

SOVIET PHYSICS

JETP

A translation of the Journal of Experimental and Theoretical Physics of the USSR.

SOVIET PHYSICS JETP

VOL. 36(9), NO. 6, pp.1151-1426

DECEMBER, 1959

MOMENTUM SPECTRUM OF PARTICLES OF THE HARD COMPONENT OF COSMIC RAYS AT AN ALTITUDE OF 9 KM

L. T. BARADZEĬ, M. V. SOLOV'EV, Z. I. TULINOVA, and L. I. FILATOVA

Nuclear Physics Institute, Moscow State University

Submitted to JETP editor December 12, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1617-1620 (June, 1959)

The momentum spectrum of particles of the hard component of cosmic rays was measured at an altitude of 9 km, with the aid of a cloud chamber placed in a magnetic field, in the range $0.3 \times 10^9 - 6 \times 10^9$ ev/c. The particles were also grouped according to the charge. It was found that the $(1 - 5) \times 10^9$ ev/c protons comprise $(50 \pm 10)\%$ of the total number of particles.

MEASUREMENTS of the momentum spectrum of particles of the hard component of cosmic rays at an altitude of 9000 m were carried out, using a cloud chamber in a magnetic field.

A schematic representation of the setup is given in Fig. 1. The apparatus was operated by 5-fold coincidences $C_1C_2C_3C_4C_5$, so that the particles had to pass through an absorber of lead 9 cm thick, placed between the counter trays C_4 and C_5 . The side counters a (in the projection b , Fig. 1) were

connected in anticoincidence. The topography of the magnetic field in the gap is given in Fig. 2. The average value of the magnetic field amounted to 9090 oe. Deviation of the intensity value within the volume of the chamber from the average was not greater than 3%.

During the fourteen hours of operation of the array, approximately 700 cloud chamber photographs were taken. A total of 445 tracks was selected for measurements of the trajectories of

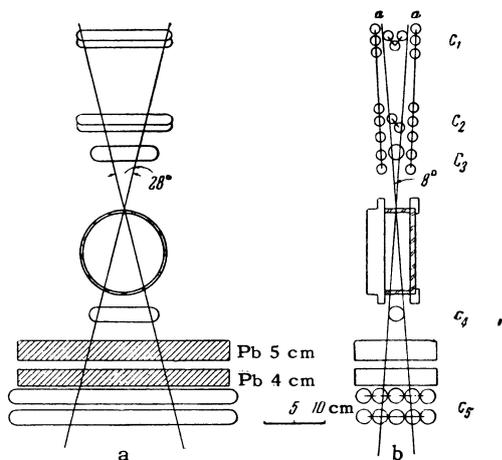


FIG. 1. Diagram of the array.

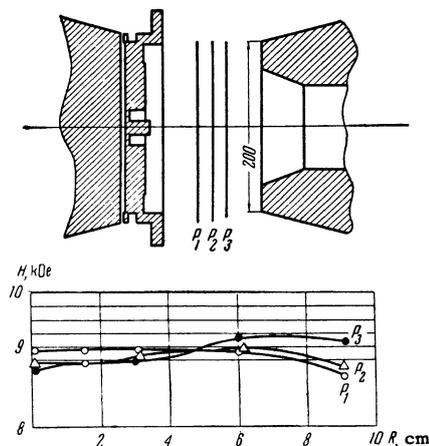


FIG. 2. Topography of the magnetic field in the gap.

particles which passed within the acceptance angle of the array, were not accompanied by other particles, and had a length of 15 to 17 cm. The curvature of the tracks was measured with an IG-22 optical compensator. The error of measurement for the tracks of the specified length was not greater than $\pm 0.02 \text{ m}^{-1}$. The value of the apparent curvature of tracks in the chamber was determined from check photographs obtained with the electromagnet shut off. Check photographs were alternated with the photographs of actual events. The curvature of tracks was measured on approximately 100 control photographs. The distribution of apparent curvatures obtained coincides with the normal distribution for the value of the standard deviation $\Delta(1/R) = 0.03 \text{ m}^{-1}$ and the systematical curvature $(1/R)_{\text{sys}} = (-0.013 \pm 0.003) \text{ m}^{-1}$.

Since the tracks used for constructing the momentum spectrum formed angles smaller than 4° with the plane of the chamber, the inaccuracy in the value of the particle momentum due to a conical projection of the track in photographing was not greater than 1%.

Thus, the foregoing value of $\Delta(1/R)$ for check tracks can be taken as the standard error of the measurements of the curvature of a track. For the intensity of magnetic field used, the value of the maximum detectable momentum amounted to $\sim 9 \times 10^9 \text{ ev/c}$.

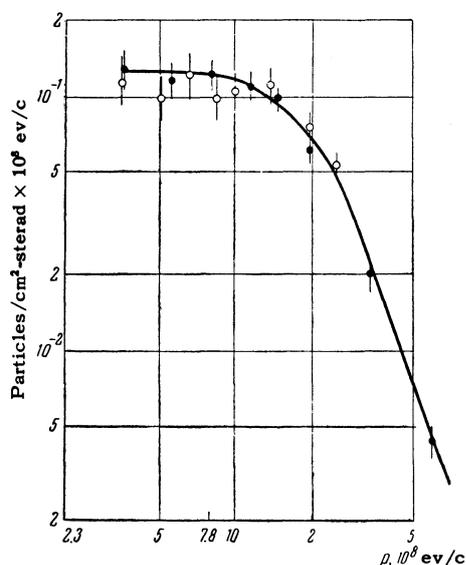


FIG. 3. Momentum spectrum of the particles of the hard component of cosmic rays at the altitude of 9000 m (black and light points – data of two different series of measurements).

The momentum spectrum of the particles of the hard component of cosmic rays at 9000 m is shown in Fig. 3 (black points). The absolute intensity of the spectrum corresponds to the integral intensity of the hard component equal to 3.0 ± 0.15 particles

$-\text{cm}^{-2}\text{-min}^{-1}\text{-sterad}^{-1}$. This value is in good agreement with the data of other experiments.¹ In the momentum range $(2 \text{ to } 6) \times 10^9 \text{ ev/c}$, the spectrum can be represented by a power function with an exponent of 2.8 ± 0.5 . If the particles of the hard component were μ mesons, then the minimum momentum of particles in the chamber determined by ionization losses in the filter should amount to $2.3 \times 10^8 \text{ ev/c}$. The minimum momentum of particles recorded by the array was found to be equal to $(2.5 \pm 0.1) \times 10^8 \text{ ev/c}$.

If the above method is used for chamber triggering, the intensity of particles with small momentum may be underestimated as a result of their being blown away by the field of the electromagnet. The calculation showed that the number of particles with momentum $3.5 \times 10^8 \text{ ev/c}$ is 10% too low because of such an effect. Accordingly, the first point in the spectrum was corrected by this amount. For the next point of the spectrum, the correction because of this is negligible.

In the range of small curvatures, the shape of the spectrum is distorted because of the error in the measurements of the curvature. To estimate the magnitude of these distortions, the change of the shape of the experimentally-found spectrum was calculated for varying values of the track curvatures for a specified error. Results of the calculation for measurements of curvatures with standard deviations of 0.03 m^{-1} (dotted line) and 0.15 m^{-1} (dot-dash line) are given in Fig. 4. In

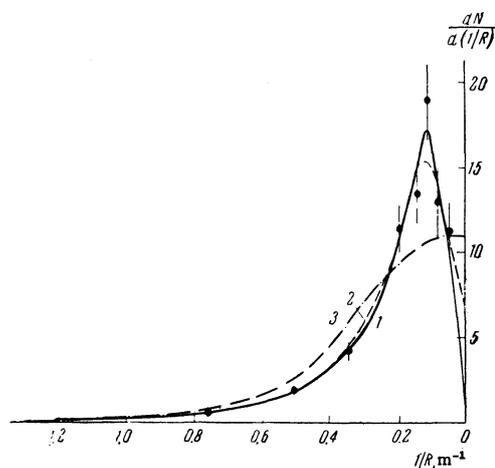


FIG. 4. Solid curve – spectrum of curvatures obtained in the experiment; dot and dot-dash curves – data of calculations for measurements of curvatures with standard deviations equal to 0.3 m^{-1} and 0.15 m^{-1} respectively.

the calculation, the distribution of errors was assumed to be Gaussian. From the figure shown, one can conclude that, for an error of 0.03 m^{-1} for curvatures $> 0.04 \text{ m}^{-1}$ (momentum $\sim 7 \times 10^9 \text{ ev/c}$) one can neglect the distortion of the spec-

trum, considering the statistical accuracy obtained.

Data on the momentum spectrum of penetrating particles of cosmic radiation were also obtained in a series of experiments devoted to the study of nuclear-active particles. The position of the counters triggering the chamber was, in this case, such that the effect of "blowing away" the particles with small momentum was absent. In this series of measurements, a thin beryllium plate was placed in the chamber, as a result of which the error in the measurement of the momentum was increased to 0.15 m^{-1} . The light points in Fig. 3 represent data obtained in this series of experiments. The intensities are corrected according to calculated data of Fig. 4. The data of both experiments are consistent.

The momentum spectrum of negatively-charged particles (curve 1) which, according to present ideas, are μ mesons, is shown in Fig. 5. Particles with momentum $< 2.3 \times 10^8 \text{ ev/c}$ are absent.

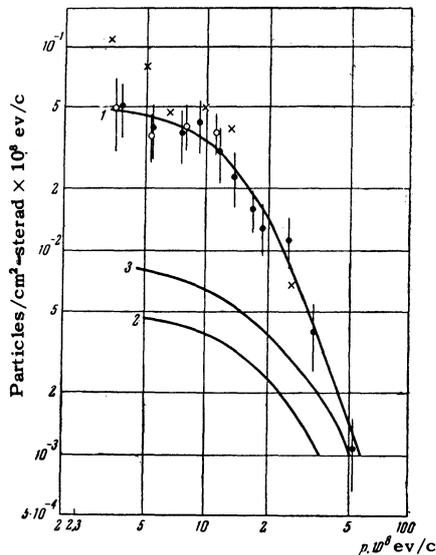


FIG. 5. Spectrum of negatively charged particles (curve 1) at the altitude of 9 km: O, ● – data of two series of measurements, × – from the data of references 2 and 3. Curve 2 – spectrum of μ mesons at sea level, arriving from the altitude of 9 km. Curve 3 – spectrum of μ^- mesons at sea level according to references 5 and 6.

As has been stated above, this momentum is the minimum value for μ mesons passing through the lead absorber. For comparison, data are given on the spectrum of μ mesons obtained by Anderson et al.³ The spectra are normalized for the number of particles with momentum between 1×10^9 and $3 \times 10^9 \text{ ev/c}$. The reason for the observed discrepancy in the momentum range of $\sim 5 \times 10^8 \text{ ev/c}$ is evidently the inaccurate method

of taking into account the number of electrons which were recorded by the setup of Anderson.³

Using the value given by Sands⁴ for the probability that a μ meson with momentum p at an altitude h_1 reaches the altitude h_2 , one can obtain the spectrum of μ^- mesons arriving from the altitude of 9 km at sea level (curve 2, Fig. 5). Comparing this spectrum with the experimentally-observed spectrum of μ^- mesons at sea level^{5,6} (curve 3, Fig. 5), one can conclude that, in the momentum range from 5×10^8 to $3 \times 10^9 \text{ ev/c}$, about 60% of μ mesons reaching sea-level are produced at altitudes greater than 9 km.

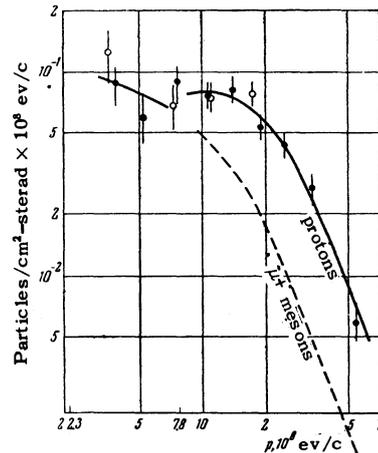


FIG. 6. Spectrum of positively charged particles at 9 km altitude; ●, ○ – data of two series of measurements.

The momentum spectrum of positively-charged particles is shown in Fig. 6. Since, for the passage through the lead absorber, protons should have a momentum $> 7.8 \times 10^8 \text{ ev/c}$, the particles with smaller momenta are μ^+ mesons. The ratio of the number of positive to negative μ mesons in the momentum range from 3 to $7 \times 10^8 \text{ ev/c}$ amounts to 1.7 ± 0.4 .

For momenta larger than $7.8 \times 10^8 \text{ ev/c}$, the measured spectrum of positive particles contained both μ^+ mesons and protons. The fraction of protons among the positive particles can be determined if the value of the positive excess $k = \mu^+/\mu^-$ is known. Direct measurements of k for the momentum range under consideration at the altitude of 9 km are not available. Data obtained at sea level and at mountain altitudes show that the value of the positive excess does not depend strongly both on momentum and on altitude, and lies between 1.2 and 1.3 (reference 7). It was stated above that more than half of the μ mesons are produced above 9 km. The value of the positive excess cannot therefore greatly exceed the values at sea level and at mountain altitudes. For the extreme as-

sumption that, for μ mesons produced below 9 km, the value of the positive excess is zero, we can conclude that, at the altitude of 9 km, the value of the positive excess amounts to 1.4. Therefore, the value of the positive excess changes little with variation of altitude up to 9 km.

If we assume a value $k = 1.25$ for the momentum range above 10^9 ev/c, we can determine the intensity of μ^+ mesons for this momentum range (dotted curves). Then, in the momentum range from 1 to 5×10^9 ev/c, protons amount to $(50 \pm 10)\%$ of the total number of penetrating particles. It should be mentioned that, in the momentum range $(2 \text{ to } 5) \times 10^9$ ev/c, the spectra of negative and positive particles can be represented by power functions with identical exponents, within the limits of error.

In conclusion, the authors take the opportunity to express their gratitude to Yu. A. Smorodin for devoted guidance and discussion of results.

¹S. N. Vernov and A. N. Charakhch'yan, Dokl. Akad. Nauk SSSR **91**, 478 (1953).

²R. V. Adams and C. D. Anderson, Revs. Modern Phys. **20**, 334 (1948).

³Adams, Anderson, and Cowan, Revs. Modern Phys. **21**, 72 (1949).

⁴M. Sands, Phys. Rev. **77**, 180 (1950).

⁵W. L. Whittemore and R. P. Shutt, Phys. Rev. **86**, 940 (1952).

⁶Glaser, Hamermesh, and Safonov, Phys. Rev. **80**, 625 (1950).

⁷B. G. Owen and J. G. Wilson, Proc. Phys. Soc. **A64**, 417 (1951).

Translated by H. Kasha
340