THE AZIMUTHAL EFFECT OF COSMIC RAYS AT LAHORE

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THE theory of the motion of charged particles in the earth's magnetic field in its application to cosmic-ray particles was worked out by Lemaitre and Vallarta.[1] One aspect of this theory leads to the study of the azimuthal variation of cosmic-ray intensity, special cases of which are the East-West and North-South asymmetries. Albagli Hutner[2] made a quantitative study of the azimuthal effect of cosmic radiation (variation of cosmic-ray intensity at a given point on the earth's surface and fixed zenith angle but for different azimuths), using a constant zenith angle of 60°, at a geomagnetic latitude of 20° N. This geomagnetic latitude was chosen because the penumbra[3] (the reader is referred to Shremp's paper for reference for details about the penumbra), which makes possible the determination of the energy spectrum of the primary cosmic rays, makes a significant contribution at intermediate latitudes (between 10° and 40° geomagnetic latitude). The author undertook to perform an experiment at Lahore (geomagnetic latitude 22° N.) to find the predicted azimuthal effect for a fixed zenith angle of 60°. Preliminary reports[4] on the experiment appeared earlier. This report sums up the results of the three separate runs of the experiment. The resolving power of the telescope was increased in each successive run.

In the first two runs four cosmic-ray telescopes were used, each consisting of three triple coincidence G-M counter tubes with lead filter of 10·2 cm. while in the third run of the experiment only two telescopes were used. The solid angle range covered in the first, second and third runs were 14·5°, 8·07° and 7·15° in the vertical and 65°, 38·87° and 37·93° in the lateral planes respectively. The telescopes were mounted on the four edges of a square table which was rotated back and forth through an angle of 180°. Interchanging of opposite telescopes, in the first run, was done automatically after an interval of 35 minutes while in the second and the third run the interchanging was done by hand at frequent intervals. The azimuths were changed by steps of 10° each time. During the second run each of the four telescopes swept the whole sky for the fixed zenith angle at intervals of 10° at least twice and some azimuths were covered more than twice. The two or more readings of one telescope at the same azimuth, though taken about a month and a half apart, do not differ from each other by more than their statistical fluctuations and thus showed the systematic working of the telescope for the whole experimental period. These readings were taken between October 31, 1941 and February 21, 1942.

Compared with the solid angle range of the first run of the experiment, that of the second run was reduced giving therefore a resolving power three times as great. The number of counts per unit time for each new telescope should therefore be one-third of the number of counts per unit time in the earlier experiment. The only other difference between the new telescopes and the old was that among the four some of the individual G-M tubes had

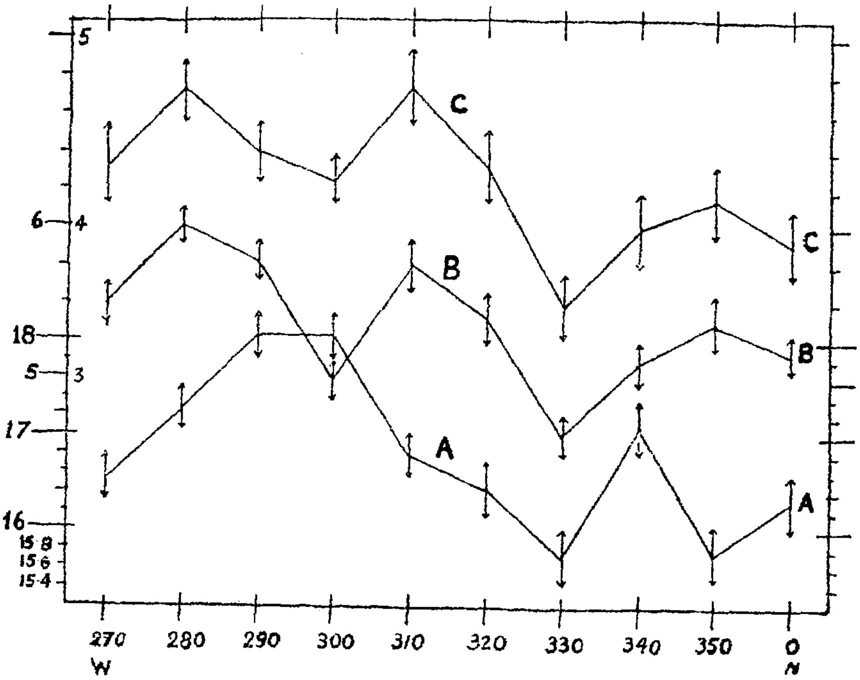

FIG. 1. The azimuthal variations of cosmic-ray intensity for a fixed zenith angle of 60° at Lahore. The vertical scale for each curve is given at the left.

been interchanged. Another rough check on the systematic working of the tubes was provided by the fact that the ratio of the counts per day in the new experiment to that in the old was 1 : 3·12. In the third run the two telescopes covered the azimuths due North-West and South-East directions only. The G-M tubes used in this experiment were of a larger size than those used in the first two runs of the experiment. For the third run the data presented in this paper, were taken between November 25, 1944 and December 22, 1944.

The apparatus was installed in a special observatory constructed for the purpose on top of the Physics Laboratory of Forman Christian College. The roof of the observatory was made of a single sheet of galvanized iron and was thus virtually open to the sky.

Curves of Fig. 1 represent the data of the second run of the experiment. Curves A, B, C. and D of Fig. 1 represent the number of triple coincidences per hour obtained by telescopes A, B, C and D for each 10° interval of azimuths for the fixed zenith angle of 60°. Each telescope made a complete turn of the horizon, except for the azimuths where one of the amplifying tubes or one of the power tubes or one of the G-M tubes was not functioning properly. These exceptions are indicated by the gaps in the graphs. An examination of these four curves clearly shows the marked irregularities in the North-West quadrant. The humps in the curves in this quadrant occur at the same angles in each curve. No such marked variations at consistent azimuth angles are shown in other quadrants.

Curves A and C represent the data collected by opposite telescopes A and C during the same period, and curve E is the mean of A and C. Similarly curve F is the mean of B and D and represents the data collected by two opposite telescopes B and D during the same period. In other words each point of curve F represents data taken about forty days after the data taken for the corresponding point of curve E. In taking the means it is assumed that the efficiency of the two opposite telescopes in each case is the same. By and large the number of counts at each angle is doubled, and therefore the statistical errors are reduced. It should be noted that in the N-W quadrant all the points of curve F coincide with those of curve E within the probable errors except at 350°. Even for this angle the general form of the curves is the same. The parallelism between curves E and F is clear enough, with the exception of regions between 140°-70° and between 210°-50°.

Curve G is the weighted mean of all the four telescopes. The means of all the ordinates for a complete turn of the horizon of curve A, and similarly of curves B, C and D were taken separately. These means were weighted with reference to the mean of all the ordinates of the four curves (A, B, C, D) and it turned out to be the same as that of telescope A. That is, all the points of curves B, C and D were multiplied by the ratio of their respective means to the general mean or that of curve A. It is again to be noted that in the N-W quadrant curve G has marked azimuthal irregularities.

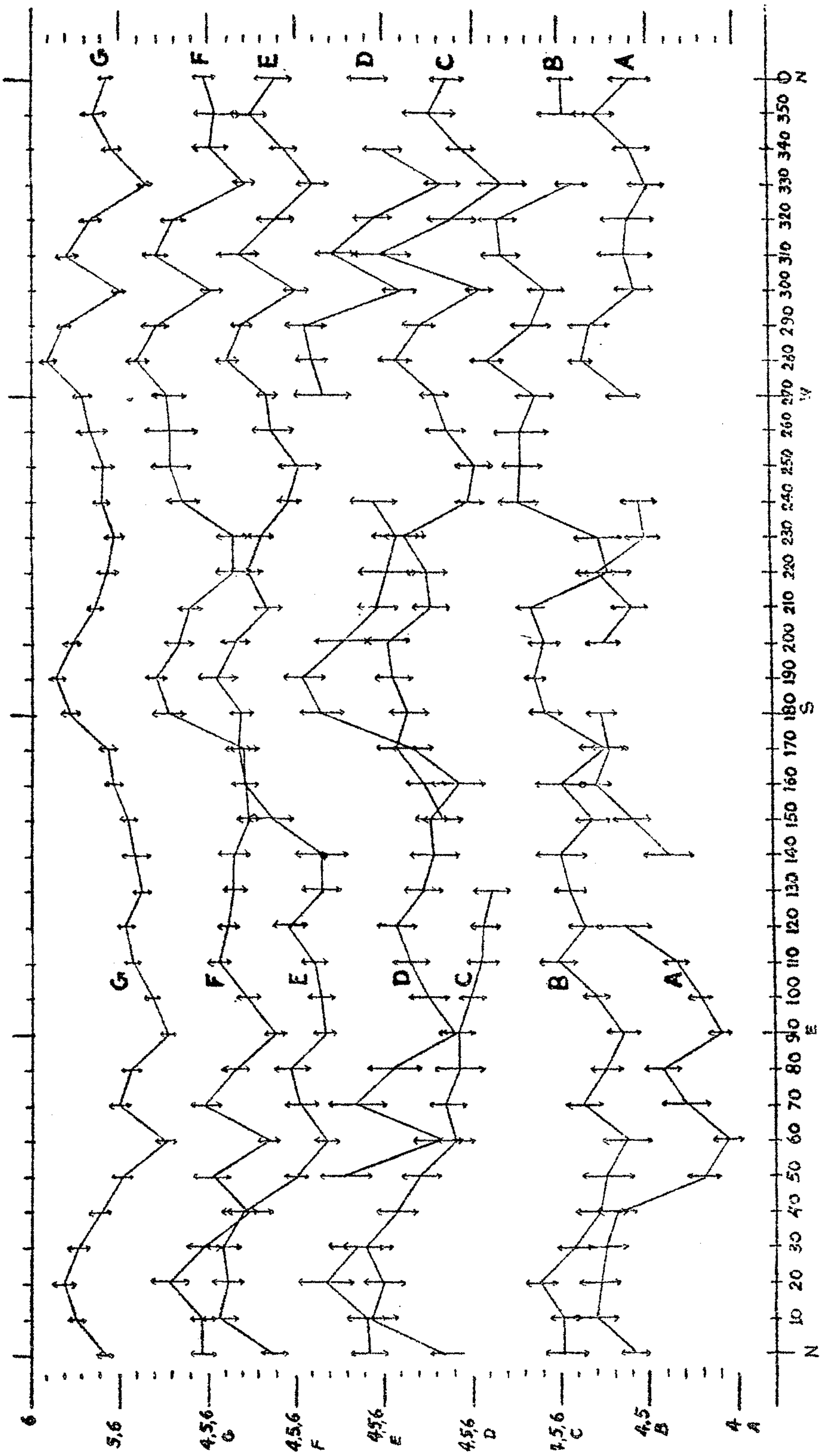

FIG. 2. The azimuthal effect in the N-W quadrant as given by curves A, B, C representing successively decreasing cones subtended by the telescopes.

Two humps, one at 280° and the other at 310° are prominent in this qudrant. The curve in the N-E quadrant varies considerably less. This is in agreement with Hutner's conclusion that in the northern hemisphere, the curve between the N and E directions should be less irregular because of the supposed predominance of positive particles.

Curves of Fig. 2 represent the data of all the three runs of the experiment in the N-W qudrant, where the azimuthal irregularities are much more pronounced and where comparison with the theoretically calculated curve is possible. Curves A, B, C of Fig. 2 are the results of the 1st, 2nd and 3rd runs of the experiment respectively. For a wider angle of the telescope in the lateral plane the azimuthal effect averages out as is apparent from curve A. With a smaller angle the widths of maxima and minima in the azimuthal curve should be more pronounced. This is exactly the case as is clearly shown in the curves B and C. Even for these two curves the angle of the telescope in the lateral plane is much larger than the widths of the maxima and minima which are no more than 20°. The real curve should show far more pronounced maxima and minima and with this in view the resolving power of the telescope is further increased by decreasing the lateral angle of the telescope to near about 15°. The new results will be published later.

The cone of the telescope used for obtaining curve B is slightly larger than that for curve C and the parallelism between these two curves is significant. The maxima and minima occur at the same angles and are more pronounced in curve C than in B as should be expected. Another point to be noted is the lesser prominence of the hump at 280° than that at 310° for the smaller cone (curve C). This would indicate that as the solid angle subtended by the telescope becomes smaller the 280° maxima begins to flatten out and the 310° maxima comes more and more into prominence. For a very small cone the experimental curve seem to approach the theoretically calculated curve of Hutner, giving the maxima at 310° instead of 305°. This difference in the position of the maxima may also be wiped out for still narrower cones if the telescope is directed towards 305°.

Hutner's results refer strictly to primaries before they enter the atmosphere. In the present experiment the secondaries were filtered off by 10·2 cm. of lead and therefore telescopes recorded the passage of hard secondaries presumably having the same direction as the primaries which were responsible for producing them.

The East-West and North-South Asymmetries

Special cases of the azimuthal effect are the E-W and N-S asymmetries, Tables I and II give the experimental results on these asymmetries at Lahores

TABLE I

Counts per minute in N-W qudrant (N_A) and in the S-E quadrant (N_B)

Angle	N_A	Angle	N_B	$\alpha = 2\frac{N_A - N_B}{N_A + N_B}$
0	0·272±0·005	180	0·298±0·006	− 0·091±0·027
350	0·263±0·005	170	0·280±0·005	− 0·062±0·026
340	0·285±0·005	160	0·273±0·005	+ 0·043±0·028
330	0·262±0·005	150	0·267±0·005	− 0·019±0·027
320	0·274±0·005	140	0·267±0·005	+ 0·026±0·026
310	0·280±0·004	130	0·290±0·004	− 0·035±0·016
300	0·301±0·004	120	0·278±0·004	+ 0·080±0·020
290	0·301±0·004	110	0·272±0·004	+ 0·101±0·020
280	0·288±0·004	100	0·252±0·004	+ 0·133±0·016
270	0·276±0·004	90	0·256±0·004	+ 0·075±0·016

TABLE II

Counts per hour from N-E-S (x) *and from S-W-N* (y)

Angle	X	Angle	Y	$\alpha = 2\frac{x - y}{x + y}$
0	5·14±0·10	180	5·53±0·12	− 0·073±0·029
10	5·46±0·11	190	5·69±0·12	− 0·041±0·029
20	5·60±0·13	200	5·52±0·12	+ 0·014±0·032
30	5·44±0·13	210	5·26±0·11	+ 0·021±0·032
40	5·19±0·15	220	5·12±0·13	+ 0·013±0·038
50	4·96±0·13	230	5·04±0·13	− 0·016±0·037
60	4·47±0·12	240	5·18±0·12	− 0·147±0·035
70	4·98±0·13	250	5·16±0·16	− 0·035±0·040
80	4·86±0·13	260	5·30±0·20	− 0·087±0·046
90	4·44±0·09	270	5·40±0·12	− 0·195±0·030
100	4·62±0·09	280	5·80±0·09	− 0·226±0·025
110	4·83±0·11	290	5·61±0·11	− 0·149±0·030
120	4·92±0·12	300	4·99±0·10	− 0·014±0·031
130	4·73±0·12	310	5·60±0·14	− 0·167±0·035
140	4·81±0·18	320	5·32±0·14	− 0·100±0·045
150	4·89±0·11	330	4·70±0·11	+ 0·040±0·032
160	5·05±0·13	340	5·08±0·12	− 0·006±0·035
170	5·10±0·12	350	5·29±0·16	− 0·037±0·038

(geomagnetic latitude 22° north) for a fixed zenith angle of 60°. Table I is the same as Table I already published[4] except for the probable errors, which were not correctly calculated. A correction for these errors was sent but due to the present conditions causing delays in mails, the author has not seen it published. Table II gives the results of the 2nd run of the experiment. (x) represents the counts per hour for each angle from N-E-S while (y) gives the counts per hour from S-W-N. The asymmetry $\alpha = 2\frac{x-y}{x+y}$ is calculated at each 10° interval.

A notable feature of these asymmetries is that the maximum E-W difference does not coincide with the magnetic E-W plane, but is found to occur in the 280°-100° plane. Each of the four telescopes gives the maximum E-W difference at the same angle (280°-100°). This becomes more significant when we look at Table I, which also shows that the maximum E-W difference occurs in 280°-100° plane.

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SUMMARY

Four triple coincidence cosmic-ray telescopes directed at a common zenith angle of 60° were mounted on a turn table. Each telescope represented a vertical plane 90° from that of its neighbour. In each was inserted 10·2 cm. of lead. By 180° reversals each telescope was interchanged in its position with the one directly opposite. Countings were made at settings of the table for every 10 degree of azimuth angle. Azimuthal variations in the North-West and North-East quadrants check qualitatively those theoretically predicted by Hutner. The data are still not sufficient to warrant quantitative comparison. It has been found that the maximum East-West asymmetry does not coincide with the magnetic East-West plane, but occurs at 280°-100° plane.

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