Magnetic Cloud-Chamber Analysis of Cosmic Rays at 3.4 Kilometers*

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About 18,000 magnetic cloud-chamber photographs (magnetic field of 8000 Gauss) have been taken at an altitude of 3.4 kilometers at Climax, Colorado. These were counter-controlled with single counters above and below the chamber forming a twofold telescope. The photographs were taken under three conditions: with no absorber over the chamber, and with 5 and 20 cm of lead above the chamber. The momenta of singly occurring particles have been measured and plotted to give momentum distributions. With sufficient absorber over the chamber, selection of exposures showing a single track has the effect of eliminating electrons. The momentum spectrum of the residual particles (mesons and some protons) shows a distribution closely similar to that found for mesons at sea level. Contrary to previously published reports, no appreciable increase in the relative number of low energy mesons is found. Particles selected in this way show a positive to negative ratio of 1.5±0.05 as compared to reported values of about 1.3 at sea level. This confirms previous reports of an increase in this ratio with altitude. However, it is shown that the increase in positive excess is due in part to a greater number of protons at higher altitudes, and it is suggested that the entire increase may be thus accounted for, the positive excess of mesons remaining constant with altitude. Some estimate has been made of the abundance of protons at 3.4 kilometers.

I. INTRODUCTION

FEW studies in which a cloud chamber has been operated in a magnetic field sufficiently strong to give good momentum measurements have been made at higher altitudes. The observations of Adams, Anderson, *et al.*[1] in which a magnetic cloud chamber was operated from a B-29 airplane at altitudes between 30,000 and 40,000 feet, in particular their detection of large numbers of protons at this altitude, made a detailed study at an intermediate altitude seem worth while.

With this in mind, some 18,000 counter-controlled magnetic cloud-chamber photographs have been taken at an altitude of 3.4 kilometers at Climax, Colorado. Of these, 3000 are for a field strength of 10,000 Gauss while the remainder were taken with a field of 8000 gauss. To get additional information, and in order to remove effectively the electron component, exposures were made in which 5 and 20 cm of lead absorber were placed above the chamber, in addition to those exposures made with no absorber above the chamber.

The momenta of all singly occurring particles have been measured. Exposures showing a single and apparently counter-controlled track constitute about 60 percent of all photographs taken. Selection of single tracks for those exposures in which lead absorber was placed above the chamber effectively removes the electron component. The distribution in momenta for all singly occurring tracks and for the subgroup of heavily ionizing single tracks (protons) have been obtained.

II. THE APPARATUS

Figure 1 shows schematically the arrangement of magnet, cloud chamber, Geiger counters and absorbers used. The diaphragm type cloud chamber is 17 cm in diameter with a usable and illuminated depth of one inch. It differs from the conventional chamber of this type in being expanded through a $2\frac{1}{4}$ in. diameter hole through one of the pole pieces of the magnet with the pneumatic diaphragm outside the magnet structure. It is filled with argon gas and the saturated vapor of a 60–40 *n*-propyl alcohol-water mixture to a total pressure of 1.8 atmos. A very great improvement in its operating characteristics was achieved by loosely packing the tube connecting the chamber proper and the expansion compartment with a coarse form of copper wool. With this addition the tracks as photographed show an almost complete absence of background fog droplets, and the stability of operation is such that the expansion ratio need not be adjusted more often than once a day.

The camera photographs the chamber face through one of the magnet poles as shown in Fig. 1. Illumination is provided by the flash of four Sylvania Type R-4340 photo-flash lamps each operated from the discharge of a 32-μf condenser charged to 2600 volts. Each lamp is backed by a reflector and has its light partially collimated by a cylindrical lens between it and the chamber. The time interval between the occurrence of a coincidence count and the flash of the lamps can be set at any desired value. In this investigation delays of 0.04 to 0.06 sec. were used. The exact time for completion of expansion of the chamber is not known; however, the fact that tracks can be faintly photographed at 0.02 sec. following a coincidence count and the track width (0.5 to 0.7 mm) indicates an expansion time of less than 0.01 sec.

The magnet used was originally constructed for use aboard an aircraft and so was designed for minimum weight rather than most economical power consumption. The completed magnet weighs one ton, with the weight about equally distributed between copper and iron. The magnet coils are wound from 0.25×0.80 in. solid copper strip and are contained in a housing which

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[1] R. V. Adams, C. D. Anderson, *et al.*, Rev. Mod. Phys. **20**, 334 (1948).

TABLE I. Coincidence counting rate in counts/second.

	No absorber	5 cm lead	20 cm lead
Field off	0.045	0.030	0.023
Field on	0.034	0.028	0.023

also forms the external portion of the magnetic circuit and through which transformer oil is circulated to provide cooling. The windings are similar to those used in most cyclotron magnets but with more efficient cooling and more rapid oil circulation. The oil is circulated through the magnet and a suitable water cooled heat-exchanger at a rate of 100 gallons per minute. With this circulation continuous current densities as high as 7000 amp. per square inch of copper can be used. The temperature of the oil as it enters the magnets is maintained constant to 0.01°C by use of a resistance thermometer which actuates a bypass on the heat-exchanger. The temperature rise in the oil in passing through the magnet structure (for 8000 gauss and 25 kw power consumption as used in most of the present work) is about 3.0°C. The magnet arrangement is such that the cloud chamber temperature is determined entirely by the temperature of the magnet structure which completely isolates the chamber from external influences. The magnet current was continuously recorded during the course of a run and occasional adjustments made.

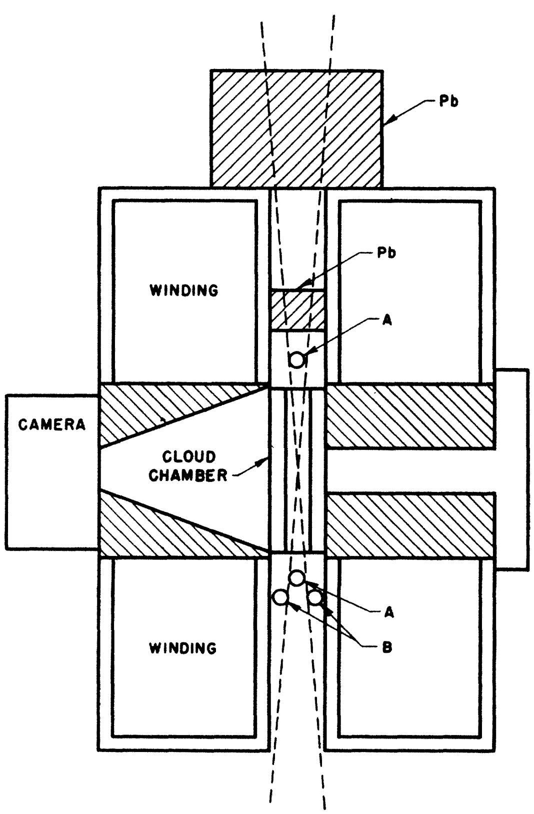

FIG. 1. Schematic diagram of the magnet, cloud chamber, counters and absorbers.

Only short period fluctuations as large as 1 percent occurred.

III. THE EXPERIMENT

The apparatus was installed on a surplus radar truck with power supplied to the magnets from a motor-generator set on a second truck. Exposures were made almost continuously for a period of six weeks at Climax, Colorado (elevation 3.4 kilometers). As is shown in Fig. 1, the chamber was triggered following a coincidence count from the A counters. These counters were $\frac{3}{4}$ in.×6 in. and were placed directly above and below the chamber. They define a cone which does not include any of the magnet structure. Exposures were divided between those taken with no absorber above the chamber (except for the light weight sheet steel truck roof), with 5 cm of lead above the counter telescope and with 20 cm of lead placed above the magnet structure. Two counters, located as shown at B in Fig. 1, were used in anticoincidence with the A counters. These were included to reduce the number of shower photographs which were not of particular interest in the investigation. Exposures were taken both with and without the B counters in use. The counting rates of the A telescope showing the effect of the field and absorbers are shown in Table I. The rates do not include the 90 sec. chamber recovery time used.

The ratio of 2:1 of the no-absorber rate to the 20 cm lead rate (with field off) is just the ratio of the total to hard component at this altitude, as given by Rossi.[2] The agreement must be in part fortuitous since the two-counter telescope used was hardly adequate for a reliable rate determination. With no absorber above the telescope the field shows a strong effect in reducing the rate from 0.045 to 0.034 count/second. This reduction corresponds to the presence of large numbers of low energy electrons whose momenta lie below the magnetic cut-off of the equipment used. This cut-off comes at about 50 Mev/c as will be explained later. As shown by the rates in Table I, the field does not reduce the counting rate for the radiation that has been hardened by passage through 20 cm of lead.

IV. SELECTION OF TRACKS FOR CURVATURE MEASUREMENT

As explained previously, in obtaining momenta distributions only singly occurring tracks have been measured for curvature. However, tracks accompanied by others which from their appearance are obviously post or pre-expansion tracks have been included. Also, those single tracks whose angle in the chamber indicates that they could not have been counter-controlled have been excluded. These latter constitute only a few percent of all single tracks, which is a good indication that in the case of most single tracks the particle photographed was actually the counter-controlling particle

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

and so could not have originated in any part of the surrounding absorber (with the exception of the lead absorbers deliberately placed above the chamber to modify the radiation). If this were not the case there is no obvious reason why large numbers of single tracks should not occur with angles in the chamber indicating that they could not have passed through both coincidence counters. As mentioned earlier, some 60 percent of all exposures showed single tracks. Because of the large number of tracks available only the longest (15 cm long or longer out of a chamber diameter of 17 cm) have been used. In this way only tracks long enough for good curvature measurements were used and those passing close to the chamber wall and so subjected to larger turbulence distortion were avoided. These selection criteria should be in no way selective. However, the selection of single tracks does discriminate strongly against electrons, except for those exposures taken under no absorber. In the case of most air showers, not more than one electron would be expected to be incident on the small cross-sectional area (about 30 cm^2) represented by the equipment used. With no absorber above the chamber this electron usually would not form secondaries as the chamber wall and upper coincidence counter represent only a fraction of a radiation length. Other shower electrons intercepting the magnet structure are unlikely to produce secondaries which will reach the chamber because of the large amount of interposed absorber. For these reasons those single tracks photographed with no absorber above the chamber are expected to include large numbers of electrons. This is clearly shown by the large number of low momentum particles included in the momentum distribution for this case (Fig. 2). On the other hand, single tracks photographed under 5 or 20 cm of lead should include almost no electrons.

TABLE II. Momentum distribution for single tracks (of both signs) with no absorber over chamber.

Momentum in Bev/c	Number of particles in interval
0.00–0.08	25
0.08–0.13	64
0.13–0.21	99
0.17–0.27	100
0.21–0.31	67
0.27–0.39	87
0.35–0.49	104
0.41–0.57	131
0.49–0.68	144
0.57–0.88	176
0.68–0.88	160
0.88–1.20	115
1.03–1.46	154
1.20–1.85	167
1.46–2.50	204
1.85–2.50	130

V. MEASUREMENT OF TRACK CURVATURES

Curvatures were measured by direct comparison with standard curves. The standards were scribed full scale on Aquadag-coated plate glass by means of an Evans type mechanical linkage. In this way a graded set of

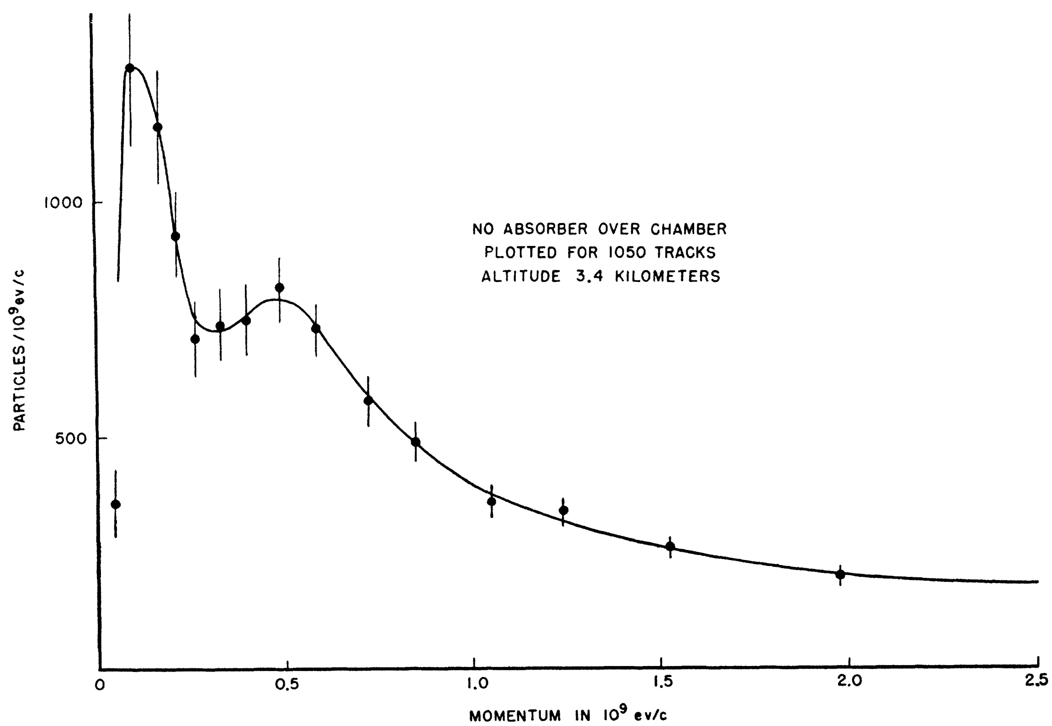

FIG. 2. Momentum spectrum of single tracks (positive and negative) with no absorber over chamber other than that represented by the glass chamber wall and upper coincidence counter. Includes mesons, electrons and protons.

TABLE III. Momentum distribution for single tracks with 5 cm of lead absorber over chamber.

Momentum in Bev/c	Number of particles in interval Positive	Negative
0.00–0.08	4	2
0.08–0.17	12	9
0.13–0.21	16	11
0.17–0.27	25	21
0.21–0.31	24	23
0.27–0.39	40	20
0.35–0.49	60	32
0.41–0.57	61	38
0.49–0.68	63	40
0.57–0.88	96	56
0.68–1.03	108	59
0.88–1.20	96	57
1.03–1.46	107	76
1.20–1.85	135	90
1.46–2.50	164	105
1.85–2.50	89	59

arcs increasing smoothly but in ever longer steps from a radius of 0.3 to 10.0 meters was prepared. The standards prepared in this way were photographed under identical conditions as in the photographing of actual cloud tracks. The photographs were then projected onto the screen of a comparator and the screen replaced by a photographic plate on which the image was recorded. The plates obtained in this way formed the standards which for comparison purposes were placed in contact with cloud track photographs projected on the same screen. Care was taken to show that no distortions resulted from different positioning in the field of the standard arc and cloud track during the photographic and projection processes. The comparator used gave an enlargement of 1.5 over the original track size in the chamber. Actually, each standard arc consisted of two arcs of the same radius and separated along the radius by 0.7 mm. In comparison the projected image of the cloud track was observed between these two arcs. The curvature range from 0.3 to 10.0 meters was divided into 48 segments and each track recorded as lying in one of these segments. The segments increased in length from about 0.1 meter at 0.3 meter radius to 1.5 meters at 10 meters radius. To obtain an idea of the consistency of measurement, a group of several hundred tracks were measured by different observers and their individual results plotted against each other as abscissa and ordinate. For perfect consistency this would give points all lying on the line $y=x$. The result gave a symmetrical distribution of points about this line showing agreement to 10 percent or better up to 3.5 meters and becoming rapidly worse at larger radii; at 10 meters the accuracy of measurement is not considered to be better than ± 3 meters. No attempt was made to estimate curvatures greater than 10 meters. No error resulted from non-uniformity of the magnetic field as this was found by measurement to be uniform to ± 1.0 percent over the usable volume of the chamber. The magnetic field for most of the exposures was 8200 Gauss. A radius of one meter is taken to correspond to a momentum of 250 Mev/c.

As stereoscopic pictures were not taken, lack of knowledge of the exact position and angle of the tracks in the chamber is a source of error in curvature measurements. Considering the limited depth of the illuminated region and the fact that the tracks used lie entirely in this region and extend almost a chamber diameter, the maximum possible error from this source is 4 percent and the average error less than 2 percent. For counter-controlled tracks the possible track displacement and

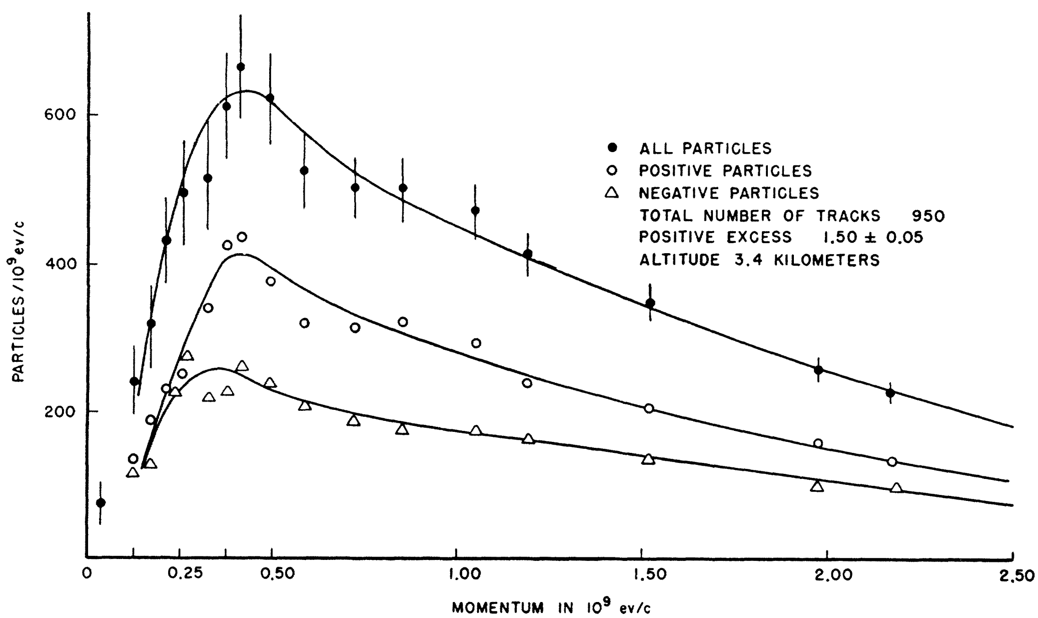

FIG. 3. Momentum spectrum of single tracks with 5 cm of lead absorber over chamber. Spectrum includes mesons and protons.

TABLE IV. Momentum distribution of heavily ionizing particles—including those found under no absorber and under 5 cm lead.

Momentum range Bev/c	Number of particles
0.00–0.25	0
0.25–0.30	7
0.30–0.35	12
0.35–0.50	49
0.43–0.58	44
0.50–0.65	39
0.58–0.75	31
0.65–0.88	27
0.75–1.00	16
>1.00	5

corresponding error in curvature measurement is about half this large (average error = 1.0 percent).

VI. MAGNETIC CUT-OFF

The twofold coincidence triggering arrangement, used with counters above and below the chamber, has the effect of discriminating against particles of low momentum because of deflection by the magnetic field. This effect has been computed by use of a graphical construction and integration. Actually, the effect has been somewhat overestimated. For ease of computation the field was considered to extend in full strength to the position of the counters. Actually, it decreases very rapidly just beyond the chamber walls. For the computation, a knowledge of the intensity variation with zenith angle is necessary and the usual cosine-squared law was assumed. A less rapid decrease with zenith angle would give less cut-off while a much more rapid decrease seems unlikely for the low momentum range of interest here. The result shows complete cut-off for particles of momentum below about 50 Mev/c, 10 percent cut-off at 100 Mev/c and negligible cut-off for momenta above 150 Mev/c. As the intensity found for the non-electronic component is small at 100 Mev/c the effect of cut-off here is unimportant as compared with statistical uncertainties. It is assumed then that the momentum distribution found for protons and mesons is not seriously affected by magnetic cut-off above 100 Mev/c; the plots have not been continued below this value. On the other hand, the sudden decrease in intensity of low momentum particles shown in Fig. 2 is due to magnetic cut-off and occurs at the expected value. As will be shown later, the particles extending to cut-off here are electrons.

VII. RESULTS

A. Momentum Distribution with No Absorber over Chamber

The method of track selection has been explained. In addition, it may be well to point out that no single track meeting the specified length requirement (15 cm long) was omitted because of track quality or other considerations, except that several complete rolls of film were not used, being of rather poor quality. This left a residue of 1050 tracks of momentum less than 2.5 Bev/c for the no-absorber case, with a momentum distribution as given in Fig. 2. An additional 479 tracks were recorded as having momenta greater than 2.5 Bev/c. Figure 2 is plotted for overlapping intervals, the data being given in Table II. Each interval in Table II includes at least 3 of the 48 intervals into which the range from 0 to 2.5 Bev/c was divided in originally recording the curvatures. The deviations plotted in Fig. 2 are for statistics only.

B. Momentum Distribution under 5 Cm of Lead Absorber

The data for this case are given in Table III and plotted in Fig. 3. In addition to the 950 particles included in the plot, 535 were recorded as having momenta >2.5 Bev/c.

C. Particles under 20 Cm of Lead

Here only one-third as much data was taken as for the no absorber and 5 cm of lead cases, so the statistics are not adequate for a meaningful plot. In addition, exposures were made on Eastman Linograph Pan film, instead of the Linograph Ortho used in the other cases. This film proved too grainy for good momentum measurement. So far as can be told, the distribution does not differ appreciably from that of Fig. 3.

D. Heavily Ionizing Particles

The data of Figs. 2 and 3 include all single tracks regardless of their densities. Some show a density clearly indicating an ionization well above minimum. Of 5040 single tracks examined for the no absorber case, 99 (or 2.0 percent) clearly correspond in density to a particle of above minimum ionization. These figures are for *all* single tracks; not merely those of length 15 cm as plotted in Figs. 2 and 3. Similarly, of 2940 single tracks under 5 cm of lead, 50 (or 1.7 percent) are

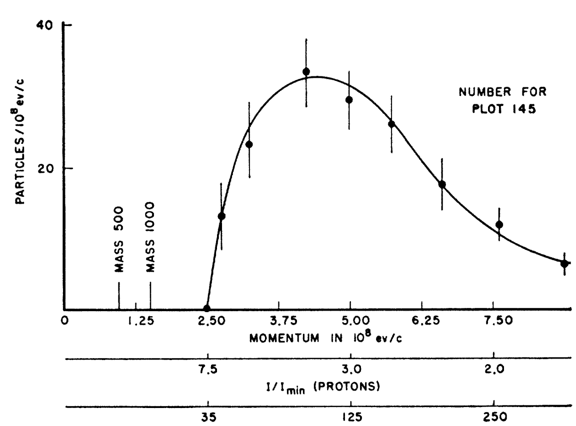

FIG. 4. Momentum spectrum of single heavily ionizing particles (protons), including those found under no absorber and those under 5 cm of lead.

heavily ionizing, while under 20 cm of lead the corresponding figures are 1560 and 12 (or 0.8 percent). Of the total of 161 heavily ionizing single tracks for the three cases, all but three show a direction of curvature corresponding to a positive particle moving downward.

The momentum distribution of the single heavily ionizing particles is given in Fig. 4 and the data of Table IV. Particles found under no absorber as well as under 5 cm of lead are included. Tracks 12 cm long and longer have been used. The distribution has been drawn to zero for the lowest momentum found for any single heavily ionizing track of length 12 cm. Within statistics the momentum distributions for heavily ionizing particles under no absorber and those under 5 cm of lead as plotted separately do not differ from the combined distribution of Fig. 4. The combined distribution is given to improve statistics and to show the low momentum cut-off which, as will be explained, does not depend on the nature of the absorber above the chamber.

VIII. DISCUSSION

A. Momentum Distribution

Momentum distributions from magnetic cloud-chamber measurements at sea level and at 30,000 feet have been given by Wilson[3] and by Adams, Anderson, *et al.*[1] In the case of Wilson's sea level measurements, sufficient absorber was used to insure cascade multiplication of electrons which were eliminated in this way. The distribution is then that of the non-shower-producing particles at sea level and as such is assumed to represent the meson distribution. This sea level result is quite similar to that found in the present investigation as given in Fig. 3. The 3.4 kilometer data of Fig. 3, as will be discussed later, contains significant numbers of protons. The distribution of experimental points as plotted in Fig. 3 seems to show a small secondary maximum at about 0.8 Bev/c; this is particularly true of the distribution of the positive particles only and does not show in the distribution of the negative particles. However, within the statistical uncertainty of the data no significance can be attached to this small maximum, and it is not included in the continuous curve sketched in. Figure 3 does not show the presence of large numbers of low energy mesons at higher altitudes (as compared to the number at sea-level) as found by Moore and Brode,[4] by Hall,[5] and others. Hall,[5] working at 14,000 feet, has obtained an integral range spectrum (in lead) from which a momentum spectrum has been derived through use of the meson range-momentum relationship. In this way he finds a sharp (meson) maximum at between 100 and 200 Mev/c and a rapid decrease in intensity at higher momenta. Hall's work is at an altitude 3000 feet higher than the present investigation. As he has pointed out, this large low momentum maximum would be unstable with increasing depth because of meson decay and in fact could reasonably exist at 14,000 feet only in the case of strong local production of low momenta mesons. Even allowing for decay (and no production) between 14,000 and 11,000 feet, the two results would not agree exactly, besides which it would be strange to find strong production of low momenta mesons at 14,000 feet, but not at 11,000 feet. In the present investigation momenta are measured directly without the assumption of any particular range-momentum relationship. The transformation from range

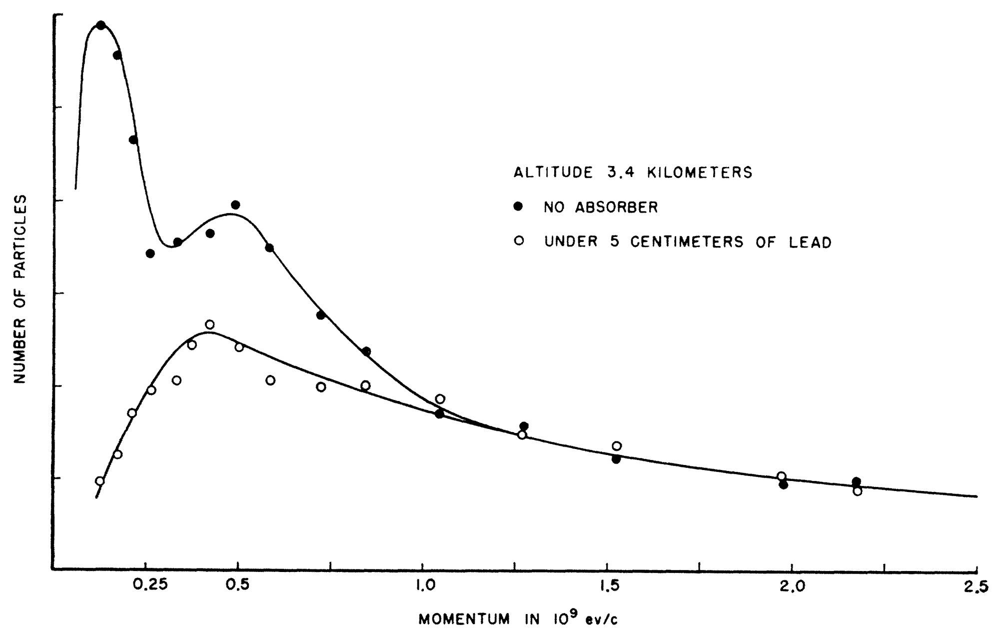

FIG. 5. Comparison of the momentum spectra under no absorber (electrons, mesons and protons) and under 5 cm lead (mesons and protons).

[3] J. G. Wilson, Nature **158**, 414 (1946).
[4] D. C. Moore and R. B. Brode, Phys. Rev. **73**, 532 (1948).
[5] D. B. Hall, Phys. Rev. **66**, 321 (1944).

to momenta, as made in Hall's work, would, if there were an appreciable number of protons in the range 0 to 1.0 Bev/c, have just the effect of giving incorrectly too many particles below 200 Mev/c. In the present work there is a strong magnetic cut-off for momenta below 100 Mev/c, but this is negligible at 200 Mev/c. At this latter momentum there is no obvious reason why large numbers of mesons, if present, should not be detected. Possibly Hall's experimental arrangement fails to eliminate electrons completely, and certainly scattering in the lead absorbers has been inadequately considered. The strong maximum he has found at 100 to 200 Mev/c depends critically on the initial slope of the integral range curve where discrimination against electrons is difficult. From cloud-chamber observations made at 30,000 feet, Adams, Anderson, and Cowan[6] also point out that they fail to find large numbers of low energy mesons.

In the case of the momentum distribution obtained at 30,000 feet by Adams, Anderson, *et al.*,[1] no appreciable amount of absorber was present over the chamber so that the data includes electrons in addition to protons and mesons. The rapid rise that they find in the distribution at very low momentum is almost certainly due to electrons. The maximum occurring between a magnetic rigidity of 1 and 2 ($H\rho$ in 10^6 gauss-centimeter) is interpreted as due to protons, since when the distributions for positive and negative particles are plotted separately the maximum is present only for the positive particles. Protons could not be recognized (as they could in the present investigation) by their ionization density, as a bronze casting present between the cloud chamber and lower coincidence counter gave a proton cut-off at a momentum above that at which the increased density is easily recognized. Their result is to be compared to the distribution (Fig. 2) found in the present investigation and giving a similar plot obtained with almost identical experimental conditions but at a lower altitude. Figure 2 shows a small maximum at about the same momentum as the much more pronounced maximum found by Adams, Anderson, *et al.*[1] However, the maximum at about 0.5 Bev/c in Fig. 2 is so small as to be just resolved within the statistics, and it is doubtful that it is due entirely to protons, since the meson distribution (Fig. 3) also shows a maximum at about this momentum. In the present investigation the amount of absorbing material between the sensitive volume of the chamber and that of the coincidence counter below it was such as to give a proton cut-off at 250 Mev/c and so allowed identification of protons through their increased ionization density as will be discussed later.

In Fig. 5 we give a comparison of the momentum distribution of single tracks under no absorber to the distribution found for single tracks under 5 cm of lead. The distributions have been normalized to a common basis from a knowledge of the relative counting rates. The difference between the two distributions below a momentum of 1 Bev/c is considered to be due to electrons. As previously explained, for the no-absorber case there is not sufficient material above the chamber to insure cascade multiplication of single electrons incident on the equipment.

B. Positive Excess

Measurements of the ratio of the number of positive to negative mesons at sea-level have given values near 1.3. Thus, Jones[7] and Hughes[8] from magnetic cloud-chamber observations have given values for the positive excess of 1.22 ± 0.07 and 1.29 ± 0.05, respectively. The measurements in both cases extend to 10 Bev/c and do not in either case indicate a variation in positive excess with momentum; however, the statistics are not adequate to make this certain. More recently Brode[9] has measured the ratio at sea-level by a method depending on the deflection of charged particles in magnetized iron plates with Geiger counter detection, and has obtained a positive excess of 1.32 ± 0.24. The experimental work of Brode includes mesons between 1 and 2.5 Bev. Adams, Anderson, *et al.*,[1] have reported a very large positive excess at higher altitudes. However, the number of tracks on which this observation was based was inadequate to give much statistical weight to the observation. The present work confirms an increase in positive excess with increasing altitude. Figure 3 shows the momentum spectrum found for both positive and negative particles at 3.4 km as observed under 5 cm of lead. The method of track selection to eliminate electrons has been explained previously. The result gives a positive excess of 1.5 ± 0.05. This result is for mesons of momentum between the magnetic cut-off at 50 Mev/c and the maximum momentum measured of 2.5 Bev/c. Within statistical error no trend in the positive excess with momentum is indicated. It is difficult to understand why the ratio of positive to negative mesons should vary with altitude, and it is certain that the increase above the sea-level value is due in part, and perhaps entirely, to the greater number of protons (which are not distinguished from mesons in determinations of positive excess previously reported) at higher altitudes. As has been indicated, in the present investigation heavily ionizing protons alone were found to constitute 2 percent of all non-electronic charged particles under 5 cm of lead. Including only those particles below 2.5 Bev/c for which the positive excess of 1.5 was found, heavily ionizing protons constitute about 3 percent of all such non-electronic charged particles found. As only heavily ionizing protons (momenta below 500 Mev/c) could be recognized in this investigation, *all* protons at 3.4 km may well constitute

[6] Adams, Anderson, and Cowan, Rev. Mod. Phys. **21**, 73 (1949).

[7] H. Jones, Rev. Mod. Phys. **11**, 235 (1939).
[8] D. J. Hughes, Phys. Rev. **57**, 592 (1940).
[9] R. B. Brode, Phys. Rev. **76**, 468 (1949).

the 8 percent required to give the increase in positive excess from about 1.3 at sea-level to 1.5 at 3.4 km. Statistical uncertainties in both the sea-level and 3.4 km values are such that an even smaller percentage of protons may be adequate to account for the observed difference.

C. Protons

Figure 4 gives the distribution in momentum of heavily ionizing particles, combining those observed under no absorber and under 5 cm of lead. Only those tracks clearly more dense than the general run of tracks were included in the group selected. While this method of selection involves somewhat arbitrary judgment, it was found that different observers agreed almost absolutely on those tracks to be included. In any case, for protons of momenta below 500 Mev/c a mistake can hardly be made. At higher momenta it is probable that all protons have not been included. While the group of heavily ionizing tracks were selected on the basis of density alone, it was later found that all but three corresponded in direction of curvature to a positive particle moving downward; a good indication of the adequacy of the method of selection. The rapid decrease in numbers of protons at lower momenta, as shown in Fig. 4, results from the nature of the apparatus. The cut-off found at about 250 Mev/c represents the minimum momentum necessary for a proton to get from the sensitive volume of the chamber to the sensitive volume of the lower coincidence counter through the intervening absorbing material. Within experimental error the cut-off at 250 Mev/c checks the value to be expected for a proton and the amount of absorbing material present. Among all tracks examined, not a single heavily ionizing particle with a momentum less than 250 Mev/c was found. With increasing momentum the decreasing density of ionization for protons is such that the decrease in numbers above 500 Mev/c, as shown by Fig. 4, is almost certainly due in part to failure to distinguish their tracks from those of mesons. Thus, the form of the distribution (Fig. 4) is strongly influenced at low momenta by absorption cut-off (this occurs above the magnetic cut-off which thus has no effect) and at high momenta by failure to recognize the tracks of protons. Neither of these distortions is important for a momentum band from about 350 to 500 Mev/c between which values it is possible to use this information in estimating proton rates as measured by our apparatus. For protons in this momentum interval it is found that the rate does not change appreciably in passing from the no absorber case to the measurements made under 5 cm of lead. The agreement between the proton rates for the two cases may be in part fortuitous, as under 5 cm of lead there has been both proton absorption and production as compared to the original radiation. On the other hand, the meson intensity in this momentum interval should not be appreciably affected in passage through 5 cm of lead. In this way, by comparing the hourly proton rate as measured under no absorber with the hourly rate for all particles under 5 cm of lead, one finds that for this altitude the number of protons with momenta between 350 and 500 Mev/c is approximately 10 percent of the number of mesons lying in the same momentum interval. From the results obtained under 5 cm of lead and the assumption of no proton production in the lead, computation involving the range momentum relationship shows some 20 percent of the ionizing non-electronic component in the momentum band near 600 Mev/c to be protons. The assumption of no production of protons in the lead is very uncertain and further experimental work is being undertaken in an attempt to determine the proton intensity for this and higher momenta.

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