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The Variation of the Hard Component of Cosmic Rays with Height and the Disintegration of Mesotrons

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The vertical intensity of the hard component of cosmic rays was measured at different altitudes with a threefold coincidence counter tube arrangement. Measurements were taken with and without a graphite layer above the counters in order to compare the absorption of the hard component in air and in carbon. The counting rate observed under a given mass of air-plus-carbon was found to be considerably larger than the rate observed under the same mass of air alone. We interpret the difference as due to the spontaneous decay of the mesotrons which form the hard component of cosmic rays.

INTRODUCTION

THEORETICAL considerations suggest that the mesotrons, which form the hard component of cosmic rays, may disintegrate spontaneously, each into an electron and a neutrino.

It has been pointed out that some hitherto rather obscure experimental results, such as the variation of intensity with zenith angle and with atmospheric temperature, could find a plausible explanation in the disintegration hypothesis. A lifetime of 2 or 3×10^{-6} second should be ascribed to the mesotrons in order to fit the observations.

The problem of the disintegration of mesotrons was thoroughly discussed at the Cosmic Ray Symposium recently held in Chicago,[1] with the conclusion that the experimental evidence for the disintegration could not yet be regarded as conclusive. There was, indeed, considerable uncertainty as to the real meaning of the temperature effect.[2] Also, the different data about the variation with zenith angle were not quite in agreement (see B.R., reference 1). Moreover, cloud chamber and counter experiments had failed to detect the electrons which should occur, as a product of the decay, when the mesotrons are stopped (see B.R.).

New experiments were therefore necessary and the most direct way to test the disintegration hypothesis appeared to us to be an exact comparison between the "absorption" of the vertical mesotrons in air and in some dense material. Actually, if the mesotrons do disintegrate with a lifetime of a few microseconds, the number of mesotrons which disappear by disintegration should be comparable to the number absorbed

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[1] See especially the paper by B. Rossi "The Disintegration of Mesotrons," Rev. Mod. Phys. **11**, 296 (1939). This will be referred to as (B.R.).

[2] Experiments by W. P. Jesse (Rev. Mod. Phys. **11**, 167 (1939)), for instance, seemed to indicate that a temperature effect larger than at sea level existed in the upper atmosphere, where it could not obviously be accounted for by the disintegration of mesotrons.

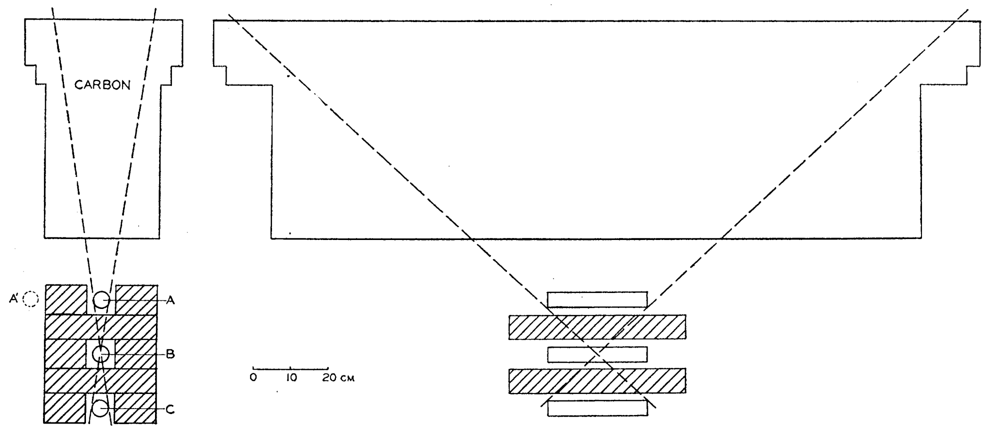

FIG. 1. Experimental arrangement.

by ordinary energy loss when the particles are traveling in air. In a dense absorber, however, where the energy is much more readily dissipated, the number of mesotrons which are expected to disintegrate is negligible as compared with the number of those which are absorbed. Thus, a given layer of air should reduce the number of mesotrons more strongly than a solid or liquid layer having the same stopping power as far as the energy loss due to ionization is concerned.

From the observed difference one can calculate directly, without further assumption, the average range of mesotrons before decay, while, in order to calculate the same quantity from the temperature effect or from the variation with zenith angle, one has to make a special assumption as to the height where the mesotrons are produced. Furthermore, the interpretation of the zenith angle effect is based upon the assumption that the mesotrons keep the direction of the primary rays from which they are produced, and that these primary rays are isotropically distributed outside the atmosphere (see B.R.).

In the present experiment, the intensity of the cosmic-ray mesotrons was measured at different stations up to the height of 4300 m, both with and without a carbon absorber. Carbon was chosen as the dense absorber because the ionization loss of mesotrons should be practically the same in equal masses of carbon and air. Thus a different absorption per g/cm^2 of air and carbon should only be expected if the mesotrons have a finite lifetime.

The experiments were extended to the maximum possible elevation because the difference in the mass "absorption" due to the disintegration should obviously increase as the density of the air decreases.

EXPERIMENTAL ARRANGEMENT

Figure 1 shows schematically the experimental arrangement used.

The three Geiger-Müller tubes A, B, C, were 4 cm in diameter and 27 cm long. They were of the self-quenching type and had been prepared according to the technique of Trost.[3] Threefold coincidences between the G-M tubes were recorded with a conventional coincidence circuit, having a resolving time of about 0.8×10^{-4} second. Control measurements with a radioactive source near the tubes showed no change of efficiency with a change in the number of single pulses per minute, from the sea-level rate to that observed at the top of Mount Evans. This was to be expected because of the very short recovery time of the self-quenching tubes.

The G-M tubes were arranged in a vertical plane with a separation of 14.6 cm between their respective axes. Lead blocks were placed between and on both sides of the tubes in order to filter out the soft component and to prevent coincidences from air showers, which are very numerous at high altitudes. The total thickness of lead between the tubes was 12.7 cm and that on the sides was 11 cm.

The carbon absorber was made of graphite blocks and was arranged above the G-M tubes so as to cover the whole solid angle subtended by the tubes themselves. Under these conditions,

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[3] A. Trost, Zeits. f. Physik, **105**, 399 (1937).

no appreciable error can be introduced in our measurements by scattering. In fact, the scattering of mesotrons is small in elements of low atomic number. Besides, the average angle of scattering is practically the same in equal masses of air and carbon, and the same amount of scattering results in the same decrease of coincidences, since both absorbers are placed above the G-M tubes. This would not have been the case if the solid absorber had been placed between the tubes.

The G-M tubes as well as the amplifier and the batteries were enclosed in a thermally insulated box which was kept at a constant temperature in the neighborhood of 20°C by thermostatic control.

The whole apparatus was set up in a truck. At each station the position of the truck was so adjusted as to bring the centers of the G-M tubes on a vertical line and their axes in the East-West direction. Measurements at different stations were carried out alternately in order to check the reproducibility of the results.

RESULTS

Measurements were taken in Chicago (180 m), in Denver (1616 m), at Echo Lake (3240 m) and at the top of Mount Evans (4300 m). The three last stations are in Colorado, at a geomagnetic latitude of about 49°N, while the geomagnetic latitude of Chicago is 53°N. Therefore, no geomagnetic latitude effect is to be expected and the variation of intensity is to be regarded as due to the variation of altitude entirely.

The results of the individual readings are collected in Table I, while the averages are summarized in Table II. Some absorption measurements in equal masses of carbon and lead were also performed, with the same apparatus, on the top floor of the Ryerson Laboratory in Chicago. These results are collected in Table III. For easy comparison of the data, the thickness of the absorbers, as well as the atmospheric pressures, are given in g/cm^2. The errors given are the standard deviations. An analysis of the data shows that the differences between the results of measurements taken under similar conditions

TABLE I. *Individual readings at different altitudes with and without the carbon absorber.*

DATE	PLACE	AVE. BAR. PRESS. IN G/CM^2	CARBON ABSORBER IN G/CM^2	TOTAL COUNTS	COUNTS PER MINUTE
8/24; 25	Chicago	—	0	4,143	5.31 ± 0.08
8/29; 30; 31	Denver	855	0	15,399	6.92 ± 0.056
9/1; 2	Echo Lake	701	0	18,411	9.68 ± 0.071
9/3; 4	Mt. Evans	620	0	15,406	11.83 ± 0.095
9/4; 5	Mt. Evans	617	79	14,367	11.03 ± 0.092
9/5; 6	Mt. Evans	617	87	9,341	11.03 ± 0.114
9/6; 7	Echo Lake	698	0	13,657	9.81 ± 0.084
9/7; 8	Echo Lake	701	87	13,047	9.00 ± 0.079
9/10; 11	Mt. Evans	614	87	13,238	11.03 ± 0.096
9/11; 12	Mt. Evans	614	0	13,365	11.93 ± 0.103
9/12; 13	Echo Lake	698	0	12,868	9.60 ± 0.085
9/13; 14	Echo Lake	698	87	12,203	8.72 ± 0.079
9/15; 16; 19; 20	Denver	859	0	15,109	6.81 ± 0.055
9/18; 19	Denver	856	87	14,167	6.43 ± 0.053
9/24; 25; 26	Chicago	1010	0	16,789	5.23 ± 0.039

TABLE II. *Averages of the readings at different altitudes with and without carbon.*

PLACE	AVE. BAR. PRESS. IN G/CM^2	CARBON ABSORBER IN G/CM^2	TOTAL COUNTS	COUNTS PER MIN.	CORRECTED VALUE (N)
Chicago	1010	0	20,932	5.25 ± 0.036	5.24 ± 0.036
Denver	857	0	30,508	6.86 ± 0.039	6.84 ± 0.039
Denver	856	87	14,167	6.43 ± 0.054	6.36 ± 0.079
Echo Lake	699	0	44,936	9.70 ± 0.046	9.65 ± 0.046
Echo Lake	699	87	25,250	8.86 ± 0.056	8.72 ± 0.097
Mt. Evans	617	0	28,771	11.88 ± 0.070	11.79 ± 0.070
Mt. Evans	616	84*	36,946	11.03 ± 0.057	10.76 ± 0.114

* This value is the weighted average of the thickness of the carbon absorbers used during the measurements.

are within the statistical fluctuations. (The measurements in the truck and in the Laboratory in Chicago are, of course, not exactly comparable, because of the different thicknesses of the roofs above the apparatus in the two cases.) We conclude that neither changes in the efficiency of the outfit, nor fluctuations of the cosmic-ray intensity are likely to have affected our experiments.

Some systematic errors, however, may have been introduced in our results by Auger's extensive showers penetrating the lead shield, or by Bhabha's ionization showers generated by the mesotrons in the absorber.

(a) Correction for extensive showers

In order to test the effect of the extensive showers, we carried out some measurements moving the upper G-M tube A to the position A' (Fig. 1). The results are given in Table IV. In Chicago and in Denver the counting rate, both with and without graphite, was approximately equal to the expected number of chance coincidences. At Echo Lake and at Mount Evans the coincidences were in excess over the calculated number of chance coincidences and increased when the graphite absorber was put above the counters. The rapid variation of the counting rate with height strongly suggests that the coincidences $A'BC$ observed at high altitude were actually due to Auger's showers not completely stopped by the heavy lead shield. This is in agreement with the results of Auger at the Jungfraujoch showing the existence of showers containing penetrating particles.[4] The increase of coincidences due to the graphite may be explained as a geometrical condensation effect on the air showers.

We may correct for the extra counts due to extensive showers or to chance coincidences by subtracting from the counting rate ABC the counting rate $A'BC$ recorded under the same conditions. As a matter of fact, the number of coincidences due to extensive showers must be nearly the same for the two positions of the G-M tubes and the chance coincidences are so few that a change in their number is altogether immaterial.

TABLE III. *Absorption measurements in carbon and lead. (Chicago, Ryerson Laboratory.)*

ABSORBER	TOTAL COUNTS	COUNTS PER MIN.	ABSORPTION %
0	80,920	5.122 ± 0.018	
87 g/cm^2 C	77,776	4.908 ± 0.018	4.2 ± 0.5
87 g/cm^2 Pb	78,658	4.960 ± 0.018	3.2 ± 0.5

(b) Correction for ionization showers

A mesotron, traversing the two lower G-M tubes and missing the upper one, may still give rise to a coincidence by producing above the apparatus an ionization shower which discharges the upper tube. Since this can only happen if some dense material is present above the tubes, some extra counts may have been recorded in the measurements under carbon or lead and the absorption in the dense materials may have been underestimated.[5]

In order to evaluate the order of magnitude of the effect we carried out some measurements with the arrangement represented in Fig. 2. In Chicago, under 87 g/cm^2 of graphite, 8 ± 0.5 coincidences per hour were recorded. We regard them as due to mesotrons traversing the lower tube and coming in accompanied by an ionization shower.[6] Almost half as many coincidences, however, were still present when the graphite was removed and only the lid of the thermostatic box was left above the tubes. The counting rate was reduced to about 2 per hour by removing the lid also, and finally only one coincidence in 16 hours was recorded when the distance between the upper counters was increased by shifting one of them.

These results show that the correction for the ionization showers cannot be very large, both

TABLE IV. *Test for extensive showers (position A', B, C).*

PLACE	CARBON ABSORBER IN G/CM^2	TOTAL COUNTS	COUNTS PER MIN.
Chicago	0	19	0.007
Denver	0	20	0.021
Denver	87	21	0.017
Echo Lake	0	37	0.043
Echo Lake	87	65	0.065
Mt. Evans	0	96	0.09
Mt. Evans	87	99	0.18

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[4] P. Auger, R. Maze, P. Ehrenfest, Jr., and A. Fréon, J. de phys. et rad. **10**, 39 (1939).

[5] We are greatly indebted to Professor E. Fermi for calling our attention to this source of error.

[6] An investigation of the ionization showers with essentially the same arrangement as represented in Fig. 2, has been carried out by Schwegler, Zeits. f. Physik, **96**, 62 (1935).

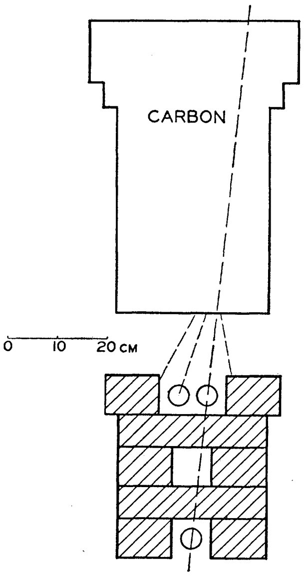

FIG. 2. Test for ionization showers.

because the number of these showers turns out to be small and because some of them originate in the lid or in the lead at the side of the counters and are, therefore, present also without the absorber.

In an attempt to determine more exactly the correction for the absorption measurements in carbon, we repeated this measurement in Chicago, placing a 3.8-cm thick lead plate permanently between the upper tube and the carbon absorber. In this way the effect of the ionization showers was eliminated since the ionization showers from the carbon were stopped by the lead, while the ionization showers from the lead were present in the same number both with and without the carbon absorber. The results are given in Table V.

The decrease of the counting rate by the carbon amounts to (5.0±0.7) percent, while the previous measurements without the lead plate gave a decrease of (4.2±0.5) percent. Since no appreciable variation of the absorption coefficient of the mesotron beam can be produced by increasing the lead filter from 12.7 to 16.5 cm, we may assume the difference (5.0–4.2) = (0.8±0.9) percent to represent the effect of the ionization showers. As expected, this effect is very small, not larger, indeed, than the average statistical error. We may account for it by subtracting (0.8±0.9) percent, from the counting rates under graphite. The percent correction, of course, is the same at the different altitudes because the number of extra counts due to the ionization showers is proportional to the mesotron intensity.

The counting rates N, corrected for the extensive showers and for the ionization showers, are given in the last column of Table II. We assume this corrected value of N to furnish a measure of the vertical intensity of the hard component, i.e., a measure of the number of vertical mesotrons with sufficient energy to traverse 12.7 cm of lead.

DISCUSSION

The logarithms of the observed intensities N are plotted in Fig. 3 against the total mass per cm^2, h, of air and carbon above the G-M tubes. The circles refer to measurements taken without graphite. Hence, the solid curve connecting the circles represents, on a logarithmic scale, the variation of the vertical mesotron intensity as a function of the depth below the top of the atmosphere. As far as we know, no similar data of comparable accuracy have been published previously.

The solid dots refer to measurements taken under the graphite absorber. The dotted lines, connecting the points taken at the same altitude with and without graphite, give, therefore, the initial slopes of the logarithmic absorption curves in carbon of the mesotron beam under 616, 699, and 856 g/cm^2 of air. These slopes are much smaller than the corresponding slopes of the air absorption curve, showing that the mesotron intensity is reduced much more by a given mass of air than by the same mass of carbon.

This is exactly what the disintegration hypothesis predicts. We will, therefore, analyze our data from the point of view of this hypothesis, assuming that the difference between the number of mesotrons found under h g/cm^2 of air

TABLE V. *Absorption measurements in carbon with a 3.8 cm thick lead plate above the counters. (Chicago, Ryerson Laboratory.)*

ABSORBER	TOTAL COUNTS	COUNTS PER MIN.	ABSORPTION %
0	35,904	5.078±0.027	
87 g/cm^2 C	34,036	4.825±0.026	5.0±0.7

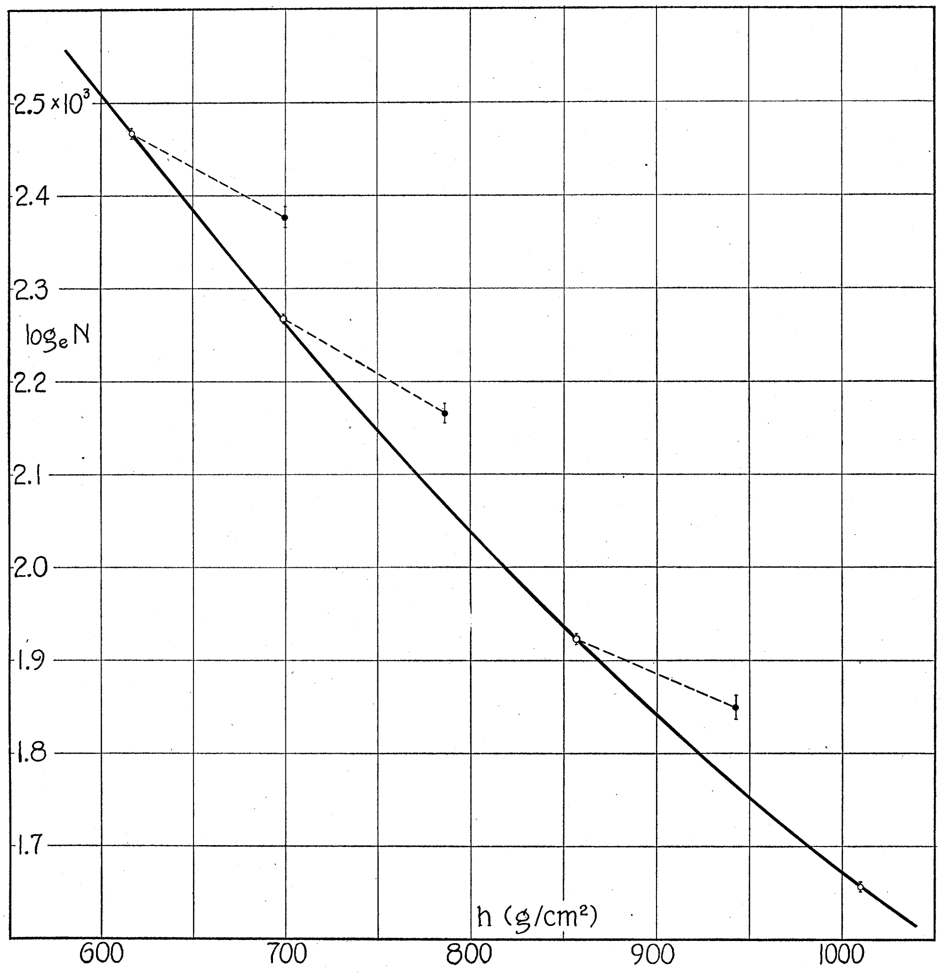

FIG. 3. Intensity of cosmic-ray mesotrons as a function of the depth.

plus δh g/cm² of graphite and the number of mesotrons found under $h+\delta h$ g/cm² of air alone represents the number of mesotrons disintegrating in the air layer δh. This is correct even if some mesotrons are generated in this air layer, provided that the same number of mesotrons is generated in the equivalent layer of carbon.

Let δz be the thickness in cm of the air layer δh. We may then define the average range L of the mesotrons before decay by the equation

$$\frac{\delta N}{N}=\frac{\delta z}{L} \quad \text{or} \quad \frac{1}{N}\frac{\delta N}{\delta h}=\frac{1}{L}\frac{\delta z}{\delta h}, \qquad (1)$$

where N is the number of mesotrons incident at a given altitude and $-\delta N$ is the number of those which disintegrate in traveling the distance $-\delta z$ down from this level.

For a homogeneous group of mesotrons, $L=v\tau$, where v is the velocity of the mesotrons and τ their lifetime. From the relativistic variation of time intervals with velocity, it follows that $\tau=\tau_0/(1-v^2/c^2)^{\frac{1}{2}}$, where τ_0 is the lifetime of the mesotrons at rest. Hence

$$L=v\tau_0/(1-v^2/c^2)^{\frac{1}{2}}=p\tau_0/\mu_0,$$

where p is the momentum and μ_0 the rest mass of the mesotrons.

For a nonhomogeneous group of mesotrons, $1/L$ in formula (1) is to be understood as the average of the reciprocal range for the single monoenergetic components, i.e.,

$$1/L=(\mu_0/\tau_0)\langle 1/p\rangle_{\text{Av}}=(\mu_0c^2/\tau_0c)\langle 1/pc\rangle_{\text{Av}}. \qquad (2)$$

Our experimental results enable us to calculate the average range for the mesotron beam at different depths.

Figure 3 gives directly the relative number of mesotrons $-\delta N/N = -\delta(\log N)$ which disintegrate in the depth intervals $616 < h < 700$, $699 < h < 786$, $857 < h < 944$ g/cm². Accordingly, we can calculate three values of $\mu_d = -(1/N) \times (\delta N/\delta h)$. We may, incidentally, note that μ_d represents the probability of disintegration in 1 g/cm² of air and is also equal to the difference between the absorption coefficients μ_a and μ_c in air and in carbon respectively, as given by the slopes of the corresponding logarithmic absorption curves. The quantity $-\delta z/\delta h$ can be similarly deduced, for the same depth intervals, from the curve which gives the altitude z as a function of the depth h. This is practically a logarithmic curve, as shown by Fig. 4, where the logarithms of our average barometer readings are plotted against the altitude. The observed points lie fairly close to a straight line represented by the equation

$$\log (h/h_0) = -z/(8.35 \times 10^5),$$

where $h_0 = 1.03 \times 10^3$.

The experimental values of μ_a, μ_c, μ_d, $-\delta z/\delta h$ and the corresponding values of the average range L are listed in Table VI against the depth intervals to which they refer. A set of values for an altitude near sea level is also given in the last row, in which μ_a is the slope of the logarithmic absorption curve in air at $h = 1010$ g/cm², μ_c is the absorption coefficient in carbon from the measurements in Table V and $-\delta z/\delta h = (8.35 \times 10^5)/h$.

The four values of L deduced from our experiments turn out to be the same within the experimental errors and equal to about 9.5 km.

The lifetime τ_0 is connected with the average range L by Eq. (2). The uncertainty in the value of τ_0, however, is larger than the experimental error in the value of L, since neither the mass, nor the energy spectrum of the mesotrons is known with accuracy. As already stated, only mesotrons above a certain momentum p_0 are recorded on account of the lead screen of 12.7 cm thickness between the G-M tubes. If the mesotrons are absorbed by ionization and we assume $\mu_0 c^2 = 8 \times 10^7$ ev, it follows from the Bloch formula that $p_0 c = 3 \times 10^8$ ev. At *sea level* the average value of $1/pc$ for mesotrons with momentum larger than p_0 can be estimated from Blackett's energy measurements, which give $\langle 1/pc \rangle_{\mathrm{Av}} = 1/(1.3 \times 10^9)(\mathrm{ev})^{-1}$. Inserting the above values of L, $\mu_0 c^2$, $\langle 1/pc \rangle_{\mathrm{Av}}$ in Eq. (2) we finally obtain $\tau_0 = 2 \times 10^{-6}$ sec.

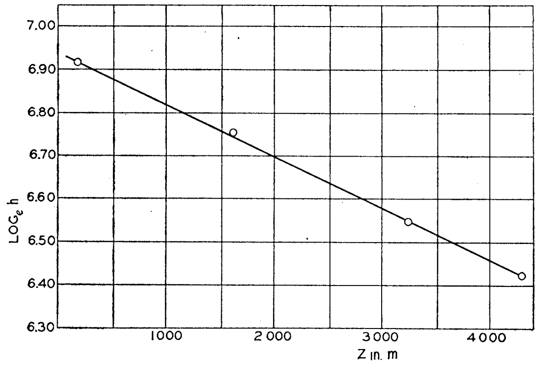

FIG. 4. Atmospheric depth as a function of the altitude.

TABLE VI. *Experimental values of μ_a, μ_c, μ_d, $-\delta z/\delta h$ and the corresponding values of the average range L.*

DEPTH INTERVAL IN G/CM²	μ_a 10^{-3} CM²/G	μ_c 10^{-3} CM²/G	μ_d 10^{-3} CM²/G	$\delta z/\delta h$ 10^3 CM³/G	L 10^5 CM
616–700	2.42	1.08	1.34	1.26	9.4±0.9
699–786	2.295	1.16	1.135	1.12	9.9±1.2*
857–944	1.824	0.84	0.984	0.93	9.5±1.7*
1010	1.47	0.59	0.88	0.825	9.4±1.6*

The errors marked with * have been increased above the standard deviation to allow for possible error in the interpolation.

This value of τ_0 is of the same order of magnitude, although somewhat smaller, than the values deduced from the zenith angle and from the temperature effects (see B.R.). No great accuracy, however, is claimed for the above figure, especially since our most exact determination of L is that at the highest elevation, while the energy spectrum is only known at sea level.

On one point our results failed to verify the predictions of the disintegration hypothesis. Eq. (2) shows that the average range L increases with increasing energy. The hardening of the mesotron beam, which is apparent from the decrease of the absorption coefficient in carbon (see Table VI), indicates an increase of the average mesotron energy with increasing depth. We should, therefore, expect L to increase as well, while the experimental values are practically constant.

To this argument we may offer the objection that the large variation of μ_c does not necessarily imply an equally large variation of $\langle 1/pc \rangle_{\text{Av}}$. As a matter of fact, our absorption measurements were only carried out with comparatively thin absorbers. Woodward and Street,[7] using much thicker absorbers, found no large difference in the absorption of mesotrons between Cambridge, Massachusetts, and Echo Lake. This would indicate that the energy spectrum, on the whole, does not change very much from 3240 m down to sea level, although the relative number of slow mesotrons is strongly reduced. It is, therefore, questionable whether we should expect an actual variation of the average range larger than the experimental errors of our measurements.

While we do not feel as if much weight should be attached to the apparent disagreement discussed above, it is perhaps worth while to examine briefly an alternative interpretation of our results, namely that the observed behavior is due not to decay but to a difference in stopping power between air and carbon. This would imply an energy loss in air more than twice as large as in the same mass of carbon.

As far as the ionization loss is concerned, no difference between air and carbon should be expected according to the Bloch formula. In fact, the atomic number of carbon is very close to the average of the components of air, and the Bloch formula predicts a very slow variation of the ionization loss per unit mass with atomic number.

Experimentally, also, the absorption of mesotrons was found to be roughly proportional to mass, even comparing elements of widely different atomic number. This is, in particular, true for the absorption measurements in carbon and lead referred to in Table III which have been performed with exactly the same arrangement as used for measuring the absorption in air and carbon. Thus, quite independent of any assumption as to whether or not the mesotrons loose energy by ionization only, it appears very unlikely that the energy loss might be much larger in air than in carbon. Such an extra loss, as a matter of fact, would apparently imply the existence of nuclear phenomena occurring in air alone of all the materials so far investigated.[8]

Moreover, the hypothesis of a difference in the energy loss in air and in carbon would not bring our results into agreement with those on the variation of the intensity with zenith angle. Actually, neglecting the decay, the intensity of the mesotron beam should depend only upon the thickness of the atmosphere in the direction from which the mesotrons are coming. Now, Auger and his co-workers, for instance,[9] have found the vertical mesotron intensity at the depth of 680 g/cm^2 to be 1.45 times that of the mesotrons coming in at 30° from the vertical direction, i.e., under $680/\cos 30° = 786$ g/cm^2 of air. From our curve, on the contrary, the ratio between the vertical intensities at $h = 680$ and $h = 786$ g/cm^2 turns out to be 1.3. This discrepancy is in the direction predicted by the disintegration hypothesis, since in the first case the change in the distance traversed by the beam is much greater than in the second case.

CONCLUSION

The reduction in number of cosmic-ray mesotrons was found to be much larger in a given mass of air than in the same mass of carbon.

A careful investigation showed that disturbing effects such as coincidences due to extensive showers or to ionization showers cannot be

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[7] R. H. Woodward and J. C. Street, Phys. Rev. **49**, 198 (1936).

[8] Professor E. Fermi kindly communicated to us recently the results of some calculations showing that a diminution of the stopping power of dense materials as compared with gases has to be expected if one takes into account the dielectric polarization of the absorber in the electric field of the passing particle. An abstract of these calculations has just been published (see Phys. Rev. **56**, 1242 (1939)). The influence on our measurements of the effect outlined by Fermi can be evaluated as follows. The mesotrons recorded without any absorber above the counters are those coming in with momentum larger than p_0. When an absorber is placed above the counters, the mesotrons recorded are those which reach the top of the absorber with momentum larger than $(p_0 + \Delta p)$, where Δp is the momentum loss in the absorber. Since the air or carbon absorbers compared in our measurements were not very thick (87 g/cm^2), Δp is small ($c\Delta p \simeq 1.7 \times 10^8$ ev). Thus, if we neglect the decay, μ_a and μ_c should be proportional to the energy losses in air and carbon of mesotrons with $p \simeq p_0$. If we take $p_0 c = 3 \times 10^8$ ev and the dielectric constant of carbon equal to 2, it follows from the formula given by Fermi that $\mu_a/\mu_c = 1.08$, while the experimental values of μ_a/μ_c are $\geqslant 2$, (see Table VI). It does not appear, therefore, as if Fermi's correction could account for more than a small fraction of the differences found under the conditions of our experiments.

[9] P. Auger, P. Ehrenfest Jr., A. Fréon and A. Fournier, Comptes rendus **204** 257 (1937).

responsible for more than a small fraction of the observed difference.

Similarly, it does not seem possible to account for this difference by a difference in the energy loss of mesotrons in air and in carbon.

Consequently our results strongly support the hypothesis of the instability of the mesotrons which form the hard component of the cosmic radiation.

The apparent lack of dependence of the average range upon atmospheric depth does not seem serious at the present because there is no definite knowledge about the variation of the mesotron energy spectrum with altitude and because the statistical fluctuations in the experimental values of the average range L are still large.

The writers acknowledge with thanks the helpful discussions and the support given to this work by Professor A. H. Compton. They are greatly indebted to Dr. J. C. Stearns for the facilities made available in Colorado and to Mr. O. E. Polk and Mr. W. Bostick for their generous assistance throughout the experiments. Finally, they wish to express their appreciation to the National Carbon Company for facilitating these experiments by lending them the large amount of graphite required.

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Electrons Arising from the Disintegration of Cosmic-Ray Mesotrons

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A simple theoretical expression is deduced for the ionization produced by the electrons arising from the disintegration of cosmic-ray mesotrons.

SEVERAL experimental facts indicate that the mesotrons which form the hard component of cosmic rays are unstable and that a considerable number of them actually disintegrate as they come down in the atmosphere. In each disintegration process an electron is supposed to be produced which carries the electric charge of the mesotron, while, in order to fulfill the requirements of the conservation laws, the emission of a neutrino is also postulated. The electron gets, on the average, half of the total energy of the mesotron and it then multiplies according to the cascade theory. Thus, the decay should increase the number of electrons which accompany the mesotron beam in the atmosphere, as compared with the number of those present in a condensed material. In the latter, of course, the disintegration practically does not occur until the mesotrons are stopped by ordinary energy loss and then the decay electrons have only a relatively small energy (half of the rest energy of the mesotrons, i.e., about 40 million ev).

The number of electrons arising from the decay has been estimated by Ferretti and by Euler.[1] The calculations involve the multiplication theory and are accurate to the same extent as the multiplication theory itself. This theory gives reliable results only for electrons with energies sufficiently larger than the critical energy E_c ($E_c = 1.5 \times 10^8$ ev in air), while most of the observed electrons have energies of the same order or smaller than E_c.

I wish to show that more definite conclusions can be reached by computing directly the amount of ionization produced by the decay electrons without recourse to the multiplication theory. The method is very obvious, but it may be of some interest since it provides a fairly accurate relation between measurable quantities, thus suggesting a further experimental test of the disintegration hypothesis.

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[1] B. Ferretti, Nuovo Cimento **15**, 421 (1938); H. Euler, Zeits. f. Physik **110**, 692 (1938). See also H. Euler and W. Heisenberg, Ergebn. d. Exakt. Naturwiss. **17**, 1 (1938).