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An Experimental Test of Schremp's Theory of Cosmic-Ray Fine Structure*

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From a consideration of geomagnetic and absorptive effects upon the energy spectra of primary cosmic rays, Schremp some years ago inferred the existence of an anomalous directional intensity pattern in the sky, the analysis of which might be expected to yield detailed information concerning the identity of the primary cosmic rays, their energy spectra at infinity, and their interaction with absorbing matter. An east-west directional intensity survey has recently been carried out at Washington University, St. Louis, to test these predictions with apparatus of high angular resolution. In the curve of directional intensity *vs.* zenith angle z, the present results indicate the existence of symmetrical prominences at $z=\pm 20°$ and further suggest that other symmetrically disposed prominences may exist in the neighborhood of $z=\pm 10°$ and $z=\pm 40°$. This symmetry, in the light of the theory, carries implications concerning the character of the primary cosmic rays.

1. INTRODUCTION

A BRIEF summary of the Schremp fine structure theory is given in another paper.[1] An important case of such a fine structure occurs when the intensity $I(z)$ recorded by a coincidence counter telescope is plotted against the zenith angle z in the east-west plane. The well-known empirical relation is

$$I(z)=I(0)\cos^2 z. \tag{1}$$

The fine structure, susceptible of resolution by telescopes of small angular aperture, consists of prominences and depressions in the smooth curve of Eq. (1). The theory further contemplates an east-west positional symmetry of these irregularities under certain circumstances.[1] The present investigation was undertaken to establish the existence or non-existence of this fine structure and, if such exists, the presence or absence of positional symmetry.

2. THE COSMIC-RAY TELESCOPE

The coincidence counter array is somewhat over two meters high and comprises three triple-coincidence Geiger-Müller trains in parallel planes. The cathodes of the counter tubes are 9 cm in diameter and 71 cm long. The large scale of the apparatus affords an appreciable counting rate under the condition of small angular aperture for the array. The steel framework supporting the counter boxes has a cross section 95 cm by 114 cm and is extensible in the long direction. It was set for the survey at 207 cm. At this extension each triple-train subtends an angle of 5° in the plane in which it can rotate and 38° in the plane of the counter wires.[2] The framework is equipped to turn about a horizontal axis, and a goniometer reads the angular setting to one minute of arc.

* The investigation here reported forms the subject of a doctoral dissertation submitted to the Board of Graduate Studies of Washington University.

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[1] E. J. Schremp and H. S. Ribner, a paper read at the Chicago Cosmic-Ray Symposium, June 27–30, 1939, to appear in *Reviews of Modern Physics*, July–October, 1939.

[2] Half of the rays counted, however, traverse the center 30 percent of each of these angular ranges.

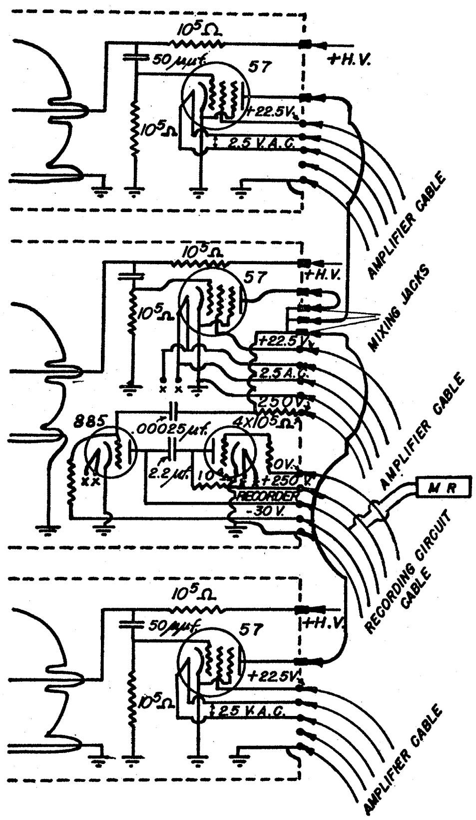

FIG. 1. Schematic circuit for one triple-train. Power supplies not shown. Top box: G-M tube and amplifier. Middle box: G-M tube, amplifier (above), and recording circuit (below). Bottom box: G-M tube and amplifier. The grid leaks of the recording circuit 885 tubes are each 5×10^6 ohms. "MR" signifies "message register."

The coincidence and recording circuit of each triple train is located in its center counter box. There is provision for external change-over from triple-coincidences to double-coincidences between any pair of counters or single pulses from any one counter. The circuit diagram for one triple-train, with power supplies omitted, is shown in Fig. 1. The counter quenching circuit employs straight resistance quenching[3] and is conventionally coupled to the amplifier of the Rossi coincidence circuit.[4] The recording circuit was designed by Mouzon.[5] The power supply includes a high voltage unit for the counters, employing the circuit of Schmitt,[6] which is stabilized against input and load fluctuation, a low voltage unit for the amplifiers of the conventional unstabilized type, and a separate low voltage RCA type TMV-118-B stabilized unit for the recording circuits. The recording assembly consists of three message registers to count the triple-coincidences of their respective trains, and a high speed stop-watch type recorder, used in testing, to count the pulses from a single counter.

The Geiger-Müller tubes are of a type which quench satisfactorily with a resistance of only 10^5 ohms. Hence resistance quenching[3] is used instead of the usual vacuum tube circuit.[7] With the constants shown the pulse length is 2×10^{-5} second. The method of construction, due to Neher,[8] involves oxidation of the cathode and filling with argon in the presence of xylol.[9] The tubes were filled to a pressure at which the threshold, at 20°C, was in the neighborhood of 1400 v. With the 5-mil tungsten anode wires initially used the counter pressure was 9 cm, while with the 10-mil wires finally used the pressures range from 4 to 8 cm. In most cases the plateau extends to 2000 volts.

Tests on the discrimination of the Rossi coincidence circuit against partial coincidences were conducted as follows: a triple train was connected for normal operation, but with the high voltage disconnected from one of the three counters. Under this circumstance single pulses and double-coincidences were incident on the mixing circuit, but no triple-coincidences. If the discrimination between partial and total coincidences were imperfect some counts would be recorded. None was recorded in tests lasting at least forty-five minutes.

From the oscillograph value of the pulse length (2×10^{-5} second) and the measured twofold accidental counting rate[10] (1.8 ± 0.2 counts per

[3] Cf. John Strong, *Procedures in Experimental Physics*, p. 276.
[4] B. Rossi, Nature **125**, 636 (1930).
[5] J. C. Mouzon, Rev. Sci. Inst. **7**, 467 (1936).
[6] O. H. A. Schmitt, Rev. Sci. Inst. **5**, 435 (1934).

[7] For vacuum tube quenching methods cf. Strong, reference 3, p. 277ff.
[8] Cf. H. V. Neher's discussion of construction methods for fast counters in Strong, reference 3, pp. 269–270.
[9] It has been observed that the optimum xylol content is rather critical: with too little, the threshold voltage is low and the plateau very short; while with an excess, the vapor pressure dependence on temperature leads to a marked temperature dependence of the counter characteristic curve.
[10] Obtained by subtracting from the twofold horizontal rate, which includes both accidentals and showers, the threefold horizontal rate, which consists almost wholly of showers. The twofold accidental rate then furnishes a reliable estimate of the true single counting rates, which was not available otherwise because our single pulse recorder missed an appreciable fraction of the counts at high single rates.

minute) the threefold accidental rate was computed[11] to be one count in eleven hours.

3. Experimental Procedure

The cosmic-ray telescope was set up on a portion of the roof of the Wayman Crow Hall of Physics of Washington University which provides a clear view of the eastern horizon and to within 15° of the western horizon. The axle of the framework was oriented north and south so the rotation would be in the local magnetic east-west plane.

The exploration of the east-west plane was carried out by what we shall call the "method of cycles." This method consists in the exploration of a section of the east-west intensity curve, consisting usually of six or seven distinct angles z. If each angle is exposed just once, in any order, for ten minutes, then in a period of a little over one hour the whole section will be exposed. The complete exposure of these six or seven points, in any order, at the rate of ten minutes per point, constitutes one cycle. The method of cycles then consists in recording the counting rate $I(z)$ and internally normalized values of $I(z)$ (cf. below), as primary data, and in averaging the latter for a large number of cycles. By describing each cycle in random order any secular drift of sensitivity of the apparatus within a single cycle is converted into random fluctuations about some mean sensitivity. The latter may vary from one cycle to the next but is canceled out in the normalization process, which involves only ratios of intensities. Hence only changes of sensitivity within a cycle remain effective, but these are converted into random fluctuations the only effect of which is to augment the probable error of the average of the normalized $I(z)$'s somewhat. This probable error can, of course, be computed by the method of residuals from the normalized $I(z)$'s for the complete set of cycles.

Table I. *Results for separate sections.*

1 Section Number	2 Number of Cycles	3 Zenith Angle z Degrees	4 Total Counts N	5 Deviation $\Delta(z)$	6 Probable Error $\sigma_r(z)$ from Residuals	7 Probable Error $\sigma_c(z)$ from Counts
I	20	0E	2974	+0.002	0.011	0.012
		5E	2965	+ .003	.012	.012
		10E	2902	+ .007	.013	.013
		15E	2736	− .013	.011	.013
		20E	2671	+ .024	.013	.013
		25E	2392	− .025	.012	.014
II	21	0W	2205	+ .012	.014	.014
		5W	2222	+ .028	.014	.014
		10W	2116	+ .003	.014	.015
		15W	2037	+ .003	.014	.015
		20W	1907	− .011	.014	.015
		25W	1742	− .035	.016	.016
III	18	15E	1493	+ .015	.020	.017
		20E	1376	− .011	.020	.018
		25E	1282	− .009	.018	.019
		10W	1548	+ .012	.019	.017
		15W	1415	− .026	.014	.018
		20W	1420	+ .028	.014	.018
IV	27	0	2381	+ .044	.012	.014
		30E	1652	− .035	.017	.017
		40E	1319	− .014	.016	.019
		50E	942	− .002	.019	.022
		30W	1698	− .008	.014	.016
		40W	1352	+ .014	.023	.018
		50W	940	− .008	.019	.022

4. Results and Discussion

Table I presents the individual results of each of the separate sections surveyed during the course of this investigation. In all, four sections in the east-west plane were explored. The zenith angles comprised within the separate sections are indicated in column 3 of this table. The total number of cycles in each section and the total number of counts[12] are indicated in columns 2 and 4, respectively. The quantities $\Delta(z)$ in column 5 constitute a measure of the deviation of the observed east-west distribution curve $I(z)$ from the empirical $\cos^2 z$ distribution. In column 6 are given the probable errors $\sigma_r(z)$ of $\Delta(z)$ as computed from residuals. These probable errors include any fluctuations in the over-all efficiency of the counter telescope. For comparison, we give in column 7 the probable errors $\sigma_c(z)$ of $\Delta(z)$ as computed from the total number of counts (column 4). The relative magnitudes of the two sets of probable errors provide a criterion for judging the reliability of the counter telescope. Of these two sets of values, the probable errors from residuals are the more significant.

Table II presents the final results, obtained

[11] By means of the formula for accidentals given by $A_{123}=3N^3\tau^2$, where N is the single counting rate and τ is the resolving time.

[12] The total counts here indicated may be used to form a reliable intensity curve for the angles within a single section, but not for all angles and all sections. Thus in Table II, we may not compare intensities at two angles by means of their total counts unless both angles are covered throughout in the same sections.

from an appropriate superposition at each zenith angle, of the data of the four sections of Table I. The column headings of Table II are identical with those of Table I, but they refer in this case to superposed values of the quantities designated.

The following relations serve to define the several quantities involved and to indicate the method of superposition used. The first ten relations suffice to form Table I. The last four relations tie together the entries of Tables I and II.

(1) $I(z)$ = the number of counts per 10 minutes at zenith angle z, for a given cycle.
(2) $I_0(z) = I(z) \sec^2 z$.
(3) $\bar{I}_0$ = the average, over z, of the $I_0(z)$'s for a given cycle.
(4) $I_0(z)/\bar{I}_0$ = the value of $I_0(z)$, normalized with respect to $\bar{I}_0$ for the purpose of reducing the given cycle to a basis comparable with all other cycles of the same section, when similarly reduced.
(5) $\langle I_0(z)/\bar{I}_0\rangle_{Av}$ = the average of $I_0(z)/\bar{I}_0$, over all cycles of a given section.
(6) $\Delta(z) = \langle I_0(z)/\bar{I}_0\rangle_{Av} - 1$ = the fractional deviation, at z, of the observed distribution from the $\cos^2 z$ distribution.
(7) $\delta(z)$ = the deviation of $I_0(z)/\bar{I}_0$ from $\langle I_0(z)/\bar{I}_0\rangle_{Av} \equiv$ the residual.
(8) $\bar{\delta}(z)$ = the average of $\delta(z)$, over all cycles of a given section.
(9) $\sigma_r(z) = 0.845\ \bar{\delta}(z)/(\text{no. cycles})^{\frac{1}{2}}$ = the probable error of $\Delta(z)$ computed from residuals.[13]
(10) $\sigma_c(z) = 0.675/(\text{no. counts})^{\frac{1}{2}}$ = the probable error of $\Delta(z)$ computed from total counts.
(11) $\Delta_i(z) = \Delta(z)$ for section i (i = I, II, III, or IV).
(12) $\Delta_0(z) = (w_i/w_0)\Delta_i(z) + (w_j/w_0)\Delta_j(z)$ = the weighted mean of $\Delta(z)$ for two superposed sections i and j.
(13) $w_i = k/\sigma_i^2$ = the weight of $\Delta_i(z)$, in terms of its probable error σ_i, where k is an arbitrary constant.
(14) $w_0 = k/\sigma_0^2 = w_i + w_j$ = the weight of $\Delta_0(z)$, which defines the probable error σ_0 of $\Delta_0(z)$.

TABLE II. *Combined results.*

1 Section Number	2 Number of Cycles	3 Zenith Angle z Degrees	4 Total Counts N	5 Deviation $\Delta(z)$	6 Probable Error $\sigma_r(z)$ from Residuals	7 Probable Error $\sigma_c(z)$ from Counts
IV	27	50W	940	−0.043	0.019	0.022
IV	27	40W	1352	− .022	.023	.018
IV	27	30W	1698	− .043	.014	.016
II	21	25W	1742	− .035	.016	.016
II, III	39	20W	3327	+ .007	.010	.012
II, III	39	15W	3452	− .011	.009	.011
II, III	39	10W	3664	+ .006	.011	.011
II	21	5W	2222	+ .028	.014	.014
I, II, IV	68	0	7560	+ .006	.008	.009
I	20	5E	2965	+ .003	.012	.012
I	20	10E	2902	+ .007	.013	.013
I, III	38	15E	4229	− .007	.009	.010
I, III	38	20E	4047	+ .014	.011	.011
I, III	38	25E	3674	− .020	.010	.011
IV	27	30E	1652	− .070	.017	.017
IV	27	40E	1319	− .049	.016	.019
IV	27	50E	942	− .037	.019	.022

The $\Delta_i(z)$'s contemplated in relations 11–14 should in general be adjusted to give the same average over z for those portions of any two superposed sections which overlap. Sections I and II, strictly speaking, overlap only in the zenith direction. However, it is known from measurements of the east-west effect[14] that the means of these two sections must agree to within less than one percent. Hence it was considered preferable to retain the original $\Delta_i(z)$'s for these two sections. The resulting superposition of Sections I and II yields the modified zenith value in Table II. In superposing Section III upon the combined Sections I and II, again it was found possible to retain the original $\Delta_i(z)$'s. In the case of Section IV, however, the only point which overlaps the combined Sections I, II, III is the zenith, and here the difference of the zenith values was too large to neglect. Accordingly, the $\Delta(z)$'s for Section IV were adjusted to effect an equality of the zenith values. This readjustment practically amounts to a rigid displacement of the curve for Section IV sufficient to bring the zenith values into coincidence.

The results of Table II are plotted in the top graph of Fig. 2. The ordinates indicate the absolute deviation[15] of the observed distribution from

[13] We here make use of a simplified formula for the probable error, based upon the normal law. That this simplification is sufficiently accurate has been ascertained by forming frequency polygons for each angle, and comparing them with the normal distribution.

[14] Cf. T. H. Johnson, reference 17; and T. H. Johnson and E. C. Stevenson, reference 18.

[15] As may be seen from the foregoing definition (6) of the fractional deviation $\Delta(z)$, the absolute deviation is, in effect, $\Delta(z)\cos^2 z = \{I(z)/I_0\} - \cos^2 z$. The latter quantity

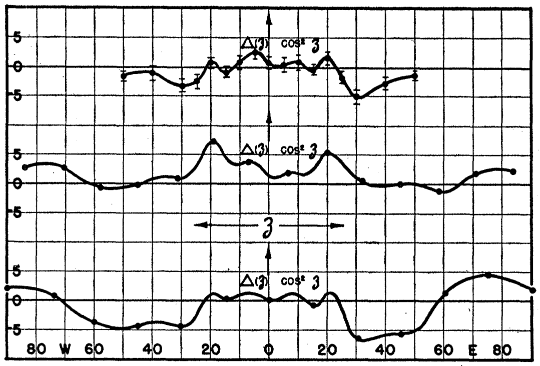

FIG. 2. East-west section of the cosmic-ray directional intensity pattern. z is the zenith angle in degrees. $\Delta(z)\cos^2 z$ is the absolute deviation, in percent of the zenith value, of the observed intensity from that given by the $\cos^2 z$ relation. Top graph: results of the present investigation. Middle graph: pattern deduced from the data of Johnson, reference 17, interpolated between experimental points. Bottom graph: pattern deduced from the data of Johnson and Stevenson, reference 18, likewise interpolated between experimental points.

the $\cos^2 z$ distribution, in percent of the zenith value. The probable errors are indicated for each experimental point. As a matter of additional interest, we have reproduced in the lower two graphs the earlier, less closely spaced data[16] of Johnson[17] and of Johnson and Stevenson,[18] respectively. The two curves interpolated between their experimental points are so drawn as to agree, qualitatively with respect to their form, and quantitatively with respect to the location of peaks, with our own curve. Since the interpolations have been effected without violation of any experimental points, there is no evidence of a discrepancy among the several surveys.

Our own curve, taken alone, indicates the existence of a pair of peaks, symmetrically disposed about the zenith, at angles $z=\pm 20°$. There are suggested also additional pairs of peaks near $z=\pm 10°$ and $z=\pm 40°$. The second curve confirms the peaks at 20°.

The east-west positional symmetry of the prominences in our own curve confirms the symmetry which was earlier pointed out[16, 19] to exist in the data from which the lower two curves were derived. The implications of this symmetry are discussed elsewhere.[19]

The existence of such peaks constitutes the sought-for Schremp effect.

The present evidence has been corroborated by recent independent results of Cooper,[20] and, in combination with the latter, seems to have securely established the above-mentioned effect. However, as has been pointed out elsewhere,[19] much additional experimental information remains to be found from an extension of this type of survey to other azimuths and localities, and from the development of cosmic-ray telescopes of sufficient aperture to permit a study of time variations in the directional intensity pattern.

In conclusion, the writer wishes to take this opportunity to express his appreciation to Dr. E. J. Schremp, who conceived this problem, for the very considerable extent to which his assistance and advice contributed to its completion.

is to be identified with Cooper's $\Delta(\theta)$ (cf. reference 20 below).

[16] These reduced data do not appear in the original articles quoted, but form a part of certain unpublished calculations of Dr. E. J. Schremp which he kindly made available to the writer. Since these data are based on total counts, the question arises as to the extent to which they may reflect sensitivity fluctuations in the apparatus. In general, a reduction of data based on total counts should agree closely with one based on ratios of intensities, provided that the primary data are obtained by a method involving frequent interchanges of directions, properly distributed over the whole angular range. We have verified this conclusion by comparing the two methods of reduction of our own primary data. Apparently the data of Johnson (reference 17) satisfy this condition, but those of Johnson and Stevenson (reference 18) do not. The possibility that the prominences in Johnson's curve are spurious instrumental effects would therefore seem quite remote. The experimental points of Johnson and Stevenson's curve, on the other hand, might be expected to show a spurious instrumental effect. However, they exhibit in themselves no prominences susceptible of such an interpretation. Instead, they straddle the prominences of the other two curves and otherwise agree fairly well with corresponding points of the latter.

[17] T. H. Johnson, Phys. Rev. **48**, 287 (1935).

[18] T. H. Johnson and E. C. Stevenson, Phys. Rev **44**, 125 (1933).

[19] Cf. E. J. Schremp and H. S. Ribner, reference 1; also E. J. Schremp, Phys. Rev. **53**, 915A (1938).

[20] D. M. Cooper, Phys. Rev. **55**, 1272 (1939). Subsequent results privately communicated to us by Professor N. S. Gingrich and Mr. Cooper continue to show three symmetrical pairs of prominences in the east-west plane, approximately at $z=\pm 7°, \pm 20°, \pm 35°$. These positions agree closely with the approximate positions given above by us, at $z=\pm 10°, \pm 20°, \pm 40°$. The ratios of the magnitudes of these prominences to their probable errors, in the light of all results up to date, are in excess of 7, 7, 3, respectively.