STUDY OF THE ANISOTROPY OF COSMIC RAYS WITH NARROW ANGLE TELESCOPES

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When appropriate corrections to remove terrestrial influences are applied to the daily variation of meson intensity, it shows up the anisotropy of the primary cosmic radiations as viewed by an apparatus fixed to the spinning earth. Early data relate almost exclusively to measurements made with ionisation chambers for study of the various types of time variations of cosmic ray intensity. In these the instruments measure radiation from all directions and are therefore not particularly appropriate for study of the daily variation of intensity. Several later studies have been made with counter telescopes having directional characteristics. However in an effort to secure a high counting rate and good statistical reliability of the results, the telescopes generally subtend large angles and hence most of them ignore the requirements for a specialised study of the daily variation. From available determinations it has been in consequence erroneously assumed by several workers that the meson intensity at sea level does not exhibit a daily variation with an amplitude in excess of 0·2 to 0·4%. The notable exceptions to this way of thinking have been the Japanese group of workers and the group at Physical Research Laboratory, Ahmedabad.

Sekido and his co-workers have drawn attention in a series of papers[1,2,3] to the remarkable differences observed in the nature of the daily variation and its changes during periods of magnetic disturbance when measurements are made with vertical telescopes having semi-angles of 12°, 40° and 85°. Having concluded that the daily variation is better observed with narrow angle telescopes they[4] have conducted an experiment with a telescope having a semi-angle of 5° to determine sources of cosmic rays in the galaxy.

About three years ago experiments were commenced at Ahmedabad to determine the result of pushing the technique of narrow angle telescopes to what was considered a practical lower limit. Observations have been made by one of the authors (P. D. B.) with a triple coincidence telescope having a semi-angle of 1·8° in the E-W. plane and a semi-angle of 6·7° in the N-S. plane. The intensity relates to the component of cosmic radiation which can penetrate a minimum thickness of about 27 cm. of iron at sea level. The experiment was conducted from November 1952 to August 1953 and the mean bi-hourly rate was about 35 counts. The percentage mean daily variation is shown in Fig. 1. In view of the large probable error of each bi-hourly deviation, moving averages over three consecutive bi-hourly values have been taken. Harmonic analysis of the daily variation given by the bi-hourly percentage deviations from mean, before taking moving averages, shows that the diurnal amplitude M^D is $2 \cdot 2 \pm 0 \cdot 5\%$ and occurs at noon. The semidiurnal component with an amplitude of $0 \cdot 4 \pm 0 \cdot 5\%$ is not significant but has a negative correlation of $-0 \cdot 81$ with the semi-diurnal component of the daily variation of barometric pressure.

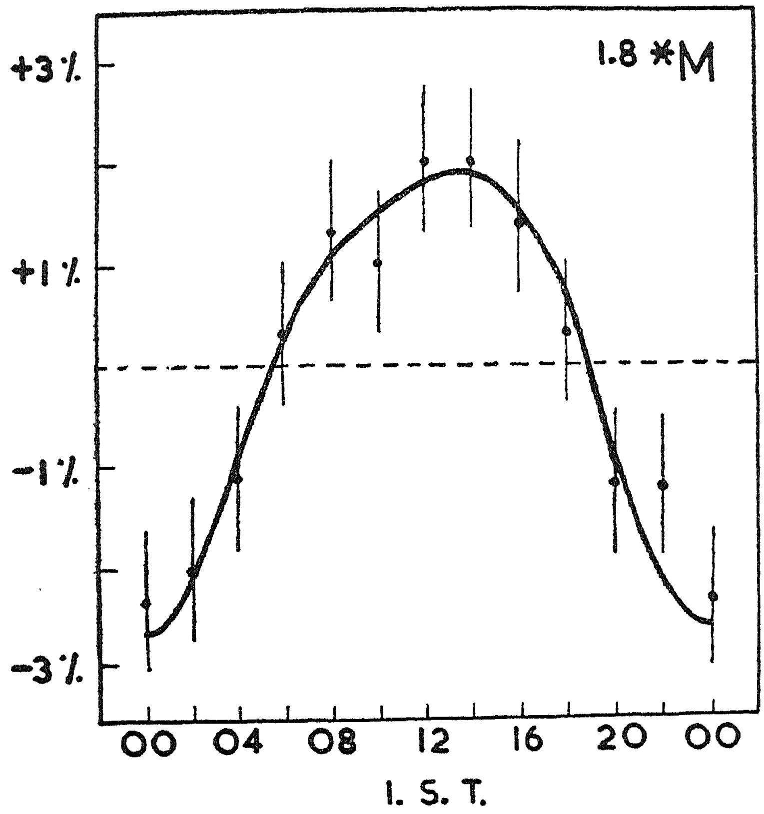

FIG. 1. Daily variation measured with $^{1\cdot8}T$.

The large amplitude of the daily variation found in this experiment with a narrow angle telescope has prompted us to make a more elaborate study involving simultaneous measurements with telescopes of different angles. It was hoped thereby to determine with some precision the profile of the anisotropy of primary cosmic radiation and also to establish an optimum experimental technique for study of the daily variation of meson intensity.

In Fig. 2 we show the arrangement of counters in an experiment set up by one of the authors (N. W. N.). The apparatus furnishes triple coincidences from three independent telescopes $^{2\cdot5}T$ having semi-angles of $2 \cdot 5°$, from two

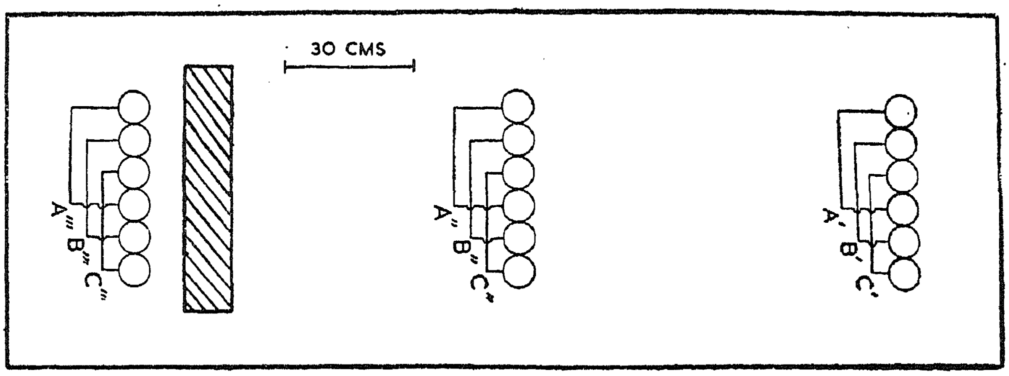

FIG. 2. Experimental Arrangement.

$^{2\cdot5}$T —A′ A″ A‴, B′ B″ B‴, C′ C″ C‴.
^{5}T —(A′B′) (A″B″) (A‴B‴), (B′C′) (B″C″) (B‴C‴).
^{15}T —(A′B′C‴) (A″B″C″) (A‴B‴C‴).
^{90}T —(A‴B‴C‴).

telescopes ^{5}T with semi-angles of 5° and from one telescope ^{15}T with a semi-angle of 15° in the E-W. plane. All telescopes have semi-angles of 19° in the N.-S. plane. In addition, the total rate ^{90}T from a battery of counters has been taken to give the omni-directional intensity. 12 cm. of lead has been used as shielding in every case. To increase the counting rate of telescopes without change of semi-angle, duplicate sets of counters are placed horizontally displaced from the first set, but connected with them in parallel. This introduces no error except for a negligible contribution from penetrating air showers.

In Table I are given details of the telescopes, their characteristics and period of operation. Since it is known that the daily variation of meson

TABLE I

Details of Telescopes

Telescope	$^{2\cdot5}$T	^{5}T	^{15}T	^{90}T
Daily Variation	$^{2\cdot5}$M	^{5}M	^{15}M	^{90}M
Semi-angle of Telescopes ..	2·5°	5°	15°	90°
No. of Telescopes ..	6	4	1	1
Period for which data available	1954 Jan.-May. Sep.-Dec. 1955 Jan.-March	1954 Jan.-May Sep-.Dec. 1955 Jan.-March	1954 Sep-Dec. 1955 Jan.-March	1954 Jan.-May Sep.-Dec. 1955 Jan.-March
Mean bi-hourly counting rate per Telescope	199	251×4	448×16	499×1024

intensity can alter with the passage of time, it is obviously necessary to compare the performance of the different telescopes over a period when all instruments have simultaneously been working. For such a period we show in Fig. 3 the mean percentage daily variations ${}^{2\cdot5}M$, ${}^{5}M$, ${}^{15}M$ and ${}^{90}M$, superposing the data of as many similar telescopes as have been simultaneously in operation. Figures 3 *a* and 3 *b* relate respectively to the daily variations before and after application of a barometric pressure coefficient $\beta = -2\cdot2\%$ per cm. of Hg. The amplitudes and the times of maxima of the diurnal and the semi-diurnal harmonic components of the daily variations measured with different arrangements are given in Table II. The diurnal components are also shown on harmonic dials in Fig. 4. The values before and after correction for the daily variation of barometric pressure are shown alongside of each other, the former being indicated by asterisks.

The following features emerge from a comparison of the daily variations of meson intensity observed with the different types of instruments.

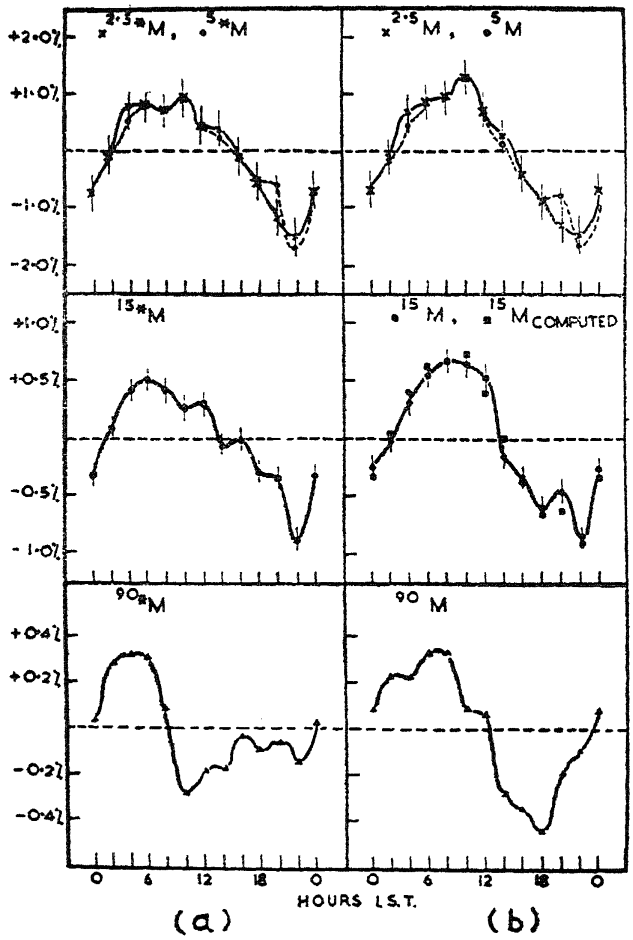

FIG. 3. Daily variations measured with ${}^{2\cdot5}T$, ${}^{5}T$, ${}^{15}T$ and ${}^{90}T$. Figures (*a*) and (*b*) relate respectively to values before and after applying correction for daily variation of pressure.

TABLE II

Percentage amplitudes and the times of maxima of the 1st and the 2nd harmonics of the daily variation measured with different telescopes

Variation	$^{2.5*}$M	$^{2.5}$M	^{5*}M	^{5}M	^{15*}M	^{15}M	^{90*}M	^{90}M
dard Error	±0·15%	±0·15%	±0·08%	±0·08%	±0·05%	±0·05%	±0·007%	±0·007%
M^D	1·05%	1·21%	0·96%	1·15%	0·44%	0·68%	0·21%	0·31%
$M\phi^D$	134°	133°	135°	134°	122°	121°	50°	80°
M^S	0·32%	0·13%	0·28%	0·06%	0·20%	0·02%	0·16%	0·06%
$M\phi^S$	114°	84°	133°	154°	133°	—82°	135°	—53°
γ	—0·950	..	—0·992	..	—0·999	..	—0·998	..
β	—0·30	..	—0·20	..	—0·20	..	—0·16	..

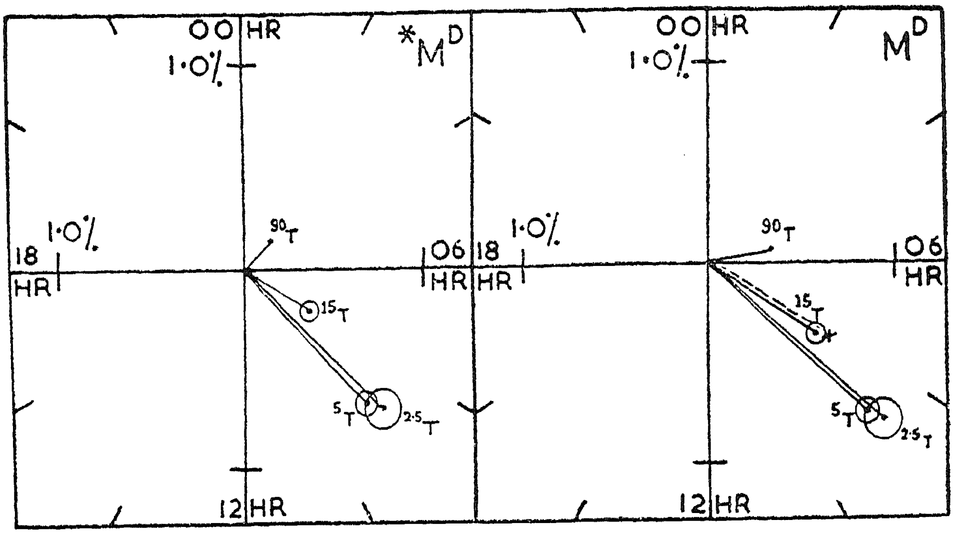

FIG. 4. Harmonic dials showing diurnal components of ${}^{2\cdot5}M$, ${}^{5}M$, ${}^{15}M$ and ${}^{90}M$ before (L.H.S.) and after (R.H.S.) applying correction for daily variation of pressure.

1. ${}^{2\cdot5}M$ and ${}^{5}M$ are almost identical. They differ markedly from ${}^{15}M$ and again from ${}^{90}M$.

2. The percentage amplitude of the diurnal component ${}^{2\cdot5}M^{D}$ is slightly greater than ${}^{5}M^{D}$, but not significantly so. However the amplitude which is about 1·2% for the narrow angle telescopes, decreases rapidly for wider semi-angles beyond 5°, and is only about 0·25% for the omnidirectional intensity.

3. The time of maximum $M\phi^{D}$ of the diurnal component corresponds to about 0900 hours for ${}^{2\cdot5}M$ and ${}^{5}M$ but becomes progressively earlier with wider semi-angles. ${}^{90}M\phi^{D}$ corresponds to about 0500 hours.

4. The semi-diurnal component of the daily variation does not alter as much as the diurnal component when measurements are made with the different instruments. There is an indication that the amplitude M^{S} decreases with increasing angle of telescope, but not to the same extent as M^{D}. The time of maximum is fairly constant.

5. There is high negative correlation between the semi-diurnal variations of meson intensity and of barometric pressure, the omnidirectional intensity having the highest correlation. The application of a uniform correction for the daily variation of barometric pressure using a coefficient $\beta = -2\cdot2\%$ per cm. of Hg, results in a virtual elimination of the semi-diurnal components in ${}^{2\cdot5}M$, ${}^{5}M$ and ${}^{15}M$. However ${}^{90}M$ is still left with a significant semi-diurnal component.

The choice of $\beta = -2\cdot2\%$ per cm. of Hg is dependent on considerations described elsewhere,[5] but it is not clear whether the application of the same coefficient to ${}^{90}T$ as well as to the narrower telescopes is fully justified.

It will be observed that in $^{2.5}$T and ^{5}T, the barometric correction with a coefficient of this magnitude makes relatively little difference to the daily variation of meson intensity. Hence, there is likely to be no great ambiguity in interpretation on account of the operation of uncertain meteorological influences.

Computation shows that meson intensity incident on ^{90}T from directions inclined less than 5° from the vertical, makes a contribution of less than 1·0% to the total omnidirectional counting rate. Thus ^{90}M with a diurnal amplitude of 0·24% represents the integrated daily variation of intensity incident from all directions, and is little affected by the special features of the daily variation characteristic of intensity in directions close to the vertical. On the other hand $^{2.5}$M and ^{5}M indicate that the intensity which exhibits a large daily variation of diurnal amplitude 1·2% is confined almost exclusively to a narrow vertical cone of incidence with a semi-angle of about 5°.

If we assume that intrinsically there are two types of daily variations, the V-type characteristic of the vertical intensity and the O-type characteristic of the omnidirectional intensity, then we have V $\approx {}^{5}$M $-$ ^{90}M and O $\approx {}^{90}$M. These are shown in Fig. 5. ^{15}M is compatible with a superposition of the two types with appropriate weightage factors. This is clear from Figs. 3

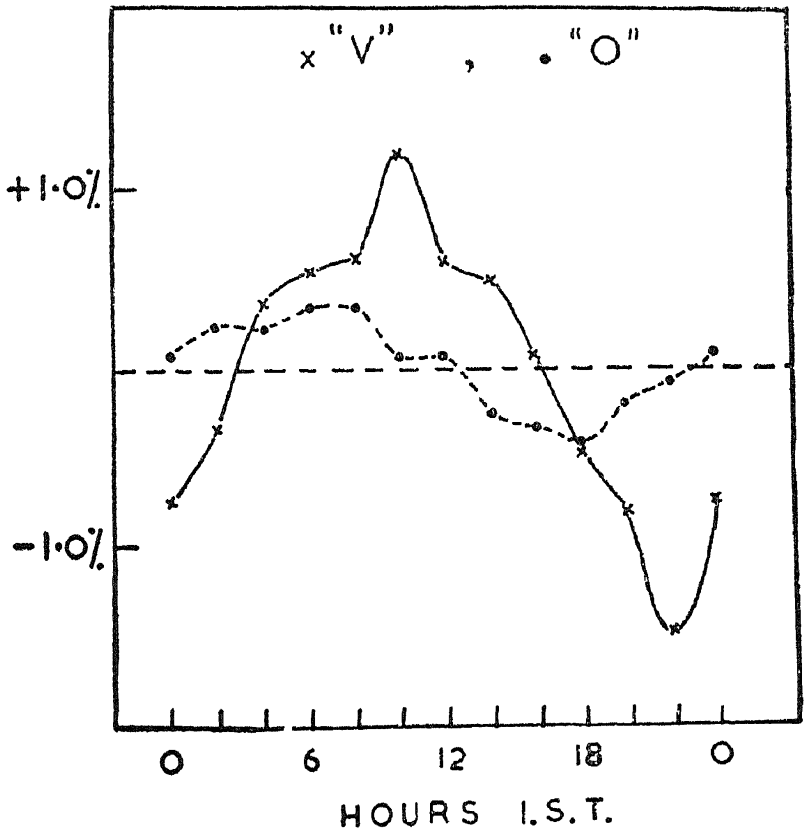

FIG. 5. The V and the O types of daily variations of meson intensity.

and 4 where we show the experimental and computed values of ^{15}M and its diurnal component respectively. The weightage factors have been evaluated from considerations of the geometry and dimensions of ^{5}T, ^{15}T and ^{90}T.

It is remarkable that there is sharp attenuation of intensity showing V-type of daily variation for incidence at angles exceeding 5° with the vertical. Simpson *et al.* have reported for local production of neutrons a daily variation comparable in amplitude to V. Since the nucleonic component of cosmic radiation, which is responsible for the local production of neutrons, gets rapidly attenuated with increasing zenith angle, the neutron monitor essentially measured vertical intensity. Thus a large amplitude of the daily variation appears to be a characteristic of a radiation, which can only penetrate to low levels of the atmosphere at small zenith angles. The main difference in amplitudes of the daily variations[6] observed with Simpson's neutron monitor and the Sitkus ionisation chamber could possibly arise from considerations of directional sensitivity of the measuring instruments rather than from difference in mean energies of primaries to which they respond.

It is important to understand the O variation and its origin. This is dependent on study with narrow angle telescopes pointing towards directions making different angles with zenith in the E.-W. plane. If, as appears likely, the O variation does not arise due to an integration of daily variations vastly different in character for different zenith angles towards east and west, we might be here dealing with a general modulation of the cosmic ray intensity. This would presumably occur near the top of the atmosphere but be under solar control.

Narrow angle telescopes open up a wide new field for experimental investigation of the anisotropy of primary cosmic rays. With low counting rates, data have to be averaged over an extended period to get significant results. Since the nature of the anisotropy changes, often radically, with passage of time, the averaging of the daily variations for several days is rather unsatisfactory. We can however, get around this difficulty by having simultaneous measurements with an array of several independent narrow angle telescopes. Work is now in progress along these lines and a report will be published separately.

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