Projection of the spin of the system L_{12}	Charge of the system $(T_{12}+{}^1/_2)$	
	0 (neutron)	1 (proton)
$-{}^1/_2$	$\frac{1}{\pi\sqrt{2}}C_1^v$	$\frac{1}{\pi\sqrt{2}}C_3^v$
$+{}^1/_2$	$\frac{1}{\pi\sqrt{2}}C_2^v$	$\frac{1}{\pi\sqrt{2}}C_4^v$

The C_k^v are defined by Eq. (35) of I.

The calculated eigenvalues of the charge and spin projections of the system consisting of a nucleon that strongly interacts with the vacuum vibrations of the meson field, coincide with the observed values.

In subsequent papers we shall consider, on the basis of the theory developed above, the scattering of π mesons on nucleons, the magnetic moments of nucleons, quasi-statistic nuclear forces and other phenomena.

Translated by R. T. Beyer
57

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Meson Component of the Cosmic Radiation at an Altitude of 3200 m Above Sea Level

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The momentum spectrum of μ-mesons was measured in the momentum range $0.4 \leq p \lesssim 14$ bev/c at an altitude of 3200 m above sea level. The ratio of the number of protons to μ-mesons at this altitude was determined. The ratio of positive to negative μ-mesons was found as a function of momentum.

In 1951 we began an investigation of the proton and meson components of the cosmic radiation at an altitude of 3200 m above sea level. For this purpose there was constructed a special magnetic spectrometer, a description of which was given in Ref. 1. The proton component was determined as a result of the investigation. The actual shape of the spectrum was determined for the meson component. By using a series of improvements, the momentum of the particles in the magnetic field was determined with great precision.[1] The relative error in determining the momentum of the particles is equal to

$$\sigma = [(0.035\,p)^2 + (0.018\,/\,\beta)^2]^{1/2}. \qquad (1)$$

Here and everywhere below the momentum p of the particles is measured in units of bev/c; β is the velocity of the particles, measured in units of the velocity of light.

1. Protons in the Hard Component

In a second variation of the determination of Ref. 1, in which there was no lead above the magnet and under the magnet was located $x_1 = 45.2$ gm/cm^2 of lead and $x_2 = 139$ gm/cm^2 of [1]copper, then simultaneously with particles which were stopped in the absorbers, we also detected those particles which had gone through the complete system of absorbers. In contrast with the former particles the latter are called the "hard" component. The hard component consists principally of μ-mesons with momenta greater than 0.370 bev/c (i.e., kinetic energy $E \geq 260$ mev), and a certain

[1] N. M. Kocharian, J. Exptl. Theoret. Phys. (U.S.S.R.) 28, 160 (1955); Soviet Phys. JETP 1, 128 (1955).

number of protons(here we have in mind the components of the hard component at the entrance to the system of absorbers, i.e. in the air; following the passage through the absorbers the constitution of the hard component changes; in the flux of these particles there appear π-mesons, nuclear fragments and electrons.). In very great absorber thicknesses (approximately 21 radiation units long) we can conclude that the hard component is practically free of electrons. The relative number of protons in the hard component is not very small, and in order to determine the differential μ-meson spectrum, it is necessary to take it into account. Protons with momentum $p \geq 1.11$ ($E > 500$ mev) have an ionization range greater than the overall absorber thickness and may emerge from it. As a result of the work in Ref.1, we can determine the number of protons in the hard component. In 267 hours there passed through the magnetic field of the apparatus 680 protons with momenta $1.11 \leq p \leq 2.33$, which stopped in the absorbers and were removed from the hard component. The number of protons with $p > 2.33$ may be determined from the power law for the integral spectrum

$$n(p) = 1{,}46 \cdot 10^{-3} / 1{,}65 \cdot p^{1{,}65} \qquad (2)$$

given in Ref. 1. We determine from Eq. (2) that the number of protons with $p > 2.33$ is equal to 300.

Hence the number of protons with momentum $p > 1.11$ equals 970. Of this number 450 protons were detected as having stopped in the absorbers. At the same time 19, 150 hard component particles were detected. Consequently, the protons constitute $(970-450)/19150 = 2.7\%$ of the total number of particles found in the hard component, and the hard component consists principally of μ-mesons. We have compared the relative number of protons with $p > 1.1$ and μ-mesons with $p > 0.37$ in the hard component. If we compare the number of protons and mesons in the hard component with $p > 1.1$ then the number of protons is greater, consisting (see Table 1) of about 8% of the number of μ-mesons.

TABLE 1
Momentum Spectrum of Hard μ-Mesons

Interval	Average Momentum	Number of Hard Particles +	Number of Hard Particles −	Luminosity of Spectrometer	Number of Particles Corrected for Luminosity +	Number of Particles Corrected for Luminosity −	Number of Protons Among Hard Particles	Number of μ-Mesons Following Subtraction of Proton Background	Total Number of Mesons	Number of Mesons in the Momentum Interval x 10^3
	2	3	4	5	6	7	8	9	10	11
19—15	0,411	414	402	0,825	501	488	0	501	989	8,0
15—13	0,500	336	306	0,890	378	344	0	378	722	7,5
13—11	0,583	475	427	0.929	512	460	0	512	972	7.4
11—9	0,778	618	545	0,952	649	572	0	649	1221	6,48
9—8	0,823	410	344	0,965	425	356	0	425	781	6,01
8—7	0,933	509	363	0,975	522	372	0	522	894	5,33
7—6	1,075	625	458	0,982	635	466	94	541	1007	4,52
6—5	1,271	854	637	0.987	864	645	128	736	1381	4.45
5—4	1,552	1037	689	0.995	1040	692	112	928	1620	3,48
4—3	2,000	1336	855	1,0	1336	855	78	1258	2113	2,75
3—2	2,800	1537	1158	1,0	1537	1158	77	1460	2618	1,73
2—1	4,660	1575	1066	1,0	1575	1066	83	1492	2558	0,611
1—0	14,000	993	725	1.0	993	725	41	952	1677	0,0446

2. Momentum Spectrum of μ-Mesons

In Table 1 are presented the results of studying the trajectories of the particles which make up the hard component. In the first column are given intervals of range $\delta = 7/p$ where p, as elsewhere, is measured in bev/c. In the second column is given the average momentum, corresponding to the interval δ in the first column. In the third and fourth columns are given the number of positive and negative particles. In the sixth and seventh columns are given the numbers of these particles corrected for the luminosity of the apparatus. The number of protons in the hard component (column 8) is calculated from the results given in Ref. 1. As was already stated above, only protons with $p > 1.1$ can get into the hard component, hence the hard component particles with $p < 1.1$ are only mesons. The number of protons with momentum $1.1 \leq p \leq 2.33$ entering with the hard component is taken from Ref. 1. For $p > 2.33$ the number of protons is calculated from the formula

$$(1.46 \cdot 10^{-3} / 1.65)(p_1^{-1.65} - p_2^{-1.65}) - \Delta n, \quad (3)$$

where n is the number of protons with $p_1 < p < p_2$, stopped in the absorbers. This number was taken from the result given in Ref. 1. Subsequently, we subtract the proton background in the ninth and tenth columns and give the number of positively charged and the total number of mesons. In the eleventh column we calculate the ordinates of the differential meson spectrum, i.e., the number of mesons arriving in a momentum range equal to 1 bev/c. The numbers in this column are obtained by dividing the numbers in the preceding column by the value of $ks\omega t = 1.344 \times 10^6$ cm^2 ster. sec.[1]

In Fig. 1 there is represented the differential momentum spectrum of μ-mesons on a log log scale. On the axis of abscissas is plotted the logarithm of the momentum in bev/c and on the ordinate axis is plotted the logarithm of the number of mesons (number in column 11).

In Table 2 there is shown the calculated intensity of mesons with momenta greater than a given p (p in units of bev/c, $n(p)$ in units of cm^{-2} sec^{-1} ster^{-1}).

TABLE 2.

Intensity of the Vertical Flux of μ-Mesons with Momentum Greater than p

p	$10^3 n(p)$	p	$10^3 n(p)$
0,370	13.8	1,165	8,90
0,466	13,09	1,40	7,87
0,539	12,53	1,75	6,67
0,636	11,80	2,33	5,1
0,777	10,90	3,50	3,15
0,875	10,32	7,00	1,25
1,00	9,65		

Rossi[2] gives for the intensity of mesons with an ionization range greater than 167 gm/cm^2 of Pb (i.e. with momentum $p \geq 0.305$) at the same altitude, a value of $n(0.3) = 15.2 \times 10^{-3}$ particles/cm^2 sec ster. It is difficult to find any agreement with this value from the corresponding momentum deduced from Table 2.

As can be seen from Fig. 1 the differential momentum spectrum of μ-mesons is determined up to the momentum $p = 14$. In other work [3,4] the μ-meson spectrum at mountain altitudes was determined up to a momentum of $p = 7$. In this range of momentum, within the limits of experimental error, our results agree with the work cited.

We can now derive a comparison of the intensity of the vertical flux of protons and μ-mesons. The result of this comparison is shown in Fig. 2. The upper curve in this figure represents the relative number of protons and μ-mesons at a definite momentum. The lower of these curves represents the relative number of protons and μ-mesons with momenta greater than that which is designated on the axis of abscissas. At the beginning, the ratio of the differential spectra increases rapidly with the value of the momentum. For momentum $p \approx 0.9$ this ratio reaches its maximum value and, for further increases in the momentum of the particles, decreases rapidly. At the peak ($p \approx 0.9$) the number of protons constitute $\sim 20\%$ of the number of mesons at this momentum. The ratio of the ordi-

[2] B. Rossi, Revs. Mod. Phys. 20, 537 (1948).

[3] J. G. Wilson and others, Progress in Cosmic Ray Physics, Amsterdam, 1952, pp. 358 and 360.

[4] W. L. Whittemore and R. P. Shutt, Phys. Rev. 86, 940 (1952).

nates of the integral spectra of protons and μ-mesons decreases monotonically with increasing momentum of the particles. For $p > 0.4$ the protons constitute ~ 12% of the number of mesons, for $p > 1$ ~ 9% and for $p > 8$ about 2.7%.

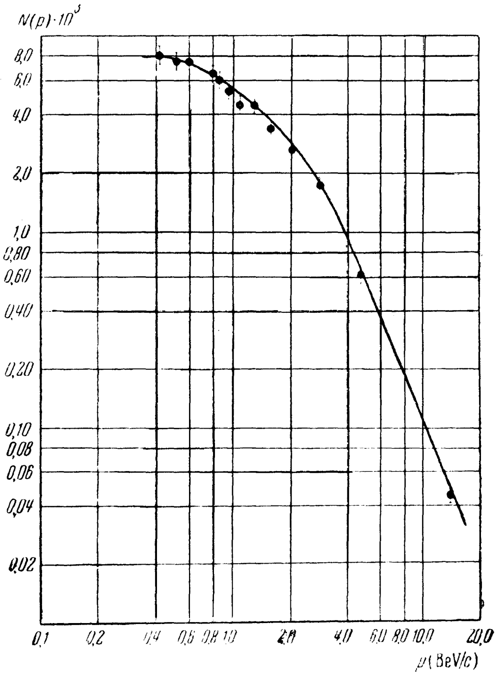

FIG. 1.

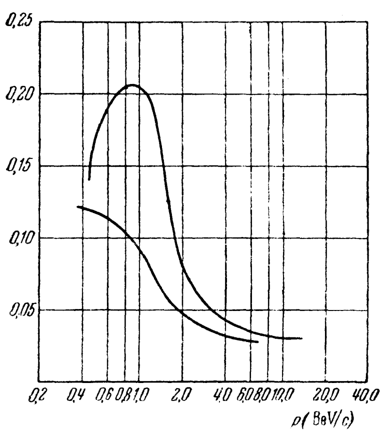

FIG. 2.

Whittemore and Shutt[4] found that at an altitude of 3400 m above sea level the number of protons with momentum $p > 0.3$ constitute $19 \pm 2\%$ of the number of μ-mesons of the same momentum. If we take into account the difference in altitude and recalculate for an altitude of 3200 m, then we obtain a value of 17%. This result does not agree with ours, where for this momentum the number of protons is ~ 12% of the number of μ-mesons. The difference that is found is beyond the limits of the experimental errors.

We found more serious differences between the cited work and our own work. The relative numbers of protons and μ-mesonswith momenta in the range given in Whittemore and Shutt increases monotonically with decreasing momentum of the particles down to $p = 0.3$, whereas our curve of this ratio has a sharp maximum at $p \approx 0.9$.

However, our results are in accord with those of Miller et al.[5] In this work it was found that protons of momentum ~ 0.6 constitute approximately 20% of the number of μ-mesons of this momentum. In a later work of these authors[6] there is deduced the result concerning the relative numbers of μ-mesons which agrees with ours.

3. The Positive Excess

The magnetic spectrometer also allows one to determine the charge of the particles which are present in the hard component. Hence we have the possibility of determining the dependence of the ratio of the number of positive and negative mesons on their momenta: $k(p) = N_+(p) / N_-(p)$, where $N_+(p)$ and $N_-(p)$ are respectively the ordinates of the curves of the differential spectra of + and − mesons. These ordinates are presented in the ninth and seventh columns of Table 1.

The function k is shown in Fig. 3. The logar-

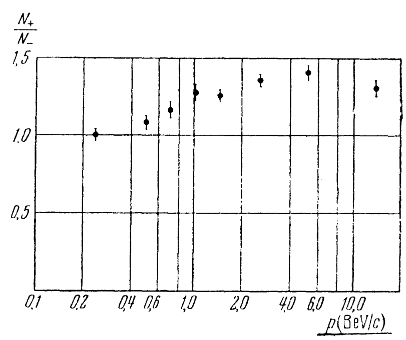

FIG. 3.

ithm of the momentum is plotted along the absicssa, and the relative number of + and − mesons at the

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[5] C. E. Miller, J. E. Henderson, D. S. Potter, J. Todd Jr., and W. Wotring, Phys. Rev. **79**, 459 (1950).

[6] C. E. Miller, J. E. Henderson, G. R. Garrison, D. S. Potter, W. M. Sandstorm and J. Todd Jr., Phys. Rev. **94**, 167 (1954).

given momentum is plotted along the ordinate. From this figure it is seen thatin the limit of smallmomentum $p \approx 0.2$ the numbers of mesons of opposite sign are equal (this point was made in Ref. 7). The ratio $k(p)$ increases with increasing momentum and at first proceeds at a relatively rapid rate up to the value of $p \approx 1$, then the rate decreases and apparently, for very large momenta, the ratio $k(p)$ begins to decrease.

The origin of the positive excess, as already noted in the literature, is closely linked to the nature of the primary particles of cosmic radiation. In fact, starting from the known spectrum of μ-mesons which are generated at different depths of the atmosphere[8,9] it is not difficult to show that mesons with $p > 0.2$ originate on the average at a depth of ~ 400 gm/cm^2, and 50% of these particles are generated at depths from 400 to 700 gm/cm^2, i.e., not far from the location of the points of observation. At these depths the numbers of protons and neutrons capable of generating fast μ-mesons are approximately equal, and hence, on the average, generate the same number of mesons of both signs. For momentum $p > 1$, the mesons generated at an average depth of 260 gm/cm^2 are 25% of the total number produced at the depths from 0 to 100 gm/cm^2, where the number of protons is considerably in excess of the number of neutrons. Hence for this part of the μ-meson spectrum we may observe a positive excess.

A comparison of our work on the positive excess and the work of other authors performed at sea level[10,11] seems to indicate that the value of $k(p)$ at sea level is smaller than at the altitude of Aragats (700 gm/cm^2). This circumstance determines the nature of their explanation that the mesons at sea level are on the average generated at greater depths of the atmosphere than those mesons that are observed at mountain altitudes.

As may be seen from Fig. 3, for $p \approx 14$, the ratio of the number of positive to negative mesons is equal to 1.30 ± 0.04. Clearly, these mesons are generated at the expense of nucleons with energy considerably in excess of 14 bev/c. As is well known, at these energies we have the place of multiple meson production[12-15]. However for multiple meson production the mesons of both signs that are produced should be of nearly equal numbers, i.e., $k(p) = 1$. Hence it follows that our experiment rejects the mechanism of multiple meson production. The larger values of $k(p)$ may be explained qualitatively, if we assume that the main number of μ-mesons with $p \approx 14$ are formed in nuclear collisions in which the number of secondary particles that is generated is comparatively small. In regard to those μ-mesons, which appear as products of nuclear collisions with large numbers of secondary particles, most of these appear with low energies, and hence they disintegrate in the upper part of the atmosphere and do not reach us.

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45