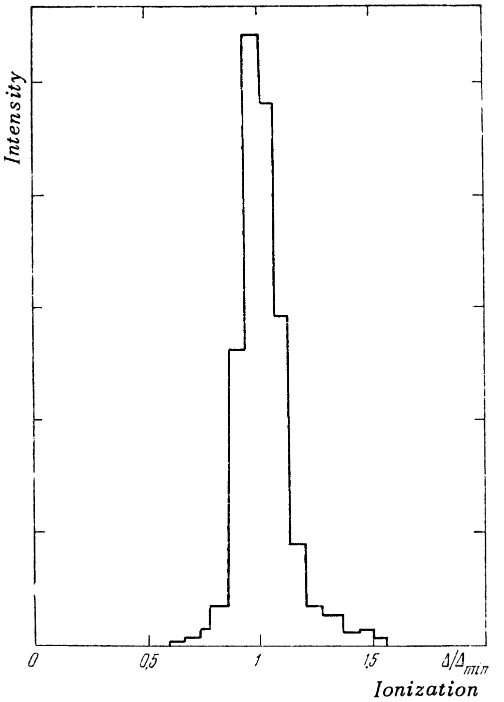

FIG. 1. Ionization spectrum for the hard component

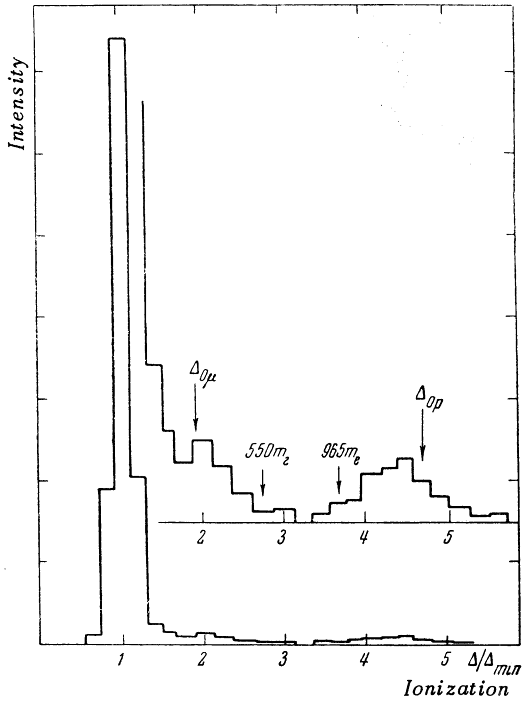

FIG. 2. Ionization spectrum for particles with ranges 1–1.5 cm Pb.

soft component are similar to the one in Fig. 2. Two well separated groups of particles are visible. The right-hand group consists of protons, the left-hand one of μ-mesons and electrons. The total spectrum for ionization by the soft component can be obtained by adding all the data for a given group. For example, Fig. 3 shows the sum of the five spectra corresponding to ranges 0.7–1, 1–1.5, 1.5–2, 2–3 and 3–5 cm of lead. We see that in the total spectrum the large range interval (0.7 to 5 cm of lead) has smeared out the distinction between protons and μ-mesons and electrons, so that we have a smooth ionization curve.

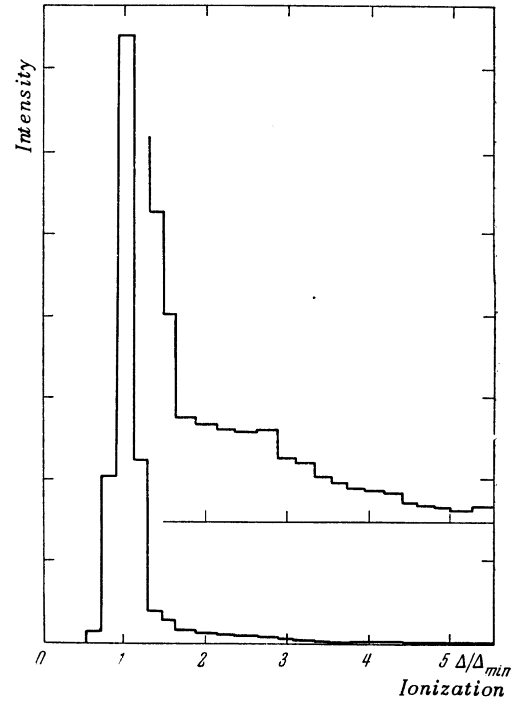

FIG. 3. The total ionization spectrum for particles in the soft component (ranges 0.7 to 5 cm Pb.)

Can our method detect particles with masses intermediate between those of the proton and μ-meson? From Fig. 2 we see that the left-hand edge of the proton spectrum overlaps the calculated most probable ionization due to K-mesons, so that it is hardly likely that our spectra can separate these particles from protons.

Indeed, since there was little matter above our apparatus, one would not expect many K-mesons to appear in our spectra. There are, however, a considerable number of particles in the interval corresponding to the most probable ionization by mesons of mass 550 m_e[4]. The resolution, as obtained from Fig. 1, and the number of μ-mesons with ranges 1–1.5 cm of lead are not large enough to account for these particles as the right-hand side of the μ-meson ionization spectrum. Calculations show that almost all the particles with ionization 2.4 to 3.2 $\Delta_{\min}$ can be accounted for as non-ionizing protons stopping in the layer corresponding to ranges 1–1.5 cm of lead, and hence nothing definite can be said about the presence in this spectrum of mesons with mass of about 500 m_e.

Our spectra lead to certain conclusions about the proton component of cosmic rays 3250 m above sea level and with ranges 0.7 to 15 cm of lead. The results are shown in the following Table, which also gives the number of multiple traversals of particles through our system.

The proton momentum spectrum shown in Fig. 4 was drawn from the results in the Table. The absolute value of the vertical proton current was obtained from the vertical current of μ-mesons with range more than 15 cm Pb. The latter current was taken to be 1.56 $\text{cm}^{-2}\ \text{sec}^{-1}\ \text{sterad}^{-1}$, in agreement with Rossi.[5] The spectrum is corrected for non-ionizing protons.

Range interval cm Pb	Number of protons observed	Number of protons, corrected for those which stop without ionizing	Number of protons in % (corrected for those which stop without ionizing)		Number of multiple traversals
			Relative to the total number of particles in a given range interval	Relative to the number of particles with range more than 15 cm Pb	
0.7—1.0	58	59	3.50±0.46	0.407±0.053	0
1.0—1.5	83	85	3.38±0.37	0.610±0.066	0
1.5—2.0	75	79	5.09±0.57	0.540±0.060	2
2—3	318	346	7.08±0.39	0.863±0.047	10
3—5	338	365	15.15±0.80	1.395±0.072	14
5—9	414	480	18.69±1.87	1.870±0.187	20
9—15	362	500	24.91±4.00	2.110±0.338	42
0.7—5			6.18±0.19	3.820±0.114	
0.7—15			9.71±0.77	7.810±0.610	

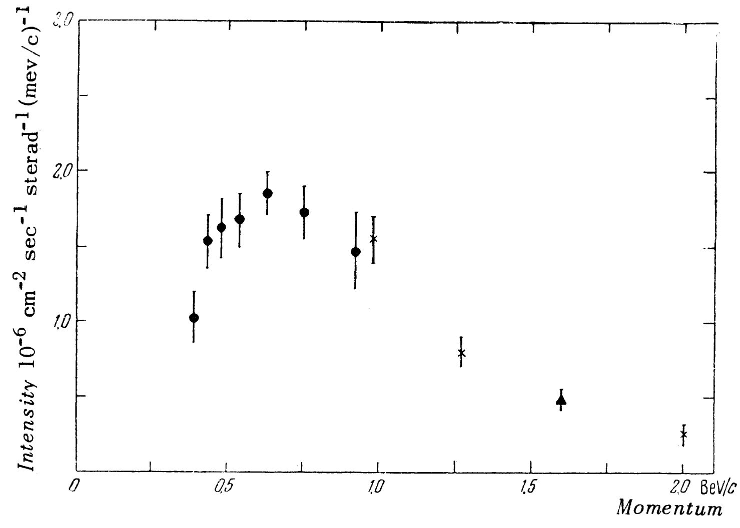

FIG. 4. Momentum spectrum of protons 3250 m above sea level; ×—Ref. 7, ▲—Ref. 6, ●—our data.

In the momentum range 0.36–0.6 bev/c our spectrum agrees well with that obtained by Kocharian[6], who used a magnetic spectrometer. For momenta greater than 0.6 bev/c our curve lies above Kocharian's data, but agrees well with the data of Miller *et al.*,[7] which were obtained by a Wilson cloud chamber in a magnetic field. For momenta larger than 1 bev/c, where we have no data, we show several points obtained by other workers.[6,7]

In conclusion we should like to express our deep gratitude to A. I. Alikhanian, who made the present research possible at Alagez, and to A. D. Maiorov for his help in carrying out the experiments.

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Investigation of σ-Stars Induced by Negative π-Mesons

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The properties of σ-stars produced by π^--mesons stopping in an emulsion chamber were investigated. Data obtained from the analysis of 938 σ-stars were used to determine the distribution of the number of prongs as well as the energy distribution of secondary particles. The obtained energy spectrum is compared to the data on σ-stars produced by K^--mesons.

1. THE properties of σ-stars, produced by π^--mesons stopping in emulsion, were investigated by Menon, Muirhead and Rochat[1]. In particular, data were given on the energy distribution of the secondary particles formed in the interaction. This information is of considerable interest for the sake of elucidating of the capture process of π^--mesons by nuclei, and for comparison with σ-stars produced by other unstable particles, for instance, the K^--mesons. This is especially true for secondary particles of energy higher than 30 mev.

The experimental data, however, are grossly inaccurate in this energy region. This is due to the fact that the particles under consideration have a very long range, and therefore cannot come to a stop in relatively thin single emulsion layers used by the authors of Ref. 1. The energy could therefore have been determined only by ionization measurement or, in a few cases, by multiple scattering, procedures which are connected with large errors.

In order to avoid this limitation, the σ-stars were investigated in the present work by means of an emulsion chamber, consisting of a large number of stripped emulsion layers. An appreciable part of the secondary particles came to a stop within the chamber, which made it possible to determine their energy simply from the value of their ionization range. The emulsion chamber used consisted of 126 type P emulsion layers, each 450 μ thick. The layers had the shape of a circle 10 cm in diameter. The chamber was exposed in the stratosphere for 7 hours.

For every disk, the central part only, 4 cm in diameter, was scanned at a low magnification. Since the range of the investigated secondary particles is not larger than 3 cm, the particles of even highest energy could leave the chamber through its top or bottom surface only, which permitted a simple calculation of the geometrical corrections. In fact, these corrections were necessary only for the case

these corrections were necessary only for the case of protons with energy greater