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Counter Studies on Cosmic Rays at Sea Level

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Part I: Rossi transition curves for lead up to 400 g/cm^2 were studied with a triple coincidence counter arrangement in various geometrical configurations with shower angles from 4° to 60°; variations of cosmic-ray intensities were recorded simultaneously with a twofold vertical coincidence set and every point of the transition curves corrected accordingly. Even with small angle showers in an arrangement practically identical with Bothe and Schmeiser's no second maximum of the Rossi curve could be found. Absorption of shower particles and back scattering were studied.

Part II: Time variations were recorded with a vertical coincidence set giving daily mean values for one year in New York City. The temperature coefficient for the winter months (-0.155 percent per degree C) is about 5 times greater than the one for the summer months (-0.033). The total seasonal variation (maximum in winter, minimum in summer and fall) amounts to about 5.6 percent and is reduced to about 2.8 percent when the values are corrected for the same temperature. Thus a true seasonal variation with an amplitude of ±1.4 percent was found, in agreement with measurements elsewhere with ionization chambers. Various nonperiodic changes in cosmic-ray intensity were studied: the effect of the passage of cold and warm fronts, of the passage of barometric depressions and the effect of magnetic storms. The magnitude of these effects, as recorded in a vertical coincidence set agrees very well with the effects found with ionization chambers.

INTRODUCTION

IN the spring of 1939 cosmic-ray studies were begun in the Physics Department of Fordham University under the direction of the senior author (V.F.H.).

The following is a report on some preliminary work done on production of showers, absorption of shower particles, back scattering and on time variations observed with coincidence counter arrangements.

PART I: STUDY OF PRODUCTION AND ABSORPTION OF SHOWERS

During the Cosmic-Ray Symposium in Chicago (June, 1939) the existence or nonexistence of the second maximum, found first in 1934 by Ackermann and Hummel and by Drigo,[1] at a thickness of about 17 cm in lead (30 cm in iron) was a matter of controversy among several participants of this convention. Shortly before, Nielsen, J. E. Morgan and K. Z. Morgan[2] had published experiments on the shower production in iron up to thicknesses of 320 g/cm^2 at various shower angles and had not found a second maximum around 200 g/cm^2 as expected with either large or small angle showers. This is contradictory to the findings of Bothe and

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[1] A. Ackermann and I. N. Hummel, Naturwiss. **22**, 169 and 170 (1934); A. Drigo, Ricerca Scient. **5**, 88, 89 (1934).

[2] W. M. Nielsen, J. E. Morgan and K. Z. Morgan, Phys. Rev. **55**, 995 (1939).

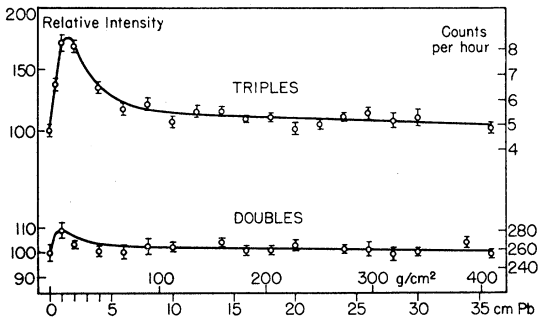

FIG. 1. Rossi transition curves for lead. The shower angle was 9.6°.

Schmeiser.[3] Bothe pointed out that the higher penetrating power of small angle showers may be mainly responsible for the second maximum of the Rossi curve and he published a curve where, with a shower angle of 4°, the second maximum was very well pronounced and nearly as high as the first maximum at 1–2 cm of lead while with an angle of 15° in the neighborhood of the critical thickness no hump at all was visible. Clay and Jonker[4] on the other hand found with a shower angle of 39° only a very slight indication of a second hump.

It seemed interesting to study the Rossi transition curve for lead up to thicknesses of more than 30 cm of the scattering block with double and triple coincidence counter sets and in various geometrical arrangements in order to clarify, if possible, the contradictory statements of the authors cited above.

Each point of the curve necessitated a recording of coincidences for several days, and since time variations of the general intensity of cosmic rays (barometer effect, air mass effect, magnetic storms, etc.) may amount to several percent it seemed advantageous to correct for time variations as much as possible by having a second set of apparatus giving the vertical coincidence counting rate for every day of operation at the same time.

1. Experimental arrangement

Two sets of three Geiger-Müller counting tubes arranged in a Rossi circuit with the usual extension amplifiers and recording units operating watch recorders were used for most experiments. A third set consisted of a twofold coincidence arrangement with the two counters set up permanently in a vertical plane and was operated continuously for almost one year to obtain the average cosmic-ray intensity for each day.

In the first-mentioned triple coincidence apparatus large Geiger-Müller counting tubes were used (diameter of the copper cathode cylinders 3 cm, length 30 cm).

The three high voltage sources used throughout these experiments were constructed by one of us (H.N.W.) and were similar to the stabilized high voltage circuit devised by N. S. Gingrich.[5] It was found desirable to make certain changes in the circuit. A description of this will be published elsewhere.

Most of the experiments were performed in the basement laboratory of Fordham University where the temperature changes encountered during the year are relatively small, namely between 20 and 27°C.

For reasons given above we thought it necessary to reduce all counts to normal barometric pressure. The barometer effect was determined with our twofold coincidence set.

2. Experiments with various angle showers

Since the second maximum was found first with arrangements where rather wide showers were causing the coincidences[6] we carried out one series of experiments where the three counters were placed parallel to each other in a horizontal plane with their centers 5 cm apart and the lead scatterer set up directly above this row of counters ("Hummel arrangement").

We obtained the typical Rossi transition curve with a first maximum at 1.3 cm lead. No second maximum between 10 and 20 cm was discernible.

The next series was taken with the usual "triangle arrangement." Here again no clear indication of a second maximum for lead thicknesses between 15 and 25 cm was found. Another series with the counter cross section forming an isosceles triangle of 30° (extended for a period of 2 months) showed slight indications of a hump

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[3] K. Schmeiser and W. Bothe, Naturwiss. **25**, 669 (1937); Ann. d. Physik **32**, 161 (1938); W. Bothe, Rev. Mod. Phys. **11**, 282 (1939).

[4] J. Clay, Rev. Mod. Phys. **11**, 287 (1939).

[5] N. S. Gingrich, Rev. Sci. Inst. **7**, 207 (1936).

[6] D. K. Froman and J. C. Stearns, Rev. Mod. Phys. **10**, 133 (1938).

and at least greater irregularities between 14 and 24 cm of lead.

Therefore we tried next an experiment where single rays and very narrow showers could cause coincidences. Three counters were placed above each other in a vertical plane, with the scattering lead plates above them. Double coincidences of the first two upper tubes and triple coincidences of all three tubes were registered separately for various thicknesses of the scattering lead up to 21 cm. For the double coincidences the shower angle as measured from the lower surface of the scattering plate to the contour of the middle tube was 12°, for the triples (as taken from the scattering block to the contour of the bottom tube) only 7°. This experiment, therefore, gives an approximate comparison of the Rossi curves at these two angles. The first maximum of these transition curves, well pronounced in both cases, was reached at about 2 cm.

Again no second maximum, at thicknesses beyond 15 cm lead was found.

It may be noted also that in this particular arrangement a great percentage of coincidences is due to single rays and therefore these curves still cannot be considered as unambiguous evidence against the possible existence of this second maximum.

3. Narrow angle showers

Next we carried out a long series of coincidence counting with a triangular arrangement, where the top tube (1) was placed directly under the scattering lead block (its thickness was varied in small steps from 0 to 36 cm of lead) while the lower two tubes (2) and (3) were arranged 25 cm from the upper tube. The minimum shower angle of two-particle showers effecting all three tubes or the two lower tubes (doubles) was thus about 9.6°. The total number of double coincidences used for each point of the following curves was from 1000 to 5000 (average counting rate 260 c/hr.), for triples 250 to 1700 (average counting rate 5 to 8 c/hr.). The actual counting rates for each thickness of the scattering block (22 cm×33 cm) were corrected for accidentals and then reduced to normal pressure.

The statistical errors computed for each individual point are indicated in Fig. 1.

At first glance we see that indications for a second hump are very slight. The curve for triples shows upward deviations at 13 and 25 cm slightly greater than the statistical error but none at 20 cm. The double coincidence curve is smooth showing no hump except at the rather well-known first maximum between 1 and 2 cm of lead.

This curve indicates that double coincidences in our arrangement were to a great extent caused by side showers and two-particle showers traveling downwards in oblique directions from the scattering surface to the two bottom counters. Dubious points were repeatedly checked.

The next step was to choose an arrangement which was identical to the one used by Bothe and Schmeiser.[3] In order to get a higher absolute counting rate these authors placed four counters at such a distance from the lower surface of the lead scatterer that the angle subtended from any point near the center of the lead surface to the centers of the lower two counters was only 4°. Counters 1 and 2 were connected in parallel and triple coincidences between these upper tubes (1 and 2) with the lower counters 3 and 4 were registered. This arrangement is shown in Fig. 2. Between the two rows of counters a lead plate of 0.7 cm thickness was placed and a lead bar of 1 cm thickness was used between counters 3 and 4. The 0.7-cm lead plate between the two rows of counters was used to exclude any soft shower

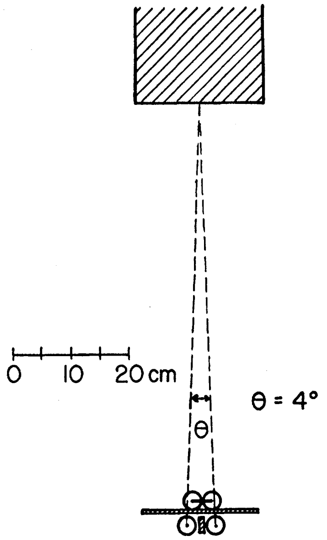

FIG. 2. Arrangement of counters for experiments similar to those of Bothe and Schmeiser.

particles which would tend to blur the effect of the hard narrow showers sought. The 1-cm lead bar used as a partition wall between the two lower counters served the same purpose and was also used by Zeiller[7] and by Schmeiser and Bothe.

These authors also reported that the second maximum was relatively more pronounced when the experiments were performed in the basement instead of on the top floor. This again would indicate that the hard component (mesotrons) is mainly responsible for the second maximum. We, therefore, made all experiments in the basement of the Physics Building of Fordham University with four stories above the experimental arrangement.

The curve shows no indication of any second hump, in complete contradiction to the findings of Bothe and Schmeiser who claim that the second maximum shows up clearly in narrow angle showers. We are at a loss to explain this disagreement. A final experiment was a repetition of the last described, but with no lead plates between the two rows of counters and with increased surface of the scatterer (30 cm×33 cm). The result was again negative.

4. Absorption of shower particles and back scattering

The absorption of shower particles was studied by using a triple coincidence set with two counters in a vertical plane, the third in a parallel position, but out of line, while the scatterer (lead) was placed above the third counter. The great inhomogeneity of the shower particles was demonstrated by the fact that for the thicknesses of the absorbing plates (between the second and third counter) up to 6 cm lead the absorption coefficient shows a steady decrease.

TABLE I. *Monthly means of cosmic-ray intensity.*

MONTH	UNCORRECTED INTENSITY c/hr.	BAROMETRIC PRESSURE INCH Hg	BAROMETER CORRECTED INTENSITY c/hr.	TEMPERATURE °F	TEMPERATURE-CORRECTED INTENSITIES	
					UNIFORMLY c/hr.	SEASONALLY c/hr.
Jan.	112.9	29.79	111.6	25.2	109.2	109.2
Feb.	—	—	—	—	—	—
Mar.	109.7	29.77	108.3	35.0	107.1	106.9
Apr.	108.1	29.78	106.8	46.0	106.3	106.4
May	108.9	29.76	107.5	59.6	108.3	107.7
June	108.0	29.76	106.6	68.4	108.2	106.9
July	107.5	29.88	106.8	74.6	108.9	107.3
Aug.	107.2	29.81	106.1	76.8	108.3	106.6
Sep.	106.4	29.89	105.8	67.4	107.2	106.1
Oct.	106.4	29.87	105.7	56.4	106.3	105.8
Nov.	109.3	29.99	108.9	43.2	108.3	108.3
Dec.	111.4	29.69	109.9	36.2	108.7	108.6
Average	108.7	29.82	107.6	53.5	107.9	107.3

Back scattering was studied with three parallel counters in a horizontal plane. The secondary radiation created in a block of lead (2 cm thick) was gradually absorbed in interposed sheets of aluminum (which itself gives a very small back scattering effect). The absorption coefficient in aluminum of secondary radiation from lead scattered backwards was found as 5.02 cm^{-1}.

PART II: TIME VARIATIONS

1. Barometer effect

Cosmic-ray daily means were obtained from readings taken at about 8 A.M. each day, throughout the year. Two argon-oxygen filled G-M tubes (effective area 1 cm×15 cm) were used in form of a telescope—the distance of the axes of the tubes in the vertical was 4 cm. The readings were taken from July 28, 1939, to July 31, 1940, with the exception of almost all of February.

Barometer data were taken from the publications and records of the New York Meteorological Observatory in Central Park (courtesy Mr. Morris). In order to obtain the mean barometric pressure corresponding to our 24-hour periods, the 2 P.M. and 9 P.M. data were averaged with the 7 A.M. datum of the successive day and related to the reading taken around 8 A.M.

The simple class correlation method was used for computation of the barometer coefficient and correlation coefficient (r). The barometer coefficient found was $k=-2.18$ percent of intensity per cm Hg ($r_{i,b}=-0.349$). All data were reduced to 30.00 inches Hg.

Table I may give an idea of the actual amount of this correction. This table gives the monthly means of cosmic-ray intensity uncorrected, the barometric pressure, the temperature, the cosmic-ray intensities reduced to 30.00 inches barometric pressure, and also the intensities corrected for temperature effect, as discussed in the following paragraph, reduced to 10°C (50°F).

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[7] O. Zeiller, Zeits. f. Physik **96**, 121 (1935).

2. Temperature effect

a. Correction with uniform coefficients.—Hourly temperature data were obtained from the Monthly Meteorological Summary of the Weather Bureau, Battery Place, New York City, through the courtesy of Dr. James H. Kimball. The daily mean temperature was computed corresponding to the 24-hour periods for which cosmic-ray intensity averages were obtained. The correlation of these averages with the mean temperatures of the same periods was thus found to be $r(i, T_d) = -0.482$ (T_d standing for daily temperature means). The temperature coefficient α_d was found to be $\alpha_d = -0.154$ percent of intensity per degree centigrade. The means for every day were then reduced to 50° Fahrenheit, resulting in the monthly means given in the table (under "Uniformly temperature-corrected intensities").

To exclude statistical fluctuations further, monthly barometer corrected means were directly correlated with the monthly temperature means. Here a much better correlation was obtained, namely $r(i, T_m) = -0.832$, but the coefficient was found to be essentially the same: $\alpha_m = -0.150$ percent of intensity per degree centigrade.

b. Correction with variable coefficients.—From the work done by Hess and collaborators in Tyrol a seasonal variation of the temperature coefficient was to be expected.[8] The fact that the temperature coefficient in turn depends upon temperature (being much smaller in summer) indicates that the air mass distribution is differently correlated with the same change of ground temperature in summer and in winter.

In order to investigate this dependency of the temperature coefficient two separate correlations were made for winter and summer. The result is given in the following table, the symbols employed being the same as before.

Summer	$T°\text{F} = 73.3$	$r = -0.054$	$\alpha = -0.033$ percent/°C
Winter	31.2	-0.272	-0.155 percent/°C

c. Discussion.—The absolute values of the temperature coefficient for the whole year found by us with our coincidence counter arrangement (-0.15) agrees very well with Blackett's theoretical value and with experimental values obtained with ionization chambers. The latter according to Compton and Gill[9] are small in the equatorial zone and reach a maximum of -0.25 percent per degree centigrade at latitudes beyond the "knee." In the geomagnetic latitude of New York (51°N) therefore our value seems somewhat low, but it must be remembered that at about the same geomagnetic latitude, Clay and Bruins[10] in Amsterdam found a value of -0.21 percent per degree, while on the Hafelekar (Austria) the average α for several years was about -0.1.

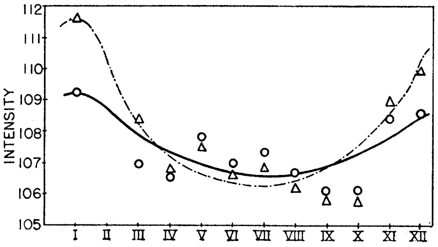

FIG. 3. Seasonal variation of cosmic-ray intensity.

The large variation of α from winter to summer found first at this station in Central Europe[8] is now fully confirmed by our measurements in New York. There is no doubt that the coefficients in the hot season are much smaller indicating that correlation between ground temperature and cosmic-ray intensity becomes almost zero.

d. Seasonal variation.—Figure 3 shows the seasonal variation of cosmic-ray intensity according to our measurements in 1939/40. The broken line corresponds to the barometer corrected values (without temperature correction) which are indicated by small triangles. The full line curve (points indicated by small circles) corresponds to the values corrected to a mean temperature (10°C), with two different coefficients of α (as mentioned in Section *b*), for the winter and summer months.

From the two curves it is quite obvious that the seasonal variation cannot be explained solely as a thermal effect although the temperature correction reduces the amplitude of the

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[8] V. F. Hess, Rev. Mod. Phys. **11**, 153 (1939); Phys. Rev. **57**, 781 (1940).

[9] A. H. Compton and P. S. Gill, Rev. Mod. Phys. **11** 136 (1939); P. S. Gill, Phys. Rev. **55**, 1154 (1939).

[10] J. Clay and E. M. Bruins, Physica **6**, 628 (1939).

seasonal change from about ±2.8 to about ±1.4 percent. This is in good agreement with results of a recent analysis of the Hafelekar data by the senior author.[11]

3. The front passage effect

Loughridge and Gast[12] presented evidence of an effect of the passage of air mass fronts on cosmic-ray intensities at the point of passage.

To study the effect of front passage on our counter telescope, front data were obtained from the weather stations at LaGuardia and Newark Airports.

During the whole year, 53 cold fronts and 14 warm fronts were usable for our purposes. Of the 53 cold fronts, 29 were accompanied by an increase of cosmic-ray intensity upon passage, two showed no change and 22 showed a decrease. The changes varied between +8.5 and −7.5 counts per hour, but give on the average an increase of +0.8 percent intensity per cold front passage.

Of the 14 warm fronts 7 were accompanied by an increase and an equal number by a decrease, the latter, however, being preponderant in value. The average was −0.7 percent intensity per warm front passage. Both of the values check well with the ones obtained by Loughridge and Gast.

4. The effect of the position of barometric lows

Y. Nishina, Y. Sekido, H. Simamura and H. Arakawa[13] published a survey of cosmic-ray intensities of Tokyo according to direction and distance of that city with respect to the relative position of depressions (lows): the center of the depression is taken as the center of 5 concentric circles with radii 222, 444, 667, 889 and 1111 km, (2 degrees latitude), respectively. Diameters were drawn at intervals of 30° dividing the 4 rings in 12 sections each, but leaving the innermost circle as single whole section, thus totaling 49 sections. This scheme was applied so that one diameter coincided with the north-south direction. The same scheme was used for our New York data. The 109 positions of the depressions and their respective times were taken from the 6-hourly weather maps which were also used to obtain front passage data.

It was found that about half the lows centered about a northwesterly position, making the number of cases for the other sections rather small and subject to great statistical uncertainties. The scheme showed clearly a maximum of cosmic-ray intensity in the southwest to south-southwest and a minimum in the northeast of the center of the depression. This is in good qualitative agreement with the Japanese findings. An indication of a smaller minimum in the West seems to exist also and the negative area is slightly more extended than for Tokyo, covering even the center.

5. The magnetic storm effect

Magnetic storm data were obtained from the Magnetic Observatory of Cheltenham, Maryland which are published[14] and from a private communication of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, D. C. giving the report which appears in September in the same journal. The reports give the exact time of a magnetic disturbance, i.e., its beginning, its end and its time of maximal activity, as well as the ranges of the deviation of the declination, the vertical and the horizontal intensities. However, they do not give the sign of the deviations from normal values nor the average deviation on a disturbed day which should be expected to have a closer relation to cosmic-ray intensity changes. Our numerical results, in this connection, must be taken with precaution.

The cosmic-ray intensities of the day of maximal disturbance were taken and compared with the preceding undisturbed or little disturbed day. It was found that out of 20 magnetic storms (in the course of 11 months) 16 lowered the cosmic-ray intensity and 4 increased it. In the latter 4 cases the ranges of variations of the horizontal intensity H were, however, relatively small, namely not higher than 225 gammas, whereas the ranges for the negative (lowering) cases extended up to 850 gammas. Furthermore it could be clearly seen that there was a rough proportionality between

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[11] V. F. Hess, Phys. Rev. **57**, 781 (1940).

[12] D. Loughridge and P. Gast, Phys. Rev. **56**, 1169 (1939); **58**, 194A (1940).

[13] Y. Nishina, Y. Sekido, H. Simamura and H. Arakawa, Nature **145**, 703 (1940).

[14] Cheltenham Magnetic Observatory, Terr. Mag. Atmos. Elec. **44**, 400 (1939); **45**, 48 (1940); **45**, 227 (1940).

the ranges and the (negative) differences of the intensity rates of corresponding counting periods yielding a correlation coefficient of $r_{i,H}=-0.56$ and a "magnetic storm coefficient," $m=-1.97$ percent of cosmic-ray intensity per percentage range of H. The cosmic-ray intensities used for this correlation had been corrected for pressure and temperature.

Considering the fact that in our analysis not individual magnetic storm effects but rather a general mean of this effect is obtained, it is of the expected order of magnitude (-2 percent). In individual magnetic storms this effect may be -15 percent, in others almost zero.[15]

Summing up our results on time variations it has been shown that it is possible to get cosmic-ray data with sufficient accuracy over a period of one year with a very simple double coincidence counter telescope. They allow conclusions on the variation of the temperature effect during the year, on the seasonal effect, on air mass effects connected with the passage of lows or of cold and warm fronts and on the magnetic storm effects.

The authors wish to thank Dr. W. F. G. Swann for placing the facilities of the Bartol Research Foundation at their disposal. They also express their indebtedness to Dr. J. A. Fleming, Director of the Department of Terrestrial Magnetism, to Dr. James H. Kimball (New York Meteorological Observatory) and to the Meteorological Staff of the Airports in Newark and La Guardia Field, Queens, N. Y., for supplying the necessary magnetic and meteorological data.

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[15] S. E. Forbush, Terr. Mag. Atmos. Elec. **43**, 203 (1938). Following a suggestion of Dr. J. A. Fleming our results on day to day variations of cosmic-ray intensities were compared by Dr. S. E. Forbush with results from the Compton model C meter placed at the Observatory at Cheltenham, Maryland. It was found that variations observed at both stations over the whole 11-month period were in good agreement.

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The Genetic Relation Between the Electronic and Mesotronic Components of Cosmic Rays Near and Above Sea Level

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The hypothesis that the cosmic-ray electrons observed at sea level are mostly due to the disintegration of the mesotrons has been tested (a) by comparing the ratio *soft component/hard component*, found at sea level in free air, with the same ratio found at 2050 m under a dense absorbing layer; (b) by comparing the Rossi curves for small showers under the same conditions; (c) by an especially detailed study of the increase of the soft component with increasing altitude. The results indicate that the proper lifetime of the mesotron is at least four microseconds and that the soft radiation observed at sea level is not entirely due to secondary processes of the mesotron.

§1. Introduction

It is now generally believed that the mesotrons, which form the penetrating component of cosmic rays, are unstable and have a mean life of a few microseconds. The evidence bearing on this very important hypothesis is twofold. First, the instability of the mesotron easily explains the long known and puzzling fact of the anomalous absorption of the hard component in air.[1] Second, there is the evidence concerned with the secondaries ("disintegration electrons") emitted when the mesotron disintegrates.[2]

The work described in this paper is chiefly concerned with this second aspect of the problem, which seems to us to be in a far more unsettled state than is generally thought. The

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[1] H. Euler and W. Heisenberg, Ergeb. d. exakt. Naturwiss. **17**, 1 (1938); see also B. Rossi, Rev. Mod. Phys. **11**, 296 (1939).

[2] The mesotron is usually identified with Yukawa's hypothetical particle which disintegrates spontaneously into an electron and a neutrino. H. Yukawa, Proc. Phys. Math. Soc. Japan **17**, 48 (1935); further literature in the papers of reference 1.