Cosmic-Ray Protons at 3.4 Kilometers*

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A magnetic cloud chamber and an appropriate arrangement of coincidence and anticoincidence Geiger counters were used to photograph tracks of charged particles with ranges of 0.4 to 15 cm and 0.4 to 30 cm of lead. The momentum intervals corresponding to these range intervals are sufficiently different for protons and mesons that there resulted a large momentum interval in which only protons were stopped due to ionization losses. At higher momenta, most of the protons were stopped by nuclear interaction because of the large thicknesses of absorber used. At lower momenta, where both protons and mesons were stopped, the protons were distinguished by track density.

The result is an accurate proton momentum spectrum for the interval 0.7 to 2.0 Bev/c, in which it is found that protons form 20±2 percent of all ionizing nonelectronic particles. From the number of protons stopped in 15 and 30 cm of lead the path length for removal of protons in lead by nuclear interaction is calculated to be 206±30 g/cm² in the momentum interval 0.9 to 2.5 Bev/c.

I. INTRODUCTION

ALTHOUGH protons are considered to constitute the major part of the primary cosmic radiation, measurement of their intensity and energy distribution is difficult because of their similarity to other charged particles. Previous work of this laboratory[1-4] has shown that the magnetic cloud chamber, along with an arrangement of absorbers to give range selection, is especially suited to the separation of singly occurring protons from other charged particles. Although the earlier experiments demonstrated the feasibility of the method, it was immediately clear that for an accurate determination of the proton momentum spectrum certain improvements in equipment were necessary. Large corrections were previously required to account for the protons lost from the counter telescope because of scattering and nuclear interaction. The basic objective of the present work is to eliminate these losses and thus obtain a reliable momentum spectrum over the entire interval from 0.7 to 2.0 Bev/c. In addition, information is obtained on the nuclear interaction path length of protons in lead.

II. EXPERIMENTAL ARRANGEMENT

Figure 1 shows schematically the arrangement used. Although most of the equipment is the same as that used in previous work,[1-4] the arrangement differs considerably. The principal changes are the use of a 2-fold rather than a 3-fold coincidence in the counter telescope and a greatly improved anticoincidence tray.

Counters $C1$ and $C2$ are used in coincidence to define a beam of particles through the chamber. The six $A1$ counters all lie just outside the coverage defined by counters $C1$ and $C2$ and are used in anticoincidence with these. They serve to reduce the recording of shower-type events. The counters $A2$ completely surround a large block of lead absorber so that a charged particle traversing $C1$ and $C2$ will not be recorded if it, or one of its charged secondaries, penetrates this absorber. The 2.5 cm of lead absorber above the equipment serves to multiply the density of electron showers penetrating it and thus aids in their recognition through

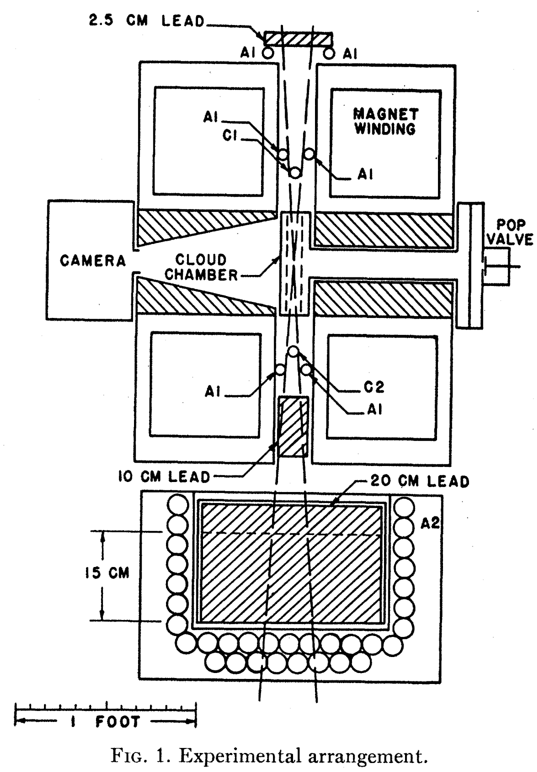

FIG. 1. Experimental arrangement.

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† A division of the Department of Physics.
[1] Miller, Henderson, Potter, and Todd, Phys. Rev. **79**, 459 (1950).
[2] Miller, Henderson, Potter, and Todd, Phys. Rev. **84**, 981 (1951).
[3] D. S. Potter, Ph.D. dissertation, University of Washington, 1951 (unpublished).
[4] Jay Todd, Jr., Ph.D. dissertation, University of Washington, 1952 (unpublished).

actuation of one of the $A1$ counters (in which case they are not recorded), or by the appearance of more than one track in the chamber.

The $A2$ counters are arranged to prevent particle leakage between counters. These are metal-walled counters arranged with adjacent counters in contact. Below the absorber an extra row of counters is used to cover the small dead spaces between counters. Along the sides the single rows are considered adequate as very few particles will be so scattered as to traverse these counters and, in addition, they would have to be traveling almost horizontally to pass through the small dead space between adjacent counters.

The corrections for loss of protons by scattering and nuclear interaction within the counter telescope have, with the present arrangement, been made negligible. This is primarily due to the use of a 2-fold coincidence. The chamber and counter walls are the only absorber in the C train that may cause scattering or nuclear interaction. Scattering in this material may be into or out of the coverage of $C2$ and thus the scattering error is nearly compensated. Since the material is only about 2 percent of the proton nuclear removal path length, the loss in the C train due to nuclear interaction is negligible. Scattering out of the $A2$ coverage has been nearly eliminated by extending the $A2$ coverage so that particles must be scattered 50 degrees or more in the absorber layer below $C2$ in order to miss the $A2$ counters.

III. MESON-PROTON SEPARATION

The minimum range of the particles recorded is the amount of absorber between the sensitive volume of the chamber and that of the counter $C2$ (equivalent to about 3.7 g/cm^2 of lead). The maximum range is the absorber between the sensitive volume of the chamber and that of the anticoincidence counters $A2$. Because of the difference in their range-momentum relationship protons and mesons in the defined range interval will appear in displaced momentum intervals. Measuring the momentum of all particles thus separates the protons from the mesons, except at momenta where the intervals overlap. Using various thicknesses of absorber, the proton intensity is obtained over a large momentum interval.

At momenta above the proton ionization cutoff, large numbers of protons are also included due to nuclear interactions in the absorber between $C2$ and $A2$. By using an absorber whose thickness is nearly twice the removal path length, approximately 80 percent of the protons are included at the highest momentum measured (2.5 Bev/c). At momenta where both protons and mesons are recorded, the track density of protons is considerably greater so that the protons can be selected by examination of the tracks of the particles in the photographs.

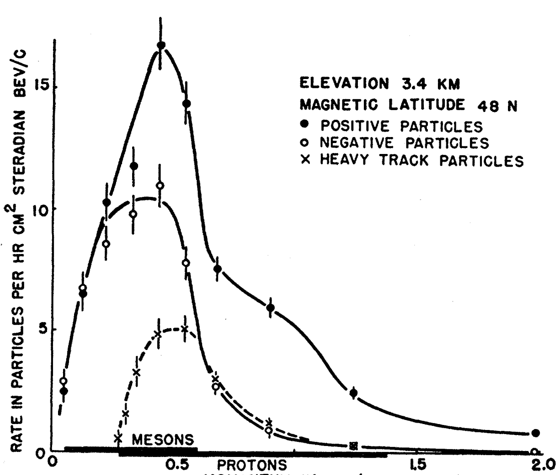

FIG. 2. Momentum spectrum for the 30-cm case.

IV. THE EXPERIMENT

Two sets of observations were made which differed only in the thickness of lead absorber between $C2$ and the anticoincidence tubes; 30 cm in one case and 15 cm in the other. They are referred to here as the 30-cm case and the 15-cm case, respectively. For the 15-cm case, the absorber was placed in the lower position as shown in Fig. 1.

The equipment was oriented with the chamber axis in a north-south direction. The maximum entrance angle from the vertical for the particles was four degrees to the north and south and 26 degrees to the east and west, resulting in a longer path through the absorber for some of the particles. The effective path length for the measured particles has been calculated to be 3 percent greater than the thickness of the absorber.

The observations were made at Climax, Colorado at an elevation of 3.4 kilometers and magnetic latitude 48 degrees north during the summer and fall of 1950. Approximately 6500 cloud-chamber expansions were photographed for the 30-cm case and 6300 for the 15-cm case.

V. MEASURING TRACK CURVATURE

In general the method consisted of enlarging the photographs and comparing the tracks directly with a circular arc of known radius. Thus, from a number of prepared arcs, the one that fitted the track best was selected. The method, described in detail in an earlier paper,[1] was capable of measuring tracks with radii between 0.3 and 10 meters. For each track, the sign of the charge and the momentum corresponding to the measured radius were recorded.

Only single tracks with length at least 88 percent of the chamber diameter were measured. Shorter tracks were not used because they cannot be measured as accurately and their position nearer the chamber wall leads to greater track distortion. With the exception of the few tracks whose widths indicated that they were not time coincident with the triggering pulse, all single tracks of the necessary length were included regardless of quality or track density.

VI. RESULTS AND DISCUSSION

A. Momentum Distribution

Measurement of the track curvatures gives the momentum distribution of all particles recorded by the counter telescope. The absolute rate is determined from the *C-A* counting rate in the manner described in reference 2, part D. In Figs. 2 and 3 are given the rates, as a function of momentum, of singly occurring particles selected by the experimental arrangement used. From the design of the experiment these should represent the momentum spectra of charged particles other than electrons at an altitude of 3.4 kilometers and magnetic latitude 48 degrees north which have ranges in lead from 3.7 to 388 g/cm^2 and from 3.7 to 210 g/cm^2, respectively. These, of course, do not include all charged particles at this altitude. Indeed, the vast majority of mesons at this altitude have ranges in excess of the upper limits imposed here, as shown by previous work[1,3] in which the total spectrum was obtained. For protons, however, the 30-cm case should include almost all of those present in the radiation and having momenta above 0.3 Bev/c. The determination of this proton intensity is the primary objective of this experiment.

At the bottom of each figure is indicated the momentum interval for mesons and protons corresponding to the ranges in lead as imposed by the experiment. These have been taken from the range values given by Gross.[5] The ranges are based on energy loss through ionization only and are not expected to be correct for protons which undergo occasional catastrophic losses through nuclear interaction. Mu mesons are known to have nuclear interaction path lengths in lead many times longer than the absorber thicknesses used here so that the indicated ranges for these particles are expected to be correct.

From the standpoint of the present experiment, it is important to show that the probability of obtaining a single electron track of energy greater than 100 Mev which could not then be distinguished from a meson is very small. The small frequency of occurrence of single tracks of angle beyond the counter-telescope acceptance limits, and absence of tracks below the absorption cutoff in other experiments with this equipment,[3,4,6] show the number of single electron tracks photographed to be small even compared to the statistical uncertainty of the meson intensities. It may seem odd that showers often show up as either multiple tracks or blank photographs but rarely as single tracks. However, appearance of at least one electron track of energy greater than 100 Mev almost assures, according to fairly well-established shower theory, that it will be accompanied by other tracks, thus the data probably include very few electrons.

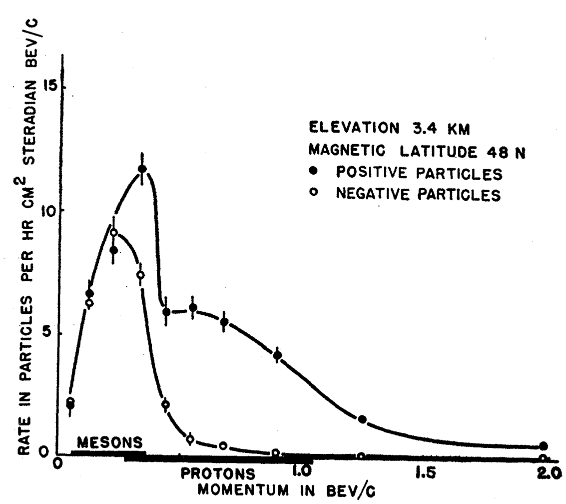

FIG. 3. Momentum spectrum for the 15-cm case.

The particles included in the distribution are thus believed to be only mu mesons and protons with the exception (at low momenta) of a small number of electrons that would not affect the observed values within statistics. Assuming this to be true, the spectra of negative particles are for mesons only while the positive spectra are for positive mesons plus protons. The decided difference between the positive and negative distributions for the two cases is an indication of the magnitude of the proton intensity. This difference would exactly represent the proton intensity if positive and negative mesons occurred in equal numbers. From many investigations[6–11] the positive meson intensity is known to exceed that of the negatives by some 20 percent.

Failure of the negative distribution to drop more sharply above the meson cutoff is attributed, in part, to scattering outside the $A2$ coverage since sufficient A protection was not provided in the long dimension of the beam cross section defined by the coincidence telescope. It is due also to the limited momentum resolution that results from grouping the particles into the rather wide momentum intervals needed to keep the statistical errors small. This is particularly evident for the 30-cm case where the intensity at 0.7 Bev/c is the average intensity for an interval of 0.165 Bev/c. Inclusion of these high-energy mesons above the cutoff has only the effect of adding some statistical uncertainty to the proton intensity determination. The difficulty is

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[6] F. M. Charbonnier, Ph.D. dissertation, University of Washington, 1952 (unpublished).
[7] M. Correll, Phys. Rev. **72**, 1055 (1947).
[8] W. L. Whittemore and R. P. Shutt, Phys. Rev. **86**, 940 (1952).
[9] Bernardini, Pancini, Conversi, Scrocco, and Wick, Phys. Rev. **68**, 109 (1945).
[10] I. F. Quercia *et al.*, Nuovo cimento **7**, 277 (1950).
[11] R. B. Brode, Phys. Rev. **76**, 468 (1949).

avoided in the 15-cm case by using no measurements below 0.5 Bev/c in determining the proton intensity.

At higher momenta, well above the meson cutoff, the two effects mentioned above should disappear. However, an intensity remains consisting of about 2.5 percent of the total negative intensity (obtained in earlier work[2]) for the 15-cm case and 3.0 percent for the 30-cm case. Previous work[12] at sea level showed also a small negative intensity at high momenta. This was satisfactorily explained as leakage due to anticoincidence counter dead time. In fact, during later observations at sea level[13] for which the coincidence circuit was blanked during the dead time, no negative particles were detected at high momenta. The intensity observed at 3.4 kilometers, however, is considerably greater than the calculated leakage due to dead time of the anticoincidence counters. A small anticoincidence tray leakage of this magnitude would not have been objectionable for the present work; thus this measured negative flux at high momenta is not presented as positive evidence of some high-momentum particle with range less than the thickness of absorber used.

Figure 2 shows, in addition to the distribution of total positives and negatives, the momenta of those tracks selected as having greater than minimum density. These tracks were selected without regard to sign of curvature. Of the 351 tracks so selected for the 30-cm case, one with momentum 0.54 Bev/c showed negative curvature. Of the corresponding 395 tracks for the 15-cm case, two with momenta 0.35 Bev/c were of negative curvature. Among all tracks judged as heavily ionizing, this 0.4 percent showing negative curvature probably represents protons backscattered from the absorber below the C train. A similar small percentage of such tracks was found in earlier work.[1,3] The intensities shown for these heavily ionizing tracks may not represent true proton intensities as their determination is based, in part, on one's ability to recognize these tracks. At a momentum of 0.5 Bev/c, protons have an ionization density of three times minimum; and this density increases rapidly at lower momentum where it is probable that most protons have been found in this way. Indeed, here the intensity of heavily ionizing tracks accounts for most of the difference in intensity between total positives and negatives. At 0.75 Bev/c, protons have an ionization density of two times minimum. At this and higher momenta few of the protons present are recognized through track density as will be seen by comparison with the total proton intensity, discussed in the following section.

As is expected from the experimental arrangement, the distribution of heavy tracks shows a sharp cutoff on the low-momentum side. For the 30-cm case, three heavy tracks were found with momentum near 0.28 Bev/c while none were found at lower momenta. The distribution of Fig. 2 is drawn to zero at this value. Similarly for the 15-cm case, a heavy track was found at both 0.25 and 0.28 Bev/c with none at lower momenta. These experimental cutoffs correspond satisfactorily with that for protons as computed from the minimum range for the experiment.

[12] Jay Todd *et al.* (unpublished).
[13] W. R. Davis, Phys. Rev. **92**, 406 (1953).

B. Proton Spectrum

The problem now is to combine all available data to give a best estimate of the proton spectrum at Climax. This is obtained in part from the difference between the positive and negative intensities, and in part (at momenta below 0.5 Bev/c) from the intensity of heavily ionizing tracks. At momenta above 1.0 Mev/c, a small correction involving a knowledge of the nuclear removal path length is necessary. This path length is estimated and discussed in the next section. For comparison, data from earlier work,[4] in which particles stopping in 5 cm of lead were studied, are included.

The difference between the positive and negative rates for each interval have been plotted in Fig. 4 separately for the 15- and 30-cm cases. For the 15-cm case, only those positive-negative differences above 0.5 Bev/c are included. At lower momenta the increasing meson intensity makes the magnitude of the difference uncertain, and a correction would have had to be made for the positive meson excess. Similarly, for the 30-cm case, only differences above 0.65 Bev/c are included. The intensities plotted at 0.33 and 0.45 Bev/c are taken from the heavy track distributions which probably give a better estimate of the proton intensity at these momenta than is given by the positive-negative difference. Also included in Fig. 4 are similar values from earlier work with 5 cm of absorber.

The agreement in Fig. 4 between the maximum intensities for the various cases is considered satisfactory. For the 15- and 30-cm cases the peak intensities agree well within the indicated statistics. For the 5-cm case, the peak intensity is somewhat low. Here the sharp maximum (corresponding to the small absorption range

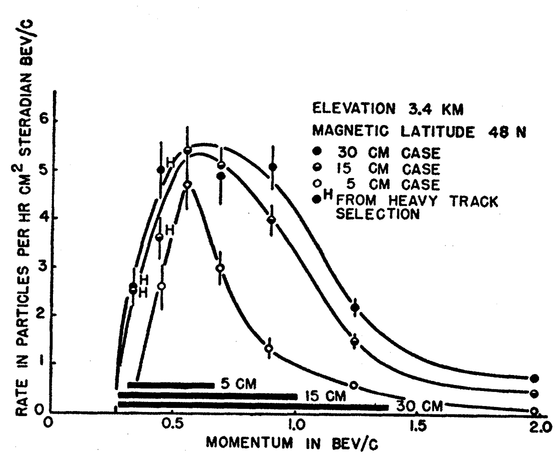

FIG. 4. Momentum spectrum of protons stopped in the absorber.

used) cannot be expected to be properly resolved without obtaining intensities at more closely spaced intervals. Also, the arrangement of counters and absorbers used here led to errors of scattering not present in the present observations. For all three cases in Fig. 4, the low-momentum cutoff is an instrumental effect and occurs at the same momentum since the minimum ranges selected were the same.

Figure 5 gives total proton intensities as computed from the three distributions of Fig. 4. To some extent the intensities of Fig. 5 need to be discussed point by point. The intensities for each case lying well within the interval where protons stop due to ionization have been transcribed without change. For the 5-cm case, the intensities at 0.45 and 0.70 Bev/c have been omitted as uncertain due to scattering. For each case, intensities well above the ionization cutoff have been corrected to total intensities assuming a nuclear removal path length of 206 g/cm^2. The method of doing this will be

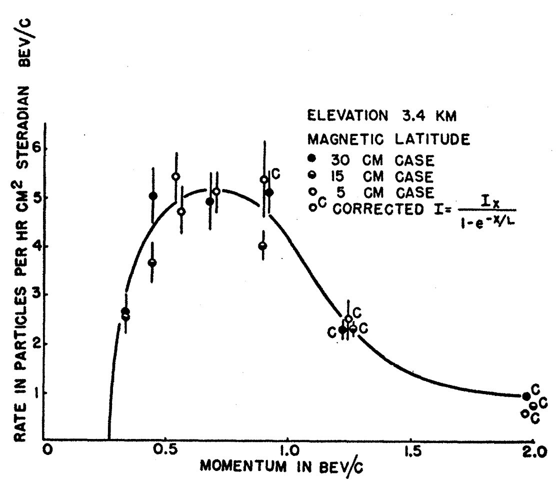

FIG. 5. Momentum spectrum of protons under 2.5 cm of lead.

explained in the next section. The points in Fig. 5 show some spread, but since they come from different sets of observations and have rather large statistical uncertainties, the agreement among the various estimates is considered quite good.

In Fig. 6 the various estimates of intensity have been combined to give a single value at each momentum. The intensities of Fig. 5 are all for the radiation as observed under the 2.5-cm lead absorber used above the chamber. In Fig. 6 a correction has been made for this absorber and, in addition, for the counter $C1$, the top of the chamber, and the roof of the trailer, assuming the path length as previously mentioned. This amounts to multiplying each intensity of Fig. 5 by 1.21 and plotting the result at the momentum the protons would have had before entering the lead. The difference in shape, as well as the higher-momentum cutoff, of Fig. 6 as compared to Fig. 5 is due to this correction. Figure 6, then, is expected to give the atmospheric intensities of

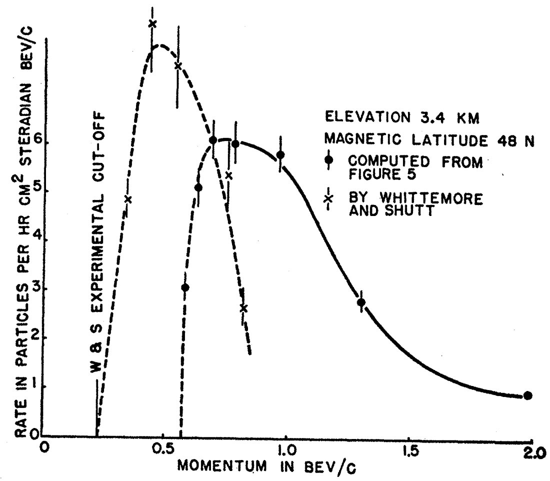

FIG. 6. Momentum spectrum of protons at 3.4 kilometers.

protons at the altitude 3.4 kilometers between momenta of 0.7 and 2.0 Bev/c. The rapid decrease in intensity below 0.7 Bev/c is, of course, instrumental. In any case, the actual intensity must fall rapidly at low momentum as protons of momenta 0.2 Bev/c, for example, have a range in air at this altitude of only two meters.

Whittemore and Shutt[8] obtained information on the proton momentum spectra at 3.4 kilometers by using two cloud chambers with a magnetic field between. In the lower chamber were placed lead absorbers to aid in the energy determination and a threefold coincidence telescope selected particles in a vertical direction. All particles with heavy tracks stopping in a 6-cm absorber in the lower chamber were considered to be protons. The proton intensities thus determined have been plotted in Fig. 6. The use of very thin-walled coincidence counters resulted in a much lower momentum cutoff. Their intensities near 0.5 Bev/c are higher than any intensity found in the present investigation, but occur below the absorption cutoff of the present work. At higher momenta their intensities are low, as protons cannot be recognized by track density at such high momenta. Also, protons with momentum greater than 0.7 Bev/c would not be stopped by ionization losses in 6 cm of lead. The results obtained by Whittemore and Shutt complement the present work by extending the proton momentum spectrum down to 0.5 Bev/c.

Whittemore and Shutt have also calculated the proton intensity at higher momenta from their measurements of the total positive component and the total negative component. They assumed that the positive excess of mesons remains constant as these mesons travel from 3.4-kilometers altitude to sea level and that the meson positive excess is equal to the positive excess for all particles at sea level. Their calculated results show no disagreement, considering their rather large statistical error, with the curve of Fig. 6.

TABLE I. Calculation of L, the removal path length of protons in lead. The average L and the errors were calculated in the manner shown to give the proper weight to each of the two calculations of L.

Case	Momentum interval	Particles Pos.	Particles Neg.	Difference	Normalization factor	Rate
5 cm	0.82–1.33	61	4	57	0.0318	1.87[a]
30 cm	0.82–1.33	297	37	255	0.0267	6.81
15 cm	1.20–2.50	207	22	185	0.0195	3.61
30 cm	1.20–2.50	226	29	219[b]	0.0267	5.85
Cases	N_0-N_x	$N_0/(N_0-N_x)$		$\ln[N_0/(N_0-N_x)]$	x	L
5 and 30 cm	4.94	1.38		0.322	62.4	194±37
15 and 30 cm	2.24	2.61		0.960	207	221±41
					Average	206±30

$$e^2(L)=(\partial L/\partial N_0)^2e^2(N_0)+(\partial L/\partial N_x)^2e^2(N_x)$$
$$\bar{L}=(L_1e_1^{-2}+L_2e_2^{-2})/(e_1^{-2}+e_2^{-2})$$
$$[e(\bar{L})]^{-2}=e_1^{-2}+e_2^{-2}$$

[a] Corrected for difference in absorber between the chamber and final coincidence counter for the two cases.
[b] Corrected for the protons passing through 30 cm of lead without nuclear interaction.

C. Nuclear Interactions of Protons in Lead

In addition to the loss of energy due to ionization' protons occasionally suffer catastrophic losses by collisions with nuclei. The result of the collision may be a scattering of the proton or a disruption of the nucleus with the emission of a number of secondary particles. The removal of protons as a result of such collisions is usually described by assuming that the intensity at x cm of absorber is given by

$$N_0-N_x=N_0e^{-x/L}, \quad (1)$$

where N_0 is the number of protons incident on the absorber, N_x is the number stopping in x cm of absorber due to nuclear interactions, and L is the mean free path for removal of the protons. L, of course, differs from the nuclear-interaction mean free path only because of an occasional interaction that either causes so little change in the direction and energy of the incident proton that the proton continues through the absorber or else produces a secondary that penetrates the remaining absorber.

Calculation of L can be conveniently made from a measurement of the protons stopped by nuclear interaction along with a corresponding measurement of the total intensity of protons incident on the absorber. Examination of Fig. 4 shows that, for the 30-cm case, there is a large momentum interval where protons would be stopped by ionization losses. Since 30 cm is expected to be considerably greater than L, most of the protons at higher momenta will be stopped due to nuclear interaction. Thus, the interval 0.8 to 2.5 Bev/c contains nearly all the protons incident on the absorber.

For the 15-cm case the region from 1.2 to 2.5 Bev/c was selected as one in which the intensity represents protons stopped only by nuclear interaction. This intensity is compared to the corresponding intensity for the 30-cm case, which is assumed to give the total intensity, in arriving at an approximate value for L. Since the 30-cm intensity at high momenta is not quite as large as the total intensity, this approximate value of L is then used in obtaining a second approximation.

It is not immediately evident that, at 1.2 Bev/c for the 15-cm case, the effect of scattering is not present. However, from range *versus* momentum curves[5] it can be determined that a 1.2-Bev/c proton would have, after penetrating the 15-cm absorber, a residual momentum of 0.78 Bev/c. Similarly, a 1.05-Bev/c meson would have 0.78-Bev/c momentum after penetrating the absorber. Multiple scattering from Coulombic interaction is determined by the magnitude of pv/c, where p is the momentum of the particle. In the case above, the proton has somewhat higher average momentum in the absorber but smaller v/c than the meson so that the average values of pv/c are equal. Thus, multiple Coulombic scattering should be the same for a 1.2-Bev/c proton and a 1.05-Bev/c meson in penetrating the 15 cm of lead. Mesons are known to show Coulombic interaction only. The negative meson intensity at 1.0 Bev/c for the 15-cm case (see Fig. 3) is only 2 percent of the total negative intensity at this momentum. Actually the appearance of even this small number of mesons at this momentum has later been shown to be due more to A counter dead time than to scattering. Thus, no appreciable fraction of protons of 1.2-Bev/c momentum are expected to be photographed as a result of Coulombic scattering. Of course, large angle single scattering from nuclear interaction may result in a longer path length so that the proton will stop or be scattered outside the A coverage. The effects of such nuclear scattering are included in the definition of L.

For the 5-cm case a similar computation shows that, at 0.8 Bev/c, the effect of scattering is negligible. The interval chosen for the computation of L is 0.8 to 1.3 Bev/c. The intensity here is compared with the total intensity for this interval as given by the 30-cm case. Extending the interval to higher momenta would have increased the number of particles included in the protons stopped in 5 cm of absorber, but at higher momenta a correction to the 30-cm intensity would have to be made to obtain the total intensity, thus no advantage would be gained. Also, the use of 30-cm data in an interval other than that used in the previous calculation makes the two calculations independent.

Table I contains the two separate calculations of L, along with statistical errors, and the average of the two results. Since the 5-cm case involved a 3-fold coincidence, it was necessary to correct for the protons lost between $C2$ and $C3$. This was done by using an estimated value for L to compute the number lost. The result obtained for L is 206 ± 30 g/cm^2.

Calculation of L from a comparison of the 5- and 15-cm cases cannot be made with an accuracy comparable to those of Table I. This results from the inability to determine the shape of an exponential curve from two points on the fairly straight part of the curve.

In Fig. 4 the values at higher momenta for the 5- and 15-cm cases represent the number that are removed by nuclear interactions in the absorber. By using the value of L computed above, Eq. (1) can be solved for N_0 to obtain the total number of protons incident on the absorber. The two highest-momentum values for the 15- and 30-cm cases and the three highest momentum values for the 5-cm case were corrected in this manner in arriving at the total proton intensities in Fig. 5.

The value for L obtained here can be compared with a result obtained by Mylroi and Wilson.[14] They measured the momenta at sea level of all particles stopping in 5, 10, 15, and 20 cm of lead by means of a counter-absorber arrangement placed below a magnetic spectrograph. Protons and mesons were separated by nearly the same method as used by the authors. Their result of 160 ± 40 g/cm^2 is in fair agreement with ours.

Froehlich, Harth, and Sitte,[15] using a multiple-plate cloud chamber with a counter-absorber hodoscope below to measure the range, obtained a value for L of 190 ± 15 g/cm^2 for nuclear interacting particles with momentum less than 2.85 Bev/c. The events recorded as nuclear interactions were: (1) penetrating showers with ionizing primary and two or more secondaries, (2) stars with one or more heavy prongs, and (3) large showers containing heavy prongs.

D. Positive Excess for Mesons

With the foregoing determination of the proton component, it is possible to compute the positive excess for mesons alone. Use is made of the work of Potter[1,3] which gives the spectra of all positive and negative particles at 3.4 km. The positive excess is assumed to be due to the presence of protons and to a positive excess of mesons. Therefore, subtraction of the protons from the positive particles leaves only positive mesons. Dividing the intensity of the positive mesons by that of the negative mesons gives the positive excess for mesons.

One value for the meson positive excess can be obtained in the interval 0.17 to 0.60 Bev/c from the 30-cm case. In this interval both mesons and protons were stopped by ionization losses. The observed heavy track intensity was subtracted from the intensity of positive particles to give, in the manner stated above, a meson positive excess of 1.14 ± 0.07. Another determination can be made in the momentum interval 0.60 to 2.0 Bev/c. Here the total proton intensity, which was obtained in Sec. B, was used to calculate a positive excess of 1.17 ± 0.06.

Table II is a comparison of the values of the meson positive excess obtained here with values obtained by others at nearly the same altitude. A careful study of the experiments yields no explanation for the discrepancy between the high values of Whittemore and Shutt and of Brode and the lower values obtained by the authors, by Quercia, and by Bernardini *et al.*

TABLE II. Summary of the values of meson positive excess obtained by other investigators at altitudes near 3.4 kilometers.

Investigator	Method	Momentum in Bev/c	Positive excess
This experiment	Cloud chamber	0.17–0.60 0.60–2.00	1.14 ± 0.07 1.17 0.06
Charbonnier[a]	Cloud chamber	0.34–1.0 1.0 –1.67 1.67–	1.09 0.06 1.21 0.08 1.22 0.07
Whittemore and Shutt[b]	Cloud chamber	0.3 –0.7	1.35 0.10
Brode[c]	Magnetic lens	1.0 –2.5	1.30 0.03
Quercia[d]	Magnetic lens	0.23–	1.13 0.01
Bernardini[e]	Magnetic lens		1.20

[a] See reference 6.
[b] See reference 8.
[c] See reference 11.
[d] See reference 10
[e] See reference 9.

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[14] M. G. Mylroi and J. G. Wilson, Proc. Phys. Soc. (London) **A64**, 417 (1951).
[15] Froehlich, Harth, and Sitte, Phys. Rev. **87**, 504 (1952).