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# Proton-Meson Analysis of the Cosmic Radiation at 3.4 Kilometers*

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A magnetic cloud chamber has been used along with an appropriate arrangement of coincidence and anti-coincidence counters to photograph tracks of those charged particles at 3.4 km altitude having ranges of 0.5 to 5, 5.5 to 15, and 15 to 25 cm in lead. An additional 2.5 cm lead was used above the chamber to remove showers. Plotting in each case the distribution in momentum of positive and negative particles there is shown a clear resolution into protons and mesons. It is found that about twice as many protons as mesons stop in lead at ranges between 2.5 and 7.5 cm lead. The meson intensity (differential range intensity) is found to be $6.1\pm0.06\times10^{-6}$ particles per (g sec sterad) of air at 60 g air range and $12.0\pm1.0\times10^{-6}$ at 125 g air range.

## I. INTRODUCTION

THE many investigations of penetrating showers and star production give some information regarding the intensity, altitude, and latitude dependence of a generalized nuclear component of the cosmic radiation. These measurements usually cover a not too well-defined range as regards both the type and energy of processes involved. This qualitative character of the investigations makes it difficult either to interpret the results in terms of fundamental processes or to compare the results of various investigators. A knowledge of the intensity and spectral distribution of the various nuclear species, predominately protons and neutrons, throughout the atmosphere would give a better basis for the interpretation of the nuclear phenomena observed. Some progress has been made in this direction in the case of neutrons, because these are easily distinguished from other components of the radiation. Protons, particularly at higher energies, are difficult to distinguish from other charged particles, so that, although they are considered to constitute the major part of the primary radiation, little is known of their intensity and energy distribution at any altitude. Rossi[1] has summarized the scanty information available as of 1948. Recently several investigations relating to the proton content of the radiation at sea level have been published[2-4] while in previous work of this laboratory[5] it was shown that at 3.4 km protons have an intensity at least several percent of that of the penetrating component.

The present investigation is one of a series directed towards providing better information on the proton flux at lower altitudes. At an altitude of 3.4 km it is found that more protons than mesons stop in a 5 cm lead absorber. Thus, even at this altitude protons cannot be considered to constitute a negligible part of the total flux of charged particles. As the experimental method provides a separation of the meson and proton components better information is also obtained for the spectral distribution of mesons.

## II. THE APPARATUS AND EXPERIMENT

In previously reported observations[5] at 3.4 km a momentum spectrum of all non-electronic charged particles to a momentum of 2.5 Bev/$c$ was obtained. Here the magnetic cloud chamber was triggered by coincidence counters above and below the chamber. A 5 cm lead absorber above the chamber insured cascade multiplication of electrons penetrating it, and all photographs showing more than one time coincident track were ignored in obtaining the momentum distribution. This selection will be discussed later. Of the single tracks, some could be easily identified as due to protons from their density. In this way an attempt was made to find the ratio of protons to mesons in the momentum interval above the proton absorption cutoff of the equipment (250 Mev/$c$) and below 600 Mev/$c$. Because of apparent variations of track density for successive expansions (related at least in part to variations in time interval between expansions), selection of protons in this way seems not to be certain even at an ionization of three times minimum. In addition, this selection was made in a conservative way so that any error would be in the direction of too few protons. The estimate of ten percent protons in the momentum interval mentioned and arrived at in this way seems, in view of the present investigation, to have been too low.

In the present work the proton-meson separation has been based on simultaneous determination of range and momentum. Range intervals sufficiently broad to give a maximum stopping rate consistent with good separation in the momenta of mesons and protons have been used. The arrangements of counters and absorbers used to trigger the chamber are shown in Fig. 1. The chamber is triggered by an event of type $(C_1+C_2+C_3-A_1-A_2)$. This tends to define particles (as observed in the chamber) of minimum range equal to the absorbing material between the sensitive volume of the chamber and that of the counters $C_3$ and of maximum range equal to the absorbing material between the sensitive volume of the chamber and that of counter

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* Assisted by the joint program of the ONR and AEC.

[1] B. Rossi, Revs. Modern Phys. **20**, 537 (1948).

[2] Merkle, Goldwasser, and Brode, Phys. Rev. **79**, 926 (1950).

[3] Goldwasser and Merkle, Phys. Rev. **83**, 43 (1951).

[4] Nonnemaker and Street, Phys. Rev. **82**, 564 (1951).

[5] Miller, Henderson, *et al.*, Phys. Rev. **79**, 459 (1950).

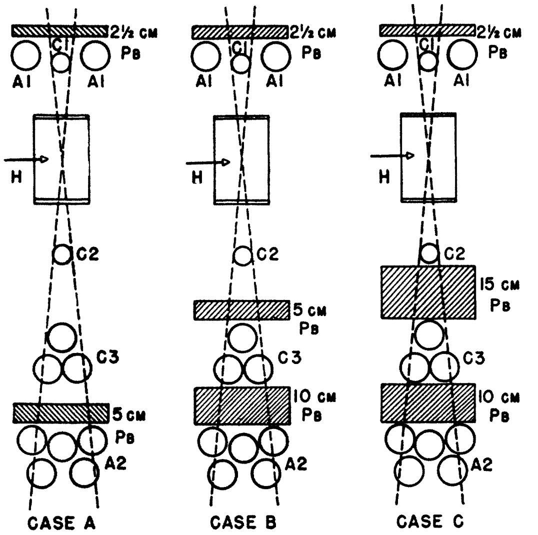

FIG. 1. Schematic of experimental arrangement for each of the three sets of observations.

group $A_2$. The $2\frac{1}{2}$ cm lead above $C_1$ is provided to produce cascade multiplication of electrons which then either block expansion of the chamber by triggering one of the $A_1$ counters, or are recognized by the appearance of time coincident tracks in the chamber. Three series of photographs were taken with the arrangements shown as cases $A$, $B$, and $C$ of Fig. 1. Including the absorbing material represented by the chamber and counter walls, the three experimental arrangements define particles of range, as observed in the chamber and for the idealized case of normal incidence and no scattering, of 0.5 to 5.5, 5.5 to 15.5, and 15.5 to 25.5 cm lead. Additional absorber of 3 cm lead equivalent is present above the chamber. Based on the expected ionization energy losses of protons and mesons, the momentum intervals of the protons and mesons selected will be well separated in each case. A plot giving the momentum distribution of particles photographed should then show maxima corresponding to protons and mesons for positively charged particles and a single maximum for negative particles. Effects of scattering and nuclear reactions of protons will be discussed later.

The magnet and cloud chamber used in the present investigation as well as the method of track selection, curvature measurement, etc., have been described in a previous paper.[5] The only essential change has been the substitution of the event selecting system shown in Fig. 1 for that previously used. All observations are for a field strength of 8000 gauss and at an altitude of 3.4 km (Climax, Colorado).

## III. DISCUSSION OF EXPERIMENTAL METHOD

### A. Event Selection

The experimental arrangements of Fig. 1 are intended to select charged particles which having passed through the chamber traverse the absorber between $C_2$ and $C_3$ and stop in the absorber between $C_3$ and $A_2$. Some cascade showers originating in the $2\frac{1}{2}$ cm lead above $C_1$ will fail to actuate the $A_1$ counters and also fail to penetrate as far as the $A_2$ group of counters and so will be photographed. As will be discussed, the probability of obtaining a photograph of a single electron track (which could not then be distinguished from a meson or high energy proton) seems to be very small. An error of exclusion occurs for those particles so scattered, after triggering counter $C_2$, as to fail to traverse one of the counters $C_3$. Errors of inclusion occur for those particles so scattered, after traversing $C_3$, as to fail to reach one of the $A_2$ counters. Errors of inclusion have only the effect of limiting the resolution of events into protons and mesons among positive particles by including some higher energy mesons. The momentum distributions for negative particles (mesons only) show the extent to which higher energy mesons have been included through scattering. For protons nuclear energy losses will cause errors of both inclusion and exclusion as compared to the idealized treatment based on ionization loss only. Accidental coincidences and all errors due to counter inefficiencies and to counter and circuit dead times and resolution either have no effect or are small compared to statistical uncertainties of the data.

### B. Elimination of Electron Component

A single electron appearing in the chamber could not be distinguished from a meson or high energy proton. The $2\frac{1}{2}$ cm of lead absorber placed above counter $C_1$ was to insure that through cascade multiplication electrons would either actuate the $A_1$ counters or reveal themselves through the appearance of multiple tracks in the chamber. Even so, there is some probability that a single electron track could appear in the chamber. In previous work[5] in which the chamber was actuated by counters $C_1$ and $C_2$ only, it was shown that the large number of single tracks with momenta near 100 Mev/$c$ photographed with no absorber above $C_1$ disappeared when 5 cm lead was placed above the equipment. The smaller shower absorber ($2\frac{1}{2}$ cm lead) used in the present case seems to have been adequate. In Case $A$ the intensity of the first positive and negative maxima match closely the intensities of the over-all spectrum at the same momentum as determined under 5 cm lead (Fig. 3). Thus, no additional electron removal seems to take place in using more than $2\frac{1}{2}$ cm lead. The proton maximum of Fig. 2 case $A$ certainly cannot be contaminated with positrons as the total negative intensity here is small, and positrons would not be expected to behave differently.

The use of anticoincidence counters and disregard of all multiple events in the chamber would, in addition to eliminating the electron component, discriminate against protons which occurred multiply or in coincidence with other charged particles. Protons from atmospheric stars would be expected to be well separated from other components of the star at the point of observation and so occur singly. However, this would not be true for stars produced locally in the $2\frac{1}{2}$ cm lead above $C_1$ and these would be discriminated against. Actually, such protons do not constitute a large fraction of the total proton flux through the chamber. In previous observations[5] in which 5 and 20 cm of lead were used above the chamber, of those tracks that could be identified as protons only a few percent were found to be accompanied by one or more other tracks. Actually, the discrimination against locally produced protons is desirable as the intention here is a determination of the atmospheric proton flux rather than local production.

### C. Counter and Circuit Efficiency

Accidental coincidences of the type $(C_1+C_2+C_3-A_1-A_2)$ are expected to have so small a rate as to be completely negligible as compared to statistical uncertainties of the experiment. Any inefficiency of the counter group $A_2$ will lead to inclusion of some higher energy particles which have penetrated the lower absorber. Experimentally, the number of particles so included is shown to be very small. As shown in Fig. 2 case $A$, this rate for negative particles of momenta above 1 Bev/$c$ is less than 0.1 particle $(\text{Bev}/c)^{-1}$ $\text{hr}^{-1}$ $\text{ster}^{-1}$ $\text{cm}^{-2}$. This compares to a total negative particle rate (Fig. 3) of about 5. Of the high momentum negative particles of Fig. 1 case $A$, some are due to scattering outside the coverage of the $A_2$ counters. Thus, the leakage due to effects other than scattering is less than two percent. The appearance of almost no particles below 250 Mev/$c$ (the meson absorption cutoff), as shown in Fig. 2 case $C$, is an indication of the efficiency of the system of selection in eliminating particles of range too small to reach counter group $C_3$.

### D. Rate Determination and Normalization

Only those single tracks of length at least 15 cm (out of a chamber diameter of 17 cm) have been measured for curvature in determining the rates as given in Fig. 2. The fractional yield among all photographs of single tracks, regardless of length, has been determined by an examination of all exposures and will be symbolized by "$f$." The $C-A$ counting rate ($r$) in counts per hour was determined during the course of each run. This is larger than the picture taking rate because of chamber recovery time. If $n$ is the number of single trakcs with momenta lying in an interval $\Delta P$ and $m$ the total number of single tracks of all momenta (both $n$ and $m$ for tracks of length greater than 15 cm) obtained during a run, then the differential momentum rate in the momentum interval $\Delta P$ is taken to be:

$$\text{Rate}=fr(n/m)(1/\Delta P).$$

For $r$ in counts per hour and $\Delta P$ in Bec/$c$ this gives the differential momentum rate in particles $\text{hour}^{-1}$

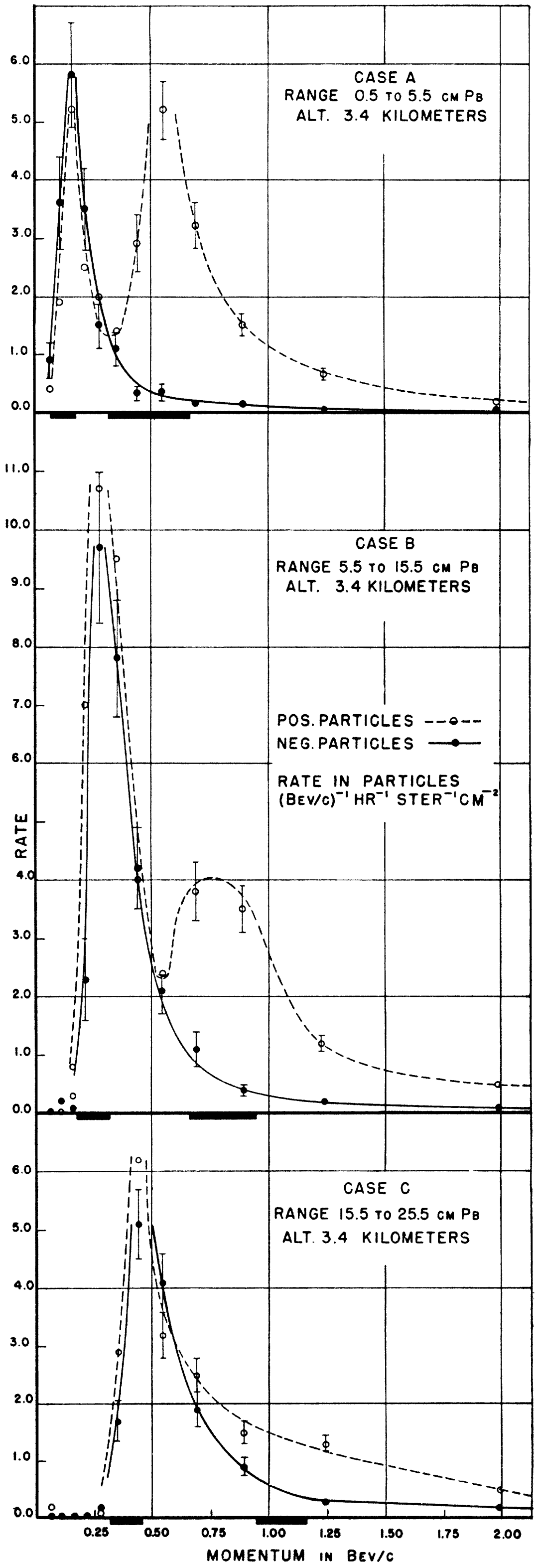

FIG. 2. Distribution in momentum of particles selected with experimental arrangements $A$, $B$, and $C$, as shown in Fig. 1. Rate is given in particles $(\text{Bev}/c)^{-1}$ $\text{hr}^{-1}$ $\text{sterad}^{-1}$ $\text{cm}^{-2}$.

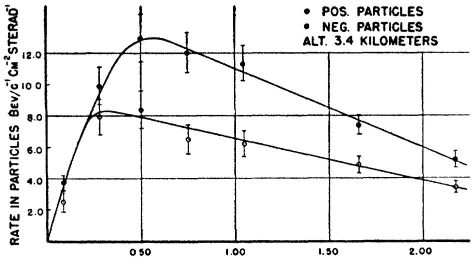

FIG. 3. Distribution in momentum of total meson plus proton radiation.

(Bev/$c$)$^{-1}$. This computation involves only the natural assumptions that the distribution of events among all $C-A$ counts is the same as that among the $C-A$ counts that occur during the active time of the circuit (that is to say, while the circuit is not sterilized during chamber recovery) and that the momentum distribution of single tracks of length 15 cm is the same as that for all single tracks.

The counters $C_1$ and $C_2$ (Fig. 1) from their effective size and separation define a coverage of 1.0 steradian cm$^2$. The counters $C_3$ include a larger angle with respect to $C_1$ and $C_2$ and are not rate determining. In other work, not yet published, in which identical counters $C_1$ and $C_2$ were used alone to trigger the chamber, total rates of the noncascade charged component were determined at sea level and at 3.4 km. These determinations were under 5 cm lead and gave rates of 0.015 and 0.0087 count per second at 3.4 km and sea level respectively. These agree almost exactly with the excellent determinations of the vertical rate of the hard component (for latitudes above 45° magnetic) as made by Rossi, Greisen, and others. Rossi[1] gives rates in particles cm$^{-2}$ sec$^{-1}$ sterad$^{-1}$ of 0.016 and 0.0084 for these altitudes. In comparing the two sets of results a correction is involved because of the inclusion of an extra 100 g cm$^{-2}$ of lead absorber as compared to our measurements in the values given by Rossi. This correction of about five percent has not been made. It is difficult to make exactly because it involves both mesons and protons. The estimate of five percent is based on the present and previous work[5] and the rates, determined as explained in the preceding paragraph, are taken to be absolute rates per cm$^2$ steradian.

## IV. RESULTS AND DISCUSSION

Figure 3 gives the total momentum spectrum as determined under 5 cm lead in previous work.[5] It is reproduced here since data were not previously available for determination of absolute rates. The spectrum is for the meson plus proton radiation. However, below 250 Mev/$c$ it should include mesons only, as the method of observation imposed a minimum proton range corresponding to this momentum. The intensities given in Fig. 3 can be compared to the particle intensities for selected range intervals as given in Fig. 2. No normalization between the two sets of data is involved.

Differential momentum distributions for cases $A$, $B$, and $C$ are given for both positive and negative particles in Fig. 2. The method of determining the rates has been explained. The rates as plotted are average rates for each of 12 momentum intervals. These intervals (the same in all cases) are: 0.025–0.080, 0.080–0.13, 0.13–0.19, 0.19–0.24, 0.24–0.31, 0.31–0.39, 0.39–0.49, 0.49–0.61, 0.61–0.77, 0.77–1.0, 1.0–1.5, and 1.5–2.5 (Bev/$c$). The uncertainties indicated are for statistics only.

The distribution of positive particles for case $A$, Fig. 2, shows a clear resolution into protons and mesons. The data are thought to contain an insignificant number of electrons. The intensity at the second positive maximum (protons) should include few positive mesons as judged by the smallness of the negative distribution at this momentum value. Effects of scattering and nuclear energy losses of protons need to be considered. An approximate computation of multiple meson scattering shows that, while a large number of those mesons with just more than sufficient range to penetrate from the sensitive volume of the chamber to the sensitive volume of the $C_3$ counters will be so scattered as to miss the $C_3$ counters, of those mesons with sufficient range to reach the $A_2$ counters very few will be lost by scattering out of the coincidence train. Thus, the meson peak value should correctly represent the meson intensity at this range (5.5 cm lead or 175 Mev/$c$). The leading edge of the meson peak is also affected by the magnetic cutoff of the equipment. This has no effect at the peak value (see reference 5). The trailing edge of the (negative) meson peak is reasonably accounted for as due to scattering in the 5 cm lead absorber. Variations in particle path lengths through the absorber also prevent a sharp high momentum cutoff. The total (positive plus negative) meson intensity at a range of 5 cm lead (or about 200 Mev/$c$) is found to be 11.0 $\pm 1.0$ particles (Bev/$c$)$^{-1}$ hr$^{-1}$ sterad$^{-1}$ cm$^{-2}$ (altitude 3.4 km). Converting to range, this gives the number of mesons stopping per second-steradian in one gram of air, at a total range including absorber above the chamber of 60 g cm$^{-2}$ air, as $6.1 \pm 0.06 \times 10^{-6}$ per second. This is appreciably smaller than the figure $1.7 \times 10^{-5}$ given by Rossi and Sands.[6, 7]

The second positive maximum of Fig. 2, $A$ is interpreted as due to protons. Here, because of the higher momentum, scattering is less important than is the case for the mesons, and there should be no loss in intensity at the maximum because of proton scattering out of the $C$ train. As is seen from the magnitude of the negative (meson) distribution, there should be no contribution (within statistics) from positive mesons at the position of the proton maximum. The heavy rectangles along the abscissa of each graph of Fig. 2 show the meson and proton limits to be expected on the basis

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[6] Rossi, Sands, and Sard, Phys. Rev. **72**, 120 (1947).

[7] M. Sands, Phys. Rev. **77**, 180 (1950).

of ionization loss only and no scattering. The low energy proton cutoff of Fig. 2, $A$ comes at the expected value. Too many protons occur above the maximum (ionization) cut-off value to be accounted for as scattering out of the coverage of the $A_2$ counters. The magnitude of the coulombic (multiple) scattering can be obtained from the negative meson distribution of Fig. 2, $A$ and the known total intensity (Fig. 3). A direct comparison between meson and proton scattering is now possible as the geometrical factors are the same in both cases. Thus, meson and proton scattering should be the same at equal values of $P\beta$. Assuming that the total proton intensity does not decrease, the intensity near 1 Bev/$c$ is at least ten times that to be expected from multiple scattering. The obvious explanation is that the appearance of large numbers of protons above the ionization absorption cutoff in Fig. 2 is due rather to nuclear energy losses of protons in the 5 cm of lead absorber. On the other hand, nuclear losses in the small amount of absorber between the chamber and $C_3$ should be too small to affect the intensity at the proton maximum. The differential momentum intensity of protons at a range of 5 cm lead is found to be $5.0\pm0.05$ particles $(\text{Bev}/c)^{-1}$ hr$^{-1}$ cm$^{-2}$. This cannot at present be converted to the differential range value because this would involve the path length for nuclear absorption and a knowledge of the complete proton spectrum. Because of the greater width of the proton maximum, Fig. 2, $A$ shows that at 3.4 km more protons than mesons (positive plus negative) stop in a 5 cm lead absorber.

For the distribution of Fig. 2, $B$ the effects of scattering and nuclear losses of protons are more important (as compared to distribution $A$) because of the greater thicknesses of absorber used. Here an approximate computation shows that fifteen percent of the mesons at a range of 15 cm lead will be lost by scattering out of the $C$ train. The directly measured intensity at the maximum (positive plus negative) is $20.4\pm2.0$. Corrected for scattering this becomes $23.5\pm2.0$ for the differential momentum intensity at a range of 15 cm lead. Converting to range, this gives $12.0\pm1.0\times10^{-6}$ mesons stopping per second-steradian in one gram of air at the range 125 g cm$^{-2}$ of air.

The proton maximum of Fig. 2, $B$ is less clearly defined than that of distribution $A$. Here, because of the increasing difficulty of momentum measurement, it is not possible to plot more closely spaced intensity values. The difference between the positive and negative distributions is clearly evident. The scattering losses to be expected are not important compared to the statistical uncertainty. Nuclear losses in the absorber between $C_2$ and $C_3$ are important. This can be judged from the distribution of Fig. 2, $A$, where the proton intensity at 1.0 Bev/$c$ is interpreted as due to nuclear losses in the 5 cm lead absorber between $C_3$ and $A_2$. The total intensity at 1 Bev/$c$ can then be approximated as the sum of the intensities of $A$ and $B$. This gives a proton intensity of 4 protons $(\text{Bev}/c)^{-1}$ hr$^{-1}$ sterad$^{-1}$ cm$^{-2}$ at a momentum of 1 Bev/$c$.

For case $C$, the effects of scattering and nuclear losses have become so important that the method is not satisfactory. Here an approximate calculation shows that forty percent of the mesons will have been lost by scattering out of the $C$ train. With this correction, the meson intensity (positive plus negative) at the range of 25 cm lead becomes $16\pm1$ particles $(\text{Bev}/c)^{-1}$ hr$^{-1}$ sterad$^{-1}$ cm$^{-2}$.

The proton maximum is not resolved in case $C$, although a real difference is found between the positive and negative distributions at higher momenta. Here, it would seem that most of the protons have been lost through nuclear reaction in the 15 cm of lead between $C_2$ and $C_3$. No attempt will be made to estimate proton intensities at momenta above 1 Bev/$c$. However, the results of cases $A$ to $C$ suggest that there is a sharp decrease in intensity at higher momenta.

## V. CONCLUSIONS

Perhaps of greatest interest here is the demonstration of the large number of protons among those charged particles of small range at 3.4 km. The integrated intensities for the distribution of Fig. 2, $A$ show as many protons as mesons. The distribution, however, includes those mesons which have been scattered outside the coverage of the $A$ counters as well as those which have stopped in the 5 cm of lead. Including only those mesons of momenta below that corresponding to 5 cm of lead, about twice as many protons as mesons stop in the absorber. Those stopping include, of course, high energy protons brought to rest through nuclear collisions. At higher altitudes the preponderance of protons among the shorter range particles probably increases rapidly. This is judged in part from the work of Adams, *et al.*[8] and from further measurements (not yet published) showing a large proton ratio between 3.4 km and sea level. At 3.4 km the differential momentum intensity of protons has not decreased much at 1 Bev/$c$ as compared to its value at lower momenta, but it seems to fall off rapidly at higher momenta.

The number of mesons stopping per (g sec sterad) in air at ranges of 60 and 125 g air are found to be $6.1\pm0.06\times10^{-6}$ and $12.0\pm1.0\times10^{-6}$ at the altitude 3.4 km. Rossi and Sands[6, 7] give the value $17.0\times10^{-6}$ per (g sec sterad) for this altitude and find the differential range intensity to be independent of range up to 80 g air. Few values for the slow meson intensity are available for altitudes above sea level. For the intensity at sea level Germain[9] has summarized the results of a large

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[8] Adams, Anderson, *et al.*, Revs. Modern Phys. **20**, 334 (1948).

[9] L. Germain, Phys. Rev. **80**, 616 (1950).

number of observers who find values varying over a factor of two depending on the method of observation.

The work described here was carried out on the grounds of the Climax Molybdenum Company at Fremont Pass in Colorado. The generous cooperation of Mr. C. J. Abrams, General Manager, and other personnel of the company is recognized. Important contributions to the research have also been made by Mr. Don Eng, Electronic Technician, and Mr. Elmer Wright, Instrument Maker, of our staff.

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# The Relative Intensity of Cosmic Rays at Sea Level at Geomagnetic Latitudes 56.8 and 83.0

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During the summer of 1950 two cosmic-ray counter telescopes were exchanged between Ottawa (geomagnetic latitude 56.8°N) and Resolute (geomagnetic latitude 83.0°N) in such a way that an accurate comparison of vertical intensities could be made. The telescopes were operated under almost identical conditions for about three weeks; then they were exchanged, the Ottawa telescope being flown to Resolute and the equipment there returned to Ottawa. Corrections were made for barometer and differences in altitude by reducing all counting rates to that at 1000 mb pressure using known barometer coefficients. Corrections were made for differences in the atmospheric temperature by integrating numerically through the mean atmosphere at each station to get the probability of meson decay between production levels and the 1000-mb layer. When all corrections were made there remained a difference in intensity of $1.76\pm0.75$ percent. No difference would be expected with the absorbers used ($14\frac{1}{2}$ inches of lead) at latitudes so high above the "knee." Arguments are presented to show that the difference is probably due to mesons produced by a group of field sensitive primaries and scattered into the telescope. This group of primaries could come from directions with large zenith angles, which would be allowed at Resolute but excluded at Ottawa.

## I. INTRODUCTION

During the summer of 1950 an opportunity arose to exchange counter trays in two sets of cosmic-ray measuring apparatus, one located at Ottawa (geomagnetic latitude 56.8°N) and the other at Resolute in the Canadian Arctic (geomagnetic latitude 83.0°N). This opportunity made possible a precise measurement of the relative intensity of vertical cosmic rays at the two stations. Corrections for atmospheric changes in intensity could be made fairly accurately since the barometer coefficients had been measured with similar apparatus at both stations. Upper atmosphere data were also available from weather stations of the Canadian Meteorological Service.

Since the discovery of the geomagnetic latitude effect many measurements have been made on the variation in intensity with latitude. The survey of Compton and Turner[1] shows the sea level latitude effect,—the so-called "knee" occurring at about 40° geomagnetic latitude. Variations in intensity at sea level at latitudes above the "knee" have been observed[2,3] but these are mostly considered to be due to differences in the mean atmospheric conditions at different latitudes. At all latitudes where the low energy cutoff due to absorption in the atmosphere, plus the absorbers in the instrument, is well above the low energy cutoff due to the geomagnetic field, the intensity would be expected to be constant except for small differences caused by different atmospheric conditions. Any effect due to a solar magnetic field seems unlikely since recent measurements by Pomerantz[4] and Dolbert and Elliot[5] show evidence against any appreciable influence of a solar magnetic field on cosmic rays.

With present knowledge of the structure of cosmic rays a reasonable estimate of the differences to be expected due to differences in the atmosphere can be made, at least for altitudes up to the mean levels of production of the $\mu$-mesons which are observed at sea level. Residual differences in intensity between the two stations after all corrections have been made may then be assumed to be due to geomagnetic effects on the primary rays, or due to some phenomenon in the process of production of mesons ($\tau$ to $\pi$ to $\mu$, or $\pi$ to $\mu$).

## II. APPARATUS

The apparatus was designed to study meteorological variations in intensity and to watch for phenomenal changes in intensity such as those associated with solar flares.[6] It was identical at both stations and consisted essentially of three counter trays in a vertical line with 6 inches of lead between Nos. 1 and 2 (No. 1 on top) and $8\frac{1}{2}$ inches of lead between Nos. 2 and 3. Number 3 had 4 inches of lead on the sides and ends and one inch

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[1] A. H. Compton and R. N. Turner, Phys. Rev. **52**, 799 (1937).

[2] Caro, Law, and Rathgeber, Australian J. Sci. **A1**, 261 (1948).

[3] P. F. Gast and D. H. Laughridge, Phys. Rev. **59**, 127 (1941).

[4] M. A. Pomerantz, Phys. Rev. **77**, 830 (1950).

[5] D. W. N. Dolbert and H. Elliot, Nature **165**, 353 (1950).

[6] D. C. Rose, Can. J. Phys. **29**, 227 (1951); and Phys. Rev. **78**, 181 (1950).