Observations of Cosmic Rays at High Altitudes*

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I. DISTRIBUTION IN MOMENTUM OF MESOTRONS AT 30,000 FEET

DIRECT measurements of the momenta of cosmic-ray particles at an altitude of 30,000 feet have recently been reported.[1] In these experiments curvatures of tracks observed in a cloud chamber in a 7400-gauss magnetic field were measured. The cloud chamber was actuated by coincidences between two Geiger counters, one immediately above and one immediately below the cloud chamber. The distributions in momentum obtained for 206 particles were reported as Figs. 15 to 18 of the previous publication and were there discussed.

For *sea level* data the selection of *single* tracks for momentum measurements effectively removes the electron component. Since electrons usually occur in showers (i.e., in groups of two or more) and since the number of showers at sea level is relatively small, only a very small proportion of singly occurring particles can be electrons. Since in addition there are few protons to be found at sea level, the single-particle spectrum represents principally the mesotron component.

For high altitude data, the single track criterion may result in the inclusion in the momentum spectrum of a considerable number of electrons. Because of the rapid increase with altitude of the electron shower component relative to the single particles, there should result a much greater probability for the appearance at high altitude of single electrons. It is the purpose of this paper to

TABLE I. Data on tracks.

Momentum in Mev/c	Less than 120	121–240	241–360	361–480	481–600	>600
No. of particles identified as electrons	5	5	1	0	0	0
No. of particles not identified as electrons	2	5	6	11	7	44

[1] Adams, Anderson, Lloyd, Rau, and Saxena, Rev. Mod. Phys. 20, 334 (1948).

present some data, additional to that presented before, which indicate that at an altitude of 30,000 feet this criterion is valid for momenta above about 250 Mev/c, but permits the inclusion in the spectrum of an appreciable number of electrons of momenta less than 250 Mev/c.

The possibility that the low momentum end of the spectrum would be expected to contain electrons was pointed out in the previous publication. In fact, *all* the particles of momenta below 90 Mev/c must have small mass, since a particle of 200 electron masses requires at least this momentum to penetrate the material between the chamber gas and the interior of the lower counter to produce a coincidence.

An estimate of the relative number of electrons occurring singly at 30,000 feet was made by means of a study of 272 photographs taken when the experimental arrangement was identical with that used for determining the momentum distribution, except for the presence of a 0.35-cm lead plate placed horizontally across the center of the chamber. The majority of these exposures showed electron showers or other associated tracks, but 86 exposures showed single tracks which would all have satisfied the single-track criterion for measurable tracks if the lead plate had not been present.

Of these single tracks a certain number which showed an excessive energy loss or produced electron pairs in the lead plate clearly could be identified as electrons. In Table I are listed the tracks in six different ranges of momenta which were identified as electrons and those which could not be so identified. With the plate in the chamber it was not possible in most cases to measure momenta above 600 Mev/c.

Although subject to large statistical fluctuations because of the small numbers of tracks, these data show clearly that below 240 Mev/c an appreciable number of electrons were included in the momentum distribution curves previously published.

On the assumption that Table I represents the

correct proportions of electrons occurring in the various momentum ranges, the momentum distributions previously published can be adjusted and the adjusted data should then correspond to the momentum distribution of the mesotrons and protons which are observed as singly occurring particles in the cloud chamber. In particular, the adjusted Fig. 17,[1] since it contains only particles of negative electric charge and no protons, should correspond to the momentum distribution of mesotrons of negative charge. These data plotted on a log log scale are given in Fig. 1. For comparison, in Fig. 2 are given results previously obtained at sea level with essentially the same equipment,[2] and in addition the results of Wilson[3] which extend to lower momenta.

Comparison of Figs. 1 and 2 shows that at 30,000 feet the maximum of the momentum distribution curve occurs at about 300 Mev/c as compared with about 700 Mev/c for the sea level data.

It may be noted that the rapid decrease in mesotron intensity with increasing momentum which was reported by D. C. Moore and R. B. Brode[4] does not appear in the data here presented. From observations on the relative number of particles which stop in different thicknesses of lead plates placed in a cloud chamber, these observers reported a relative intensity at 30,000 feet of approximately ten to one for mesotrons of momentum about 280 Mev/c (energy = 200 Mev) as compared with those of momentum 490 Mev/c (energy = 400 Mev). Since the experimental arrangements employed in the two experiments differed considerably, a close comparison in the results would not be expected. For comparison see also the energy distribution of mesotrons at 22,000 feet altitude computed by Schein, Wollan, and Groetzinger.[5]

The adjusted positive particle spectrum represents both mesotrons and protons. It is not possible to state the proportion which are protons except to say that protons are almost as abundant
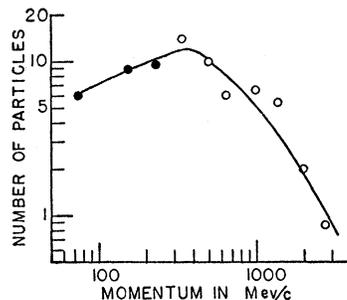
FIG. 1. Momentum distribution of negative mesotrons at 30,000 feet corrected for electrons at low energies. Ordinates represent number of mesotrons per 300-Mev/c interval. Solid dots represent number of particles after electrons have been subtracted out.

as positive mesotrons in the *momentum* range from 300 Mev/c to 1000 Mev/c.

II. ANGULAR DISTRIBUTION OF LARGE AIR SHOWERS AT 31,000 FEET

A large cloud chamber of 87-cm internal diameter and 15-cm depth has been operated without a magnetic field at altitudes up to 41,000 feet in a B-29 airplane. Thirty-two hundred photographs were made with the chamber operated at regular intervals. In addition, for some of the exposures the chamber was actuated by an array of counters which was designed to record air showers and which was being operated in the same airplane by M. Schein and H. L. Kraybill of the University of Chicago. Three plates, which had been placed in the chamber for the experiment in which the chamber was operated at regular intervals, were in the chamber during the shower experiment. The plates were supported horizontally 10 cm
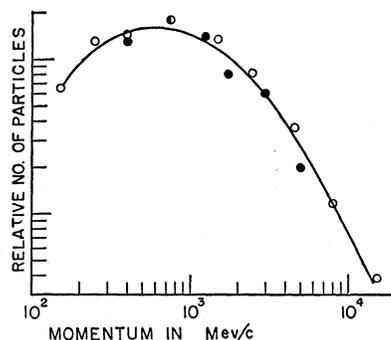
FIG. 2. Momentum distribution of positive and negative mesotrons at sea level. ● Anderson and Neddermeyer, London Conference (1934). O J. G. Wilson, Nature 158, 416 (1946).

[2] C. D. Anderson and S. H. Neddermeyer, Journal of the International Conference on Physics (London) 1, 171 (1934).

[3] J. G. Wilson, Nature 158, 416 (1946).

[4] D. C. Moore and R. B. Brode, Phys. Rev. 73, 532 (1948).

[5] Schein, Wollan, and Groetzinger, Phys. Rev. 58, 1028 (1940).
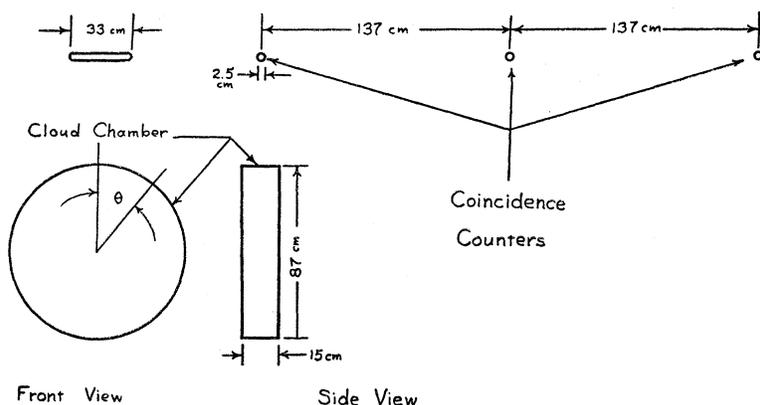
FIG. 3. Arrangement of counters and chamber.

apart, the upper one being of carbon 3.2 cm thick and the two below it of lead 1.6 cm thick.

Figure 3 shows the arrangement of the three counters, which were placed 1.37 meters apart in a horizontal line above the cloud chamber. The triple coincidence necessary to trip the chamber occurred about once every 2.5 minutes at an altitude of 31,000 feet.

Of the photographs so obtained by counter-controlled operation, 228 taken at an altitude of 31,000 feet were selected for the purpose of obtaining the distribution in zenith angle of the large air showers. The selection was made solely on the basis of the apparently satisfactory operation of the chamber and without regard to the

FIG. 4. Angular distribution of large air showers at 31,000 feet.

number of tracks appearing on the photographs. Since the majority of the photographs showed only a few tracks, often not parallel to one another, it was necessary to establish a criterion whereby photographs could be selected for measurement that would yield unique directions for the showers.

From the 228 photographs made at an altitude of 31,000 feet, a first selection of 48 photographs was made by choosing only those cases in which 10 or more tracks could be found pointing within an estimated 5 degrees of the same direction in space. The pictures were viewed stereoscopically. The count of tracks was made including tracks originating in the lead plates. Because of the diffuseness of the tracks resulting from the relatively slow motion of the piston and because of the difficulty in preventing temperature inequalities, only an estimate and not a precise count of the number of tracks was possible in most cases. No tracks were included which were obviously not time coincident with the shower.

An angular distribution for the 48 shower pictures so obtained is shown in histogram 1 in Fig. 4. The angle θ plotted as abscissa is the angle measured from the zenith to the projection of the shower direction on a plane perpendicular to a line through the counters.

Histogram 2 gives the angular distribution obtained by selecting those photographs that showed 10 or more nearly parallel tracks *above* the lead plates in the chamber, and histogram 3 gives the distribution from a selection of photographs on each of which an estimated number of more than 50 parallel tracks appeared.

Angular measurements to within 5 degrees
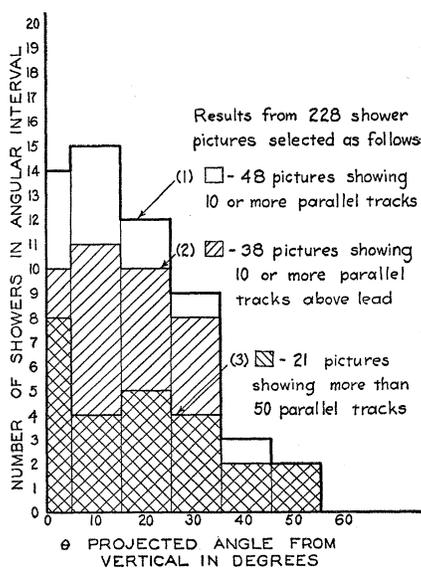
could be made on the photographs selected and in most cases more precisely. Since 5 degrees is less than the angular interval used in the histograms, which is as small as is justifiable by the number of showers recorded, any error introduced in the actual measurement of the angles is of no great importance.

Theoretical calculations by M. M. Mills[6] of the angular distribution of large air showers that would trip the particular counter array used indicate a broader distribution than that observed. A considerable discrepancy is not surprising since the selections of photographs included only about one-fifth of the total number, whereas the theoretical calculation refers to all of the showers which actuate the counters. However, the type of selection used and most of the experimental errors would be expected to make the experimental distribution too broad rather than too narrow.

[6] M. M. Mills, Bull. Am. Phys. Soc. 23, 4 (1948).

For example, any scattering of the shower particles in the atmosphere, an effect which was neglected in the theoretical calculation, would tend to broaden the observed distribution. Furthermore, the method of selecting showers in these experiments, by counting only those which showed 10 or more particles, tends to favor the more dense and fully developed air showers, and therefore the directions from which the dense showers most often come. At an altitude of 31,000 feet dense showers occur more frequently at directions away from the vertical, because of the greater path lengths through the atmosphere associated with these directions.

No correction was made for the variation with zenith angle of the projected area and thickness of the plates, nor was an allowance made for any effect of the cylindrical shape of the cloud chamber. It is estimated that these factors will affect the observed distribution to only a minor degree.

A Critique of Ionization Measurements of Nuclear Disruptions Produced by Cosmic Radiation

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Cosmic rays produce nuclear disintegrations which may be studied by the use of proportional counters. Such counters may measure slow neutrons by capture, fast neutrons by recoil, and protons. These counters will have backgrounds produced by giant showers, contamination alpha-particles and other highly ionizing processes. The counters will in general count several of these quantities simultaneously. In this paper we discuss how the counting rates produced by each of these events may be separated and evaluated. This is done by varying the shielding, counter size, pressure and nature of filling gas, and other parameters.

I. INTRODUCTION

THERE are three main techniques for the study of nuclear disruptions produced by cosmic radiation[1] at the present time. These are the uses of the cloud chamber, the ionization chamber or proportional counter, and the photographic emulsion. Each has its advantages and

[1] S. A. Korff, Rev. Mod. Phys. 20, 327 (1938).

drawbacks, and each yields information on particular phases of the problem. These several phases are diverse, so that in general the three techniques supplement each other, and together serve to give the presently available comprehensive view of the subject. None of the techniques is, however, complete, nor can we learn all we wish to know about the processes by using any or all these procedures. It is the purpose of this