523·165:550·38(54)

Azimuthal variation of cosmic ray intensity for zenith angle 60° at Hyderabad, India

S. BHAGAVANTAM and D. S. R. MURTY

Physical Laboratories, Osmania University, Hyderabad, India

(*Received 10 January 1955*)

1. Introduction

Azimuthal variation of cosmic ray intensity (at constant zenith angle) is a geomagnetic effect and its study provides a powerful method of determining the charge and energy spectra of the primary cosmic rays. An experiment of this type was first suggested by Vallarta (1939). In such experiments, the interpretation of the results depends on a knowledge of the allowed cone (Lemaitre and Vallarta 1936) and particularly of the penumbral bands (Hutner 1939). According to Hutner, who studied the penumbra at $\lambda=20°$ for a zenith angle of 60°, the penumbral effect is confined to western azimuth and particularly to the northwest quadrant for positively charged particles in the northern hemisphere while for the negative primaries, the pattern is mirror imaged along the magnetic meridian. The penumbra in the neighbourhood of the equator was studied by Yong-Li (1939). Vogelaere (1950) has slightly modified it and concluded that a comparison of Yong-Li's work with that of Hutner's shows that a part of the phenomenon calculated for latitudes very close to the equator recurs at 20°. However, the shape of the penumbral regions varies quickly.

Gill (1945a, 1945b, 1947, 1954) studied the azimuthal effect of the penetrating component of cosmic rays at Lahore ($\lambda=22°$N) and it has been shown that the experimental results of narrow cone study show a striking similarity to the theoretical curve of Hutner. He concludes from his Lahore experiments that primary cosmic rays are positively charged and the energy spectrum of the primary radiation within the energy range 385 to 500 millistörmers obeys the law KE^{-c} with $c \simeq 2\cdot8$ where K is a constant and E is the energy. His experiments at Bombay ($\lambda= 9\cdot5°$N) (Gill and Vaze 1948) indicate that the primary spectrum for energy range 350 to 640 millistörmers can be represented by KE^{-c} with $c = 2\cdot45$. Vallarta and others (1947) studied the azimuthal effect at Mexico city ($\lambda = 29°$N, $h = 2242$ m) for zenith angles 20°, 40° and 60° without using a lead absorber. The analysis of their observations yields an energy spectrum of the primary cosmic rays of the form $KE^{-1.45}$ in the energy range between 350 and 600 milliströmers. There is no evidence of primary negatives. Bhowmik and Bajwa (1952) investigated the azimuthal effect for the hard component at Delhi ($\lambda = 19°$N) for a zenith angle of 40° and found the energy spectrum to be of the form $KE^{-1.45}$. Their observations do not give any evidence of negative primaries. But later, from a critical analysis of the experimental data on the azimuthal intensity variation, Bhowmik (1953) points out that the data are consistent if the negatives form 20 per cent of the total radiation.

The azimuthal distribution of cosmic rays at very high altitudes was studied by a number of workers (Biehl *et al.* 1949, Dwight *et al.* 1950, Winckler *et al.* 1950, Van Allen and Gangnes 1950, Neher 1951, Kaplon *et al.* 1952). Most of the above experiments as well as others lead to the conclusion that it is quite likely that only one kind of incident positively charged particle exists.

The azimuthal effect is very pronounced in the equatorial regions as well as in intermediate latitudes (Gill 1954). Work of this type at low latitudes and altitudes is meagre. Hence the present investigation of the azimuthal effect for a constant zenith angle of 60° is undertaken at Hyderabad, India ($\lambda = 7\cdot7°$N, $h = 1800$ ft).

TABLE 1

Azimuthal variation of cosmic rays for zenith angle $\theta = 60°$ at Hyderabad, India ($\lambda = 7\cdot7°$ N; $h = 1800$ ft)

Azimuth α	Counts per 50 minutes $I(\alpha, \theta)$	Azimuth α	Counts per 50 minutes $I(\alpha, \theta)$
N 0°	5·355 ± 0·110	S 180°	5·420 ± 0·111
10°	5·218 ± 0·114	190°	5·542 ± 0·113
20°	5·175 ± 0·112	200°	5·453 ± 0·114
30°	5·150 ± 0·107	210°	5·615 ± 0·116
40°	5·136 ± 0·110	220°	5·630 ± 0·116
50°	5·140 ± 0·109	230°	5·573 ± 0·116
60°	5·144 ± 0·108	240°	5·645 ± 0·115
70°	5·091 ± 0·109	250°	5·663 ± 0·117
80°	5·040 ± 0·108	260°	5·652 ± 0·115
E 90°	5·050 ± 0·107	W 270°	5·667 ± 0·113
100°	5·071 ± 0·109	280°	5·682 ± 0·113
110°	5·093 ± 0·109	290°	5·550 ± 0·111
120°	5·110 ± 0·111	300°	5·640 ± 0·115
130°	5·200 ± 0·109	310°	5·710 ± 0·114
140°	5·267 ± 0·112	320°	5·503 ± 0·113
150°	5·330 ± 0·115	330°	5·410 ± 0·111
160°	5·353 ± 0·113	340°	5·379 ± 0·114
170°	5·392 ± 0·115	350°	5·431 ± 0·113

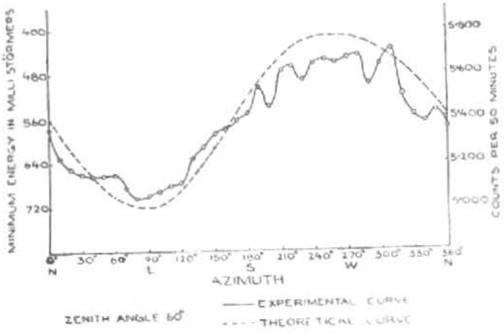

Fig. 1. Cosmic rays at $\lambda = 7.7°$N (Hyderabad, India)

TABLE 2

Azimuthal variation

$\lambda = 7\cdot7°$N		$\theta = 60°$	
α Azimuth	$E(\alpha, \theta)$ Millistörmers	$I(\alpha, \theta)$ Counts per 50 minutes	$c-1$
N 0°	555	5·355	0·45
30°	640	5·150	0·45
60°	700	5·144	0·44
E 90°	721	5·050	0·44
120°	687	5·110	0·44
150°	614	5·330	0·44
S 180°	525	5·420	0·45
210°	454	5·615	0·45
240°	418	5·645	0·46
W 270°	416	5·667	0·46
300°	438	5·640	0·46
330°	486	5·410	0·45
		Average =	0·45

2. Experimental arrangement

The apparatus consists of two identical counter telescopes pointing in symmetrically opposite directions. Each telescope consists of three pairs of G. M. counters. The counters in each pair are joined in parallel so that they act as a single counter. Each telescope subtends a solid angle of about $5 \cdot 5^\circ \times 24^\circ$. An 11-cm lead block is introduced in each telescope which means that the penetrating high energy secondaries measured by the instruments at lower elevations have practically the same direction as the primaries which produce them. The observations have been taken for every 10° of azimuth angle and the time of exposure at each azimuth angle is more than 150 hours. The counts given in Tables 1 and 2 are on the basis of 50-minute interval. The mean curve of the two telescopes is given in Fig. 1. The G. M. counters are daily checked individually to ensure their proper working.

3. Results

(a) East-West and North-South Asymmetries

Special cases of the azimuthal effect are the east-west and north-south asymmetries. The east-west asymmetry value got in this experiment is 11·5 per cent and this agrees well with the figure of 10·73 per cent obtained by us for the asymmetry of the hard component at Hyderabad at the zenith angle of 60° in separate experiments. The north-south asymmetry, as observed in this paper, is very small and the results obtained earlier at the zenith angle of 60° for such asymmetry confirm this.

(b) Energy Limits and Determination of the Energy Spectrum

The intensity in a given direction (azimuth angle α and zenith angle θ) is given by

$$I\ (\alpha,\ \theta) = \int_{E(\alpha,\,\theta)}^{\infty} F(E)dE$$

where $F(E)$ is the energy spectrum and E the energy. The lower limit $E(\alpha, \theta)$ is given by the theory of the allowed cone and depends on the location and size of the penumbra bands.

The dotted line in Fig. 1 is the theoretical curve obtained from energy considerations. The minimum energies are computed from the main cones of the Lemaitre-Vallarta (1936) theory with the help of the graphical representation given by Alpher (1950). The energy in millistörmers of the main cones are interpolated for each azimuth angle at a constant zenith angle of 60° for a latitude of 7·7°. While considering the energy limits, the eccentricity of the earth's magnetic centre must be taken into account. Corrections for the minimum energies are not applied in the present case as they are not found to be necessary at the geographic longitude of this station, namely 78°27′ (Vallarta 1948).

The energy range explored in the present study is between 416 and 721 millistörmers or an interval of 305 millistörmers.

The primary energy spectrum has been assumed to be $F(E) = KE^{-c}$ and the exponent computed in the present work is shown in Table 2. If $I(\alpha, \theta)$ is the observed intensity in a direction α, θ then we have

$$I\ (\alpha,\ \theta) = \int_{E(\alpha,\,\theta)}^{\infty} KE^{-c}\, dE = \frac{-K}{c-1} \cdot \frac{1}{E\,(\alpha,\,\theta)^{c-1}}$$

The constant K has been evaluated from six pairs of points and the mean value of K has been used in calculating the value c—1, The exponent c—1 as obtained from the results is in good agreement with that of Bhowmik and Bajwa, Vallarta and coworkers and others.

(c) Primary cosmic rays

The agreement between the theoretical and experimental curves in Fig. 1 is very satisfactory. The experimental curve in the eastern azimuth is comparatively smooth while there are significant oscillations in the western azimuth. It may be noted that there is a general similarity between the experimental curve relating to the north-west quadrant as obtained in this paper and that of Gill and Vaze (1948) at Bombay ($\lambda = 9 \cdot 5°$N). It has already been mentioned that according to Hutner, the penumbral phenomenon is confined to the western sky and particularly to the north-west quadrant for positively charged primary particles in the northern hemisphere. It can, therefore, be inferred from the graph that all the primaries are positively charged or at least the negative primaries are quite few in number.

4. Summary

The azimuthal variation of cosmic ray intensity has been studied for a zenith angle of 60° at Hyderabad, India ($\lambda = 7 \cdot 7°$N, $h = 1800$ ft). The soft component is eliminated by introducing a lead absorber of 11 cm thickness in each of the two telescopes that have been used in the experiment. The energy range explored is between 416 and 721 millistörmers. The primary energy spectrum has been assumed to be of the form KE^{-c} and the exponent c as obtained from the results is found to be $1 \cdot 45$. This is in good agreement with that obtained by the earlier workers. It has been inferred from the experiment that all the primary cosmic rays are positively charged or at least the negative primaries are quite few in number.

REFERENCES

Alpher, R. A.	1950	*J. geophys. Res.*, **55**, p. 437.
Bhowmik, B. and Bajwa, G. S.	1952	*Phys. Rev.*, **87**, p. 530.
Bhowmik, B.	1953	*ibid*, **89**, p. 327.
Biehl, A. T., Neher, H. V. and Boesch, W. C.	1949	*ibid*, **75**, p. 688.
Dwight, K., Sabin, R. and Stix, T.	1950	*ibid*, **78**, p. 324.
Gill, P. S.	1945(a)	*Proc. Indian Acad. Sci.*, **22**, p. 53.
	1945(b)	*Phys. Rev.*, **67**, p. 347.
	1947	*ibid*, **71**, p. 398.
	1954	Presidential Address, Physics Section, 41st. Session Indian Sci. Cong. Assoc.
Gill, P. S. and Vaze, G. H.	1948	*Phys. Rev.*, **73**, p. 1395.
Hutner, R. A.	1939	*ibid*, **55**, pp. 15, 614.
Kaplon, M. F., Peters, B., Reynolds, H. L. and Ritson, D. M.	1952	*ibid*, **85**, p. 295.
Lemaitre, G. and Vallarta, M. S.	1936	*ibid*, **50**, p. 493.
Neher, H. V.	1951	*ibid*, **83**, p. 649.
Tchang Yong-Li	1939	*Ann. de la. Soc. Sci. de Bruxelles.* **59**, p. 285.
Vallarta, M. S.	1939	*Rev. Mod. Phys.*, **11**, p. 239.
Vallarta, M. S., Perusquía, M. L. and Oyarzábal, J. de.	1947	*Phys. Rev.*, **71**, p. 393.
Vallarta, M. S.	1948	*ibid.*, **74**, p. 1837.
Van Allen, J. A. and Gangnes, A. V.	1950	*ibid*, **79**, p. 51.
Vogelaere, R. De.	1950	*Ann. Soc. Sci. Bruxelles*, **64**, No. 12, p. 83.
Winckler, J. R., Stix, T., Dwight, K, and Sabin, R.	1950	*Phys. Rev.*, **78**, p. 656.