Dissertation

on

A STUDY OF THE TIME VARIATION OF COSMIC RAYS AT LOW LATITUDES

presented

by

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STATEMENT

1. The daily variation of meson intensity measured with vertical telescopes, having semiangles of 22° in the E-W plane and 37° in the N-S plane, has been studied by the author during the years 1954, 1955 and 1956 at the equatorial mountain station of Kodaikanal. The 12-month mean daily variation during each year and the daily variation on individual days have been studied. The 12-month mean daily variation has been compared with the daily variation for the years 1952 and 1953 measured with the same instrument at Kodaikanal and with the daily variation of intensity measured by Carnegie Institution ion chambers at Huancayo and Cheltenham. The change of the 12-month mean daily variation has the following noteworthy features:

(a) During 1952 to 1956, changes of the time of maximum of the diurnal component and the amplitude and time of maximum of the semi-diurnal component of the 12-month mean daily variation are well correlated at the two equatorial stations of Kodaikanal and Huancayo.

(b) Change of the time of maximum of the diurnal and the semi-diurnal components at Huancayo over a period of 18 years is most clearly suggestive of a relationship with the 22-year cycle of change of polarity of the magnetic field of sunspot.

A 22-year cycle of change is clearly seen in the form of the 12-month mean daily variation unresolved into its harmonic components. The change of form takes place principally in relation to a maximum in the early morning or near noon as suggested by Sarabhai et al. The change is large at minimum of solar activity and is gradual at other periods of the solar cycle.

(c) For a proper study of the anisotropy of the primary cosmic radiation and its changes it is necessary, particularly for observations at low latitudes, to take account of the semi-diurnal component of the daily variation in addition to the diurnal component. The change of daily variation unresolved into its harmonic components can be related to a meaningful physical model of change of the anisotropy of primary radiation.

2. A comparison of the form of the 12-month mean daily variation and the distribution of parameters of the diurnal and the semi-diurnal components of the daily variation on individual days does not either confirm or refute the model of change of the 12-month mean daily variation suggested by Sarabhai et al. This model involved the change being produced through alteration of frequency of occurrence from year to year of a "day maximum type" and a "night maximum type" of anisotropy. It appears from the present study that both major states of the primary anisotropy are connected with a diurnal as well as a semi-diurnal component. They differ in relation to different

relative magnitudes of the maxima in the early morning and near noon which are observed in the daily variations produced by them.

3. A study has also been made by the author of the variation of the meson intensity measured with narrow angle telescopes of semiangle 5° in the E-W plane and 19° in the N-S plane operated at Kodaikanal during 1956. The daily variation has been compared with the daily variation measured by ^{22}T telescopes and a neutron monitor at Kodaikanal. The characteristics of the daily variation of the neutron monitor and the ^{22}T telescopes are very similar. The narrow angle telescopes exhibit or daily variation of larger amplitude than the other two instruments. Identification of the state of the anisotropy on individual days by an examination of only the characteristics of the harmonic components of the daily variation is not in general possible at Kodaikanal. However ^{5}T and ^{22}T telescopes confirm the observation of Satya Prakash with a neutron monitor, that on magnetically disturbed days the ratio r_1/r_2 of the amplitudes of the diurnal and the semi-diurnal components respectively of the daily variation, has characteristic values related to the correlated changes of anisotropy and the mean intensity of cosmic rays.

4. The average daily variation on days with different degrees of geomagnetic disturbances, as indicated by the value of Cp on individual days, suggests that a significant transition

takes place in the range of Cp from 0.85 to 1.20. The nature of change between groups corresponding to low and high Cp is not the same in 1954, 1955 and in 1956.

5. A solar flare type of increase of intensity at Kodaikanal, observed on 23rd February 1956, represents one of the first observations of this effect at a station on the geomagnetic equator. It has been interpreted as indicative of the generation on the sun, of cosmic rays in the energy range 35 to 65 Bev. in association with a type 3+ flare.

6. The present dissertation describes in Chapter II the apparatus and in Chapter III, the methods of analysis of data. Chapters IV and V deal with results of the investigations made with vertical telescopes of moderate and narrow angles of opening respectively. In Chapter VI, the principal conclusions of the investigation are discussed. The author has included at the end of his thesis a list of 167 references to original papers published in different parts of the world. The thesis mentions the specific information derived from each of them.

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CONTENTS

CHAPTER I

INTRODUCTION

The study of cosmic ray time variations has grown in importance in recent years with increasing realisation that an understanding of these variations will give a clue to the origin of cosmic rays and of the electromagnetic fields in interplanetary and interstellar space. Moreover, the close relationship of many of the cosmic ray variations with events occurring on the sun is of great interest in understanding the physics of the sun and its environment. Consequently various workers have sought to establish the main features of cosmic ray time variations and their relationships with known geophysical and astrophysical phenomena. Elliot[1] has reviewed the status of knowledge regarding cosmic ray intensity variations studied upto 1951. Since then significant advances have been made and later reviews of the progress in the subject have recently been published by Sarabhai & Nerurkar[2] and by Singer[3].

As the primary cosmic ray particles approach the earth from outer space they suffer deflection in the earth's magnetic field and interact with matter in the earth's atmosphere. What the cosmic ray recorders located at various places on the surface of the earth record, is essentially a secondary phenomena. It is necessary therefore to assess and make allowance for these terrestrial effects before one can interpret the experimentally observed variations in terms of primary radiation.

1.1 Geomagnetic effects

The early studies on the behaviour of charged particles in the dipole field of the earth were carried out by Stormer[4], Lemaitre and Vallarta[5,6,7]. They computed particle trajectories by numerical integration methods and worked out the basic theory of geomagnetic effects. Through the application of Liouville's theorem and by assuming the isotropy of primary radiation, Lemaitre & Vallarta could derive a simple and satisfactory theory that explained the principal experimentally observed geomagnetic effects and at the same time obviated the need for computation of individual particle orbits. The results of these investigations have been summarised and presented in a convenient form by Alpher[8].

The theory developed by Stormer, Lemaitre & Vallarta deals with isotropic radiation. To interpret effects such as the solar flare effect where isotropy is not observed it becomes necessary to know in detail the trajectories of particles. Schluter[9] and Firor[10] have computed individual orbits of protons of energies extending upto 10BeV. This work is further refined by Jory[11], Vallarta[12] and his group. Lust et al[13] and Lust[14] have calculated particle orbits for different source widths and declinations. From the orbits, assuming a flat rigidity spectrum at the source they have calculated the counting rates at the top of the atmosphere. Brunburg & Dattner[15] on the other hand have approached the problem by model experiments. They have determined the asymptotic coordinates of velocity vectors for protons of energy greater than 2 BeV which can arrive at specified angles to the zenith in N-S and E-W planes at various latitudes. The results have been presented in convenient graphical form. These results form a most valuable basis for the interpretation of effects caused by anisotropic radiation. The results show that the trajectories of particles arriving at a place like Kodaikanal, near the geomagnetic equator are more or less constrained to the equitorial plane of the earth and that they are much simpler compared to the trajectories of particles arriving at higher latitudes.

1.2 Relationship between measured intensity and primary cosmic radiation

In order to interpret the variations of the secondary component measured in the lower atmosphere in terms of the primary component of the cosmic radiation, it is necessary to relate the primary spectrum through an "yield function" or a "generating function", with the spectrum of the secondaries observed at a particular depth in the atmosphere. For latitude sensitive primaries this can be done without going into the details of the intervening transformation processes. If for an observing station situated at a latitude λ and level with pressure ho, intensity of i^{th} component produced by the primary spectrum F(E) is N^i_λ (h_o), then following Dorman[16]

$$N^i_\lambda (h_o) = \quad F(E)\, m^i(E, h_o)\, \partial E \; \ldots \quad \ldots \qquad (1)$$

where $m^i(E, h_o)$ is the production coefficient showing how much of N^i_λ (h_o) is supplied by the F(E) ∂E primary particles of energy E, while E^c_λ is the geomagnetic cutoff for the given latitude λ .

Variation ∂j F(E) of F(E), of the type j (which may be seasonal, diurnal etc.) produce variation ∂j N^i_λ (h_o) to N^i_λ (h_o). Varying both sides of equation (1)

$$\frac{\partial j\, N^i_\lambda (h_o)}{N^i_\lambda (h_o)} = \int_{E^c_\lambda}^{\infty} W^i_\lambda (E, h_o)\, \frac{\partial j\, F(E)}{F(E)}\, \partial E \quad \ldots (2)$$

$$\text{where } W^i_\lambda (E, h_o) = \frac{F(E)\, m^i (E, h_o)}{N^i_\lambda (h_o)}, \quad \ldots\ldots\ldots (3)$$

is the coupling coefficient showing how large the secondary variation will be due to the variation of the primary spectrum. Differentiating equation (2) with respect to $E^c_{\lambda'}$ we get

$$W^i_\lambda (E^c_{\lambda'}, h_o) = -\frac{1}{N^i_\lambda (h_o)}\, \frac{\partial N^i_\lambda (h_o)}{\partial E^c_{\lambda'}} \quad \ldots\ldots\ldots (4.)$$

For latitude sensitive primaries connected with the vertical intensity (i.e. $E_o \leq 15$ BeV), if latitude effect for a given

i^{th} component is known, the R.H.S. of equation 4 can be evaluated and the coupling coefficient may be calculated. For $E > 15$ BeV the curve E Vs. W^{i}_{λ} (E, h_o) can be extrapolated with the help of suitable parametric formulae.

Trieman[17], Fonger[18], Nagashima[19] and Dorman[16] have worked out the yield function from the latitude variation data obtained by Pomerantz[20], Simpson[21], Berry & Hess[22] and various other workers[23]. The important results are summarised by Dorman and by Fonger as shown in Fig.1 & 2 respectively. Fig.1 from Dorman indicates for $\lambda = 0$ the value of the coupling coefficients for total ionising intensity, hard component intensity and neutron intensity at sea level, and total intensity at 4300 meters altitude, for primary energies upto 1000 BeV. Fig.2 from Fonger shows that the nucleonic component as measured by the local production of neutrons at Climax ($\lambda = 48^oN$, h = 3500 m) corresponds to a mean energy primaries of 7.3 BeV whereas an ionisation chamber at sea level at a similar latitude corresponds to a mean primary energy of 46 BeV.

Attempts are often made to derive, from data concerning the solar daily variation of cosmic rays, information regarding the direction of anisotropy of primary radiation outside the influence of the geomagnetic field. Some investigators refer to an average energy of the primary spectrum corresponding to the secondary radiation which is measured,

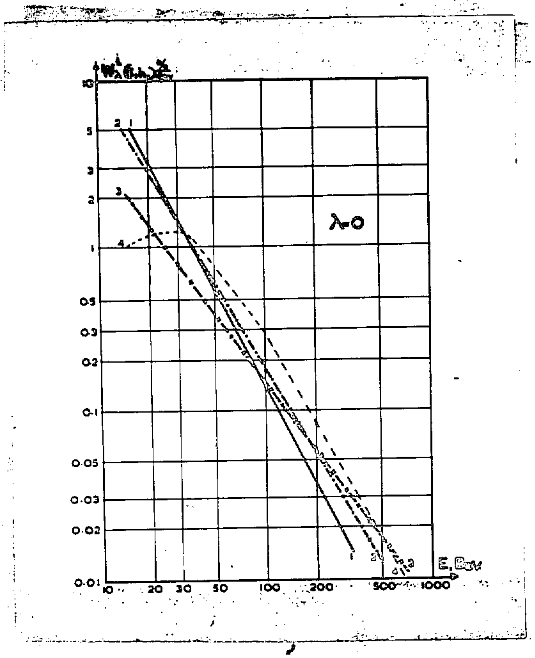

λ=0
10
5
3
2
1
0.5
0.3
0.2
0.1
0.05
0.03
0.02
0.01
10 20 30 50 100 200 500 1000

FIG 1

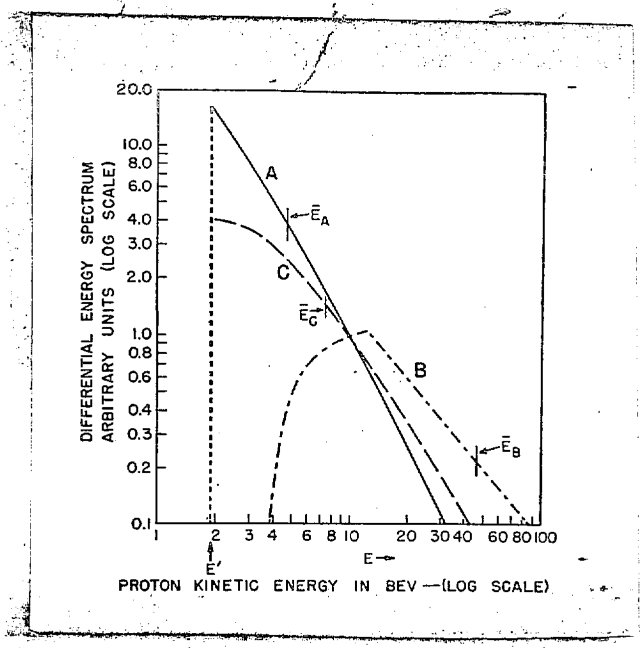

DIFFERENTIAL ENERGY SPECTRUM
ARBITRARY UNITS (LOG SCALE)
20.0
10.0
8.0
6.0
4.0
3.0
2.0
1.0
0.8
0.6
0.4
0.3
0.2
0.1
A
B
C
$\bar{E}_A$
$\bar{E}_B$
$\bar{E}_C$
1 2 3 4 6 8 10 20 30 40 60 80 100
E'
E
PROTON KINETIC ENERGY IN BEV —(LOG SCALE)

FIG 2

and then apply a correction for the geomagnetic deflection of primary particles of the appropriate average energy. Special assumptions concerning the energy dependence of the anisotropic radiation are involved before the result can be interpreted. It is however preferable, as Nerurkar[24] has done, to derive the spatial configuration of the anisotropy and its dependence on primary energy according to a particular model and then using Dorman's coupling coefficients and the results of Brunburg & Dattner regarding geomagnetic deflection, to compute a daily variation of secondary radiation which may be compared with experimental observations. Agreement can be taken to imply that the assumed model is consistent with the experimental observations.

1.3 Variations of atmospheric origin

A great deal of work has been done concerning the cosmic ray variations of atmospheric origin since Duperier presented his partial regression equation connecting the percent change of meson intensity with barometric pressure ΔP, change in height of 100 mb. level ΔH and change of mean temperature ΔT between the 100 and 200 mb.levels. A number of workers have scrutinised Duperier's equation and the physical meaning ascribed to the coefficients derived from it. Our knowledge regarding the subject has been greatly clarified by the theoretical work of Olbert[25], Maeda & Wada[26], Hayakawa et al[27], Fienberg[28] and by the experimental investigations of Barret et al[29], Trefall[30-32], Wada[33] and other Japanese workers. The state of knowledge concerning the subject till 1956 has been reviewed by Sarabhai & Nerurkar[2].

Wada & Kudo[34] have suggested a three term partial regression equation connecting ΔP, ΔH and ΔT to correct cosmic ray variations for meteorological effects, which obviates some of the difficulties encountered by Duperier's equation. They have suggested that by taking H to represent the difference between the height of mean level of meson production and an isobaric level near the ground the mean temperature of the lower atmosphere is taken care of and the possibility of decay effects being included in β is prevented. Moreover this H is independent of sea level pressure. Using this H and a mean atmospheric mass temperature, in conjunction with an appropriate temperature coefficient a satisfactory regression equation can be formed. Such an equation can be applied with advantage to diverse types of changes of pressure and temperature in the atmosphere without requiring change of values of coefficients.

Dorman & Feinberg have recently outlined a method for evaluating a correction for atmospheric effects. Starting from Feinberg's[28] work Dorman[35,36] has worked out the theory of atmospheric effects on the μ meson component taking into consideration the continuous production and ionisation loss of μ mesons throughout the atmosphere, just as Olbart did. However Dorman has carefully avoided any general assumption regarding the equilibrium of the atmosphere. He gets a general but complex analytical expression involving several variables, the chief among them being the ground pressure and the density of different isobaric levels from the top of the atmosphere down to the cosmic ray recorder. The integrals involved depend on the meson production function, on the relation between density and temperature at different levels and on the instrumental cut-off energy. The integrals are evaluated partly analytically and partly numerically and the results are summarised in the equation

$$\left(\frac{\delta I_\mu}{I_\mu}\right)_{x_0} = \beta\,\delta x_0 + \int_0^{x_0} W(x)\,\delta T(x)\,dx.$$

where δx_0 is change of pressure at the observation point, β a definite coefficient (barometric coefficient) not containing any arbitrary quantities, $\delta T(x)$ change of temperature at the level x. The function $W(x)$, which he calls "temperature coefficient density" has been calculated and plotted in a graph. If sufficient radiosonde data are available to determine $\delta T(x)$ at various standard isobaric levels the correction for meteorological effects can be easily evaluated.

The correction to be applied to the daily variation of meson intensity for the removal of variations of atmospheric origin has been considered by several workers. Sarabhai et al[37,38] have discussed the relative importance of contributions due to daily variation of barometric pressure, of heights of isobaric levels, and of temperatures of various levels in the atmosphere. They point out that significant and regular diurnal variation of temperature occurs only in the turbulent surface layer of the atmosphere upto 2 km above the ground. In the higher levels the main changes of temperature are not diurnal but of irregular day-to-day character which are expected to be smoothed out when data are averaged over a long period. The amplitude of the semidiurnal oscillation of the atmosphere at 100 mb level is not known to vary more than a few meters even at the equator. Thus in the daily variation of meson intensity there is expected to be little contribution due to the change of height of isobaric levels or of upper air temperature. Sarabhai et al therefore conclude that the barometric effect is the only atmospheric effect that has to be considered while evaluating the daily variation of meson intensity.

Glokova[39], Kuzmin[40] and other Russian workers have used Dorman's method to correct daily variation as well as other types of intensity variations. They find that the seasonal variations of cosmic ray intensity are almost exclusively of meteorological origin and that seasonal changes of diurnal variation disappears when meteorological variations are properly taken into account. They have shown that when the method is applied to the diurnal variation, the correction has an amplitude of about 0.1 % with a minimum near noon. Thus the correction almost doubles the measured amplitude of the diurnal variation at high latitudes. On the otherhand Maeda[41] has shown that the temperature variations in the atmosphere may be expected to give rise to a small diurnal variation of amplitude 0.05 % only, with a maximum at 14 hrs.

It is clear from all points of view that there would be some ambiguity of interpretation of a daily variation of meson intensity when the measured amplitude is comparable with the amplitude of the atmospheric temperature effects which are estimated to cause a variation of about 0.05 to 0.10 %.

The effects of meteorological factors on the nucleonic component are easier to establish than those for the μ meson component where decay effects complicate the problem. Simpson et al[42] have shown that the effect of atmospheric temperature variation upon observed pile neutron intensity is negligibly small, being of the order of -0.02 % per °C at $\lambda = 0$ and less than -0.006 % at $\lambda = 50°$. Barometric pressure coefficient β is essentially constant over the geomagnetic latitude range $\lambda = 0$ to $54°$ and for atmospheric depths greater than 600 gms. per cm^2. β has been estimated by them to be (-0.94 ± 0.03)%/mm.Hg. in good agreement with values reported by Adams & Braddick[43], Heerdan & Thambyphillai[44] and Rose & Katzman[45]. Lockwood & Yingst[46] get a value for β equal to $-(10.9 \pm 0.9)$%/cm.Hg.

Miyazaki[47] has recently studied the time variation of the comparatively low energy portion of the primary cosmic rays by comparing the intensity variations observed at different altitudes. He has shown that the atmospheric effect on the difference between the pressure corrected intensities of meson component observed at sea level and at a nearby mountain station is mainly caused by the mean temperature of the atmosphere between the two stations. He has also shown that the daily variation of this low energy component of cosmic ray mesons corrected for atmospheric effects has a high correlation with the pressure corrected neutron intensity.

Jacklyn[48] has made an interesting study concerning the daily variation of the barometric coefficient β. He reports a diurnal variation of about 5 % in the value of the barometric coefficient and secular changes of the same order. The experimental results are barely outside the 95 % fiducial limits of significance but have been ascribed by him to the non-uniform properties of the atmosphere at different times of the day, or to the change of the energy spectrum of primaries which is not accounted for in Duperier's equation. He also remarks that it is meaningless to correct the diurnal variations of meson intensity to conditions of standard surface pressure using a barometer coefficient averaged over the mean days if the standard pressure chosen is very different from the observed mean value.

1.4 Time variations of primary radiation

1.41 Variation of intensity with solar cycle

One of the most remarkable long term variations that has been discovered recently is the change of general intensity of cosmic radiation with change of solar activity of sunspot numbers. Forbush[49] and Glokova[50] have observed that the 12-month mean intensities measured by Carnegie Institution stations vary by about 4 % between sunspot minimum and sunspot maximum years. Forbush has shown that this change is equally present in all the four stations whose latitude range from 0^{o} to 80^{o}N. He has separated the data for magnetically quiet and disturbed days and shows that the change is present almost equally in both the groups. This indicates that the secular change in intensity is not produced by a series of storm type decreases occurring with varying frequency during different periods of solar activity.

Similar changes in total intensity have been observed at high latitudes and high altitudes by Neher[51,52,53] and Meyer & Simpson[54]. Corresponding to the change of only 4 % observed at sea level, Neher finds that at the latitudes

85^o to 88^oN there was a change in total ionisation of about 50 % at an altitude of 70,000 ft. from sunspot maximum year of 1937 to the sunspot minimum year of 1954.

1.42 Change of 'Knee' of the latitude effect

A remarkable feature that emerged out of the early studies[55] of the latitude effect of cosmic rays at various altitudes was the absence of a low energy component of primary radiation. The 'knee' in the latitude effect indicated that beyond a latitude of about 55^o there was no further change in the total intensity even at the highest altitudes that could be reached by balloons. The sharp cut-off in the cosmic ray primary spectrum at an energy of about 0.8 BeV for protons corresponding to the 'knee' has presented a difficult problem for interpretation.

Since 1951, Neher et al[52,53,56,57] have made a systematic study of the finer features of latitude variation of cosmic ray intensity at high altitudes in high latitudes beyond the 'knee'. They have developed a technique to study the 'knee' independently of the general fluctuations in intensity by conducting simultaneous flights of balloon borne instruments at various latitudes. The results of their experiments have revealed the interesting fact that the 'knee' is not stationary at a particular latitude but shifts in a way consistent with the observation of Forbush[49] regarding the inverse relation between the solar activity and cosmic ray intensity. The 'knee' appears to shift to higher latitudes as more and more soft particles arrive at the earth during sunspot minimum. Meyer & Simpson[54,58] have studied the shift of latitude 'knee' during the recent 11 year solar cycle. Their observations indicate that the low energy cut-off of primary particles in the cosmic ray spectrum went through a minimum during 1954 in which solar activity also reached a minimum in the 11 year solar cycle. They have also shown that the total cosmic ray intensity and the exponent of power law spectrum both passed through a maximum near the solar minimum in 1954.

Ellis et al[59] have pointed out that during 1953 there was a cut off for heavy primaries at about the same latitude as for protons. This indicates a cut off dependent on the rigidity rather than the energy of the primaries and suggests a mechanism involving magnetic fields as being responsible for the latitude cut off.

1.43 Change of E-W asymmetry

Jacklyn & Fenton[60] have recently reported a long term change in the high latitude E-W asymmetry during the period 1947 to 1956 measured at Hobart ($\lambda = 52^{o}S$, sea level). The E-W asymmetry has decreased during the years of decreasing solar activity. The fact that the intensity of the hard component was observed to increase during the same period suggests that the decrease in asymmetry was caused by a greater increase in the intensity from the east than from the west. However, further confirmation is necessary before one can discuss the implications of these interesting findings.

1.44 Magnetic storm type changes

As far back as 1933 some of the fluctuations of cosmic ray intensity were known to be associated with the perturbations of the earth's magnetic field (Steinmaurer & Graziadei[61]). These storm time changes of cosmic ray intensity which are invariably decreases were shown to be worldwide in nature by Forbush[62,63] and others in 1937. Since then large worldwide decreases of cosmic ray intensity upto 10 % associated with magnetic storms have been reported by various investigators. These decreases, usually called the 'cosmic ray storms' or 'Forbush events' have several remarkable features. The decrease appears, in general, most closely associated with the main phase of the storm and is followed by a slow recovery lasting for several days. All magnetic storms are not associated with decrease of cosmic ray intensity and when effective storms occur the ratio of change of magnetic field strength to the change of cosmic ray intensity is not constant from event to event. In storms such as the large storm of March 1, 1942 there is almost no latitude effect observable at different stations extending from the equator to high latitudes beyond the 'knee'. On the otherhand in some storms the low energy component of the primary radiation appears to be disturbed more than the high energy component. Fonger[18] has reported that cosmic ray storms observed by a neutron monitor are five times larger than those observed by an ion-chamber. A storm type decrease observed at 70,000 ft. over Texas by Neher & Forbush[64] was found to be four times greater than the decrease in the ion-chamber at Mt.Wilson.

Chasson[65] has made a systematic study of the time and magnitude of cosmic ray changes associated with magnetic storms. He has shown instances when the decrease of intensity occured an appreciable time before any measurable geomagnetic disturbance. Trefall[66] observes that magnetic storms with a dominent positive peak and a negative peak which is small or absent produce no change of intensity. Kitamura[67] has shown that large decreasesare accompanied by magnetic storms with sudden commencement.

Discussing the relation between the cosmic ray variations, geomagnetic activity and sunspot activity Miyazaki & Wada[68] observe that the phases of 11 year cycle of variation of cosmic ray disturbances and earth's horizontal magnetic force nearly coincide with each other, while their time of maximum does not coincide with the sunspot maximum. On the otherhand magnetic disturbance does not become small at the time of sunspot minimum but cosmic ray disturbances become very small even to the extent of natural fluctuations.

Sekido et al[69] have studied the solar relationship of cosmic ray effective and non-effective magnetic storms which they designate as 'S' and 'M' type storms respectively. They have found that the frequency of 'S' type storms varies in step with the 11 year cycle of solar activity, but same is not the case with 'M' type storms which they associated with the supposed 'M' regions on the sun. There is correlation between the occurrence of 'S' type storms and the CMP of large sunspot groups. This feature is absent from 'M' type storm. The 27-day recurrence tendency as seen with Chree diagrams shows sharp peaks for 'M' storms but sinusoidal changes for 'S' storms. From this they conclude that 'S' storms are caused by wide corpuscular clouds ejected from sunspot groups, but the 'M' type storms are caused by narrow corpuscular beams.

1.45 Day-to-day changes of intensity

Day-to-day changes of intensity studied in recent years especially after the development of Simpson's neutron monitors and the narrow angle telescopes. It is now quite evident from the analysis of neutron pile data that large and significant changes of intensity of a few percent in amplitude occur from day-to-day quite frequently. Simpson et al[70] have found close association of intensity increases with the CMP of active solar regions and particularly of regions of green coronal emission on the sun. These increases were often seen to be followed within two or three days by increased geomagnetic activity. Simpson et al[71] have shown the close association of the CMP of UM regions with cosmic ray increases during 1953. These regions as well as the increases of intensity persisted for several solar rotations.

The worldwide nature of the day-to-day variations has been demonstrated by a number of investigators. Fonger[18] has shown that changes in the neutron intensity at Climax are similar to simultaneous changes observed in the ion-chamber at Freiburg but on the average are five times greater in amplitude. Neher & Forbush[64] have demonstrated the correlated day-to-day changes occurring in the ion-chambers at Huancayo and Cheltenham, the neutron monitor at Climax and the ionisation at 70,000 ft. over Bismark. Heerdan & Thambyahpillai[44] have investigated the correlated changes measured with a neutron monitor and a counter telescope at London. They have studied the 27-day recurrence of these changes and find a decrease of mean intensity associated with increase in amplitude of the fluctuations. They have come to the conclusion that 27 day recurrence changes are caused by decreases in cosmic ray intensity of the same nature as the Forbush events. Meyer & Simpson[72] have studied the 27-day recurrence tendency in ion-chamber data of Huancayo and neutron monitor at Climax and have shown that the recurrence tendency is altered during the solar cycle. It is more pronounced during sunspot maximum when incidentally the general intensity is low and is weak at sunspot minimum when the general intensity is maximum.

1.46 Solar flare effect

Sudden increases of cosmic ray intensity which follow within a short time after large solar flares are rather rare events. Until recently only four such events had been observed in the last fifteen years. These four well-known early events (February 28, 1942, March 7, 1942, July 25, 1946 and November 19, 1949) have been studied extensively and the observational data concerning them have been summarised and discussed by Daudin[73], Elliot[1], Forbush et al[74], Biermann & Schluter[75] and Sekido & Murakami[76]. The onset of the increases was rapid, the change of intensity was large and persisted for a few hours. These increases were observed only in middle latitudes and their character depended strongly on the type of detector, its altitude, geomagnetic latitude and local solar time. The intensity decreases which followed these large flare events usually occurred with a time delay of about one or two days and were associated with geomagnetic disturbances and radio fade outs. The intensity decreases were more worldwide in nature but slower in onset and longer in duration than the flare increases.

The recent solar outburst of 23rd February, 1956 was the most energetic cosmic ray event so far observed. The cosmic ray increase was characterised by a rapid onset, a remarkably sharp rise to maximum and quick decay, the magnitude of the rise itself being highly sensitive to energy. A striking feature of this flare was that complete isotropy was established within a very short time after the rise of intensity to the peak. Largest increases were recorded at middle and high latitude stations while the equatorial stations of Huancayo (Forbush[77]) and Kodaikanal (Sarabhai et al[78]) recorded for the first time significant increase in intensity. A neutron monitor at Leeds which was in the early morning impact zone registered an increase of about 4500 % (Marsden et al[79]) while the one that was at Climax recorded 2000 % increase (Meyer & Simpson[80]) though it was far away from a favoured impact zone. However, an extensive airshower apparatus that was in operation at the high altitude station at Schauinsland registered no additional events of energy $E > 10^{12}$ eV during the erruption (Sittkus et al[81]).

Kuz'min et al[82] at Yakutusk $\lambda = 51^{\circ}$ and Brunberg & Eckhart[83] at Stockholm $\lambda = 58^{\circ}$ have noticed that the north pointing telescopes record more particles than the south pointing telescopes. From the observed N-S asymmetry the latter authors conclude that either the intensity or the energy or both of the flare primaries must be different in different asymptotic directions. They are of the opinion that flare particles did not travel in straight line orbits from sun to the earth and that the particles emitted by the sun must have suffered a deflection in a mean magnetic field of the order of 6×10^{-6} gauss before reaching the north pointing telescopes at their latitudes.

A number of investigators have tried to estimate the energies upto which particles might be accelerated during a solar outburst of the type observed on 23rd February, 1956. Sarabhai et al[78] have shown that if the observed increase at the equatorial stations are caused by solar protons travelling along more or less direct paths then the energy spectrum of flare radiation must extend upto approximately 67 BeV. They have estimated the flux of flare particles to be about 1.5 times the normal flux of background cosmic rays in the energy range 40 to 50 BeV. Thus the upper limit of energy of particles responsible for flare type increases is much higher than was hitherto believed.

Meyer et al[84] have studied the 23rd February, 1956 flare effect in detail using the data from six neutron monitors distributed over a wide range of geomagnetic latitudes. Based on the conclusions drawn from a study of the time and energy dependence of flare particle intensity, they have proposed a model to explain the cosmic ray flare effect and propagation of flare particles in interplanatary fields. The model is the well-known cavity-barrier type demanding a field free region $B < 10^{-6}$ gauss, of radius ≈ 1.4 A.U. around the sun. The barrier is supposed to scatter the flare particles back into the field free region producing a high degree of isotropy in them. The decay of intensity with time that follows a law $t^{-3/2}$ is explained in terms of diffusion of flare particles out of the cavity through the barrier. From experimental observations they find that in association with a solar flare the sun can inject particles of energy of the order of 30 BeV into interplanetary space. The integral intensity I of primary particles as a function of particle rigidity (Pc/Ze) has been found to obey a power law of the type $I \propto (Pc/Ze)^{-7}$ for several hours following maximum intensity. At high rigidities the spectrum is found to fall off more sharply with particle rigidity.

Ehmert[85] has studied the delays in onset and the decay pattern of cosmic ray increases observed during 23rd February, 1956 solar flare at various stations spread all over the world. He comes to the conclusion that the main features of the cosmic ray flare effects, especially the midnight effect and high latitude impacts can be satisfactorily explained in terms of deflection of flare particle trajectories in an interplanetary field of the order of 3×10^{-6} gauss. A verification of the above explanations would be possible from a study of seasonal dependence of the flare effect at polar latitudes, but the observational data available at present is inadequate to do this.

Firor[10] has studied the cosmic ray intensity variations during small solar flares of magnitude 1^+. He has suggested that even during small solar flares additional particles of cosmic ray energies approach the earth from the direction of the sun.

1.5 Anisotropy of primary radiation

1.51 Solar anisotropy

Once the extra terrestrial nature of cosmic radiation was proved fairly conclusively by Hess and Kolhorster, a number of investigators tried to study the variation of cosmic ray intensity with solar and sidereal time with a view to get some information on the origin of the radiation. The instruments they used were usually of omnidirectional sensitivity. In order to improve the statistical significance of the determinations it was customary to take the average of data extending over as large a period as was possible. Whilst a daily variation with sidereal time could not be established with any certainty, a small solar diurnal variation with an amplitude of about 0.2 % was observed by many workers[86,87]. However, uncertainties regarding the corrections to be made for the daily variation of meteorological elements led many workers initially to question the validity of drawing any conclusions regarding the anisotropy of the primary radiation.

To establish the existence of an anisotropy of the primary radiation which could give rise to a solar daily variation, simultaneous observations with directional telescopes pointing to two different directions inclined equally to the zenith were made by a number of workers. While the atmospheric effects were expected to be the same in the two directions, the variation due to anisotropy of primary radiation would be different for the two telescopes. When a difference between the daily variations measured by the two telescopes is taken, the atmospheric effects should cancel out leaving a residual effect which can be attributed to the anisotropy of the primary intensity.

The first measurements of this nature were performed by Kolhorster[88] in Berlin and by Alfven & Malmfors[89] in Stockholm. They found that the diurnal variation is not the same when measured in different directions and that a north pointing telescope exhibits an earlier maximum than the south. Discussing the results of his experiments Malmfors[90] pointed out that the difference between the variations for the two directions cannot be due to atmospheric effects. He showed from model experiments that the effect was unlikely to be due to geomagnetic or helio-magnetic fields. He therefore reached the conclusion that the marked difference observed in the daily variations from the north and south directions must be due to an anisotropy of primary radiation in the high energy part of the primary spectrum which suffers little deflection in the geomagnetic field.

Extensive measurements on the directional dependence of diurnal variation of cosmic ray mesons have been carried out at Manchester by Elliot & Dolbear[91]. They have confirmed the earlier results of Alfven & Malmfors for north and south directions. In addition they have found that the daily variation measured by a south pointing telescope contains a larger semidiurnal component compared to that measured by a north pointing telescope. They have noticed that the amplitude and the time of maximum of the daily variation from the south direction vary with season while only the amplitude of the variation from the north shows any seasonal variation.

The above experiments of Alfven & Malmfors and Elliot

& Dolbear showed beyond doubt that the diurnal variation of meson intensity cannot be explained away simply in terms of atmospheric or other terrestrial effects. Apart from the results of the above experiments there was other evidence indicative of the presence of a solar anisotropy of primary cosmic rays. Ehmert & Sittkus[92] revealed a difference in amplitude of the daily variations simultaneously measured by an ion chamber of omnidirectional sensitivity and by a vertical counter telescope of limited directional sensitivity. Sekido et al[93] pointed out that the amplitude of the daily variation increased from 0.19 % to 0.24 % when semiangle of the measuring telescope in east-west plane was reduced from 40° to 12°. Sarabhai et al[38] showed that at low latitudes the 12-month mean daily variation of meson intensity measured with telescopes with semiangles 22° in east-west plane had at different periods of time a diurnal amplitude ranging from 0.3 to 0.8 %. The latter amplitude is considerably larger than what can be expected from corresponding meteorological changes. These factors led the investigators to conclude that a large part of the observed daily variation can in fact be attributed to an anisotropy of primary radiation.

Elliot & Rothwell[94] and more recently Parsons[95] have cast doubt on the view that the daily variation is due to a non-isotropic flux of primary particles entering the earth's magnetic field. In their experiment on solar daily variation conducted at London, $\lambda = 50^{\circ}$ with counter telescopes inclined at 45° to the vertical pointing to E and W directions, the former authors find the daily variation measured by W telescope to be three times larger than that measured by E telescope. They have advanced the following arguments to show that the result observed by them is contrary to expectations.

According to Brunberg & Dattner's[15,96] data on trajectories, at latitude 50°, particles of energy 3×10^{10} eV whose initial directions are in the geomagnetic equitorial plane arrive from E at an angle of 45° to the vertical, while particles of same energy but whose initial directions are perpendicular to the geomagnetic equitorial plane arrive from W again at an angle of 45° to the vertical. A west telescope situated at $\lambda = 50°$ inclined at an angle 45° to the vertical therefore collects radiation from nearly the same direction throughout the day while the telescope similarly oriented to the E scans the plane of the ecliptic in the course of a day. If one assumes a mean energy of $2 - 4 \times 10^{10}$ eV for particles responsible for the daily variation observed by E and W telescopes at London, and if the direction of greatest anisotropy lies in or near the plane of the ecliptic then one would expect the east telescope to register larger daily variation than the west. Elliot & Rothwell therefore contend that the contrary result obtained by them is not consistent with the view that the daily variation is produced by an anisotropy of primary radiation existing at large distances from the earth.

Parsons has also reported similar discrepancies concerning the directional dependence of daily variation.

Elliot & Rothwell and Parsons come to the conclusion that the daily variation is probably due to modulation of primary cosmic ray intensity within the influence of the earth's magnetic field.

The discrepancies observed by Elliot & Rothwell and Parsons may perhaps be apparent. Elliot & Rothwell have assumed a mean primary energy of $2 - 4 \times 10^{10}$ eV for the particles responsible for the daily variation observed by them, and then they have deduced the asymptotic directions of particles of this energy arriving from East and West directions at their instrument. As has already been stated, in section 1.2, p. 5, this method of deriving spatial configuration of anisotropy, basing the calculations on mean energy of primary particles may well lead to conflicting results of the type reported by them.

Firor et al[97] have reported from study of the nucleonic component measured with neutron monitors at different latitudes that averaged over a large number of days the daily variation shows a peak to peak amplitude of about 1.0 % which is comparable to the amplitude observed at low latitudes in meson telescopes of moderate semiangle.

Regarding the solar anisotropy of high energy primary particles, evidence is available from measurements made at great depths underground and from extensive air-shower experiments. The intensity of the measured radiation being low, the statistical significance of the determinations is poor in most cases. The results of the underground experiments of MacAnuff[98], Sherman[99] and Barrett et al[29] exclude the existence of a diurnal variation exceeding 1.0 % in amplitude. The results of extensive air-shower experiments of Farley & Storey[100] show a solar diurnal amplitude of 1.45 - 0.25 %. The above results show the absence in the primary spectrum between 10^{12} eV to 10^{16} eV of any large solar anisotropy that can give rise to a daily variation greater than 1 or 2 %.

1.52 Galactic anisotropy

Large and persistent sidereal time variation has been reported for particles in the energy region 10^{12} to 10^{16} eV by Auger et al[101], Daudin & Daudin[102], Cranshaw & Galbraith[103] and many others. Recently the studies of solar as well as sidereal daily variations have been extended to still higher energies greater than 10^{16} eV by Crawshaw & Elliot[104], McCusker & Wilson[105] and Cranshaw & Galbraith[106]. Contrary to expectations these investigators find significant solar daily variation at these energies and no significant variation in sidereal time. McCusker & Wilson have observed variations in solar time with a large semidiurnal component in the rate of dense air showers ($>$700 particles / m^2) and also penetrating showers. These authors have considered the possibility of explaining the large semidiurnal variation observed in their experiments in terms of semidiurnal pressure oscillations in the atmosphere. They point out that the variation cannot be due simply to variations in the amount of air above the apparatus, since they obtain the usual value for the barometric coefficient, when short term variations are considered. Cranshaw & Galbraith have also reported large semidiurnal variation in the rate of arrival of extensive air showers of energy $\approx 10^{17}$ eV. They find a 13 % amplitude for the semidiurnal component with time of maxima at 0230 and 1430 hrs. and a diurnal amplitude of 9 % with mazimum at 1530 hrs. Considering the absence of sidereal daily variation for particles of energy greater than 10^{16} eV, they come to the conclusion that the highest energy particles if protons are of extra galactic in origin. Regarding the variations in solar time, they have offered no explanation. However, following the arguments of McCusker & Wilson, they have pointed out that to obtain significant change of shower rate at sea level from change in the distribution of air above the apparatus requires primaries with very large interaction cross section, larger even than that of heavy nuclei, suggesting thereby that the variations cannot be due to atmospheric pressure variations.

The anisotropy of heavy primaries has been studied in balloon experiments by Anderson et al[107], McClure & Pomerantz[108], Yngve[109], Stix[110] and Koshiba & Shine[111]. Koshiba & Shine have measured the daily variation of primaries with $Z \geq 10$ at $\lambda = 55^{o}$. They report an amplitude of $(34 \pm 7)\%$ with maximum near 9 a.m. while McClure & Pomerantz find no difference between night and day intensity. Stix and Koshiba & Shine report a value of 0.87 for the ratio of afternoon intensity to that in the morning. The anisotropy of the very low energy spectrum has similarly been studied in balloon flights by Bergstralh & Schroeder[112] and Dawton & Elliot[113]. The results again do not yield a consistent picture. These experiments are difficult to perform and present even greater difficulties of interpretation. Due to great variability of anisotropy from day-to-day, observations made in balloon flights are not strictly comparable amongst themselves and with results reported from ground stations which relate to the average of data over a large number of days.

Sekido et al[114] have made a systematic search for point sources of cosmic radiation with narrow angle alti-azimuth tellescopes inclined to the vertical at 80° to 85°. The results of their investigation provide the first reported evidence for a point source of cosmic radiation. The source is in the region of $\delta = 0$, $\alpha = 5$ h, 30 min. with an angular width $< 5^{\circ}$ and has an intensity 20 % of background intensity in the same direction. Further confirmation of this by other techniques is awaited. Rossi and his group are conducting investigations at stations in different latitudes to test the existence of galactic anisotropy of very high energy primaries.

1.53 Long term changes of solar anisotropy

The solar anisotropy as characterised by the amplitude and phase of the 12-month mean daily variation of meson intensity undergoes large long-term changes that are worldwide in character. Sarabhai et al[38,85,115] have made a systematic study of these changes as reflected in the data of Carnegie

Institution stations and the low latitude stations of Ahmedabad, Kodaikanal and Trivandrum. They have drawn attention to the correlated changes of amplitude and time of maximum of the diurnal component of the daily variation at Christchurch, Cheltenham and Huancayo during the period 1937-46. Pointing out the relationship of these changes with relative sunspot numbers and magnetic character figure they have suggested that the changes probably follow the 11-year cycle of solar activity. Extending their earlier analysis of Carnegie Institution data, to the period 1946-53 Sarabhai et al[115] find that while the changes of amplitude at different stations are not correlated in the new solar cycle, the changes of time of maximum continue to exhibit worldwide characteristics. Furthermore they find that they are better correlated with activity of 5303 Å coronal emission than with relative sunspot numbers or magnetic character figure.

The secular phase shift of the diurnal component of daily variation has also been examined by Thambyahpillai & Elliot[116]. They have shown the correlated changes occurring in it at the Carnegie Institution stations and have come to a general conclusion that the changes probably follow a 22-year cycle of solar activity.

Steinmaurer & Gheri[117] have recently compared data taken in groups of years over the past 22 years. They show that during the sunspot minimum in 1933 the time of maximum of the diurnal component was at about 7.00 a.m. comparable with the time of maximum about 20 years later in 1953-54, but was earlier than the time of maximum 11 years later in 1944. This indicates again a relationship with a 22-year cycle of solar activity. During some months in 1954 they observed the time of maximum of the diurnal variation to occur as early as 2.00 a.m. Similar changes in the phase of the diurnal variation have been reported by Possener & Heerdan[118]. They have shown that the daily variation in the north and south pointing telescopes exhibite a maximum around midnight during some months in 1953 and 1954. Conforto & Simpson[119] have demonstrated a progressive phase shift to earlier hours during 1954 in the daily variation measured by the nucleonic component and charged particle detectors.

Sekido et al[120] have studied the behaviour of the mean storm type vector representing the difference in the diurnal components of the disturbed period daily variation and the quiet period daily variation during each year. They have shown that the disturbance vector representing a storm type anisotropy points on the average towards the radially outward direction from the sun and undergoes a long term change from year to year broadly in step with the 11-year cycle of solar activity. The quiet day's anisotropy was however found to undergo a different type of secular variation. They suggest that the long term variation of diurnal variation observed by Elliot et al[116] and others which does not follow 11-year periodicity might be due to this secular variation of quiet day anisotropy.

The secular phase shift of the diurnal variation has been shown by Sandstrom[121] to be independent of the direction of measurement of particles and of the daily geomagnetic disturbances. Sarabhai et al[38] have compared the changes in time of maximum of the 12-month mean daily variation studied simultaneously by an ion-chamber at Huancayo and a vertical counter telescope at Ahmedabad. For these stations in low latitudes the changes are well correlated for the short period considered, but the magnitude of the change with counter telescopes is about 2.5 times greater than the change with the ion-chamber. Thus the semi-angle of the detecting instrument influences not only the amplitude of the daily variation but also the long term changes observed in the diurnal variation.

Sarabhai et al[38] have demonstrated that in addition to long term changes in the diurnal component of daily variation significant changes also take place in the semidiurnal component. When the daily variation is examined as a whole instead of studying in terms of harmonic components, a very remarkable sequence of changes is revealed as shown in Fig.3. At Huancayo the 12-month mean daily variation which exhibits one maximum near the noon from 1937 to 1943 changes over by 1952 to a variation exhibiting one maximum early in the morning. In the intervening period there is clear evidence of the progressive increase of the early morning maximum followed by a decrease of the noon maximum. During the period 1945 to 1950 the daily variation therefore exhibits two maxima instead of one. As can be seen from the figure, only half of the cycle of change appears to be completed in 11 years. This

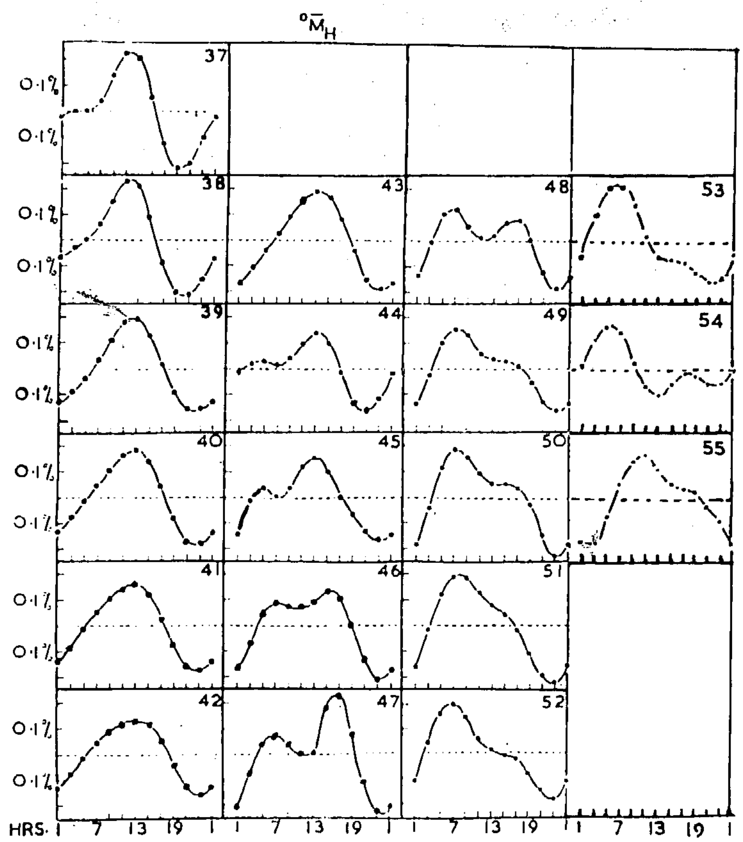


FIG. 9. The 12-month mean daily variation of meson intensity at Huancayo during different years [Sarabhai, Desai & Venkatesan (4)].

FIG 3.

again indicates a 22-year cycle of change of the anisotropy. Sarabhai et al therefore conclude that individual consideration of only the diurnal component of the daily variation does not fully reveal the physical process of change of the daily variation. According to them the most appropriate manner of studying the changes of solar anisotropy is by the examination of daily variation unresolved into its harmonic components.

Venkatesan & Dattner[122] have drawn attention to the significant differences in long term changes of diurnal and semi-diurnal components of the daily variation. They point out that the changes in the diurnal variation are worldwide and positively correlated at various stations whereas the semi-diurnal variation, although they are significant at various stations do not reveal common features. They contend that it is possible to determine the direction of the anisotropy uniquely from a study of the diurnal variation corrected for geomagnetic deflection at different stations. They have shown that long term changes of amplitude of the diurnal variation follow more closely the changes in geomagnetic activity than the solar activity represented by the sunspot numbers, suggesting thereby that the cosmic ray variations are not directly and simply connected with the sunspot number.

Sarabhai et al[38] have suggested that changes of daily variation could be considered in terms of the contributions from two distinct types of variations, one having a maximum near the noon and the other having a maximum at about 0300 hr. They have named these 'd' and 'n' type contributions respectively.

It has been shown by them that the relative change of these contributions is worldwide in character and can satisfactorily explain the observed changes from year to year at Huancayo and Cheltenham. The activity of these contributions is closely related to the solar cycle of activity and the pattern of addition and attenuation of these contributions appear to be reversed after 11 years.

1.54 Day-to-day changes of anisotropy

A study of daily variation of meson intensity clearly shows that there are significant day-to-day changes in the anisotropy of primary radiation. The change of diurnal component of the daily variation, especially on magnetically disturbed days has been extensively studied by various workers (Ref.92, 121, 123, 97, 124-127). It is found that on days with high K_p the amplitude of the diurnal component increases and its time of maximum becomes earlier. On the otherhand the semi-diurnal component of the daily variation gets reduced on magnetically disturbed days (Sekido & Yoshida[128]). Sekido & Kodama[125] have demonstrated that these effects are revealed to a greater extent in measurements made with narrow angle telescopes than with instruments having wider directional sensitivity.

Many attempts have been made to study the short term changes of anisotropy not necessarily connected with magnetic disturbances. Firor et al[97] have pointed out that the daily variation of the nucleonic component as revealed by neutron monitors is highly variable in character. A study of the quiet day variation by Remy & Sittkus[129] and Firor et al[97] revealed the presence of groups of days having a large diurnal amplitude with a maximum during the day. There were some days on which there was no appreciable daily variation and on others the daily variation appeared to have a maximum in the night. Sittkus[130] studied the amplitude of the daily variation measured by an ion chamber on individual days and noticed the tendency for large noon time maximum to occur on groups of days. He found a 27-day recurrence tendency for these groups but compared to the rest of the days, the days with large noon time amplitude were not associated with significantly different magnetic character figure. Remi & Sittkus found that days with large day time maximum of intensity was rarer in 1954 than in 1953. Sarabhai & Nerurkar[131] have made similar studies of the day-to-day changes of anisotropy as revealed by narrow angle telescopes. They find a marked tendency for the diurnal maximum during 1954 to occur either at 1200 hr. or in the early morning at about 0300 hr. local time. They find a 27-day recurrence tendency for days with large noon time maximum that usually occur in groups as observed by Sittkus.

Yoshida & Kondo[132] have analysed the ion chamber data of Huancayo in search of a recurrence tendency of the solar anisotropy. They find strong recurrence tendency extending upto two solar rotations which is more prominent than recurrence tendency in either general cosmic ray intensity or magnetic character figure. Evidence of recurrence tendency in daily variation has been presented by Kane[133]. He has shown that recurrence tendency in daily variation, unlike the tendency in general intensity remains unchanged during the three years 1951, 1952 and 1953 studied by him.

Sarabhai & Bhavsar[134] have studied the correlated day-to-day changes of anisotropy and mean cosmic ray intensity. They find that the days with night maximum are associated with decrease of mean intensity while days with maximum at day time are associated with increase of intensity after the respective epochs. The mean intensity is found to be normal for other days. This evidence is suggestive of the creation of a variable anisotropy, and changes of mean intensity depending on the nature of the anisotropy created.

1.6 Interpretation of variations

1.61 Relation between solar activity & cosmic ray variations

From the foregoing sections, it is clear that a vast amount of evidence is now available to show that the sun strongly influences cosmic radiation measured on the earth. Most of these influences have been revealed through relationships with the activity of the sun which changes markedly from time to time. It is now known that certain active regions on sun persist through several solar rotations and give rise to characteristic 27-day recurrences. General solar activity changes with an 11-year period while the state of magnetic polarity of bi-polar sunspots undergo a 22-year cycle of variation. These recurrences and periodicities are reflected in varying degrees in cosmic ray variations and may be summarised as follows.

The sun appears to influence the low energy cut-off of the primary spectrum over an 11-year cycle. Apart from this it is known also to produce a general change of intensity with a cycle of 11 years. It produces short duration changes in intensity, many of which are related to CMP of active solar regions such as sunspot groups, unipolar regions and regions of intense coronal 5303 Å emission. Occurrences of these active regions at low heliographic latitudes appear to favour their effectiveness in influencing cosmic rays.

The 12-monthly mean anisotropy undergoes a change consistent with a cycle of 22 years and perhaps constitutes the first solar influence detected so far which has a period corresponding to what may be considered the true solar cycle of activity. This requires to be verified by observations extending over several cycles which incidentally forms one of the purposes of the present work. The sun also produces day-to-day fluctuations of anisotropy some of which are related to CMP of active regions on the sun.

In association with solar flares, the sun emits cosmic rays which under certain circumstances can attain energies in excess of 50 BeV.

Some of the cosmic ray variations are closely related to geomagnetic activity. This relationship however is probably due to the common source of solar activity.

The close relationship of cosmic ray variations with solar activity has prompted various workers to investigate whether these variations are caused by the direct emission of particles from the sun. At present there is general agreement regarding solar emission only in the case of solar flare type increases. Explaining other variations in terms of modulation of intensity has found favour in recent times because of the strength of the following arguments.

a) At minimum of solar activity as judged by visual evidence from the solar disk or by comparative absence of terrestrial effects such as magnetic, ionospheric and auroral activity, there is absence of 'knee' with the presence of low energy particles down to 150 BeV. Associated with this there is an increase in general intensity, not only due to the admittance of low energy particles but due to enhanced intensity throughout the whole spectrum. This observation suggests a screening of the earth, probably by magnetised clouds of interplanetary matter whose efficiency to screen cosmic rays is governed by the solar activity. At sunspot minimum the screen is temporarily removed or made less inpervious.

b) Magnetic storms on many occasions are accompanied by decreases in cosmic ray intensity but never with increases. There is evidence to show that 27-day recurrence changes are also decreases similar to magnetic storm type decreases (Neher & Forbush[44,64]). These decreases in intensity can be taken to indicate the presence of a screening mechanism that is under solar control.

However, there is unique evidence of an increase of intensity associated with CMP of active solar regions put forward by Simpson et al[70,71]. This evidence requires strengthening by further observations. Such increases if present are hard to be explained in terms of a screening mechanism.

1.62 Geomagnetic and geoelectric models

Early workers tried to explain the variations as due to modulation of cosmic ray intensity by geomagnetic field purturbations. But it was found later that various aspects of cosmic ray intensity variations cannot be explained on the basis of observed geomagnetic field variations. Simpson[135] showed that the variations in neutron intensity at latitudes above the 'knee' of the intensity latitude curves are very similar to those observed at low and middle latitudes and thus proved that observed variations in intensity cannot be due to geomagnetic field variations.

Nagashima[19] has proposed a model involving a geo-electric field to explain the worldwide nature of cosmic ray intensity variations. His theory explains fairly well the altitude[18,56] and latitude dependence[136] of variations observed by various workers. However, it cannot explain large variations occurring during magnetically quiet periods when presumably no purturbing geo-electric fields can be present. Simpson[135] finds that in the range $\lambda = 45^{\circ}N$ to $60^{\circ}N$ the latitude dependence of fractional changes in neutron intensity during different periods does not agree with the latitude effect calculated by assuming axially symmetric geo-electric fields at different distances from the earth. After a critical study of the effects of geomagnetic and geo-electric field purturbations on cosmic ray intensity he comes to the conclusion that the variation mechanism must be of extra-terrestrial origin and its association with solar phenomena is independent of the earth's system.

The early theories which tried to explain the daily variation in terms of geomagnetic or heliomagnetic field variations became untenable because of their failure to explain the approximate latitude independence of these variations, (Ref.97,137-140).

Recently, Parker[141] has examined in a qualitative way some of the difficulties of the 'Heliocentric' models. He finds that

a) they are not sufficiently local and therefore demand immense amounts of matter and magnetic fields carried away from the sun,

b) they are called upon to preserve the observed isotropy of cosmic ray particle distribution while at the same time vary the intensity by large amounts,

c) they have failed to provide an effective removal mechanism within the volume considered to prevent eventual statistical equilibrium of intensity.

With a view to overcome these difficulties he has proposed a mechanism which operates within a few earth's radii. Interplanetary magnetic gas clouds are captured by the terrestrial gravitational field and a nebulous geocentric barrier is formed. This barrier gives rise to the observed low energy cut-off. When a cloud of magnetised plasma occasionally emitted by the sun is captured, abrupt Forbush type decreases of cosmic ray intensity are observed at the earth. The mechanism is under solar control and the intensity variations are interpreted in terms of modulation of galactic cosmic ray particles at earth.

The theory has many attractive features but at the present moment there is no evidence to show the presence of a geocentric barrier of magnetised ionised gas supported by terrestrial gravitational field.

1.63 Modulation in interplanetary space

Alfven[142] has suggested that ionised rarified jets of gas emitted by the sun which are responsible for geomagnetic storms are also responsible for cosmic ray variations. He has developed a theory of variations making use of the fact that the 'frozen in' magnetic field carried by a rapidly moving beam of ionised gas through the interplanetary space will give rise to an electric field for an observer in a fixed frame of reference. The beam is supposed to act as an electro-static modulator for cosmic ray particles passing through it and give rise to variations in primary intensity, and an anisotropy in particular directions depending on the position of the earth relative to the beam. This model has been worked in detail by Brunburg & Dattner[143] to explain the decreases associated with magnetic storms and it requires an interplanetary field of 10^{-5} gauss in the vicinity of the earth if only decreases are to be observed.

Brunburg & Dattner[96] have pointed out that seen from a fixed coordinate system the rotating sun would be strongly polarised so that there would be a voltage difference between the poles and the solar equator of the order of 10^{9} volts. The combined action of the electric field produced by the polarisation and the solar magnetic field will make charged particles partake in a general rotation with the sun so that the earth will receive an excess of radiation from the 18-hourly direction. Thus a tangential anisotropy is produced. Alfven[144] on the otherhand has shown the possibility of an outward radial flow of energy depending on the accelerating processes within the solar system. This will impart a radial anisotropy to cosmic rays which will change with the 11-year cycle of solar activity. These explanations require a general solar magnetic field of the order of 10^{-5} gauss at the earth's orbit to account for a diurnal variation of amplitude approximately 0.2 %.

Nagashima[145] has quantitatively examined the trajectories of cosmic ray particles passing through the beam under the combined influence of the electric field inside the beam and a frozen magnetic field within the beam derived from the solar dipole field. He finds that associated with every beam there is a minimum energy for primaries which can traverse it, and which alone contribute to the anisotropy. For higher energies the percentage anisotropy would fall off progressively with increasing energy. Nagashima has shown that maximum anisotropy would be produced in the direction pointing towards the sun. This is in agreement with the determination of the storm type vector by Sekido et al[120]. Nagashima's theory also explains the 11-year cycle variation of storm type anisotropy as being due to a change in the density of the solar streams and the strength of the trapped magnetic fields during the solar cycle of activity.

Nagashima has not tried to give an explanation for the occurrence of a night maximum in the diurnal variation. Nerurkar[24] has shown that by admitting random orientation for the frozen-in magnetic fields, occurrence of a night maximum at low latitudes can be explained by an extension of Nagashima's theory.

However the existing theories are still inadequate to explain the known features of the diurnal variation. It has to be mentioned that any theory advanced to interpret the solar anisotropy and its changes with time has to take account of the following experimentally observed features of the daily variation:

a) For several years in the past the 12-month mean daily variation exhibited two significant maxima. This indicates that the daily variation cannot at all times be satisfactorily described in terms of the diurnal component alone.

b) A shift of the principle maximum of daily variation by as much as 10 to 12 hours takes place over a period of years. The implication of this shift is that during some years the daily variation exhibits a principle maximum during the day while in others the maximum is shifted to the night.

c) The amplitude of the daily variation is a function of the directional sensitivity of the recording instrument. The change of amplitude of the daily variation with change of semiangle of the telescope is very much larger than can be normally expected. Large amplitudes of the order of 1.2 % have been observed with narrow angle telescopes at low latitudes.

d) The existence of a permanent anisotropy has not been proved beyond doubt. Even if such an anisotropy is present, it is masked by large variable anisotropies.

Further progress therefore depends not only in comparing with known experimental facts, the implications of various theoretical models for modulation of cosmic ray intensity, but in extending our detailed knowledge of the variations of intensity and of anisotropy. We require dependable experimental observations which can reveal the changes of the cosmic ray variations which occur at different periods of the solar cycle; at stations at different latitudes, longitudes and elevations; and of components of the primary intensity differing in composition and energy.

1.7 Statement of the problem

For a proper understanding of the nature of the anisotropy of primary radiation, it is important to study the solar daily variation of intensity in all its aspects. It has been customary to examine the daily variation in terms of its characteristics averaged over a period of months or years. Such a study however, is not complete unless it is supplemented by a study of the daily variation on individual days, and its changes from day-to-day. This is because the average variation could be nothing more than the arithmetical average of a variation which is intermittent or recurring in nature, so that days with large variations are combined with days with no variation.

We know from the investigations of Firor et al[97], Sarabhai et al[131], Sekido et al[120,124-128], Remy & Sittkus[129] and Sittkus[130] that large day-to-day changes take place in the nature of the daily variation during magnetically disturbed as well as during quiet periods. Sarabhai & Nerurkar[131] have examined the distribution of the time of maximum of the diurnal component of the daily variation on individual days measured with narrow angle meson telescopes. However, a detailed study of the pattern of distribution of all characteristics describing the form of the daily variation on individual days in relation to the form of the average variation over a group of days has not been systematically undertaken. This has handicapped the physical interpretation of the characteristics of the average daily variation. While the examination of the daily variation on individual days is inherently subject to a larger statistical error than if data are averaged over an extended period, the result of sampling on individual days from a population which is constant can be predicted from statistical theory. Thus from the distribution of characteristics of individual days, insight can be gained of the physical meaning to be attached to the characteristics of the average daily variation. The inter-relationship between the parameters defining the harmonic components of the average daily variation and daily variation of cosmic rays on individual days at Kodaikanal for a period of three years has been examined by the author in the present work.

An insight into the processes by which an anisotropy of a highly variable character is produced can be obtained by a study of simultaneous changes of anisotropy and of the mean cosmic ray intensity, and their relationship with geomagnetic disturbances. Sarabhai & Bhavsar have reported an investigation of correlated changes of daily variation and the daily mean intensity of cosmic rays measured with narrow angle telescopes at Ahmedabad. They have also examined how the correlated changes are connected with Cp the daily planetary character figure for geomagnetic disturbances. At Kodaikanal, due to frequent interruptions of the electric supply, it is difficult with counter telescopes to make continuous measurements of day-to-day changes of intensity over an extended period of time. In consequence it has been possible only to study the relationship of the daily variation with Cp. In Chapter V, the results of an investigation made by the author with narrow angle telescopes are compared with the results of Sarabhai & Bhavsar and with the results of a later study with a neutron monitor made by Satya Prakash at Kodaikanal.

CHAPTER II

THE APPARATUS

The characteristics of the daily variation depend on the direction of measurement and the cone of acceptance of the measuring apparatus. A counter telescope having a restricted cone of acceptance for the incoming radiation reveals a daily variation of more prominent amplitude than an omnidirectional device such as an ionisation chamber. Therefore it is advantageous to study the nature of the daily variation and its changes with time with directional counter telescopes. The Physical Research Laboratory at Ahmedabad commenced in 1950 continuous measurements of meson intensity with counter telescopes of standard geometry at stations in low latitudes. The Ahmedabad station ($\lambda m = 13^{\circ}$N, sea level) started with a unit consisting of four vertical triple coincidence telescopes having a semiangle of 22° in the E-W plane and 37° in N-S plane. An absorber of 8 cm. of lead was used with the telescopes. Similar units were later built and set in operation, one at Kodaikanal ($\lambda m = 1^{\circ}$N, 7688 ft.) in 1951 and another at Trivandrum ($\lambda m = 1^{\circ}$S, sea level) in 1953. In 1956 two narrow angle triple coincidence vertical telescopes were set up at Kodaikanal. All units are in continuous operation since then.

In this chapter, the requirements of an experimental technique for time variation studies of cosmic rays are first stated in section 2.1. A detailed description of the meson monitors in operation at Kodaikanal is given in section 2.2 to 2.4.

2.1 The experimental technique for time variation studies

Valid interpretation of observational data of cosmic ray time variations is possible only when measurements extend over a long period. This makes it necessary that the apparatus chosen for the studies should be stable and retains its characteristics. Longterm stability is difficult with counter telescopes, since the useful life of self quenched counters is limited. Therefore to get fairly continuous data it is necessary to run as many duplicate sets of counter telescopes of identical geometry as possible. The telescopes are designed so as to obtain the maximum counting rate consistent with the desired geometry of the telescopes. This helps to secure data of improved statistical significance.

In addition, experimental failures should be reduced to a minimum by proper design and construction of the apparatus and by efficient maintenance. Care should be taken to see that no counter with doubtful characteristics are used in the coincidence telescopes. The counter failures can be minimised by the use of suitable electronic quenching units. They improve the plateau characteristics of the self-quenched counters and thereby increase the stability and useful life of the counters. The variations of atmospheric temperature, A.C. mains voltage fluctuations, changes in the D.C. voltages supplied to the counters and their associated units and spurious pickups are some of the important factors that affect the efficiency of the unit and therefore the reliability of the data. It is extremely important to stabilise all voltages, A.C. as well as D.C., to a high degree, both for input and for load variations. Since the frequency of A.C. mains voltage may vary, the use of synchronous clocks should be avoided. The counters must be maintained in a constant temperature enclosure throughout the period of experimentation. The electronic units should be built and mounted in such a way as to avoid electrical inter feeding between the units. Properly earthed shielded cables must be used to feed the pulses from one unit to another and their lengths should be kept as small as practicable to avoid spurious electrical pickups and attenuation and distortion of signals. All the output terminals of power supplies must be decoupled with suitable condensers to avoid undesirable interfeeding. Taking these requirements of experimental technique into consideration, counter telescopes $22T_K$ and $5T_K$ were built at Kodaikanal.

2.2 $22T_K$ telescopes

A schematic diagram of the experimental set up of $22T_K$ telescopes is shown in Fig.4. It consists essentially of four vertical triple coincidence telescopes. Two identical sets of four counter trays A,B,C and D and A',B',C' and D' are mounted side by side in a constant temperature enclosure with a vertical separation of 20 cm. between the individual trays of each set. Each tray consists of four Geiger counters connected in parallel. Trays A, B, C; B, C, D; A', B', C'; and B', C', D' are connected in triple coincidence. The total sensitive area of each tray is nearly 480 cm^2., the length of each counter being 30 cm. and diameter 4 cm. The whole apparatus is aligned so that the axes of the counters lie along the N-S direction. The geometry of this apparatus

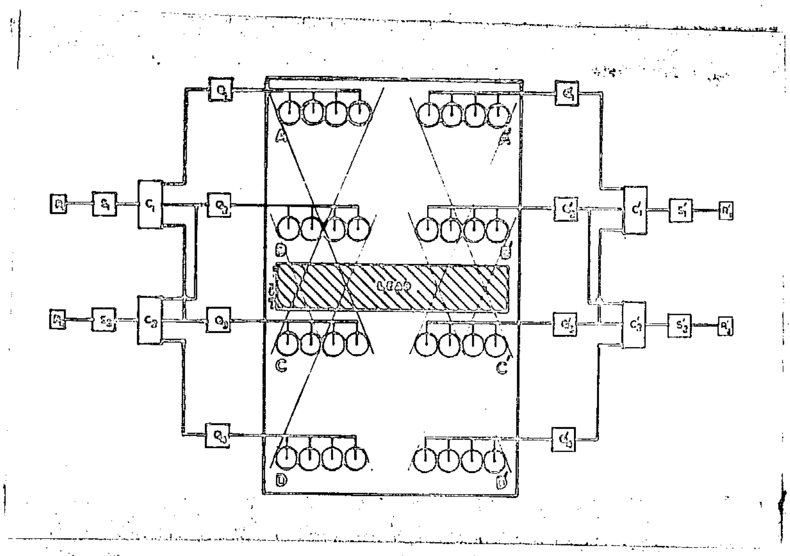


FIG 4.

gives the telescopes a semiangle of 22° in the E-W plane and a semiangle of 37° in the N-S plane. 8 cm. of lead absorber is introduced between the trays B-B' and C-C' to eliminate the soft component.

Pulse out-puts from trays A, B, C and D are fed to separate electronic quenching units Q_1, Q_2, Q_3 and Q_4 and the out puts Q_1, Q_2, Q_3 and Q_2, Q_3, Q_4 are in turn fed to fast Rossi coincidence units C_1 and C_2. The pulses from the coincidence units are scaled down by scalers S_1 and S_2 and then recorded by mechanical registors R_1 and R_2. Similar arrangement is made to record coincidences from telescopes (A'B'C') and (B'C'D'). The dials of the mechanical recorders R_1, R_2, R_1' and R_2' are photographed at hourly intervals by an automatic photographic arrangement. The telescopes ABC, BCD, A'B'C' and B'C'D' measure only the hard component of cosmic radiation which consists mostly of μ mesons. The counting rates of these telescopes can be evaluated from the hourly readings of the mechanical recorders R_1, R_2, R_1' and R_2' respectively.

2.3 $^5T_4$ telescopes

Sekido and his co-workers[93,125,128] and Sarabhai et al (ref.131,146) have drawn attention to the remarkable differences observed in the nature of daily variation and its changes when measurements are made with telescopes of different semiangles. The cosmic ray research group at Ahmedabad have studied the daily variation of meson intensity measured with vertical counter telescopes having semiangles of 2.5°, 5°, 15°, 22° and 45° in the E-W plane. They have come to the conclusion that vertical telescopes with a semiangle of 5° in the E-W plane are very suitable for the study of the daily variation and its changes with time. Because of this the author has set up a few narrow angle telescopes at the equatorial mountain station of Kodaikanal to compare with studies made, with narrow angle telescopes at Ahmedabad.

Fig.5 shows the experimental arrangement used to record mesons arriving from the zenith in a cone of semiangle 5° in the E-W plane, and 19° in the N-S plane. It consists of two independent triple coincidence counter telescopes $(x_1 x_2 x_3)$ and $(y_1 y_2 y_3)$. The trays x_1, x_2, x_3 and y_1, y_2, y_3 each contain four counters connected in parallel. The counters

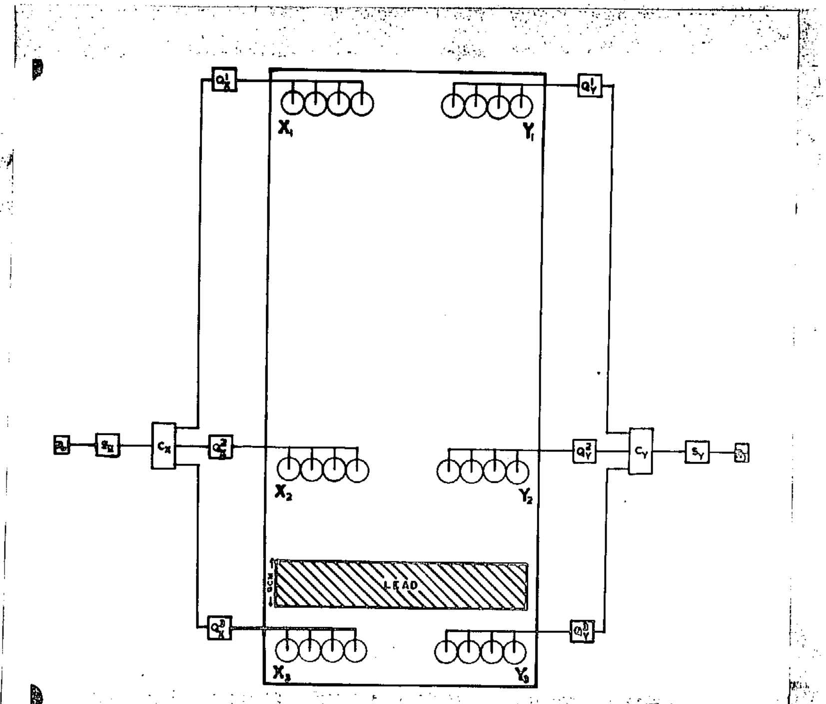


Fig 5.

used are of 60 cm length and 4 cm. diameter and provide a sensitive area of 240 cm^2. to each tray. The trays x_1, x_2 and x_3 are mounted one vertically below another; the separation between x_1 and x_3 being 180 cm. Trays y_1, y_2 and y_3 are similarly mounted by the side of x_1, x_2 and x_3 in the same enclosure. The counters are aligned along the N-S direction. 8 cm. of lead absorber is kept between the trays $x_2 - y_2$ and $x_3 - y_3$. As in the case of 22T telescopes, separate quenching units are used for each tray, and the out-put of the quenching units are fed to the triple coincidence units C_x and C_y. The coincidence out-puts are scaled by scale-of-four units S_x and S_y and are finally registered by recorders R_x and R_y.

The mechanical recorders R_x and R_y are placed along with the recorders R_1, R_2, R_1' and R_2' of the 22T telescopes in a common photo-unit and their dials photographed at hourly intervals.

2.4 Components of the apparatus

2.41 Geiger-Muller counter

G-M counters are high gain amplifying diodes operated at potentials below the continuous discharge voltage. The important property of a G-M counter is that the magnitude, duration and general character of discharge in the tube is independent of the specific ionising power of the initial particle. The theory of counter discharge, quenching and consequent development of the counter pulse in a self quenched counter has been widely discussed in literature (Wilkinson[147], Korff[148], Montgomery & Montgomery[149] and Stevers[150]).

When an ionising particle passes through a counter, it produces a few ion pairs in the sensitive volume of the counter. The free electrons trigger an avalanch and a discharge which spreads rapidly throughout the length of the counter. The discharge lasts only for a few microseconds. Soon the field conditions inside the counter are altered due to the positive space charge formed in the high field sensitivity region near the central wire and the discharge is quickly extinguished. Within a fraction of a milli-second after the triggering event, all the ions and electrons are cleared out of the interelectrode space and the counter is ready to register the next ionising event. As a result of discharge and quenching of the counter, a small voltage pulse is developed across the counter which can be suitably amplified and recorded.

The most important operational characteristics of G-M counters are (a) low operating voltage, (b) long operating range or plateau, (c) high efficiency and (d) long useful life. All the features cannot simultaneously be attained to a maximum degree since some of them are mutually exclusive, but a workable compromise is possible. The useful life of a counter is measured in terms of the number of events registered before the plateau characteristics deteriorate to such an extent that the counter can no longer be relied upon. Counters containing only permanent gases should exhibit no appreciable change with time provided there are no constructional defects. But this is not the case with self-quenched counters. In the quenching process accompanying each discharge a certain number of molecules of the quenching vapour is decomposed and hence a self-quenched counter progressively deteriorates. The deterioration is due not only to the loss of quenching molecules but also to the cormation of a dielectric coating on the electrodes by the dissociation products of the quenching vapour. This coating reduces the effective area of the electrode surfaces. Spatz[151] has estimated the useful life of a normal self-quenched counter to be of the order of 10^{10} counts. The deterioration can however be retarded by working the counter on low "over voltages" and at the same time using an external electronic quenching unit to limit the extent of discharge in the counter.

All the G-M counters used during the present investigation were prepared by the author at Kodaikanal. The constructional procedure followed is described in the following.

Fig.6 shows a typical metal counter prepared at Kodaikanal. The cathode is made out of thin walled brass tubing of 4 cm. diameter. The counters for 22T telescopes

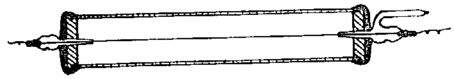


FIG 6

are prepared out of 36 cm. long tubes and those for 5T telescopes are made out of 66 cm. tubes. Thin tungsten wire of 4 mil. diameter is used for the anode. The ends of the brass tube are machined properly and the inside surface is polished by steel wool. Tubes having depressions or grooves running parallel to the axis of the counter are rejected. The selected tubes are fitted with end pieces which are cut from a brass rod of 4.5 cm. diameter. These discs are turned on a lathe to the required diameter so that they fit tightly inside the brass tube. The inside surface of these brass pieces is polished with steel wool as before. Holes are then drilled at the centre of these discs to fit the glass seals that hold the anode wire in its place and at the same time provide for evacuation and filling of the counter. The holes drilled are made a bit conical by using a reamer so that the tapering ends of the glass seals sit tightly in them.

Before assembling the parts the inside surface of the counter tubes and the end pieces are carefully cleaned with commercial ethyl acetate and then rinsed with pure ethyl acetate to remove metalic powder, dirt, grease etc. Locher[152] and others have stressed the importance of removing dirt, dust and contamination from the cathode surface, since dust particles create strong local fields inside the counter which distort the main field and give rise to spurious counts.

The parts of the counter are then assembled as shown in Fig.6 and a suitable length of 4 mil. tungsten wire is threaded through the capillary of the glass seals. The ends of glass seals introduced on either side extend atleast 3 cm. into the counter thereby forming protective sleeves over the ends of the anode wire[153]. The surfaces of all the closely fit metal to metal and glass to metal joints are cleaned and warmed to 280°F to 300°F and araldite (a thermosetting plastic) is applied to the joints keeping the counter rolling all the while so that an even coating of araldite is formed over the joints. All the joints are kept warm till the araldite sets and then allowed to cool gradually to room temperature. The araldite seals are then coated with a thin coating of Apiezon high vacuum wax 'W'. The anode wire is spot welded at both ends to thick tungsten studs which are then sealed to the thin capillary ends of the glass seals keeping the central wire taut in its place all the while. The thick tungsten studs protruding outside the sealed glass ends are then soldered to copper wires using an alloy of nickel and silver to provide for external electrical connection to the anode.

The counters thus prepared are then connected to a vacuum system and evacuated. While evacuating, the counters are warmed slightly to drive out moisture and the central wire is glowed to incandescence by passing a current through it. This is necessary to burn out dust and sharp points on the wire. About ten hours after evacuating, the counters are tested for leakage and the leakproof counters are filled with 90 % of argon and 10 % of pure ethyl acetate to a total pressure of 10 cm. of Hg. Argon is a good filling gas since it has a large cross-section for ionisation, a sufficiently high ionisation potential to allow electron transfer with most polyatomic molecules, does not form negative ions, is inexpensive and readily available to the required degree of purity. Ethyl acetate is used as the quenching agent as it exhibits band absorption spectra blanketting the region between 1020 and 790 Å which happens to be the region in which the radiation emitted by excited argon also lies. Therefore the ethyl acetate molecules can readily absorb photons emitted by excited argon and in addition they have the important property of not re-emitting the absorbed energy.

The filling gases are allowed to mix for about two hours and the characteristics of the counters are then checked individually for their plateau characteristics. If the counting rate does not exceed more than 2 % for every 100 volt increase above the threshold for 200 volts the plateau of the counter is taken to be satisfactory and the counter is sealed at the constriction provided in the glass sleeving. Then the counters are 'aged' by working them for about sixteen hours at the middle of their plateau and their characteristics are rechecked. The counters that retain their characteristics after this process are taken for use.

2.42 Electronic units

A. Quenching unit :- The characteristics of a self-quenched counter change after a certain period of continuous use and the counter tends to develop spurious pulses due to improper quenching action. As explained earlier, an external electronic quenching unit is used to suppress spurious discharges (Putman[154]). Elliot[155] has shown that the use of an external quenching unit improves the plateau and stability of the self-quenched counter, and extends its useful life. If a quenching pulse of well defined duration and magnitude ~~is~~ applied to the central wire it not only quenches the initial discharge but also limits its spread on the central wire. Thus the number of dissociating molecules per discharge is limited and therefore the useful life of the counter is improved.

The quenching circuit used in the present investigation (Fig.7) consists of a univibrator and a differentiating network

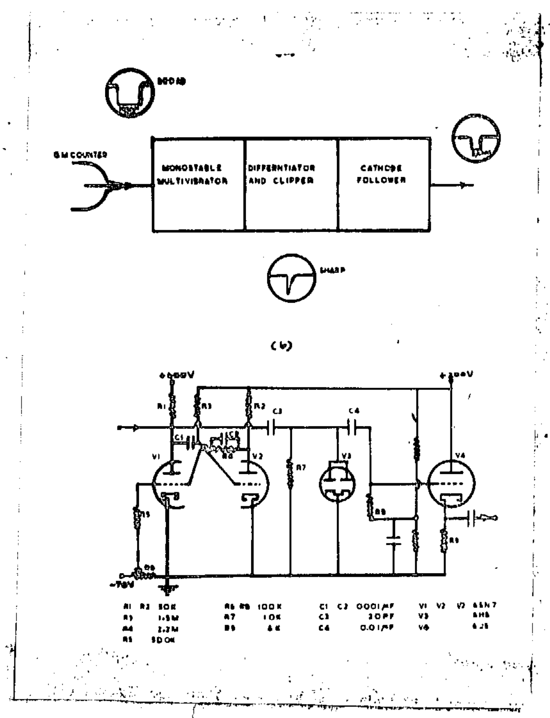
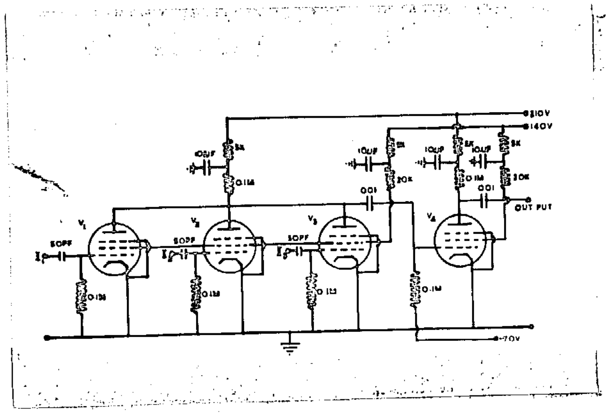


FIG 7

followed by a diode clipper and cathode follower. A high conductance twin triode 6SN7 is used for the univibrator. The negative pulse from the counter triggers the univibrator as a result of which a rectangular negative pulse of about 350 volts and of duration 1000 microseconds develops at the anode of the counter. This brings down the voltage across the counter far below the threshold and keeps it low until the discharge in the counter is quenched.

The rectangular negative pulse developed at the anode of V_1 is differentiated by means of an RC network having a short time constant of the order of 0.5 microseconds. On such a differentiation the leading edge of the rectangular pulse which represents the onset of the discharge produces a sharp negative pulse. This is followed by a positive pulse after 1000 microseconds. The positive pulse is bypassed by the clipping diode which offers a low impedence path for positive signals. The negative pulse is fed to the coincidence circuit through a cathode follower. When pulses are to be fed to several circuits through shielded cables it is advantageous to use a cathode follower to prevent loss of signals[156].

B. <u>Coincidence circuit</u> :- The coincidence circuit used is of the well known Rossi type (Fig.8). The important property of the circuit is that an output pulse is obtained only when the input pulses from various channels arrive within a very short interval of time of the order of a few microseconds. To secure high resolution and good descrimination between partial and total coincidences sharp cutoff pentodes with low interval resistance are used. The plates of the coincidence



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tubes are tied together to a common plate load resistor R. The control grids are connected to the individual trays of the telescope. To avoid the small pulses of partial coincidence that might be developed due to the finite internal impedence of the 6SJ7 tubes a level discriminator is used at the output which selects the large pulses of threefold coincidences only and passes them on to the scaling circuits. The resolving time of the circuit is of the order of 5 microseconds.

C. <u>Scaling and recording circuits</u> :- A scaling circuit performs two important functions. First it scales down the counting rate to a level suitable for the mechanical recorder to follow without loss and secondly it removes the randomness of coincidence pulses to a certain extent[157]. It has been observed by Stevenson & Getting[158] that the fractional variation in the time between every r^{th} pulse taken from a distribution initially random, decreases as r increases. In fact the fractional standard deviation of the variation in the time between every r^{th} pulse is given by $\left\{1/(1 + r)\right\}^{\frac{1}{2}}$. This means that in the output of a scaler there are fewer short intervals and that by suitable choice of the scaling factor the losses due to the mechanical recorder can be obviated.

The design of the scalers used in the present investigation is based on that of the well known Eccles-Jordan trigger circuits. Each stage of the scaler is a scale-of-two

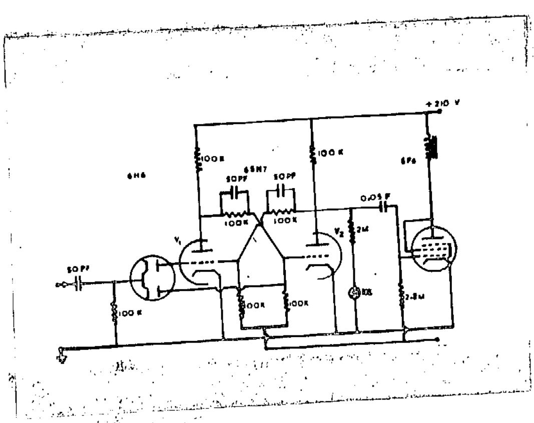


FiG 9.

unit and a number of such stages can be put in cascade to get higher scaling factors. The counting rates of 22T telescopes are scaled down by a factor of 8 before recording and those of 5T by a factor of 4. The Fig.9 shows the basic scale of two circuits used and the recorder circuit that drives the register. The scale-of-two circuit has two stable states of operation. In the first state one triode V_1 of the 6SN7 is conducting while the other V_2 is non-conducting. In the second state it is the reverse. Now if a sequence of negative pulses are applied at the input the circuit flips from one state to the other as successive pulses arrive. The flipover time which decides the resolving time of the scaler is of the order of 15 microseconds. The output of the scaler, on differentiation, produces alternate positive and negative pulses and scaling is achieved by accepting the pulse of one polarity and rejecting the other. This function is performed by the coupling diode 6H6. When scale-of-two units are connected in cascade, an indicating neon is used at the end of each stage to show whether the particular stage is functioning properly or not. The final output of the scaler is fed to the grid of a biased power pentode. The plate voltage is applied to this tube through the solenoid of the mechanical recorder. The tube conducts and actuates the mechanical recorder only when a positive pulse arrives at its grid.

D. <u>Power supplies</u> :- The A.C. mains supply at Kodaikanal is far from satisfactory. The voltage varies from

180 V. to 240 V. and power failures are quite frequent especially during the monsoon months. A good 5 K.V.A. constant voltage transformer giving an output of 220 ± 4 V. at loads greater than 2.5 K.W. when the input voltage varies from 180 V. to 240 V. was used to stabilise the mains voltage. The power for the various D.C.Regulators and filaments of vacuum tubes were derived from the regulated output of the constant voltage transformer.

The D.C. voltages supplied to the counters and their associated units were stabilised by means of electronic regulators both for input and load variations.

The most desirable features of a regulated D.C. power source are high stabilising power, low internal resistance and low ripple output. Hunt & Hickman[159] have discussed in detail various types of voltage stabilising circuits and have shown that the simple degenerative type are in general most satisfactory. Hence for the present investigation mostly degenerative type stabilising circuits are used.

<u>High voltage power supply</u> :- Fig.10 shows the circuit diagram of the high voltage supply used for providing voltages for G-M counters. By means of the potentiometer P, the output voltage can be varied over a wide range of 1000 to 1700 volts but the stabilisation is better at the lower end of the range. The sharp cut off pentode 6SJ7 is operated as a 'starvation amplifier' (Volkers[160]) so that it gives a very

high amplification to the fed-back difference voltage. This gives high regulation to the output voltage. The regulation obtained by this circuit is of the order of ± 2 V. at 1300 V. for an input variation of 180 to 240 V. In the present

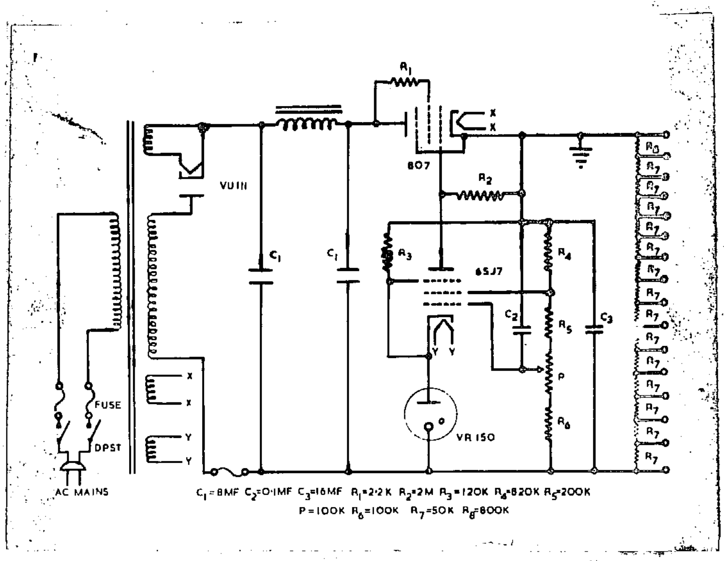


FIG 10.

investigation the power supply is adjusted to an output of 1200 volts and the various voltage tappings for counters are obtained from the bleeder circuit shown in the diagram. Each tapping of the bleeder is biased with 0.005 Mf. condenser to avoid inter feeding of counter pulses which may result in spurious counts.

<u>Low voltage power supply</u> :- All the circuits described earlier in this section are designed to function on plate and screen voltages of 420, 210 and 150 volts and a bias voltage

of -75 volts wherever this is required. Circuit diagram of the power supply used to get 210 V. stabilised voltage is shown in Fig.11. Similar circuits are used for constructing the 420 and 150 V. stabilised power supplies. Since the load

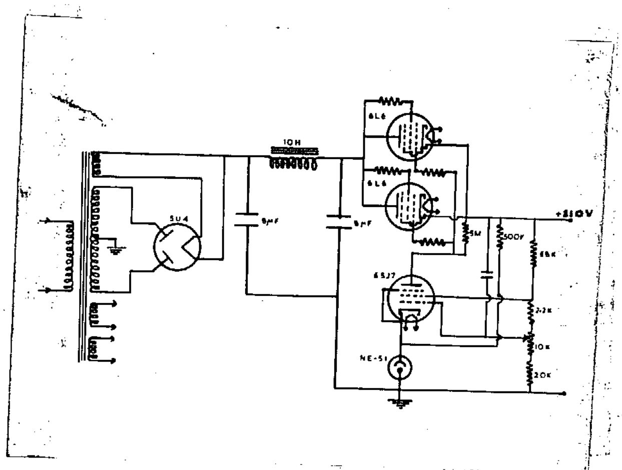


Fig. 11

on the bias supply is of the order of 20 MA only, a VR75 tube is used for stabilising -75 bias voltage.

E. <u>Automatic photographic device</u> :- The details of the camera unit used is shown in Fig.12. The electro-mechanical recorders registering the counts, a clock and a calender are mounted on one side of a light tight box with an easily detachable camera fixed on the opposite side. The camera is of an open shutter type and has a good quality short focus lens. At a time, the camera can hold about 30 ft. of 35 mm. Kodak Super XX film. E_1 and E_2 are two lamps that flash at intervals determined by the photo-unit triggering clock. The spool in the camera which takes the exposed film (S_2) is geared to the shaft of a low speed motor which rolls the film through one frame after each exposure.

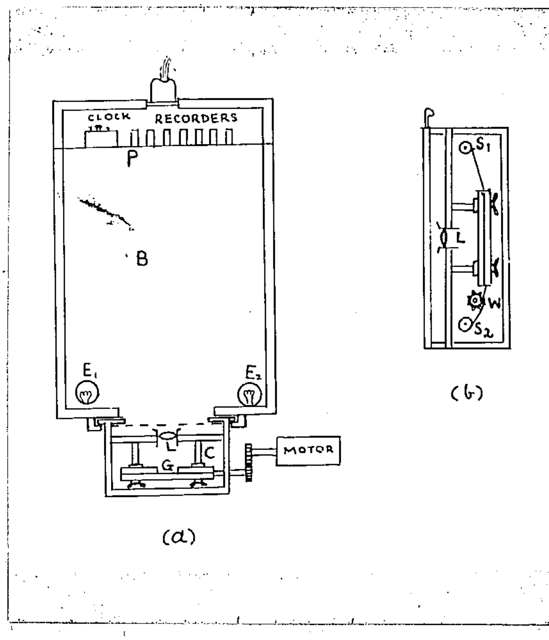
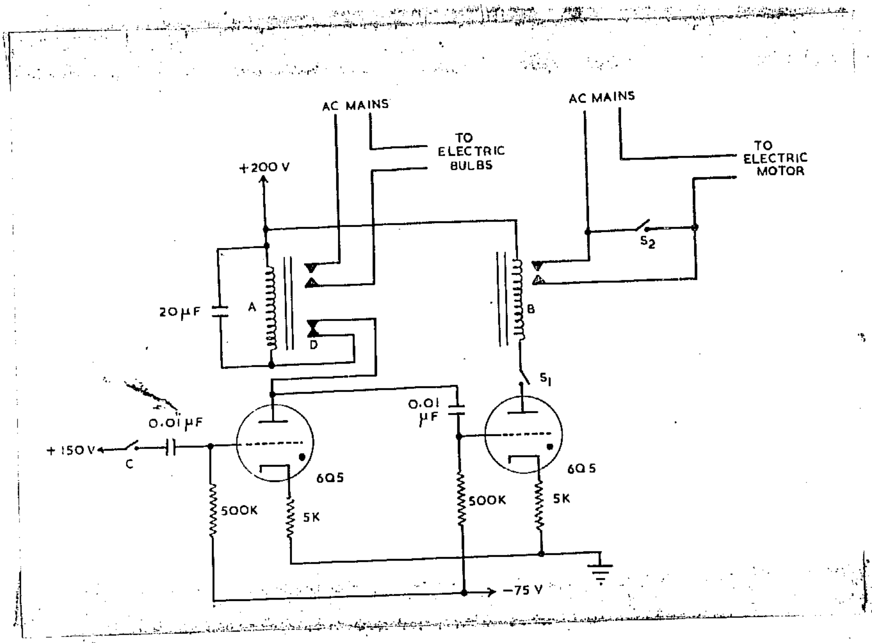


FIG 12

The sequence of operation is as follows: The minute hand of a clock set to I.S.T. gives electrical contacts at hourly intervals. At each hourly contact the lights inside the camera flash momentarily and the panel of registers is photographed. Immediately after the lights go off, the film winding and resetting motor starts and rolls the exposed film by one frame and keeps fresh film ready for the next exposure.

The circuit that controls and makes the whole process automatic is shown in Fig.13. It consists of two triggered thyratron switches working in succession. The first one controls


AC MAINS
TO ELECTRIC BULBS
AC MAINS
TO ELECTRIC MOTOR
+200 V
S2
20 μF
A
B
D
S1
0.01 μF
0.01 μF
+150 V
C
6Q5
6Q5
500K
5K
500K
5K
−75 V

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the flashing of bulbs and the next operates the motor. The circuit gets automatically reset after 30 seconds of each exposure. In the present investigation exposures were taken at hourly intervals.

Every day in the morning the exposed film was removed for developing after the 9 a.m. exposure. The readings of the mechanical recorders were noted down from the negatives. A typical enlarged photograph of the panel of registers is shown in the Fig.14.

CHAPTER III

METHODS OF ANALYSIS

3.1 Cosmic ray data

The readings of hourly photographic records of mechanical counters corresponding to different telescopes provide the basic cosmic ray data. For the purpose of the present investigation readings corresponding to only odd hours namely 2300 hr. of the previous day and 0100, 0300 .. .. .. 2300 hr. are tabulated and the differences in successive readings are evaluated. This gives, for any particular telescope 'i' on each day a sequence m_0^i, m_1^i .. .. .. m_{11}^i of 12 bihourly counting rates centered at 0000, 0200, ... 2200 hr. I.S.T. respectively. The mean bihourly counting rate for the day centered at 1100 hr. is given by $\bar{m}_i = (m_0^i + m_1^i + ... + m_{11}^i)/12$. The deviations Δm_0^i, Δm_1^i, ... Δm_{11}^i of bihourly counting rates from the daily mean bihourly rate $\bar{m}_i$ are then calculated for each telescope.

The 12 bihourly deviations thus obtained for different telescopes of identical geometry are tabulated side by side to examine whether within the limits of statistical significance the deviations from mean of the rates, of different telescopes, for the same bihourly interval, are similar. The data from the telescope which shows entirely different variations as compared to variations recorded by other similar telescopes is rejected. The daily mean bihourly intensities $\overline{m}^i$ are also similarly checked to see whether telescopes of similar geometry show similar day-to-day variations of intensity.

After thus selecting the good data, the deviations for the same bihourly interval as well as the daily mean bihourly values on each day for properly functioning similar telescopes are added together. The resultant data of each day thus comprises of 12 bihourly values $\sum^{n} \Delta m_0^i$, $\sum^{n} \Delta m_1^i$, ... $\sum^{n} \Delta m_{11}^i$ centered at even hours of the day, expressed as the deviations from the day's total mean bihourly rate $\sum^{n} \overline{m}^i$ where n is the number of properly functioning telescopes. These 12 deviations are finally expressed as percentage deviations $^*M_o$, $^*M_1$, ... $^*M_r$, ... $^*M_{11}$ where

$$^*M_r = \frac{\sum_{i=1}^{n} \Delta m_r^i}{\sum_{i=1}^{n} \Delta \overline{m}^i} \times 100$$

3.2 Meteorological data

The daily barometric pressure and ground temperature readings for the hours 0000, 0200, ... 2200 hr. were obtained from the daily weather charts of the Solar Observatory, Kodaikanal. The daily means $\overline{T}$ and $\overline{P}$ of temperature and pressure and the bihourly deviations from mean ΔT_o, ΔT_1 etc. and ΔP_o, ΔP_1 etc. are then evaluated and tabulated along with cosmic ray deviations $^*M_o$, $^*M_1$ etc. to facilitate application of meteorological corrections.

3.3 Corrections for meteorological influences

The contributions of the daily variation of atmospheric pressure and temperature to the solar daily variation of cosmic ray meson intensity have been discussed in an earlier section (1.3). We have used a barometric coefficient $\beta = -2.2$ %/cm.Hg. for correcting the meson intensity for the daily variation as well as the day-to-day variations of barometric pressure. The bihourly deviations of meson intensity $^{*}M_0$, $^{*}M_1$, ... etc. corrected for barometric pressure variations are indicated by M_0, M_1, ...M_{11}.

No attempt has been made to correct the daily variation on individual days and day-to-day changes of intensity for atmospheric temperature variations using Dorman's method. This is because in the absence of radiosonde data the nature of the daily variation on individual days and day-to-day variations of temperature at various isobaric levels above Kodaikanal are not known. From radiosonde data at Ahmedabad, Desai & Venkateswaran[161] have shown that significant and regular daily variation of temperature occurs only in the turbulent surface layer upto 2 Km. above the ground. Kay[162], from observations made elsewhere has come to the conclusion that the daily variation of temperature at high elevations is probably less than 1°C. Kodaikanal at an elevation of about 2.2 Km. is on a narrow mountain range with plains almost at sea level on two sides of it. The daily variations of temperature of the atmosphere above Kodaikanal may therefore be taken to correspond largely to the negligible daily variation at levels above 2 Km. over the immediately adjoining plains. Over a twelve month period, day-to-day changes of atmospheric temperature would tend to average out leaving only the regularly periodic daily variation of temperature to correct for. Thus the temperature correction so derived can reasonably by applied to the 12-month mean daily variation of meson intensity. For a first approximation therefore we may compute the correction to meson intensity by Dorman's method using only the first term corresponding to the 12 monthly mean daily variation of ground temperature at Kodaikanal.

According to Dorman's equation $\left(\delta I_\mu / I_\mu\right)_T = \int_0^{x_0} W(x)\,\delta T(x)\,dx$. For practical evaluation of temperature correction, this equation can be written as $\left(\delta I_\mu / I_\mu\right)_T \approx -\sum_{i=h_0}^{50\text{ mb.}} K_i\,\delta T_i$ where δT_i is the temperature variation at the i^{th} standard isobaric level and K_i the partial temperature coefficient obtained by integrating $W(x)$ over the corresponding layer. The value of K for 800 mb. has been given by Dorman as equal to 0.022 %/°C. We have used this coefficient to correct the 12 monthly mean daily variation of meson intensity at Kodaikanal using the atmospheric temperature measurements near ground.

An estimate of the correction, derived later in shows that its amplitude is of the order of 0.05 to 0.1 % for meson intensity at Kodaikanal. The appropriate correction has been applied to the 12-month mean daily variation of meson intensity and in years when the amplitude of the latter is small (of the order of 0.2 %) the correction is quite significant. The 2 σ level of significance adopted to judge the significance of the daily variation on individual days corresponds to an amplitude of 0.6 % for ^{22}T data and 1.6 % for ^{5}T data. Therefore the omission of temperature correction does not materially alter the conclusions drawn in respect of days on which the daily variation on individual days is significant at the 2 σ level.

3.4 Normalisation of mean intensity

If on a particular day, one of a set of n telescopes of identical geometry goes out of order due to counter failure, the total daily mean intensity will not be same as what it would have been, had all the n telescopes been functioning properly. Moreover when counters fail, it is hardly possible to replace them with new counters of identical physical characteristics. Therefore it is necessary to normalise the daily mean counting rates to a common base before employing them for the study of day-to-day or long term changes of meson intensity. This is done as follows :

Suppose 4 telescopes of a similar type are in operation and that N_1^1, N_2^1, N_3^1 and N_4^1 are daily mean bihourly rates of the telescopes for the 1st day and N_1^2, N_2^2, N_3^2 and N_4^2 are for the second day and so on. The mean bihourly counting of all telescopes for any day γ is given by $N_1^\gamma + N_2^\gamma + N_3^\gamma + N_4^\gamma$. If on a day x, N_1^x is missing due to counter failure then the mean bihourly rate for this day, had all the four telescopes were working, is given by

$(N_2^x + N_3^x + N_4^x)\dfrac{C}{A}$ where $C = \sum_{k=x-1}^{x-5} (N_1^k + N_2^k + N_3^k + N_4^k)$ and

$A = \sum_{k=x-1}^{x-5} (N_2^k + N_3^k + N_4^k)$. After thus predicting the mean counting rate for the day x comparable to $\sum^{n} \overline{m}^{i}$ of previous day, the series of total daily mean counting rates that starts after the break x is normalised to the level of the series before the break by multiplying the terms of the series after the break by a factor

$\dfrac{C.B}{A.D}$ where $B = \sum_{k=x+1}^{x+5} (N_2^k + N_3^k + N_4^k)$ and $D = \sum_{k=x+1}^{x+5} (N_1^k+N_2^k+N_3^k+N_4^k)$.

3.5 Fourier analysis

In order to understand the nature of periodicities involved in the daily variation of meson intensity, and the relationships of these periodicities with the known geophysical and astrophysical periodicities, it is often convenient to resolve the variation into its harmonic components.

Any experimentally observed variation can be expressed in terms of a Fourier series of the type,

$$F(x) = a_0 + (a_1 \cos x + b_1 \sin x) + (a_2 \cos 2x + b_2 \sin 2x) + \ldots$$

$$= a_0 + \sum_{n=1}^{\infty} (a_n \cos nx + b_n \sin nx) \text{ where } 0 < x < 2\pi .$$

If the experimental curve is defined by 12 equally spaced ordinates $U_o, U_1, \ldots \ldots \ldots U_{11}$ corresponding to the times $t_o, t_1, \ldots \ldots \ldots t_{11}$ respectively, then harmonic analysis consists in determining the coefficients a_o, a_n and b_n such that $\{U_i - F(t_i)\}$ is as small as possible. The coefficients a_n and b_n corresponding to a 12 ordinate scheme is given by

$$a_n = (\sum_1^{12} U_i \cos nx_i)/6 \quad \text{and} \quad b_n = (\sum_1^{12} U_i \sin nx_i)/6$$

where values of n = 1, 2, ... etc. correspond to first, second, ... etc. harmonics respectively. F(x) can also be written as

$$F(x) = a_o + \sum_1^{\infty} r_n \sin(nx + \psi_n) \quad \text{where } a_n = r_n \sin \psi_n$$

and $b_n = r_n \cos \psi_n$. r_n and ψ_n are called the amplitude and phase of the n^{th} harmonic and can be evaluated as $r_n^2 = a_n^2 + b_n^2$ and $\psi_n = \tan^{-1} \frac{a_n}{b_n}$. When U_i are expressed as deviations from mean $a_o = 0$. In the study of solar daily variation, the 12 ordinates are taken over an interval of a solar day and therefore r_1 and ψ_1 represent the amplitude and phase of the first harmonic wave in the solar daily variation having a period of 24 hr. r_2 and ψ_2 give corresponding parameters for the second harmonic, having a period of 12 hr. The higher harmonics in the daily variation of meson intensity are small and for most purposes it would be sufficient to consider the first two harmonics. Instead of the phase angles, ψ_1 and ψ_2

it is customary to use in discussions ϕ_1 and ϕ_2, the angles representing the time of maximum of the first and second harmonics respectively. $\phi_1 = 90 - \psi_1$ and $\phi_2 = 90 - \psi_2$.

3.6 The harmonic dial

To compare the variations recorded by different instruments, or to study the relation between different periodic phenomena, it is convenient to use a graphical representation wherein the amplitude and of the phase of the harmonic component can both be represented simultaneously. One such method is the harmonic dial representation. The fourier coefficients a_n and b_n can be considered as the components of the vector r_n on mutually perpendicular axes as shown in Fig.15. The maximum of the sine wave $r_n \sin(nx + \psi_n)$

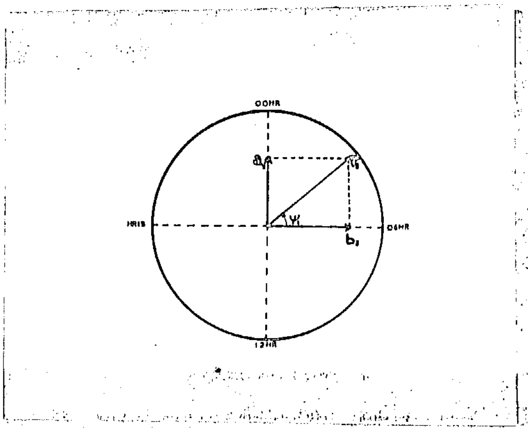


FIG 15.

occurs when $(nx + \psi_n) = 90^o$. The vector r_n therefore is directed along the time of maximum of the harmonic component n. Suitable time scale can be inserted in the figure such that it represents the first, second or higher harmonics. A circular time scale of 24 hours equal to 360^o measured in a clockwise direction from b axis is introduced to represent the first harmonic and 12 hours equal to 360^o for the second harmonic. The harmonic dial representation of periodic vectors has been frequently used in the discussion of experimental results in Chapter IV.

3.7 The errors of Fourier coefficients

The standard error σF of a quantity F which is a function of S variables C_1, C_2, ... C_S is given by

$$\sigma_F^2 = \left(\frac{\partial F}{\partial c_1}\right)^2 \sigma_{c_1}^2 + \text{----} + \left(\frac{\partial F}{\partial c_i}\right)^2 \sigma_{c_i}^2 + \text{----} \left(\frac{\partial F}{\partial c_s}\right)^2 \sigma_{c_s}^2 .$$

In our case S = 12 and

$$F^2 = r_1^2 = \frac{4}{S^2} \left\{ \sum_{i=1}^{12} (U_i \cos x_i)^2 + \sum_{i=1}^{12} (U_i \sin x_i)^2 \right\}$$

$$\therefore \; r_1 \frac{\partial r_1}{\partial U_1} = \frac{4}{S^2} \left\{ \Sigma(U_i \sin x_i) \cos x_i + \Sigma(U_i \sin x_i) \sin x_i \right\}$$

$$\text{or} \quad \frac{\partial r_1}{\partial U_1} = \frac{2}{S^2} \sin(\psi_1 + x_i).$$

$$\therefore \; \sigma_{r_1}^2 = \frac{4}{S^2} \sum \sin^2(\psi_1 + x_i) \quad \sigma_{U_i}^2$$

all U_i have equal bihourly standard errors $= \sigma_{U_i} = \epsilon$ and

$\overline{\sin^2(\psi_1 + x_i)} = \frac{1}{2}$. Therefore $\overline{\sigma_{r_1}^2} = \frac{\epsilon^2}{6}$ or $\overline{\sigma_{r_1}} = \frac{\epsilon}{\sqrt{6}}$

let $\tan \psi_1 = \theta$. This is equal to $\frac{\sum U_i \cos x_i}{\sum U_i \sin x_i}$

$$\text{Then } \frac{\partial \theta}{\partial U_i} = \frac{\cos\psi_1 \sum \cos x_i - \sin\psi_1 \cdot \sum \sin x_i}{6\, r_1 \cos^2 \psi_1} = \frac{\cos(\psi_1 + x_i)}{6\, r_1 \cos^2 \psi_1}$$

$$\therefore \overline{\sigma_\theta}^2 = \frac{1}{6} \cdot \frac{\overline{\sigma U_i}^2}{r_1^2 \cos^4 \psi_1} \quad \text{and} \quad \overline{\sigma_\theta} = \frac{1}{\sqrt{6}} \frac{\epsilon}{r_1 \cos^2 \psi_1}.$$ Since

$$\psi_1 = \tan^{-1}\theta, \; \overline{\sigma_{\psi_1}} = \cos^2\psi_1, \; \sigma_\theta = \frac{\overline{\sigma r_1}}{r_1}.$$

Thus errors in r_1 and ψ_1 are given by $\epsilon/\sqrt{6}$ and $\epsilon/r_n\sqrt{6}$ respectively. These errors are shown by drawing an error circle at the end point of the vector in the harmonic dial. The size of the error circle in relation to the length of the vector indicates the significance of the particular harmonic component.

Defining periodic variations in terms of their harmonic constants r_1, ϕ_1, r_2 and ϕ_2 has distinct advantages specially when the measured amplitudes are small and errors tend to be large. When randomly distributed events of the nature of cosmic ray arrivals are measured, a standard deviation $\sigma = \pm\sqrt{N}$ is associated with every estimate derived from N number of counts counted by the measuring device in a particular time interval. Thus each estimate of a bi-hourly percent deviation is associated with a standard deviation of $\pm \frac{100}{\sqrt{N}}$ %, where N is the mean bihourly counting rate of the day. A deviation significant at the 2 σ level corresponds to a probability of 95.4 % that it is due to non-random causes. If therefore the value of N is such that $\sigma = \pm 0.8$ % a bihourly deviation is not significant at 2 σ level, unless it exceeds 1.6 %. However, in the case of harmonic consistants derived from 12 bihourly values, the standard error gets reduced by a factor of $\sqrt{6}$ or ≈ 2.4 as shown in the previous section. At the same level of significance therefore an amplitude of 0.7 % can be considered significant.

Another advantage of representing the daily variation in terms of its harmonic coefficients is that, if the higher harmonic beyond the diurnal and the semi-diurnal are assumed to be unimportant, as is known to be the case for many geophysical phenomena, the parameters necessary to define the daily variation get reduced to four namely a_1, b_1, a_2 and b_2 instead of 12 bihourly deviations. The quantities are additive and can be scalerly added to get the average daily variation over groups of days.

3.8 The form of the daily variation

The daily variation of meson intensity on individual days has either a single maximum or two maxima. The significant feature of the daily variation may therefore be considered to be the amplitude and the time of maximum of the dominent component and relative magnitudes and the difference in the times of maxima of the diurnal and the semi-diurnal components. One can get an insight in to the change in the form of the daily variation by a study of the relative change of the diurnal and the semi-diurnal components. The parameters relevent for such a study are the ratio r_1/r_2 and the difference angle $(2\phi_1-\phi_2)/2$. In Fig.16 we show the form of the daily variation

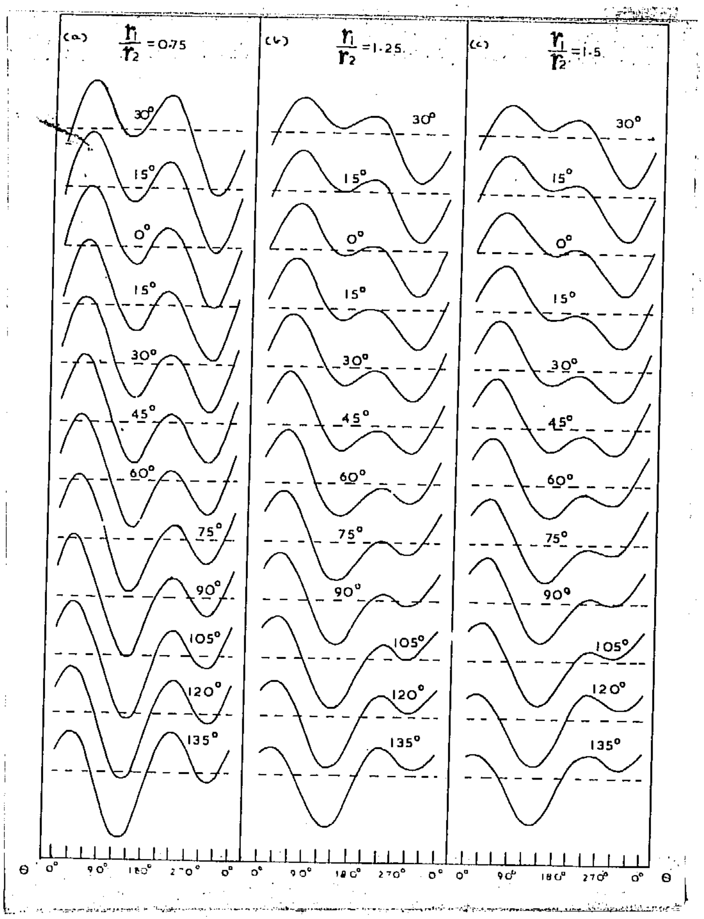


FiG 16.

produced by the superposition of $\vec{r_1}$ and $\vec{r_2}$ for three different values of r_1/r_2 and with change of the quantity $(2\phi_1-\phi_2)/2$. It is seen that for any relationship between ϕ_1 and ϕ_2 if $r_1/r_2 \geqslant 1.5$

the daily variation is mainly diurnal in nature while if $r_1/r_2 \leq 0.75$ the form of the daily variation is mainly semi-diurnal.

It has to be stated however that for a finer study of the daily variation and its changes with time it is necessary to examine the daily variation unresolved into its harmonic components.

Practical methods of harmonic analysis suitable for handling large amounts of data have been described by various authors. The one detailed by Kane[164] has been adopted here. For each working day, the daily variation of meson intensity as well as barometer pressure are harmonically analysed and the constants r_1, ϕ_1, r_2 and ϕ_2 for meson daily variation and P_{a_1}, P_{b_1}, P_{a_2} and P_{b_2} for pressure variation are determined.

3.9 Punch-card system of tabulation of data

A detailed study of various aspects of the daily variation of cosmic rays on the lines indicated in sec.1.6 requires the preparation of frequency distributions, sorting of days according to different criteria and evaluating the parameters of the average daily variation on groups of days thus sorted. For analysis of this nature it is convenient to use the punch-card system of tabulation of data so that standard electrical sorting and tabulating machines can be used to perform various computational operations. In the present investigation Hollerith cards of eighty column-ten row type were used for tabulating the primary data. The card contains the following information punched on it.

Column	Description
1, 2	Type of Telescope. 4,0 denotes ${}^{5}T_K$ 4,3 " ${}^{22}T_K$
3, 4	Year
5, 6, 7	Day of the year
8, 9	Lunar Phase 'μ'
10, 11	'Cp' index for the day
12, 13	Solar declination
14 to 37	The 12 pressure corrected cosmic ray percentage bi-hourly deviations for hours 00, 02,....22 which are described in Sec.3.3 as Mo, M1,...M_{11}
38, 39	The variance χ^2 for the day
40	Reliability indicating number of bi-hourly deviations extrapolated if any.
41	Number of telescopes working on the day
42	Range of σ in which r_1 or r_2 whichever is larger lies
43 to 46	Total mean bi-hourly rate from which percentage deviations of bi-hourly values of cosmic ray intensity are calculated
47 to 49	Normalised total mean bi-hourly rate corrected for pressure variations
51 to 58	a_1, b_1, a_2 and b_2 the Fourier coefficients of meson daily variation
59 to 62	r_1 and r_2 calculated from a_1, b_1, and a_2, b_2 respectively
63 to 66	ϕ_1 and ϕ_2 calculated from a_1, b_1, and a_2, b_2 respectively
67 to 68	Ratio r_1/r_2
69 to 76	Fourier coefficients of daily variation of barometric pressure P_{a1}, P_{b1}, P_{a2} and P_{b2}
77 to 79	Mean barometric pressure for the day
80	Blank

3.10 Correlation and lines of regression

Correlation analysis enables one to determine the relationship between two or more variates. A measure of the degree of this relationship is given by the 'correlation coefficient' usually denoted by γ. $\gamma = 0$ corresponds to absence of any correlation, while $\gamma = \pm 1$ corresponds to perfect positive or negative correlation. If there are two variates A and B then the correlation coefficient between them is given by the formula

$$\gamma_{AB} = \frac{\Sigma(\Delta A \cdot \Delta B)}{N \cdot \sigma_A \cdot \sigma_B}$$

where ΔA and ΔB are the respective deviations from the mean of the two variates, N the number of pairs of values of A and B considered and σ_A and σ_B are the standard deviations of each variate. σ_A and σ_B are given by $\sigma_A = \left(\frac{\Sigma \Delta A^2}{N}\right)^{1/2}$, $\sigma_B = \left(\frac{\Sigma \Delta B^2}{N}\right)^{1/2}$

$$\therefore \gamma_{AB} = \frac{\Sigma(\Delta A \cdot \Delta B)}{\{\Sigma \Delta A^2 . \Sigma \Delta B^2\}^{1/2}}$$

The relation between the two variates A and B is expressed by the following equation called the "regression equation". $\Delta A = \alpha \Delta B$, where $\alpha = \gamma_{AB} \cdot \frac{\sigma_A}{\sigma_B}$. This equation represents the regression line of A on B having a slope equal to the regression coefficient α. Similarly the regression line of B on A is given by $\Delta B = \alpha' \Delta A$, where $\alpha' = \gamma_{AB} \cdot \frac{\sigma_B}{\sigma_A}$. As γ_{AB} approaches the value 1 the two lines tend to be identical.

The probable error associated with the correlation coefficients is given by the formula

$$P = \frac{0.67\ (1 - \gamma^2)}{n}$$

where γ is the correlation coefficient, and n is the number of pairs of values from which γ is calculated. The larger the value of n, the smaller would be the value of P the probable error and the greater would be the significance of γ, the correlation coefficient.

NOMENCLATURE

m	Geomagnetic latitude.
β	Barometric coefficient.
σ	The standard error.
$^{22}T_X$	Telescopes having a semiangle of 22° in E-W plane, working at a station X. For stations following symbols have been used. K = Kodaikanal, A = Ahmedabad, H = Huancayo and C = Cheltenham.
$^{5}T_X$	Telescopes having a semiangle of 5° in the E-W plane.
N_K	Neutron monitor working at K.
M	The daily variation of meson intensity corrected for barometric pressure variations.
r_1, ϕ_1	The amplitude and time of maximum of the diurnal component of the daily variation on any particular day.
r_2, ϕ_2	The amplitude and time of maximum of the semi-diurnal component of the daily variation on any particular day.
Cp	The daily planetary character figure for geomagnetic disturbance.
$\overline{M}$	The 12-month mean daily variation of meson intensity corrected for barometric pressure variations.

$\overline{M}_X^D$, $\overline{M}_{\phi.X}^D$	The amplitude and time of maximum of the diurnal component of the 12-month mean daily variation determined at a station X.
$\overline{M}_X^S$, $\overline{M}_{\phi.X}^S$	The amplitude and time of maximum of the semi-diurnal component of the 12-month mean daily variation determined at a station X.
$^o\overline{M}$	Smoothed $\overline{M}$ obtained by superposition of the diurnal and semi-diurnal components of $\overline{M}$.
$x.y\ ^o\overline{M}$	$^o\overline{M}$ centered at year x, month y.
$\Delta\ ^o\overline{M}(x.y-x'y')$	The difference between $x.y\ ^o\overline{M}$ and $x'y'\ ^o\overline{M}$.

CHAPTER IV

EXPERIMENTAL RESULTS OF ^{22}T TELESCOPES

The cosmic ray recording station at Kodaikanal started functioning in May 1952. The author took charge of the station in December 1953 and operated it till the end of December 1956. The Table I shows the working of the ^{22}T telescopes during the three years 1954, 1955 and 1956. In 1954 the number of telescope days for which data are available is lower than in 1955 and 1956. This is partly due to lack of facilities during 1954 for the preparation of counters on the spot, and partly to the dislocation caused by the shifting of the laboratory to new premises. By the end of 1954 the preparation of counters was started at Kodaikanal and this ensured smooth running of the apparatus for the rest of the period.

4.1 The 12-month mean daily variation

The pressure corrected monthly mean daily variation expressed by percent bihourly deviations from monthly mean intensity is utilised to compute the 12-month mean daily variation $\overline{M}$. Even though the number of telescope days differs to some extent from month to month, equal weight is given to data for each month in calculating $\overline{M}$. For visual examination of the broad features of the daily variation it is advantageous to harmonically analyse the bihourly deviations of $\overline{M}$ and to calculate again the bihourly values of the smooth variation $^{o}\overline{M}$

Table 1

Number of days in each month of the years 1954, 1955 and 1956 for which daily variation data of $^{22}T_K$ are available and percent days in each year on which all four, three, two and one only of the $^{22}T_K$ telescopes were functioning at Kodaikanal.

No.of tels. working	J	F	M	A	M	J	J	A	S	O	N	D	Total days	%
						1954								
4	18	20	22	9	0	7	14	11	0	8	9	12	130	54 %
3	4	3	1	7	0	4	6	5	0	2	3	1	36	15 %
2	3	2	3	4	9	8	5	7	12	8	3	6	70	28 %
1				2	3	3		1					9	4 %
Total working days	25	25	26	22	12	22	25	24	12	18	15	19	245	

No.of tels. working	J	F	M	A	M	J	J	A	S	O	N	D	Total days	%
						1955								
4	24	18	19	24	21	17	24	26	27	27	26	22	275	88 %
3	3	1	3	4	1	2	1	2	1	0	1	2	21	7 %
2					3	4	4	0	0	1	0	3	15	5 %
1												1		0 %
Total working days	27	19	22	28	25	23	29	28	28	28	27	28	312	

No.of tels. working	J	F	M	A	M	J	J	A	S	O	N	D	Total days	%
						1956								
4	21	21	24	20	25	22	24	24	22	21	17	20	261	81 %
3		3	2	4	1	4	4	1	4	5	1	3	32	10 %
2	8	3	2	1	2	2	0	2	1	1	1	2	25	8 %
1	1			1							1	1	4	1 %
Total working days	30	27	28	26	28	28	28	27	27	27	20	26	322	

produced by the superposition of the first and second harmonic components.

We have discussed earlier in section 3.3 the correction that should be applied for meteorological effects connected with the diurnal variation of temperature of the atmosphere. A precise derivation of the correction is not possible in the absence of radio-sonde data for Kodaikanal pertaining to the diurnal variation of temperature at high levels in the atmosphere. Using a modification of the method suggested by Dorman, we shall now show that the correction is small. Table 2 gives the bihourly deviations of the 12-month mean daily variation of temperature $\overline{\overline{T}}$ near ground at Kodaikanal and the bihourly corrections for meson intensity derived from it. The temperature variation $\overline{\overline{T}}$ does not change significantly from year to year. The temperature correction curve has an amplitude of about 0.06 % per ^{o}C and a maximum at 13 hr.

Table 3 shows the values of $\overline{M}_{K}^{D}$, $\overline{M}_{\phi.K}^{D}$, $\overline{M}_{K}^{S}$, and $\overline{M}_{\phi.K}^{S}$ describing the diurnal and the semi-diurnal components of $\overline{M}_{K}$ centered at successive three monthly epochs. Values derived before and after application of the correction for diurnal variation of atmospheric temperature are separately indicated. In 1955 and 1956 when the daily variation of meson intensity becomes small, the application of a correction for temperature can make a difference of upto 25 % in amplitudes of the diurnal and the semi-diurnal components, but produces a negligible change in times of maxima of the two components. During the years 1953-54 the daily variation is large and the correction

Table 2

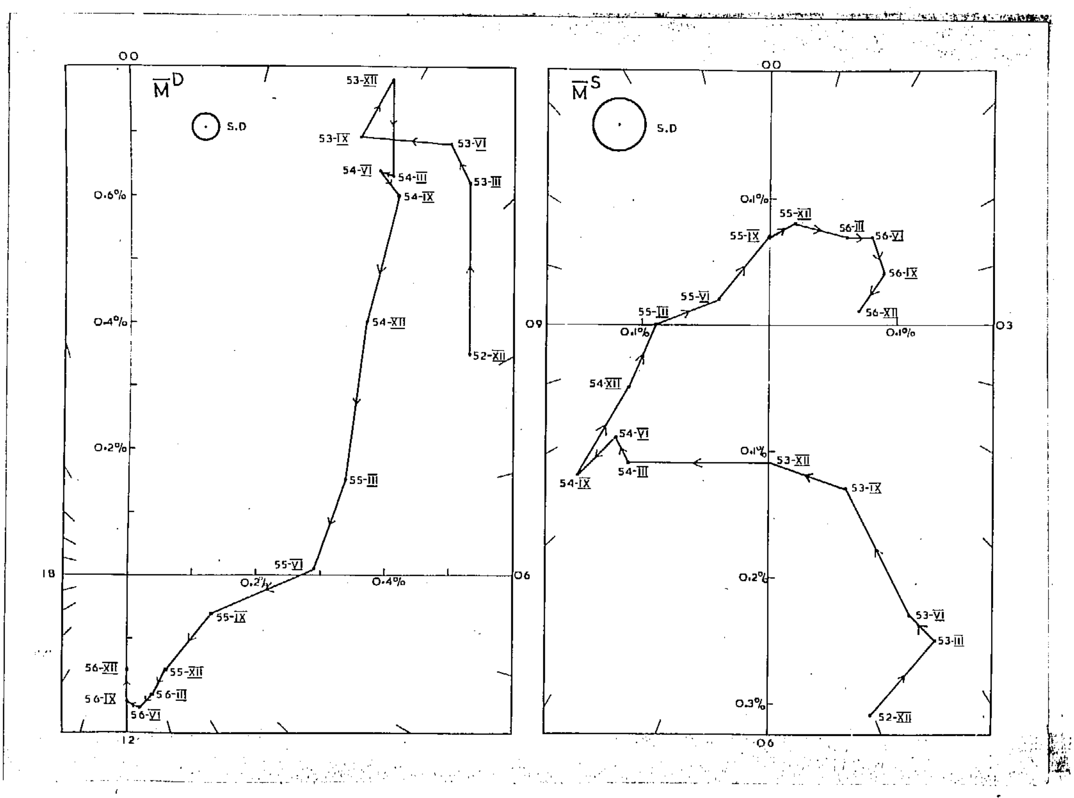
Table showing the bihourly deviations of the 12-month mean daily variation of temperature $\bar{T}$ near ground at Kodaikanal and the bihourly corrections derived from it for the mean daily variation of meson intensity.

Hours	Temperature $\bar{T}$ °C	Bihourly corrections %
0	11.3	-0.03
2	11.1	-0.04
4	10.9	-0.04
6	10.9	-0.04
8	12.4	-0.01
10	14.9	0.05
12	15.7	0.06
14	15.6	0.06
16	14.7	0.04
18	13.1	0.01
20	11.7	-0.02
22	11.4	-0.03

Epochs	Before temperature correction $\overline{M}^D_K$ %	$\overline{M}^D_{\phi.K}$	$\overline{M}^S_K$ %	$\overline{M}^S_{\phi.K}$	After temperature correction $\overline{M}^D_K$ %	$\overline{M}^D_{\phi.K}$	$\overline{M}^S_K$ %	$\overline{M}^S_{\phi.K}$
Dec.	0.54	42°	0.12	$\pi + 65^\circ$	0.50	45°	0.11 ± 0.03	$\pi + 72^\circ$
March'55	0.37	66°	0.09	-90°	0.37	71°	0.07	-83°
June	0.29	88°	0.04	-63°	0.28	99°	0.05	-40°
Sept.	0.14	116°	0.07	0°	0.15	135°	0.09	3°
Dec.	0.16	159°	0.08	13°	0.20	168°	0.10	16°
March'56	0.19	169°	0.09	40°	0.24	178°	0.12	43°
June	0.21	175°	0.11	48°	0.26	180°	0.13	47°
Sept.	0.20	180°	0.10	65°	0.25	$\pi+5^\circ$	0.11	59°
Dec.	0.15	180°	0.07	81°	0.20	$\pi+6^\circ$	0.08	68°

produces an insignificant change of amplitude and time of maximum of the diurnal and the semi-diurnal components.

The long term changes of the daily variation may be examined either by a study of the amplitude and the time of maximum of the first and second harmonic components of the 12-month mean daily variation or by looking at the composite variation ${}^{o}\overline{M}$. In Table 3 the values of $\overline{M}^D_K$, $\overline{M}^D_{\phi.K}$ and $\overline{M}^S_K$, $\overline{M}^S_{\phi.K}$ from December 1952 to December 1953 have been taken from the observations of Sarabhai et al[38] at Kodaikanal. The progressive change in the positions of the ends of vectors representing $\overline{M}^D_K$ and $\overline{M}^S_K$ from December 1952 to December 1956 are shown in harmonic dials in Figs. 17 (a) and (b).



(a) (b)

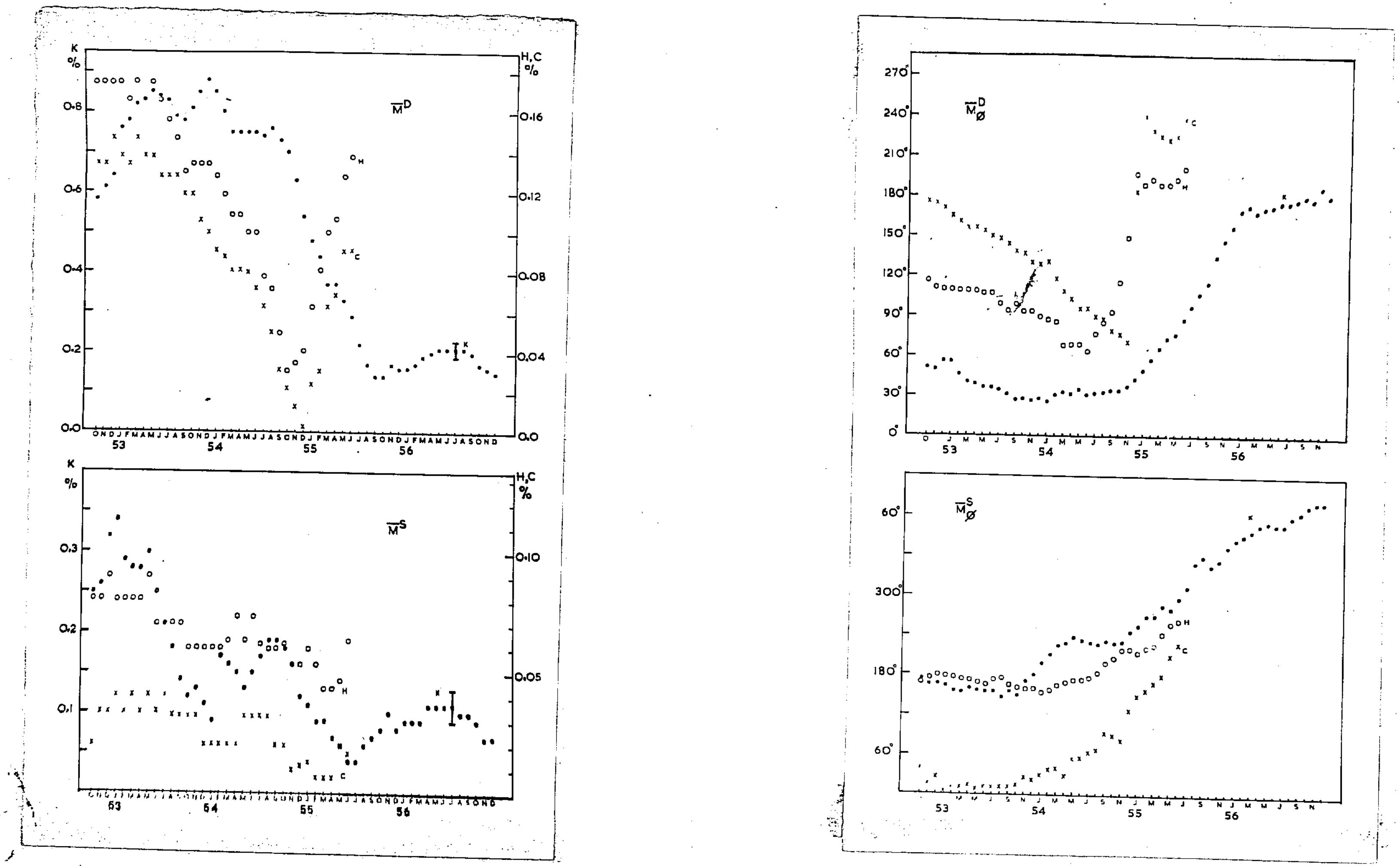
FIG 17

The time series presented in these diagrams cover one of the most important periods of the present cycle of solar activity. The solar activity gradually decreased during the years 1952-53 and went through a minimum early during 1954. In the year 1956, the activity showed a definite increase. The changes in the daily variation associated with the change of solar activity has many interesting features which merit individual consideration. For a detailed comparison of changes observed at Kodaikanal with those at Huancayo, which is also a mountain station on the geomagnetic equator and at Cheltenham at sealevel at 45°N latitude, we have taken the analysis of Venkatesan & Dattner[122] of 12-month mean daily variation of the meson intensity measured by the Carnegie Institution ion-chambers at Huancayo and at Cheltenham. The values of $\overline{M}^{D}$, $\overline{M}^{D}_{\phi}$ and $\overline{M}^{S}$, $\overline{M}^{S}_{\phi}$ for Kodaikanal, for Huancayo and for Cheltenham centered at epochs shifted successively by a month for the period October 1952 to December 1956 are given in Table 4. The curves showing comparative variations observed at Kodaikanal, Huancayo and Cheltenham of each of these parameters are given in Figs. 18 (a), (b), (c) and (d).

4.11 Changes of the amplitude $\overline{M}^{D}_{K}$ of the diurnal component

It is observed from the harmonic dial in Fig. 17 (a) that the amplitude $\overline{M}^{D}_{K}$ of the 12-month mean diurnal variation was maximum for the 12 month period centered at December 1953, almost coinciding with minimum of 12 month mean solar activity. The largest amplitude was associated with the earliest time of maximum $\overline{M}^{D}_{\phi,K}$. From December 1953 $\overline{M}^{D}_{K}$ diminished in amplitude,

(a) (c)


K %
H,C %
$\overline{M}^D$
$\overline{M}^S$
$\overline{M}^D_\phi$
$\overline{M}^S_\phi$
53
54
55
56

(b) (d)

FIG 18

Table 4 .

The values of the amplitude and hour of maximum of the diurnal and semidiurnal components of the 12-month mean daily variation observed at Kodaikanal, Huancayo and Cheltenham. The 12-month mean daily variation at each station is centered at epochs shifted successively by a month in the period October 1952 to 1956.

Month and Year	KODAIKANAL $\bar{M}^D_K$	$\bar{M}^D_{\phi.K}$	$\bar{M}^S_K$	$\bar{M}^S_{\phi.K}$	HUANCAYO $\bar{M}^D_H$	$\bar{M}^D_{\phi.H}$	$\bar{M}^S_H$	$\bar{M}^S_{\phi.H}$	CHELTENHAM $\bar{M}^D_C$	$\bar{M}^D_{\phi.C}$	$\bar{M}^S_C$	$\bar{M}^S_{\phi.C}$
1	2	3	4	5	6	7	8	9	10	11	12	13
1952												
Oct.	0.58	51°	0.25	173°	0.18	116°	0.08	169°	0.13	176°	0.02	38°
Nov.	0.61	50°	0.26	165°	0.18	111°	0.08	176°	0.13	174°	0.03	15°
Dec.	0.64	56°	0.32	166°	0.18	110°	0.09	180°	0.15	171°	0.03	26°
1953												
Jan.	0.76	56°	0.34	163°	0.18	110°	0.08	178°	0.14	165°	0.04	4°
Feb.	0.78	46°	0.29	155°	0.17	109°	0.08	176°	0.13	161°	0.03	10°
Mar.	0.82	40°	0.28	153°	0.18	109°	0.08	173°	0.15	156°	0.04	11°
Apr.	0.83	39°	0.28	159°	0.17	109°	0.08	172°	0.14	156°	0.03	14°
May	0.85	36°	0.30	156°	0.18	107°	0.09	169°	0.14	154°	0.04	8°
Jun.	0.84	36°	0.25	154°	0.17	107°	0.07	165°	0.13	150°	0.03	11°
Jul.	0.83	35°	0.21	155°	0.16	99°	0.07	173°	0.13	148°	0.04	11°
Aug.	0.79	31°	0.18	146°	0.15	94°	0.07	176°	0.13	144°	0.03	11°
Sept.	0.78	27°	0.14	155°	0.13	99°	0.07	165°	0.12	139°	0.03	11°
Oct.	0.81	28°	0.12	149°	0.13	94°	0.06	161°	0.12	137°	0.03	15°
Nov.	0.85	27°	0.13	171°	0.13	94°	0.06	160°	0.11	131°	0.03	26°
Dec.	0.88	28°	0.11	180°	0.13	90°	0.06	159°	0.10	129°	0.02	23°

Contd...

Table 4 cont...

1	2	3	4	5	6	7	8	9	10	11	12	13
1954												
Jan.	0.85	26°	0.09	π+ 18°	0.13	88°	0.06	154°	0.09	131°	0.02	30°
Feb.	0.80	31°	0.17	π+ 31°	0.12	86°	0.06	158°	0.09	118°	0.02	38°
Mar.	0.75	33°	0.16	π+ 45°	0.11	69°	0.06	165°	0.08	109°	0.02	41°
Apr.	0.75	32°	0.15	π+ 48°	0.11	69°	0.07	169°	0.08	103°	0.02	30°
May	0.75	35°	0.13	π+ 57°	0.10	69°	0.06	173°	0.08	96°	0.03	56°
Jun.	0.75	31°	0.15	π+ 53°	0.10	64°	0.07	173°	0.07	96°	0.03	56°
Jul.	0.74	32°	0.17	π+ 49°	0.08	77°	0.06	176°	0.06	90°	0.03	64°
Aug.	0.76	33°	0.19	π+ 47°	0.07	86°	0.06	184°	0.05	88°	0.03	68°
Sept	0.73	35°	0.19	π+ 51°	0.05	94°	0.05	199°	0.03	79°	0.02	94°
Oct.	0.70	35°	0.18	π+ 49°	0.03	116°	0.06	206°	0.02	77°	0.02	90°
Nov.	0.63	38°	0.16	π+ 50°	0.03	150°	0.05	218°	0.01	71°	0.01	83°
Dec.	0.54	43°	0.12	π+ 66°	0.04	197°	0.05	218°	0.00	134°	0.01	128°
1955												
Jan.	0.48	50°	0.11	π+ 75°	0.06	189°	0.06	214°	0.02	240°	0.01	150°
Feb.	0.44	58°	0.09	-90°	0.08	193°	0.05	221°	0.03	229°	0.01	158°
Mar.	0.37	66°	0.09	-90°	0.10	189°	0.04	225°	0.06	225°	0.01	169°
Apr.	0.37	73°	0.07	-74°	0.11	189°	0.04	244°	0.07	223°	0.01	180°
May	0.33	77°	0.06	-80°	0.13	193°	0.05	259°	0.09	225°	0.02	210°
Jun.	0.29	88°	0.04	-63°	0.14	201°	0.06	263°	0.09	238°	0.02	218°

Contd....

Table 4 cont.....

1	2	3	4	5	6	7	8	9	10	11	12	13
1955												
Jul.	0.22	98°	0.04	−45°								
Aug.	0.17	107°	0.06	− 9°								
Sept	0.14	115°	0.07	0°								
Oct.	0.14	135°	0.08	−14°								
Nov.	0.17	147°	0.10	− 6°								
Dec.	0.16	158°	0.08	14°								
1956												
Jan.	0.16	169°	0.09	26°								
Feb.	0.17	173°	0.09	32°								
Mar.	0.19	168°	0.09	40°								
Apr.	0.20	171°	0.11	48°								
May	0.21	172°	0.11	52°								
Jun.	0.21	175°	0.11	48°								
Jul.	0.21	175°	0.11	48°								
Aug.	0.21	177°	0.10	61°								
Sept	0.20	180°	0.10	56°								
Oct.	0.17	177°	0.09	77°								
Nov.	0.16	π+ 7°	0.07	82°								
Dec.	0.15	180°	0.07	82°								

at first gradually upto September 1954, and then rapidly till September 1955. Fig. 18 (a), which shows the change of $\overline{M}^D$ at Kodaikanal as compared to the change at Huancayo, reveals that the diurnal amplitude at Huancayo was minimum for the 12 month period centered at October 1954. Thus the minimum of $\overline{M}^D$ at Huancayo occurs earlier than at Kodaikanal by almost one year. It should be borne in mind that when $\overline{M}^D$ is minimum, the errors in its determination and in applying correction for meteorological effects become relatively large. Moreover, Sarabhai et al[115] have pointed out by comparison of data from Huancayo, Cheltenham and Christchurch that the changes of $\overline{M}^D$ at the different stations are not always well correlated. This was not merely an effect of latitude of the place of observation since changes at Cheltenham and Christchurch were also different, particularly during the solar cycle commencing from 1944. Our present results which indicate differences in changes of $\overline{M}^D$ between Kodaikanal and Huancayo during the period 1952 to 1956 are most probably due to differences in the type of the recording instrument used at the two places. The decrease during this period of $\overline{M}^D$ at Kodaikanal with a directional telescope is of 0.7 %, while the change is only of 0.14 % at Huancayo with an omnidirectional ion-chamber. It is interesting to note that from 1952 to 1956 similar changes of $\overline{M}^D$ occur at Huancayo and Cheltenham where similar instruments are in operation.

4.12 Changes of $\overline{M}_K^S$

The semi-diurnal harmonic dial in Fig. 17 (b) shows the progressive shift of the vector $\overline{M}_K^S$ in a clockwise direction from 1952 to 1956. The amplitude of the semi-diurnal wave also diminishes from 0.26 % in 1953 to 0.11 % in 1956. Table 4 and Fig. 18 (b) show the changes of $\overline{M}^S$ at Kodaikanal and at Huancayo. The changes of $\overline{M}^S$ at the two places are similar, the minima coinciding near the 12-monthly epoch centered at March 1955 and the maxima coinciding during the beginning of 1953. The correlation of the time series of $\overline{M}^S$ at the two places is +(0.84 ± 0.006) and the regression coefficient is 1.3. This shows that the change of $\overline{M}^S$ at the two places is not vastly different, as it is in case of changes of $\overline{M}^D$.

Sarabhai et al[38] from an earlier comparison of changes at Huancayo and Cheltenham, have shown that the trend of changes of $\overline{M}^S$ was very dissimilar at the two places during the period 1942 to 1951. $\overline{M}^S$ decreases between 1953 to 1955 at Cheltenham just as it does at Kodaikanal and at Huancayo. However the value of $\overline{M}^S$ is much smaller at Cheltenham than at either of the equatorial stations. In view of $\overline{M}^S$ being barely significant in 1954 and 1955, it is difficult to draw detailed conclusions concerning the relative change of the semi-diurnal component at Cheltenham. The present agreement between the changes of $\overline{M}^S$ at Huancayo and Kodaikanal would indicate that the latitude of the place of observation plays an important role in determining the magnitude and changes of $\overline{M}^S$. The worldwide character of changes of $\overline{M}^S$ is seen clearly for equatorial stations.

4.13 <u>Changes of $\overline{M}^D_{\phi,K}$</u>

The harmonic dial in Fig. 17 (a) reveals the progressive shift of the time of maximum $\overline{M}^{D}_{\phi.K}$ of the diurnal component with the advance of the solar cycle of activity. The gradual shift of $\overline{M}^{D}_{\phi.K}$ to earlier hours terminates in the sunspot minimum year of 1954 and the vector $\overline{M}^{D}_{K}$ abruptly changes its direction of movement so that the time of maximum $\overline{M}^{D}_{\phi.K}$ becomes progressively later during 1955 and 1956. The maximum of the diurnal component which was at 0400 hrs. at the beginning of 1952 gradually changes to 0200 hrs. by the middle of 1954, and then shifts to mid-noon in 1956.

Fig.18(c) shows the changes of $\overline{M}^{D}_{\phi}$ at Kodaikanal as well as at Huancayo during the years 1952-56. It can be seen that the changes of $\overline{M}^{D}_{\phi}$ at both places are well correlated. The correlation between the time series of $\overline{M}^{D}_{\phi.K}$ and $\overline{M}^{D}_{\phi.H}$ is $+(0.80 \pm .007)$. The change of $\overline{M}^{D}_{\phi}$ is a worldwide effect as has been pointed out by Sarabhai et al[38].

From a study of Hafelekar data for 1932-54 Steinmaurer & Gheri[117] have pointed out that the shift to earlier hours of the diurnal maximum during the minimum solar activity years was more prominent in 1933 than in 1944 and most prominent in 1953-54. A time of maximum $\overline{M}^{D}_{\phi}$ of twelve monthly mean daily variation as early as 2 hrs. during 1953-54 has never been observed before.

It is worthwhile to examine the monthly mean daily variation during the year 1954. The amplitude and times of maxima of the first and second harmonic components of monthly mean daily variation at Kodaikanal are given in Table 5. It can be observed that the time of maximum occurs around midnight

Table 5

The amplitude and hour of maximum of the diurnal and semidiurnal components of the monthly mean daily variation during the year 1954 observed with $22T_K$ telescopes.

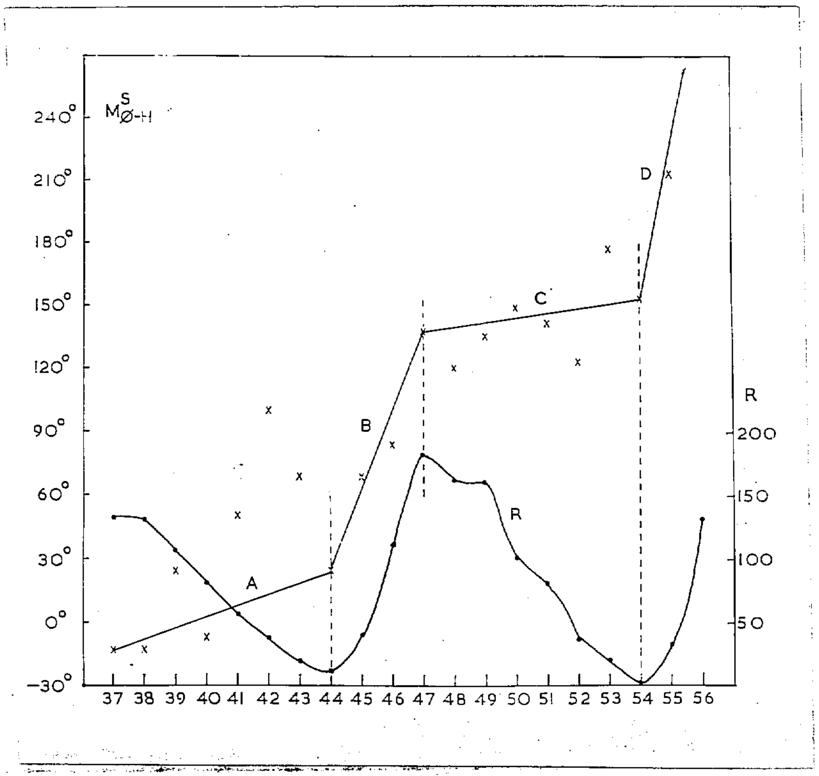
Month	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$
Jan.'54	0.86	69°	0.14	3°
Feb.	0.45	87°	0.06	36°
Mar.	0.61	58°	0.12	− 90°
Apr.	0.67	54°	0.03	47°
May	1.35	14°	0.51	π+ 35°
Jun.	1.10	25°	0.47	π+ 37°
Jul.	0.99	18°	0.22	π+ 27°
Aug.	0.92	12°	0.40	π+ 40°
Sept	1.04	18°	0.10	− 14°
Oct.	0.46	− 3°	0.26	π+ 56°
Nov.	0.54	28°	0.09	− 13°
Dec.	0.73	42°	0.14	− 86°

during the period May to October in the year 1954. Similar occurrance of early maximum at London during these months has been reported by Possner & Heerdan[118]. Their observation shows that during the period June to November in 1954, the time of maximum was at 3 hr. compared to 10 hr. for the remainder of the year. They also found that no such remarkable changes in phase occurred during the previous sunspot minimum year of 1944.

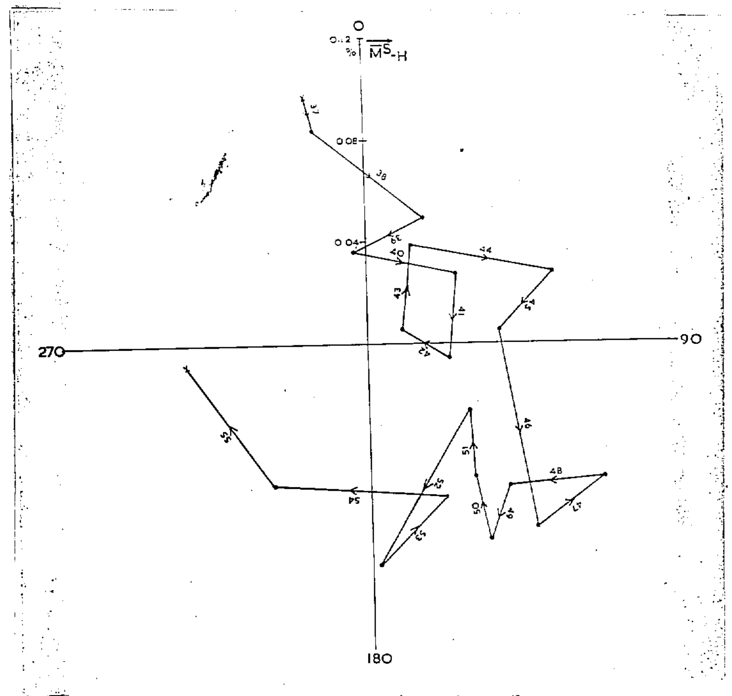
4.14 Changes of $\overline{M}^S_\phi$.K

The time of maximum of the semi-diurnal component of the daily variation of meson intensity undergoes rapid change during the years 1953-56. This is evident from the second harmonic dial in Fig.17(b). Fig.18(d) shows for purpose of comparison, the change of $\overline{M}^S_\phi$ at Kodaikanal and Huancayo. The changes at the two stations are well correlated with a correlation coefficient of (0.79 ± 0.008). The changes at the two places are of the same order of magnitudes, the coefficient of regression being 1.3. Thus the angle of opening of the measuring instrument does not seem to affect radically either the rate of change of amplitude or the rate of change of time of maximum of the semi-diurnal component of the 12-monthly mean daily variation. This is in contrast to the behaviour of the diurnal component.

Fig.19(a) shows the variation of $\overline{M}^S_\phi$ at Huancayo for the period 1937 to 1955. The change of 12-monthly mean relative sunspot number R is also shown in the same figure. It can be


$M^S_{\emptyset-H}$
240°
210°
180°
150°
120°
90°
60°
30°
0°
−30°
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
A
B
C
D
R
R
200
150
100
50

(a)


O
0.2
$\overline{M^S}_{-H}$
0.08
0.04
270
90
180

(b)

Fig 19.

seen that the change of $\overline{M}^S_\phi$ is not uniform over the years. If we consider the change of $\overline{M}^S_\phi$ between the epochs determined by the maxima and minima of solar activity, we see that the rate of change of $\overline{M}^S_\phi$ is many times larger during the rising period of solar activity, marked B and D in the Fig.19(a), than during the periods A and C of diminishing solar activity. The vector $\overline{M}^S_H$ for the period June 1937 to June 1955 is plotted in Fig.19(b). It can be seen that the vector completes about 3/4ths of a complete cycle in about 18 years. This is strongly suggestive of $\overline{M}^S_{\phi.H}$ following a 22 year cycle of solar activity.

4.15 The change of form of the 12-month mean daily deviation $^{o}\overline{M}$

We show in Fig.20(a) the pressure corrected 12 month mean daily variation centred at successive three month epochs for the period December 1952 to December 1956. As explained earlier, the variation is derived by superposition of the diurnal and the semi-diurnal components of the 12 month mean deviations of intensity for the 12 bihourly periods of the day. The 12 month mean daily variation of meson intensity corrected for temperature variations near ground, in addition to the usual correction for barometric pressure is also shown for comparison. The year to year difference curve of the daily variations is also shown.

$^{o}\overline{M}(54-53).y$ for example, is obtained by subtracting respective bihourly percent deviations from mean for 53.y $^{o}\overline{M}$ where y is any particular month at which the 12 month mean daily variation is centred.

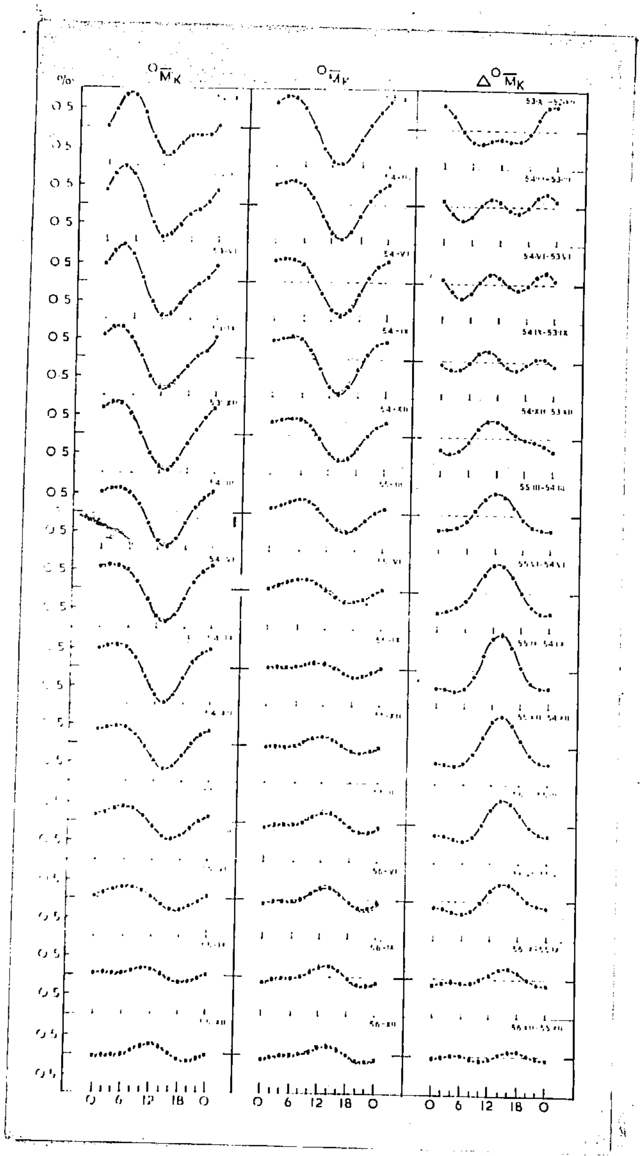


FiG 20 (a)

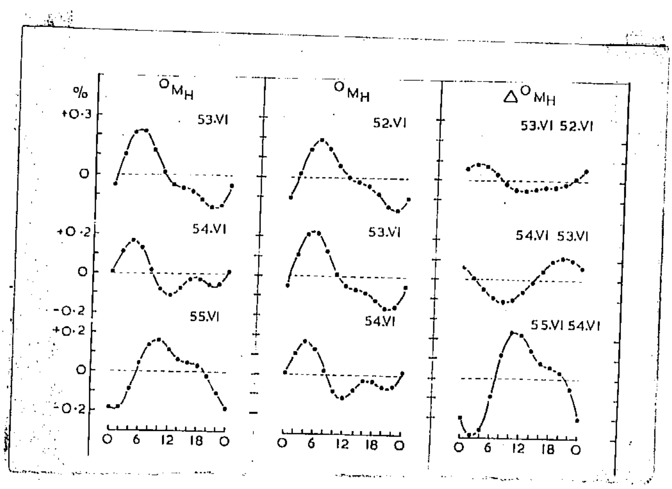


Fig. 20 (b).

It can be observed that the effect of the temperature correction on the pressure corrected 12 month mean daily variation is not appreciably in the years 1953 to 1954 when the amplitude of the variation is large. The correction becomes relatively more important in the years 1955 and 1956 when the amplitude of the daily variation is small. There is no change in the difference curves $\Delta\,{}^{o}\bar{M}$, since the average meteorological correction for a period of a year remains constant from year to year.

Sarabhai et al[38] have drawn attention to the very interesting changes observed in the form of ${}^{o}\bar{M}$ from year to year in the data of Ahmedabad and Kodaikanal and of the Carnegie Institution Stations at Huancayo and Cheltenham. They have summarised their results as follows :-

"(1) The examination of long-term changes of the amplitude and the time of maximum of only the first harmonic component does not reveal the true nature of the physical process which is operating. Similar is the handicap in looking separately at the changes of the amplitude and time of the maximum of the second harmonic component.

(2) It is important to consider changes of the daily variation $\bar{M}$ rather than of its harmonic components. However, in so far as $\bar{M}$ has generally only the first two harmonic components with significant amplitudes, it is convenient to deal with a smoothed ${}^{o}\bar{M}$ which is built by superposition of the first two components.

(3) Changes of $^{o}\overline{M}$ at Ahmedabad and Kodaikanal are suggestive of a mechanism which involves the addition or attenuation of two distinct daily contributions. Each is principally diurnal in character and while one of them has a maximum near midnight, the other has a maximum near noon.

(4) Changes of $^{o}\overline{M}_{H}$ at Huancayo, calculated from Carnegie Institution data from 1937 to 1952, reveal similarly the operation of day and night contributions. At Cheltenham also, there is some evidence of the two contributions, although the simultaneous action of both contributions is not as clearly seen as at stations in low latitudes.

(5) The activity of the two contributions is closely related to the solar cycle of activity. In general, the day and the night contributions are simultaneously added or attenuated. However, just preceding sunspot minimum there is a brief period when only the day contribution is active. This is immediately followed by a short period when only the night contribution is active. The pattern of addition and attenuation of the contributions appears to get reversed after 11 years."

These conclusions were drawn by Sarabhai et al from data of Huancayo extending from 1938 to 1952 and data from Kodaikanal covering the period December 1952 to December 1953. An extension of their study is now possible by the observations made by the author at Kodaikanal during 1954, 1955 and 1956, and through the data of Huancayo for 1953 to 1955 analysed by

Dattner & Venkatesan[122]. The changes of daily variation $^{o}\overline{M}_H$ and $\Delta\, ^{o}\overline{M}_H$ are shown in Fig.20(b). This may be examined in continuation of Fig.3 and may be compared with Fig.19(a) for Kodaikanal.

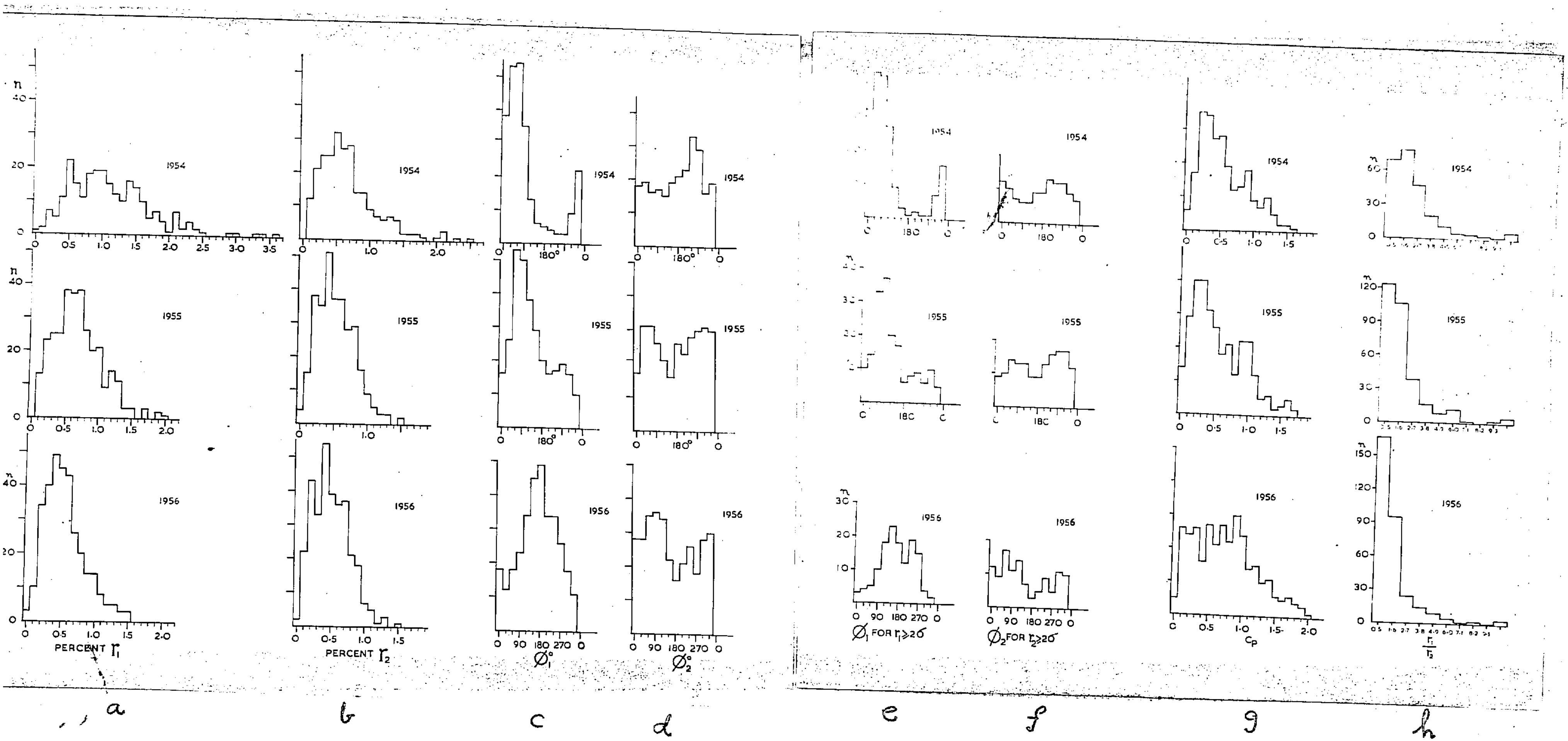
The data from Kodaikanal, which is confirmed by the results from Huancayo, shows the attenuation of the night maximum occuring at 4 to 6 hr. during the period December 1952 to December 1955. A day maximum is seen to become progressively important with the beginning of the new solar cycle from the year 1954 onwards. Thus the change of $^{o}\overline{M}_H$ which started in 1944, whereby a night maximum became progressively important and a day maximum was attenuated has reversed itself in the present solar cycle, and the daily variation at an equitorial station has now a form with a maximum during the day as it had during the last-but-one solar cycle extending from 1933 to 1944.

The difference curves also confirm the features of the daily variation $^{o}\overline{M}$ observed by Sarabhai et al. The difference curve has large amplitude for December (53-52), December (54-53) and December (55-54). However it has negligible amplitude for the period December (56-55). Thus the most rapid changes in the daily variation are seen to occur during the end of one solar cycle and the beginning of the next one. The changes $\Delta\, ^{o}\overline{M}_K$ (53-52) and $\Delta\, ^{o}\overline{M}_H$ (53-52) are opposite in form to $\Delta\, ^{o}\overline{M}_H$ (43-42), and similarly the changes $\Delta\, ^{o}\overline{M}_K$ (54-53) and $\Delta\, ^{o}\overline{M}_H$ (54-53) are opposite to the change $\Delta\, ^{o}\overline{M}_H$ (44-43). This indicates that the pattern of change goes through half a cycle in a period of 11 years.

4.2 Daily variation on individual days

In view of the long period variability of 12-month mean daily variation and the average solar anisotropy to which it is related, it is important to examine the variability of the daily variation from day-to-day before attaching physical meaning to the 12-month mean data. When we consider the daily variation on individual days, the standard error is large in the determination of the parameters r_1, ϕ_1, r_2 and ϕ_2 describing the amplitude and time of maximum of the diurnal and semi-diurnal components of the 12 bihourly deviations on each day. In this context the study of yearly frequency distributions of parameters r_1, ϕ_1, r_2, ϕ_2 and (r_1 / r_2) characterising the daily variation on individual days is undertaken and features of the distributions are compared to the characteristics of the 12-month mean daily variation. Since we know that cosmic ray variations are often associated with geomagnetic disturbances, it is also worthwhile to examine the histograms for Cp, the daily planetary character figure for geomagnetic disturbances.

Figs.21(a), (b), (c), (d), (e) and (f) show the yearly histograms for 1954, 1955, 1956 of r_1, r_2, ϕ_1, ϕ_2, Cp and ratio r_1/r_2 respectively. Only those days for which cosmic ray data are available have been considered for Cp histograms. Therefore the Cp histograms in Fig.21(e) show the relative abundance of magnetically quiet and disturbed days among the working days in each year. The percent days on which low, medium and high values of r_1, r_2, (r_1/r_2) and Cp occur in each year are shown in Table 6.



1954
1955
1956
PERCENT r_1
PERCENT r_2
ϕ_1°
ϕ_2°
ϕ_1 FOR $r_1 \geq 2\sigma$
ϕ_2 FOR $r_2 \geq 2\sigma$
C_p
r_1/r_2
a
b
c
d
e
f
g
h

FiG 21

Table 6

Table showing percent days on which low, medium and high values of r_1, r_2, r_1/r_2 and θ_p occur during the years 1954-56.

Year	No. of days.	r_1 <0.5	r_1 0.5 to 1.0	r_1 >1.0	r_2 <0.5	r_2 0.5 to 1.0	r_2 >1.0	r_1/r_2 <0.5	r_1/r_2 0.5 to 1.0	r_1/r_2 1.0 to 2.0	r_1/r_2 >2.0.	θ_p Low. ≤0.5	θ_p Med. 0.6-0.9	θ_p High ≥1.0.
1954	245	19.6	33.5	46.9	46.9	37.6	15.5	8.6	20.0	31.0	40.8	60.0	25.3	14.7
1955	311	39.9	45.7	14.5	57.9	37.9	4.2	17.2	22.3	34.0	26.5	58.2	23.5	18.3
1956	322	56.2	36.3	7.5	59.9	37.0	3.1	21.1	30.7	29.5	18.6	38.5	31.1	30.4

An examination of the frequency distribution reveals the following salient features of the daily variation and its changes from year to year.

4.21 r_1 Histograms

The r_1 histograms in Fig.21(a) show that the occurrence of large diurnal amplitudes on individual days decreases from 1954 to 1956. Days with diurnal amplitudes greater than 1 % constitute 46.9 % of total working days in 1954, but they constitute only 14.5 and 7.5 % of total days in 1955 and 1956 respectively. Corresponding to this, the 12-month mean amplitude $\overline{M}^D$ decreases markedly from 0.75 % in 1954 to 0.28 % in 1955, but only gradually to 0.22 % in 1956. Thus the decrease of the amplitude of the 12-month mean diurnal variation is also accompanied by a decrease in the amplitude of the diurnal variation on individual days.

4.22 r_2 Histograms

A major shift in the distribution of the second harmonic amplitude r_2 takes place from 1954 to 1955, but almost the same distribution obtains in 1955 as in 1956. This is in contrast to the significant change in the distribution of r_1 from 1955 to 1956. The occurrence of large r_2 values is significantly more in 1954 than in 1955 or in 1956. The amplitude of the 12-month mean second harmonic component $\overline{M}^S$ diminishes from (0.14 ± 0.02)% in 1954 to (0.05 ± 0.02)% in 1955 but increases again to (0.09 ± 0.02)% in 1956. This is due to the larger spread of time of maximum, ϕ_2 in 1955 as compared to 1956 as we can see in Fig.21(d).

4.23 ϕ_1 Histograms

A steady shift of the time of diurnal maximum to later hours from 1954 to 1956 is noticable in the ϕ_1 histograms. This is similar to what is seen in the 12-month mean daily variation $^{c}\bar{M}$ in Fig.20(a). A compasison is made in Table ~~6.~~ 7 between the most frequent ϕ_1 observed in the histograms and $\bar{M}^{D}_{\phi}$ the time of maximum of the diurnal component of the 12-month mean daily variation for the three years 1954, 1955 and 1956.

Table 7.

Year	Most frequent ϕ_1	$\bar{M}^{D}_{\phi}$
1954	30°-60°	31°
1955	60°-90°	88°
1956	150°-180°	175°

On days on which r_1 is small, and less than the 2 σ level of significance, ϕ_1 is expected to have a large error. In the histograms shown in Fig.21(c), such days are also included. In Fig.21(e) are shown the histograms for ϕ_1 for days on which r_1 is significant at the 2 σ level. Interesting features emerge from the histograms in Fig.21(e). During 1954 the vast majority of days have a time of maximum in the early morning and there is a sharp peak in the histogram for ϕ_1 between 0° to 90°. In 1955 and 1956 the peak moves to later hours and simultaneously the scatter of the time of maximum progressively increases. In consequence the sharp maximum in the histogram gets progressively reduced in amplitude and in 1956 is replaced by a broad maximum around noon. Thus the diminution of the amplitude of the 12-month mean daily variation $\overline{M}^D$ due to the reduction in amplitude of r_1 on individual days is further accentuated by wide scatter of ϕ_1. The increasing scatter of ϕ_1, as we shall see later, is related to the operation of the two components of the daily variation which were observed by Sarabhai et al during periods other than the minimum of solar activity.

4.24 ϕ_2 Histograms

A major change in the time of maximum of the second harmonic ϕ_2 from 1954 to 1955 is evident in the ϕ_2 histograms Fig.21(d). A single maximum in 1954 which was at about 240° gives place in 1955 to two maxima; one at about 60° and the other at about 300°. During 1956 the maximum at 300° becomes less important but that at 60° continues to be as prominent as it was in 1955. If one examines the histograms shown in Fig.21(f) for days on which r_2 is significant at the 2 σ level, it is seen that even in 1954, the ϕ_2 histogram exhibits a tendency for the semi-diurnal component to have a time of maximum in one of two preferred periods. The first one corresponds to values of ϕ_2 from 0-60° and the second one from 210-270°. For 1955 and 1956 the histograms of ϕ_2 for significant r_2 show the same features as is observed for all days.

4.25 r_1/r_2 Histograms

A study of the histograms of the ratio r_1/r_2 shows that the ratio decreases markedly from 1954 to 1956. This is because, as we have seen earlier, the decrease of the diurnal amplitude r_1 during the three years is not matched by the decrease of r_2.

4.26 Cp Histograms

The histograms of Cp indicate the well known feature that occurrence of days of large Cp is significantly greater in 1956 than in 1954 and 1955. In 1955 the number of days of intermediate Cp above 0.6 and upto 1.2 is significantly greater than in 1954. In 1956 for the first time very large values of Cp are observed.

4.3 Inter-relationship of Parameters of the daily variation on individual days

For the purpose of this study we consider the parameters r_1, ϕ_1, r_2, ϕ_2, r_1/r_2 and $(2\phi_1-\phi_2)/2$ of the daily variation and the value of Cp on individual days. Days are first classified according to the value of a particular parameter and the values of the other parameters and of Cp for each class are than determined. For instance, to study the relationship of r_1 with other parameters, the days in each year are sorted into groups G_1, G_2, G_3 etc., according to the value of r_1. The limits of the groups are the same for each year so that the average characteristics of the groups of one year are directly comparable with those in other years. The limits of r_1 for each group are chosen so that an adequate number of days are included in the group to make the parameter of the average daily variation of the group statistically significant. However, when the distribution of a parameter such as r_1 changes radically from one year to another, it is impossible to ensure that all groups have a representative number of days in all years.

The mean daily variation for each group is found by vectorial addition of $\vec{r_1}$ and $\vec{r_2}$ on individual days. The parameters of the harmonic components of the average daily variation of the groups are designated $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$ and $\bar{\phi}_2$. The ratio $\bar{r}_1/\bar{r}_2$, the difference angle $(2\bar{\phi}_1-\bar{\phi}_2)/2$ and mean Cp for each group are calculated. The result of the sorting of r_1 is given in Table 8. The mean vectors $\vec{\bar{r}}_1$ and $\vec{\bar{r}}_2$ are plotted on harmonic dials and the quantities $\bar{r}_1/\bar{r}_2$ and $\bar{C}p$ are plotted against corresponding $\bar{r}_1$ in Fig.22(a),(b),(c) and (d).

The relationships of the average characteristics $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$, $\bar{\phi}_2$ and $\bar{C}p$ with r_2, ϕ_1, ϕ_2 and Cp are found in exactly the same way as in the case of r_1. An examination of the results of the analysis reveals the following relationships:

4.31 r_1 Sorting

(a) The end of points 1,2,3 etc. of mean vectors $\vec{\bar{r}}_1$ for groups G_1, G_2, G_3 etc. respectively are plotted separately

Table 8

Table showing parameters of average daily variation of the groups sorted according to the value of r_1 on individual days and the $\overline{C}_p$ for each group.

Year	r_1 range	Group	$\overline{r}_1$	$\overline{r}_2$	$\overline{\phi}_1$	$\overline{\phi}_2$	$\frac{(2\overline{\phi}_1-\overline{\phi}_2)}{2}$	$\overline{r}_1/\overline{r}_2$	$\overline{C}_p$	No. of days n	Error in $\overline{r}_1, \overline{r}_2$ ±
1	2	3	4	5	6	7	8	9	10	11	12
1954	0.0-0.3	G_1	0.04	0.20	26°	$\pi+120^\circ$	$\pi+56^\circ$	0.2	0.63	15	0.08
	0.4-0.5	G_2	0.27	0.04	54°	$\pi+90^\circ$	-81°	6.8	0.55	33	0.05
	0.6-0.7	G_3	0.37	0.11	24°	$\pi+41^\circ$	-87°	3.4	0.55	26	0.06
	0.8-0.9	G_4	0.50	0.04	$\pi+117^\circ$	0°	117°	12.5	0.56	37	0.04
	1.0-1.1	G_5	0.78	0.12	27°	$\pi+5^\circ$	-66°	6.5	0.59	34	0.04
	1.2-1.3	G_6	0.83	0.21	32°	$\pi+90^\circ$	$\pi+77^\circ$	4.0	0.54	22	0.07
	1.4-1.5	G_7	1.03	0.05	45°	$\pi+37^\circ$	-64°	20.6	0.48	30	0.05
	1.6-1.9	G_8	1.19	0.43	20°	$\pi+38^\circ$	-89°	2.8	0.39	26	0.06
	2.0 & above	G_9	1.59	0.92	22°	$\pi+39^\circ$	-88°	1.7	0.46	22	0.07

Contd.....

Table 8 contd.....

1	2	3	4	5	6	7	8	9	10	11	12
1955	0.0–0.3	G_1	0.03	0.09	90°	6°	87°	0.3	0.60	61	0.04
	0.4–0.5	G_2	0.14	0.06	115°	109°	60°	2.3	0.54	63	0.04
	0.6–0.7	G_3	0.24	0.14	100°	-45°	-58°	1.7	0.52	75	0.03
	0.8–0.9	G_4	0.30	0.07	78°	$\pi+16^\circ$	-20°	4.3	0.47	46	0.04
	1.0–1.1	G_5	0.28	0.06	70°	149°	-5°	4.7	0.38	29	0.05
	1.2–1.3	G_6	0.91	0.22	80°	$\pi+87^\circ$	-54°	4.1	0.62	25	0.06
	1.4–2.1	G_7	1.19	0.64	97°	$\pi+35^\circ$	-11°	1.9	0.58	12	0.09
1956	0.0–0.3	G_1	0.05	0.06	169°	18°	160°	0.8	0.74	87	0.03
	0.4–0.5	G_2	0.14	0.09	π	71°	144°	1.6	0.66	94	0.03
	0.6–0.7	G_3	0.23	0.06	$\pi+5^\circ$	36°	167°	2.3	0.77	69	0.04
	0.8–0.9	G_4	0.39	0.18	156°	49°	131°	2.2	0.75	34	0.05
	1.0–1.1	G_5	0.62	0.15	167°	28°	153°	4.1	0.86	22	0.07
	1.2–1.5	G_6	0.70	0.24	$\pi+8^\circ$	70°	153°	2.9	0.66	16	0.08

for each year on the diurnal harmonic dial shown in Fig.22(a). The maximum standard error associated with $\overrightarrow{\bar{r}_1}$ is indicated in the Table 8. The diagram shows that $\bar{r}_1$ steadily increases as r_1

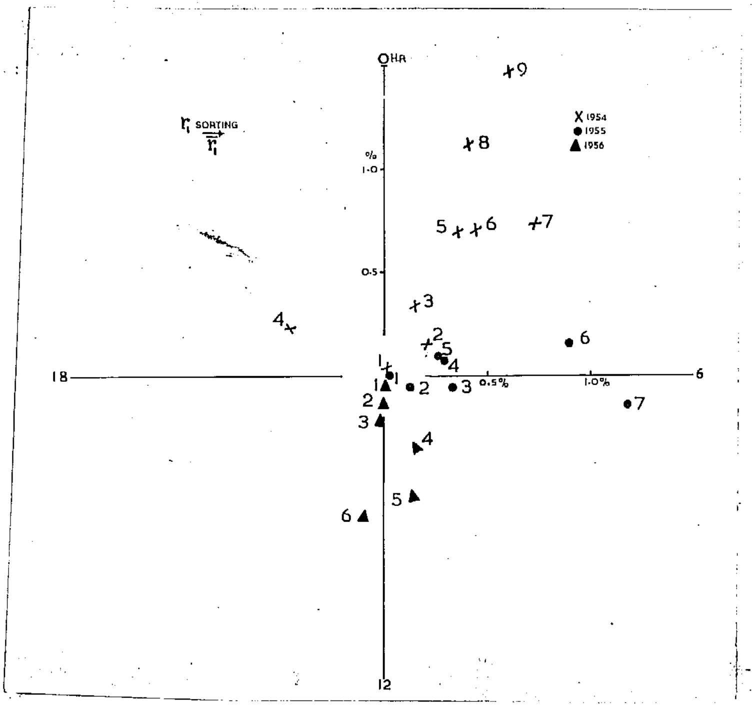


Fig 22 (a)

on individual days increases. In each of the three years studied, the constancy of $\bar{\phi}_1$ for increasing values of r_1 is strikingly revealed. The shift of the vector $\bar{r}_1$ to later hours and gradual reduction in its amplitude $\bar{r}_1$ over the three years are also noticable.

(b) The second harmonic dial Fig.22(b) shows $\overrightarrow{\bar{r}_2}$ vector plotted for each group. It shows that low $\bar{r}_1$ values are associated with low $\bar{r}_2$ values. In 1956 when there are no large $\bar{r}_1$ values, large $\bar{r}_2$ values are also absent.

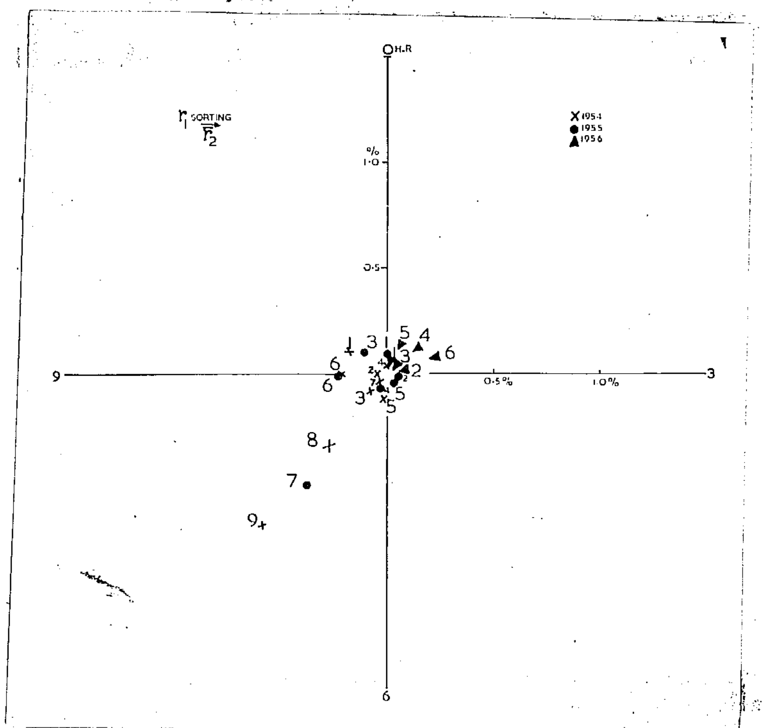


Fig 22 (b)

(c) The diagram Fig.22(c) in which $\overline{r}_1/r_2$ is plotted against $\bar{r}_1$ shows that the ratio steadily increases for increasing r_1 upto 1.0 % but for larger values of r_1 the ratio falls off.

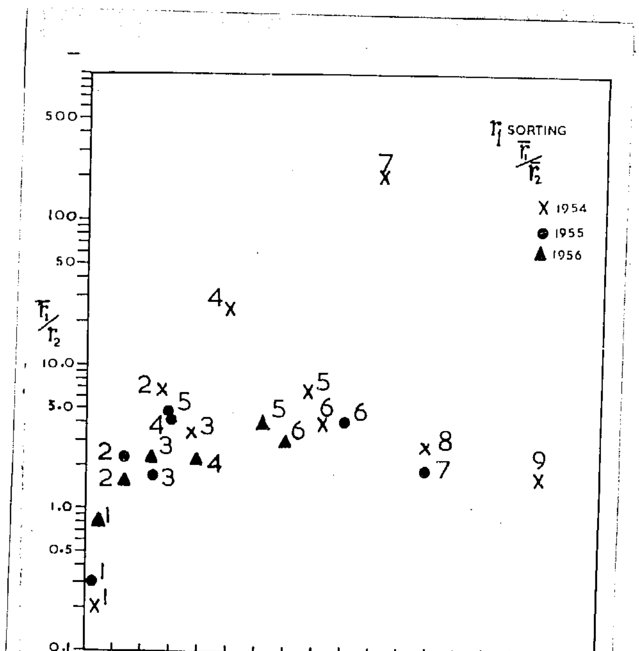


Fig 22 (c)

(d) The graph in which mean $\overline{Cp}$ is plotted against $\bar{r}_1$ shows that in 1954 low $\bar{r}_1$ values are associated with large Cp values. In 1955, and more so in 1956 this behaviour is not noticed. Thus the relation of magnitude of r_1 and Cp does not remain constant at all periods of the solar cycle.

~~4.32~~

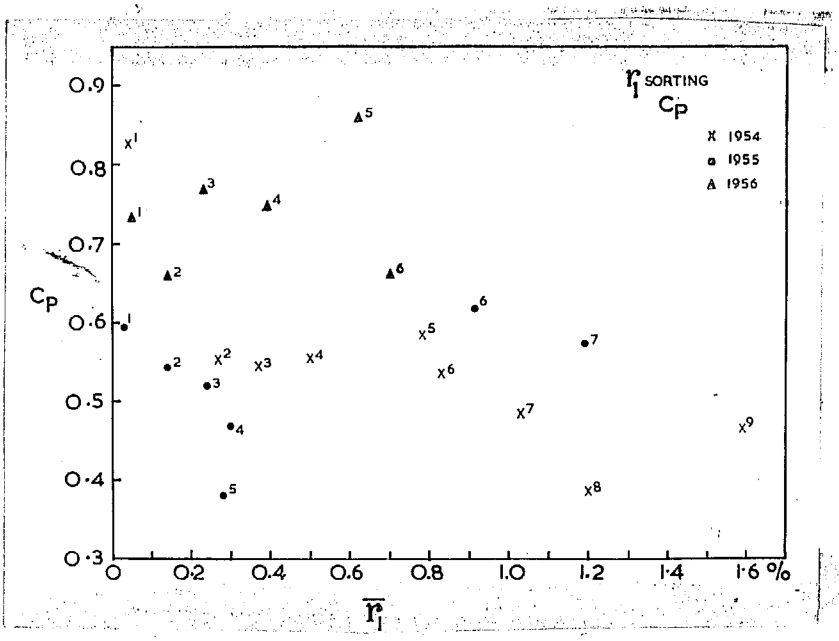


Fig 22(d)

4.32 r_2 Sorting

(a) The $\overline{r}_1$ vectors for groups sorted on r_2 values are plotted in Fig.23(a). It can be seen that $\overline{r}_1$ does not change

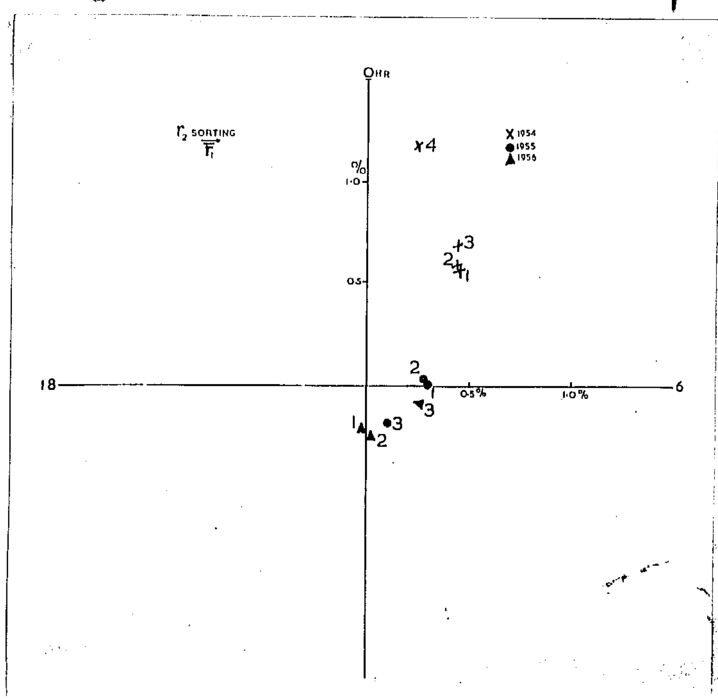


Fig 23(a)

much with increase of r_2. The exception to this is seen in 1954 when large values of r_1 are associated with large values of $r_2 = 1.5$ %.

(b) Fig.23(b) shows that for the different groups of r_2 the amplitude of the mean vector $\bar{r}_2$ does not change appreciably from group to group except for the group having

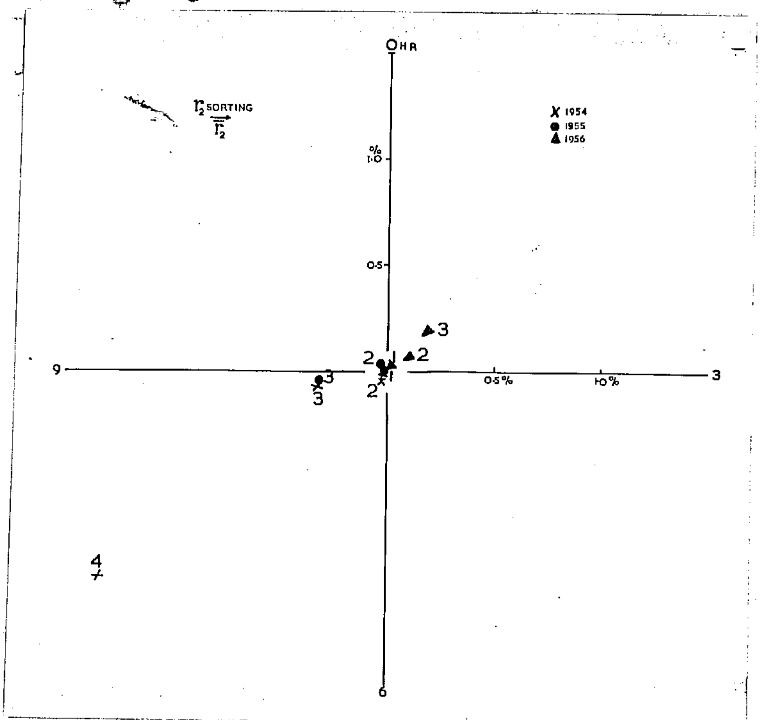


Fig 23(b)

the largest values of r_2. This is connected with the large scatter of ϕ_2, as seen in the histograms of ϕ_2 for days with significant r_2. The histograms for each year are shown in Fig.21(f).

The average values of r_1/r_2 and of Cp for various groups of r_2 show no definite relationships.

4.33 ϕ_1 Sorting

(a) Fig.24(a) shows the harmonic dial for the vectors $\bar{r}_1$

Table 9

Table showing parameters of average daily variation of the groups sorted according to the value of r_2 on individual days and the $\overline{C_p}$ for each group.

Year	r_2 range	Group	$\overline{r_1}$	$\overline{r_2}$	$\overline{\phi_1}$	$\overline{\phi_2}$	$\frac{(2\overline{\phi_1}-\overline{\phi_2})}{2}$	$\overline{r_1}/\overline{r_2}$	$\overline{C_p}$	No. of days n	Error in r_1, r_2 ±
1954	0.0–0.3	G_1	0.72	0.02	39°	$\pi+63^\circ$	-83°	36.0	0.55	58	0.04
	0.4–0.9	G_2	0.73	0.03	37°	$\pi+45^\circ$	-76°	24.3	0.58	140	0.02
	1.0–1.5	G_3	0.82	0.33	33°	$\pi+77^\circ$	$\pi+84^\circ$	2.5	0.44	37	0.04
	1.6–2.1	G_4	1.20	1.77	12°	$\pi+54^\circ$	$\pi+75^\circ$	0.7	0.30	10	0.09
1955	0.0–0.3	G_1	0.30	0.01	88°	$\pi+90^\circ$	-47°	30.0	0.56	91	0.03
	0.4–0.9	G_2	0.28	0.04	83°	-33°	-81°	7.0	0.55	198	0.02
	1.0–1.5	G_3	0.21	0.32	149°	$\pi+82^\circ$	18°	0.7	0.57	21	0.07
1956	0.0–0.3	G_1	0.21	0.02	$\pi+5^\circ$	26°	172°	10.5	0.44	100	0.03
	0.4–0.9	G_2	0.25	0.12	175°	54°	148°	2.1	0.47	205	0.02
	1.0–1.3	G_3	0.27	0.28	117°	45°	94°	1.0	0.50	17	0.07

of groups sorted on the value of $\emptyset_1$. This again shows a gradual shift of the vector $\bar{r}_1$ to later hours and reduction in amplitude $\bar{r}_1$ from 1954 to 1956.

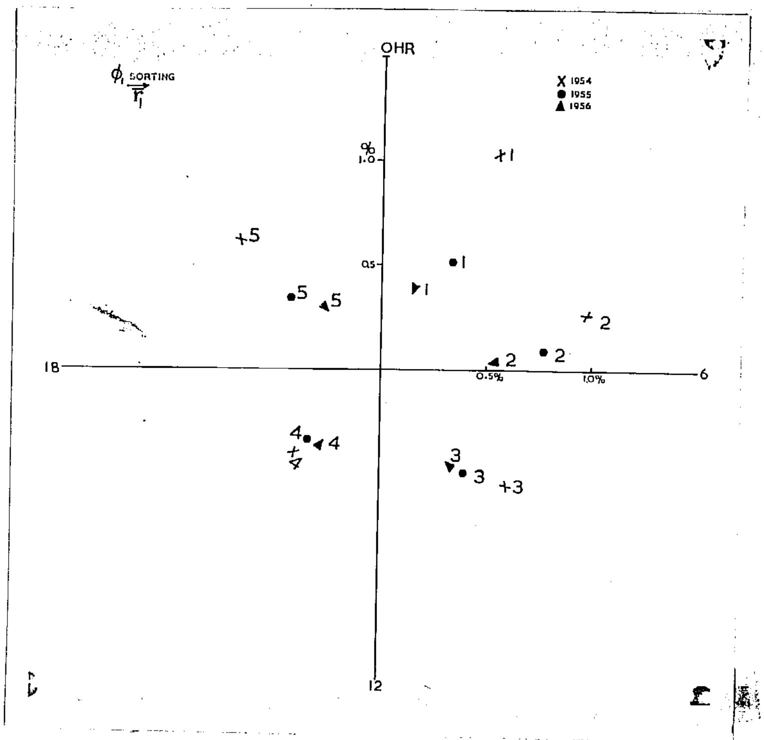


Fig 24(a)

(b) Fig.24(b) indicates that in 1954 and 1956 large r_2 values are associated with $\bar{\emptyset}_1$ values 313° and 320° respectively. In 1955 however, this association of large r_2 with occurrence of a diurnal maximum at night is not apparent.

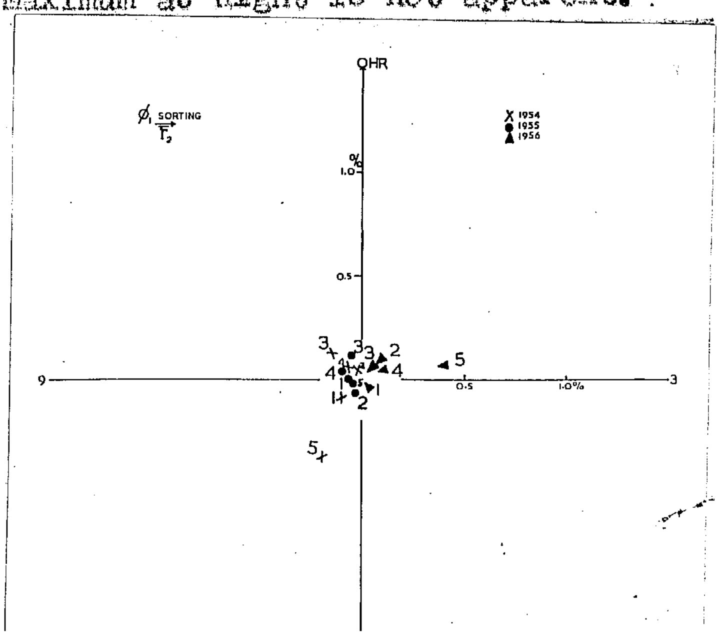


Fig 24(b)

(c) Fig.24(c) indicates that for all three years the $\bar{r}_1/\bar{r}_2$ ratio is large on days on which the time of maximum

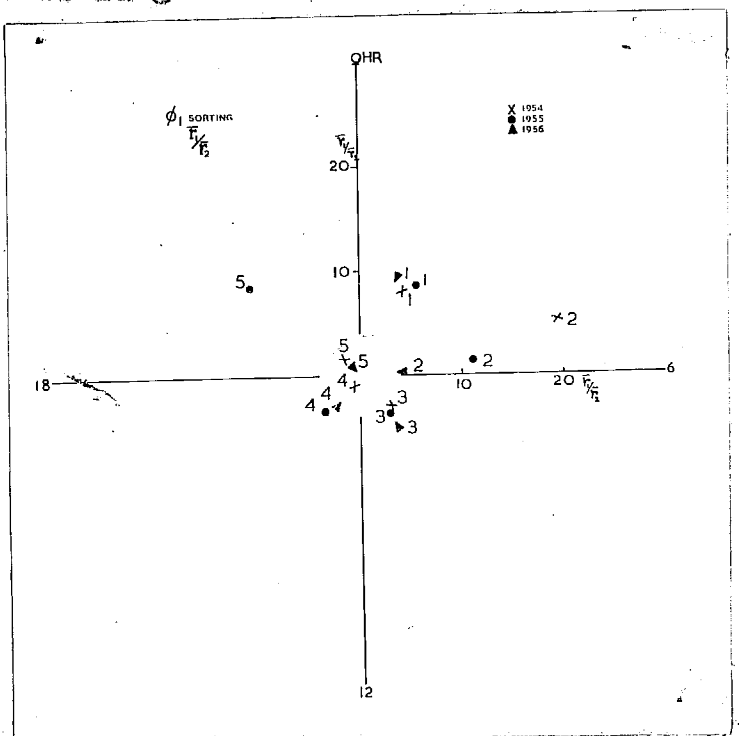


Fig 24(c)

of the diurnal component is in the early morning. It is also seen that the ratio is small when the time of maximum of the diurnal component is in the afternoon. These are common features for all three years. Thus the change that is seen in the form of the average daily variation from year to year is connected with the shift of distribution of days in each group of ϕ_1 from year to year. Table 10 shows that in group 1 corresponding to ϕ_1 = 0-50° there were 105, 56 and 30 days in the years 1954, 1955 and 1956 respectively. On the other hand in group 4 corresponding to ϕ_1 between 180° and 270° the number of days was 14, 60 and 116 in the years 1954, 1955 and 1956 respectively. It would be further noticed from the table that the amplitude $\bar{r}_1$ in the group G_1 diminishes from 1.1 % to 0.4 % between the

Table 10

Table showing parameters of average daily variation of the groups sorted according to the value of ϕ_1 on individual days and the $\bar{C}_p$ for each group.

Year	ϕ_1 range	Group	$\bar{r}_1$	$\bar{r}_2$	$\bar{\phi}_1$	$\bar{\phi}_2$	$\frac{(2\bar{\phi}_1-\bar{\phi}_2)}{2}$	$\bar{r}_1/\bar{r}_2$	$\bar{C}_p$	No. of days n	Error in r_1, r_2 ±
1954	0- 50°	G_1	1.17	0.13	28°	π+47°	- 86°	9.0	0.53	105	0.03
	60°-110°	G_2	1.01	0.05	75°	-21°	π+ 85°	20.2	0.[illegible]7	71	0.04
	120°-170°	G_2	0.82	0.19	133°	47°	- 24°	4 .3	0.66	15	0.08
	180°-270°	G_4	0.57	0.09	π+45°	-49°	69°	1.1	0.60	14	0.08
	280°-360°	G_5	0.90	0.42	-47°	π+47°	π+ 19°	2.1	0.44	40	0.04
1955	0°- 50°	G_1	0.62	0.06	33°	π+ 90°	π+78°	10.3	0.58	56	0.04
	60°-110°	G_2	0.78	0.07	83°	π+26°	- 20°	11.1	0.57	101	0.03
	120°-170°	G_3	0.64	0.13	141°	-22°	- 28°	4.9	0.55	58	0.04
	180°-270°	G_4	0.48	0.10	π+ 45°	-66°	78°	4.8	0.57	60	0.04
	280°-360°	G_5	0.54	0.04	-51°	π+63°	π+ 7°	13.5	0.43	34	0.05
1956	0°- 50°	G_1	0.42	0.05	22°	127°	- 42°	10.5	0.65	30	0.05
	60°-110°	G_2	0.54	0.13	86°	45°	62°	4.2	0.63	43	0.04
	120°-170°	G_3	0.57	0.09	144°	32°	128°	6.3	0.70	93	0.03
	180°-270°	G_4	0.46	0.12	π+ 38°	65°	π + 5°	3.8	0.73	116	0.03
	280°-360°	G_5	0.40	0.41	-42°	79°	- 82°	1.0	0.76	40	0.04

years 1954 and 1956. However in the group G_4 there is negligible change of amplitude from 0.5 % to 0.46 % during the three years.

Fig.24(d) shows the average daily variation for the years 1954, 1955 and 1956 for the two groups corresponding to ϕ_1 between 0-50° and ϕ_1 between 180° to 270°. This shows in a striking manner that the change in amplitude of the diurnal variation during the three years is mainly connected with the change in amplitude of the diurnal variation occuring with a maximum in the early morning.

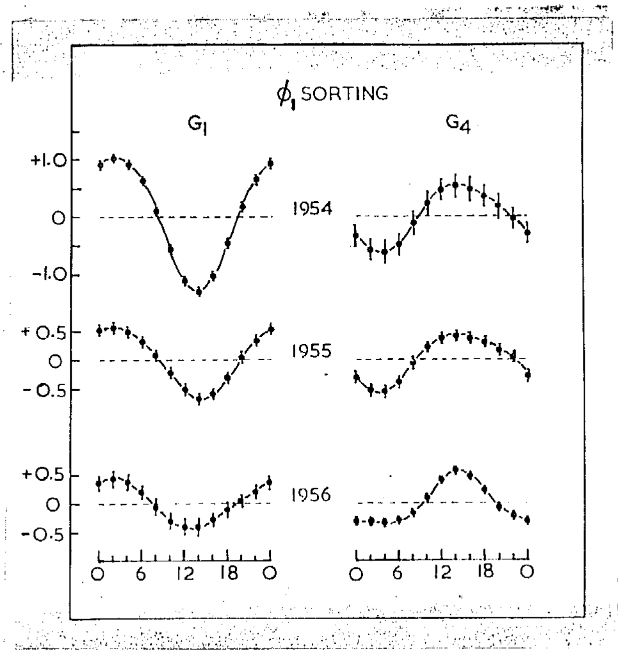


Fig 24 (d)

(d) When $\overline{Cp}$ of each group is examined in Table 10 it is found that the days with night maximum in 1954 and 1955 are associated with low Cp values. In 1956 when the number of low Cp days are few compared to those of 1954 and 1955, this association breaks down.

The results of sorting on ϕ_2 values reveal no important relationships. Table(11).

Table 11

Table showing parameters of average daily variation of the groups sorted according to the value of ϕ_2 on individual days and the $\bar{C}_p$ for each group.

Year	ϕ_2 range in degrees	Group	$\bar{r}_1$	$\bar{r}_2$	$\bar{\phi}_1$	$\bar{\phi}_2$	$\frac{2\phi_1-\phi_2}{2}$	$\bar{r}_1/\bar{r}_2$	$\bar{C}_p$	No. of days n	Error in $\bar{r}_1$, $\bar{r}_2$ ±
1954	0- 90	G_1	0.67	0.51	55°	40°	35°	1.31	0.59	68	0.04
	90-180	G_2	0.80	0.55	25°	152°	-51°	1.45	0.55	55	0.04
	180-270	G_3	0.90	0.80	20°	$\pi+51^\circ$	$\pi+84^\circ$	1.13	0.45	64	0.04
	270-360	G_4	0.77	0.54	44°	-58°	$\pi+73^\circ$	1.43	0.57	58	0.04
1955	0- 90	G_1	0.24	0.43	100°	45°	72°	0.56	0.55	92	0.03
	90-180	G_2	0.24	0.51	82°	125°	19°	0.47	0.58	52	0.04
	180-270	G_3	0.32	0.48	69°	$\pi+43^\circ$	-43°	0.67	0.51	86	0.03
	270-360	G_4	0.33	0.50	101°	-56°	-51°	0.66	0.57	81	0.03
1956	0- 90	G_1	0.24	0.47	178°	48°	-154°	0.51	0.69	109	0.03
	90-180	G_2	0.21	0.46	$\pi+5^\circ$	130°	120°	0.46	0.79	81	0.03
	180-270	G_3	0.17	0.39	156°	$\pi+55^\circ$	38°	0.44	0.82	59	0.04
	270-360	G_4	0.26	0.47	173°	-42°	14°	0.55	0.70	73	0.04

4.34 Cp Sorting

(a) Examination of Fig.25(a) shows that the relationship of daily variation with Cp is quite different in the year 1954 of of minimum solar activity, as compared to the years 1955 and 1956 of rising solar activity. In 1954 magnetically quiet days

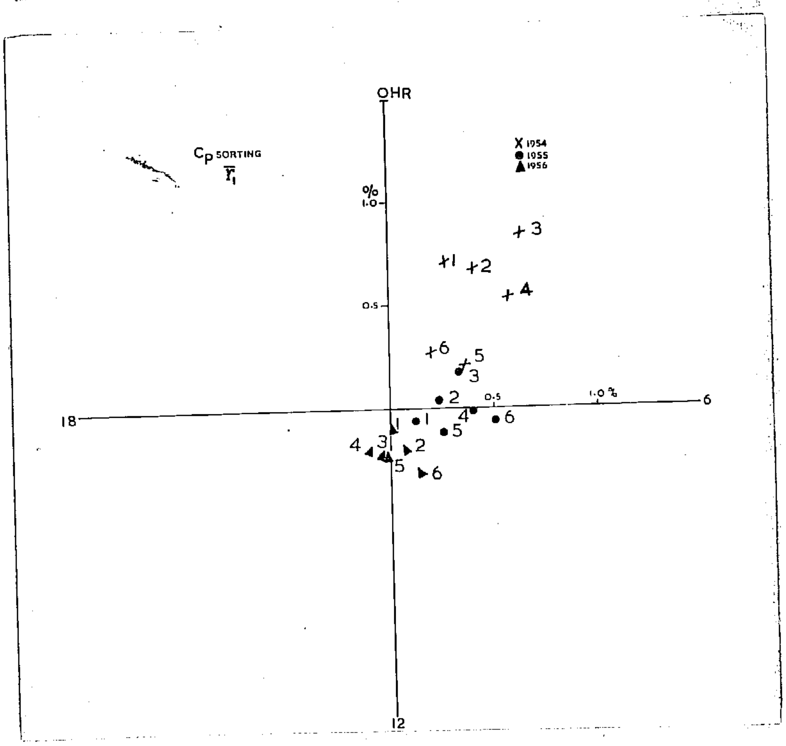


Fig 25 (a)

with Cp upto 0.85 have a larger amplitude than more disturbed days for which the amplitude $\vec{r}_1$ decreases sharply. In 1955 and 1956 the largest amplitude is observed for the most disturbed days corresponding to Cp $\geq$ 1.1. The movement of the vector $\vec{r}_1$ to earlier hours with increasing Cp is seen only during the year 1956.

(b) r_2 is not affected by Cp in any clear cut manner. However, the ratio r_1/r_2 as seen in the Fig.25(b) undergoes an abrupt change at a value of Cp in the range 0.5 to 1.0. The change of form of the daily variation with increasing Cp is

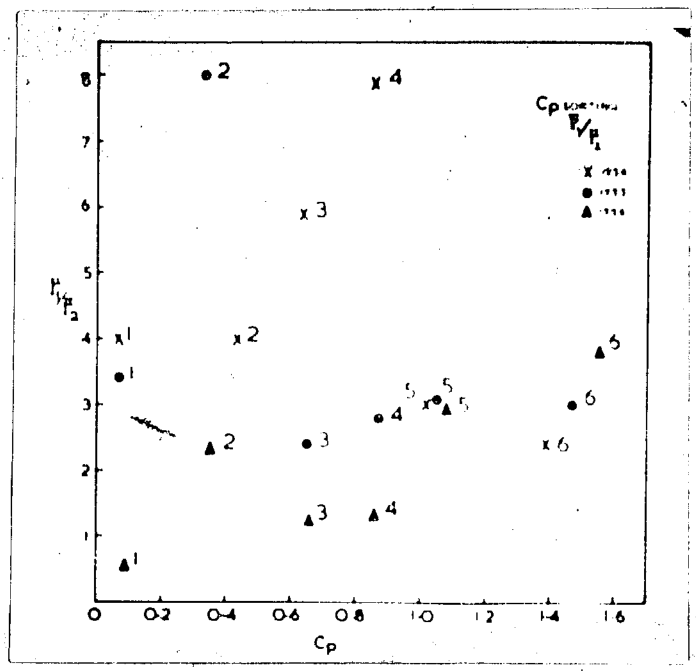


Fig 25 (b)

seen more clearly in Fig.25(c). It would be observed that in all years an abrupt change of form occurs between Cp = 0.85 and Cp = 1.2. Group 5 with an average Cp of 1.1 corresponds to the transition in all theee years.

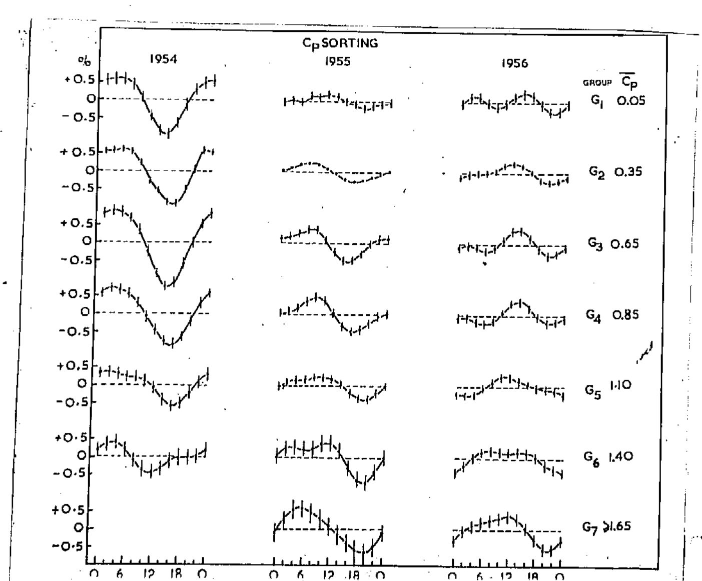


Fig 25(c)

Table 12

Table showing parameters of average daily variation of the groups sorted according to the value of C_p and mean $\bar{C}_p$ for each group.

Year	C_p	Group	$\bar{r}_1$	$\bar{r}_2$	$\bar{\phi}_1$	$\bar{\phi}_2$	$\frac{(2\bar{\phi}_1-\bar{\phi}_2)}{2}$	$\bar{r}_1/\bar{r}_2$	$\bar{C}_p$	No.of days n	Error in r_1/r_2 ±
1	2	3	4	5	6	7	8	9	10	11	12
1954	0.0–0.1	G_1	0.76	0.19	21^o	$\pi+34^o$	-86^o	4.0	0.07	23	0.06
	0.2–0.5	G_2	0.79	0.18	31^o	$\pi+53^o$	-86^o	4.0	0.44	124	0.03
	0.6–0.7	G_3	1.06	0.18	37^o	$\pi+77^o$	$\pi+88^o$	5.9	0.64	31	0.05
	0.8–0.9	G_4	0.79	0.10	47^o	-57^o	$\pi+75^o$	7.9	0.86	31	0.05
	1.0–1.2	G_5	0.42	0.14	60^o	-33^o	$\pi+76^o$	3.0	1.10	26	0.06
	1.3	G_6	0.34	0.14	38^o	115^o	$\pi+60^o$	2.4	1.39	10	0.09
1955	0.0–0.1	G_1	0.17	0.05	114^o	-21^o	-56^o	3.4	0.07	43	0.04
	0.2–0.5	G_2	0.24	0.03	80^o	$\pi+71^o$	-46^o	8.0	0.33	138	0.02
	0.6–0.7	G_3	0.38	0.16	61^o	$\pi+71^o$	-65^o	2.4	0.65	39	0.04

Contd.....

Table 12 contd.....

1	2	3	4	5	6	7	8	9	10	11	12
1955	0.8-0.9	G_4	0.40	0.15	92°	-78°	-49°	2.7	0.87	34	0.05
	1.0-1.2	G_5	0.28	0.09	114°	20°	104°	3.1	1.06	39	0.04
	1.3-	G_6	0.51	0.17	107°	40°	87°	3.0	1.47	18	0.07
1956	0.0-0.1	G_1	0.10	0.22	175°	76°	137°	0.5	0.68	31	0.05
	0.2-0.5	G_2	0.21	0.09	159°	32°	143°	2.3	0.35	93	0.03
	0.6-0.7	G_3	0.23	0.20	$\pi+9^\circ$	45°	166°	1.2	0.66	48	0.04
	0.8-0.9	G_4	0.23	0.18	$\pi+26^\circ$	40°	$\pi+6^\circ$	1.3	0.86	51	0.04
	1.0-1.2	G_5	0.23	0.08	$\pi+5^\circ$	-24°	17°	2.9	1.08	53	0.04
	1.3-	G_6	0.34	0.09	155°	122°	94°	3.8	1.55	46	0.04

4.4 A solar flare type increase of cosmic ray intensity at the geomagnetic equator

The occurrence of the large solar flare on 23rd February 1956 at 0332 hr. GMT was associated with an increase of $(4.8 \pm 1.45)\%$ in cosmic ray intensity measured with $^{22}T_K$ telescopes at Kodaikanal during the hour immediately following the flare. A similar increase was observed with an instrument of an identical type operated at Trivandrum which is at the same geomagnetic latitude as Kodaikanal, but at sea level. A similar instrument at Ahmedabad registered an increase of $(7.6 \pm 1.3)\%$. The author has reported in collaboration with Sarabhai, Duggal & Razdan an average increase of $(5.7 \pm 0.8)\%$ for the meson intensity measured with ^{22}T telescopes at Kodaikanal, Ahmedabad and Trivandrum. The increase which was later known to have occurred also at Huancayo constitutes the first solar flare type event in cosmic radiation observered at the geomagnetic equator. If the increase is due to solar protons travelling in approximately direct paths, the energy of the protons must extend from about 35-67.5 Bev. It is estimated that the average flux of such protons is approximately equal to 1.5 times the flux of general cosmic ray intensity in the same energy range. During the hour, the sun is estimated to have emitted more than 10^{28} protons of about 50 Bev energy. The full report of the event observed in India and its interpretation is given by Sarabhai et al and is enclosed as an appendix to this dissertation.

4.5 The lunar daily variation in cosmic ray intensity

Venkatesan examined the effect of the lunar atmospheric tide on meson intensity at Kodaikanal for the period May 1952 to December 1953. He found significant lunar daily variation in cosmic ray intensity with an amplitude more than two times the probable error. This was positively correlated with the lunar tide in the barometric pressure and the results therefore agreed with those of a similar study made by Duperier[167] at London. Venkatesan has extended the Kodaikanal determination by examining the cosmic ray data obtained by the author during the period January 1954 to June 1955. For this period the lunar daily variation in cosmic ray intensity has an amplitude less than the probable error and in consequence no conclusions can be drawn. A report of this work by Venkatesan & Sastry has been published and is included as an annexure to this dissertation.

CHAPTER V

EXPERIMENTAL RESULTS OF 5T TELESCOPES

The present chapter deals with the results of an investigation with narrow angle telescopes (5T) started in February 1956 at Kodaikanal. As shown by Sarabhai & Nerurkar[131] and Sarabhai, Nerurkar & Bhavsar[146], narrow angle telescopes are particularly suitable for the study of the changes of the daily variation, since changes of anisotropy are more prominently revealed by them than by instruments admitting a wider cone of radiation. The details of the apparatus set up by the author have been given in Chapter II. The instrument consists of two triple coincidence telescopes, each of which has a semiangle of 5^{o} in the E-W plane and 19^{o} in the N-S plane. 8 cm. lead absorber is kept in the instrument.

Table 13

Distribution of days of observation at Kodaikanal for 5T telescopes

No. of tels. working.	Feb	Mar	Apr	May	Jun	1956 Jul	Aug	Sep	Oct	Nov	Dec	Total days	%
2	3	21	26	21	23	22	1	26	23	17	24	207	73
1	13	6	1	6	5	6	26	2	4	2	5	76	27
Total working days	16	27	27	27	28	28	27	28	27	19	29	283	

Table 13 shows the number of days on which one and two 5T telescopes were in operation during the period of experimentation which consists of 326 days commencing from 10th February 1956. Data for daily variation is available for 283 days. This is processed in exactly the same manner as has been described for 22T telescopes. In addition, an attempt has been made to derive the daily mean bihourly intensity for an extended period of days so that day-to-day changes of intensity can be studied. For this purpose the procedure of normalisation described in Chapter 3 has been adopted.

The time series of the daily mean bihourly intensity for the period February 20th to September 19th, 1956 obtained with 5T telescopes at Ahmedabad and at Kodaikanal are shown in Fig.26. The Ahmedabad values are taken from the study of Bhavsar.

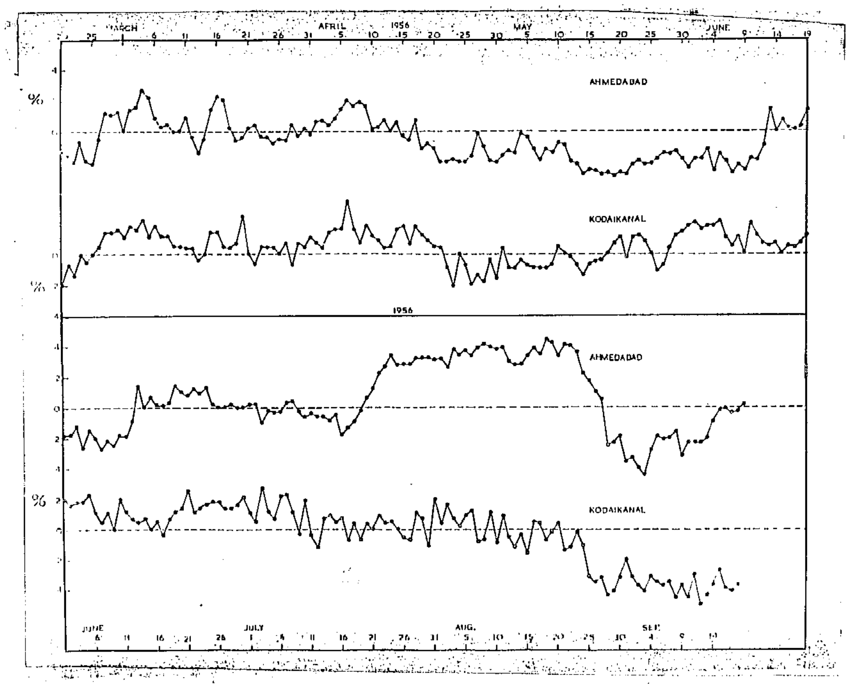


Fig 26.

It will be observed that during certain periods, namely February 20th to May 15th and again 1st August to 9th September the changes of mean intensity at Ahmedabad and Kodaikanal are well correlated. However at other periods, in particular from 15th May to 1st August the variations at the two places are quite dissimilar. As has been explained earlier, normalisation over an extended period of the value of the daily mean intensity at Kodaikanal is rendered difficult by frequent interruptions of the electricity mains supply. Fig.26 indicates that our procedure for normalisation becomes unreliable over considerable periods. In what follows therefore no attempt is made to study the correlated changes of mean intensity and daily variation.

5.1 The daily variation with narrow angle telescopes

Fig.27 shows for data of ^{5}T telescopes the histograms for r_1, ϕ_1, r_2, ϕ_2, r_1/r_2 relating to the daily variation on individual days and for Cp. For comparison, corresponding histograms for $^{22}T_K$ telescopes for the year 1956 as well as for the neutron monitor N_K operated at Kodaikanal during the period December 1956 to September 1957 are also shown in the figure. The 11-month mean daily variation of $^{5}T_K$ can be compared with the 12-month mean daily variation of $^{22}T_K$ centered on June 1956, and with the 10-month mean daily variation of N_K centered at April 1957, neglecting the small change in the daily variation that occurs between June 1956 and April 1957. The following features are note-worthy:

(a) For $^{5}T_K$ telescopes, 29% of the days during 1956 have r_1 the amplitude of the diurnal component on individual days $\geqslant$ 1.6 % which corresponds to the 2 σ limit of significance. During the same period $^{22}T_K$ has no days with $r_1 \geqslant$ 1.6 %. The histogram of r_1 for N_K is very similar to that for $^{22}T_K$, and

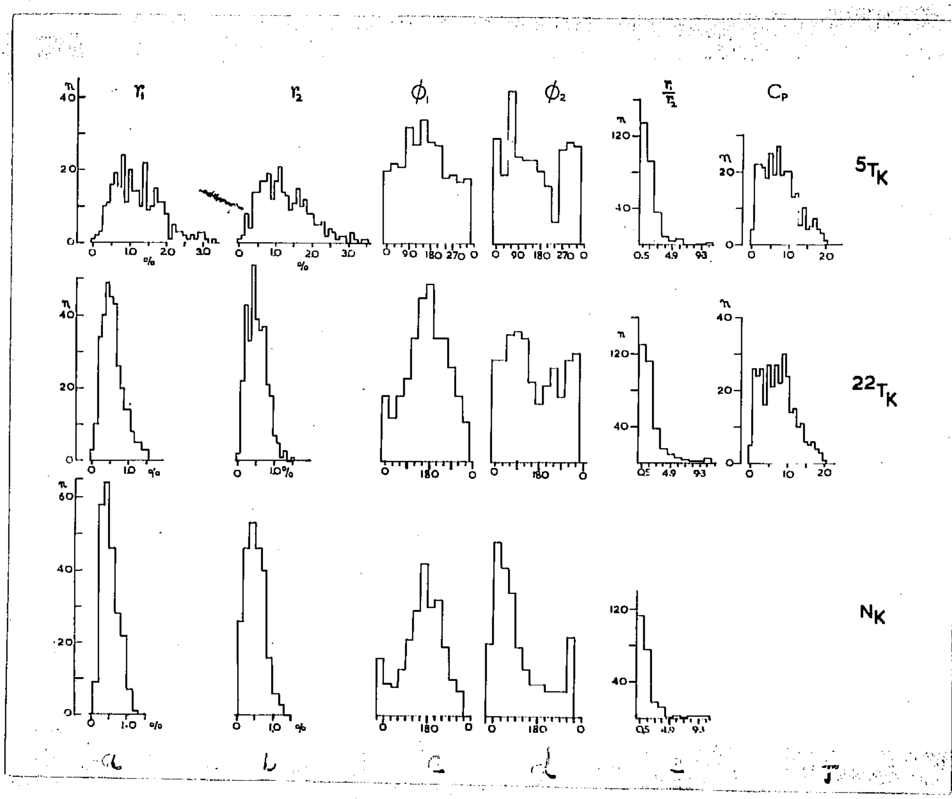


Fig 27.

for the neutron monitor there are no values of $r_1 \geqslant$ 1.6 %. Thus the amplitude of the diurnal component of the daily variation measured by a narrow angle telescope is much larger than the amplitude measured by a telescope with a wider angle or with a neutron monitor.

$^{22}T_K$ and N_K have much higher counting rates than ^5T_K. In consequence, daily variation of smaller amplitude can be measured with significance with them than with $^{5}T_K$. On 44% of days during 1956 $^{22}T_K$ telescopes show $r_1 > 0.6$ % corresponding to a 2 σ level of significance. During 1957 N_K shows on 60% of the days $r_1 > 0.4$ % which corresponds to the 2 σ level of significance.

(b) Large amplitudes of the semi-diurnal component on individual days with $r_2 \geqslant 1.6$ % occur on 32 % of the days for $^{5}T_K$ telescopes. N_K and T_K telescopes have no days with amplitude $r_2 \geqslant 1.6$ %. However, on 40 % of days $^{22}T_K$ telescopes have $r_2 \geqslant 0.6$ % corresponding to the 2 σ limit of significance. N_K shows an amplitude $r_2 \geqslant 0.4$ %, which corresponds to 2 σ limit, on 62 % of days. Thus as is the case for the diurnal component, a semi-diurnal component of larger amplitude can be observed with ^{5}T telescopes than with ^{22}T or N.

(c) For $^{5}T_K$ telescopes the frequency is almost the same for occurrence of days with significant r_1 and of days with significant r_2. Similar is the behaviour of $^{22}T_K$ telescope and N_K. Days with $r_1/r_2 < 1$ occur on 40 % of all days for $^{22}T_K$ telescopes and 48 % of all days for $^{5}T_K$ telescopes and for N_K. Thus the semi-diurnal component is relatively more prominent in the $^{5}T_K$ telescopes and in N_K than in the $^{22}T_K$ telescopes.

(d) The histogram of the time of maximum of the diurnal component of the daily variation measured by $^{5}T_K$ telescopes shows a larger scatter than the histograms of ϕ_1 for $^{22}T_K$ telescopes or for N_K. While the histogram of ϕ_1 for $^{22}T_K$ shows a sharp maximum around noon, that for $^{5}T_K$ shows a broad maximum at 1000 hr. The histogram for ϕ_1 becomes more meaningful, if only those days are considered for which r_1 has an amplitude significant at the 2σ level. In Fig.28, histograms of ϕ_1 for days with $r_1 \geqslant 2\sigma$ are shown for ^5T_K, $^{22}T_K$ and for N_K. It is

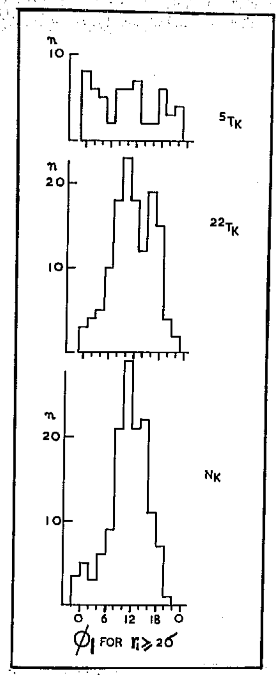


Fig 28

seen that for ^5T_K there is clear indication of the tendency for the diurnal maximum to occur in one of the two preferred periods of the day, approximately at 0100 hr. and 1300 hr. Sarabhai & Nerurkar[131] have pointed out during 1954-55 at Ahmedabad the tendency for the narrow angle telescopes to exhibit the diurnal maximum on a large number of days either at 0300 hr. or at 1100 hr. During 1956, these preferred times of maximum were found by Bhavsar in studies at Ahmedabad to have shifted to later hours namely 0700 hr. and 1500 hr. respectively. The results for the short period for which data is available for Kodaikanal for ^5T_K telescope would indicate that the preferred times of maxima for the same period are shifted to earlier hours at Kodaikanal as compared to those observed at Ahmedabad. However, on this point no conclusions can be drawn in the absence of data for an extended period of time. The tendency for the diurnal maximum to occur at preferred periods of the day is not observable in the histograms of $^{22}T_K$ and N_K, which continue to show a sharp peak around noon.

(e) The histograms of ϕ_2, the semi-diurnal hour of maximum for $^{5}T_K$, $^{22}T_K$ and N_K are similar. All three histograms exhibit one prominent maximum shortly after midnight.

(f) Fig.29 shows the 12-month mean and the 11-month mean daily variation of meson intensity measured by $^{22}T_K$ and $^{5}T_K$ telescopes respectively, and the 10-month mean intensity measured by N_K.

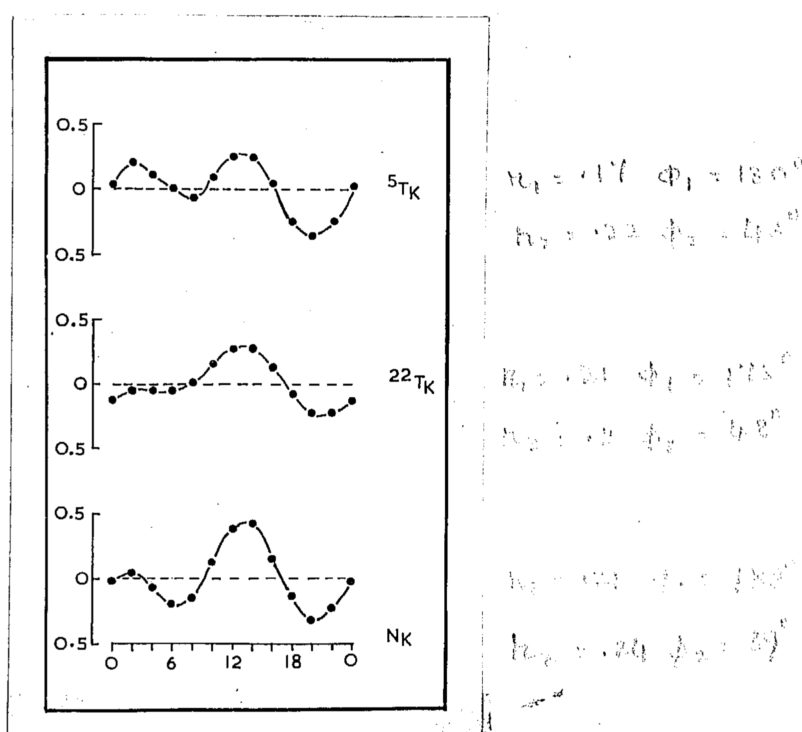


Fig. 29.

It will be observed that the mean daily variations measured by all three instruments have certain common features. These are, a maximum of intensity at 12 and 14 hours, a minimum of intensity at 20 and 22 hours, a second maximum of intensity at 2 hours and a second minimum of intensity at 6 hours. The principal maximum at mid-day and the principal minimum around 20 hours occur almost equally prominently in all three instruments, with perhaps a slightly larger amplitude in N_K as compared to ^5T_K and $^{22}T_K$. The second maximum of intensity at 2 hours occurs prominently in ^5T_K, less so in N_K and bearly shows up in $^{22}T_K$. The second minimum at 6 hours is most prominent in N_K, less so in ^5T_K and barely shows up in $^{22}T_K$. Thus the semi-diurnal component in the mean daily variation is relatively more important in N_K and ^5T_K than in $^{22}T_K$. For N_K and ^5T_K in consequence $\bar{r}_1/\bar{r}_2$ is less than 1, while for $^{22}T_K$ it is greater than 1.

5.2 Types of daily variation observed on individual days with 5T telescopes

By an examination of the form of the daily variation on individual days as measured by 5T telescopes at Ahmedabad, Sarabhai & Bhavsar[134] have suggested that there are three distinct types of variations. They have given an experimental basis for a phenomenological classification of days according to the following criteria :

"(a) 'n' type days are those days on which the daily variation has $r_1 \geqslant 2\sigma$, $r_1/r_2 > 0.75$ and the diurnal maximum occurs between midnight and noon.

(b) 'd' type days are those days on which the daily variation has $r_1 \geqslant 2\sigma$, $r_1/r_2 > 0.75$ and the diurnal maximum occurs between noon and midnight.

(c) 's' type days are those days on which $r_2 \geqslant 2\sigma$ and $r_1/r_2 \leq 0.75$."

As we have noticed earlier, the ϕ_1 histogram for ^5T_K shows preferred times of maxima earlier than at Ahmedabad, and in consequence the criteria for Kodaikanal require a modification. 'd' days at Kodaikanal correspond to ϕ_1 between 6 hr. and 18 hr. and 'n' days to ϕ_1 between 18 hr. and 6 hr. In Fig.30 are shown

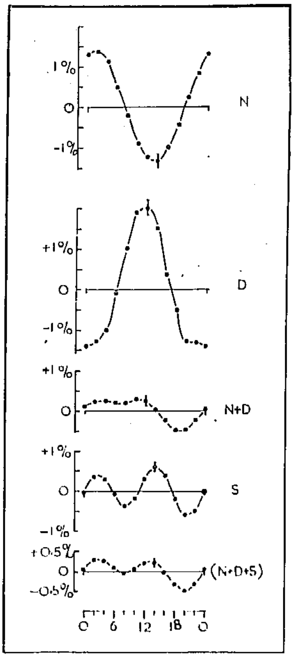


Fig 30

the mean daily variations for 'd', 'n' and 's' type days. The characteristics of the diurnal and the semi-diurnal components are given in Table 14. The daily variation for (n+d) days which correspond to $r_1 \geqslant 2\sigma$ and $r_1/r_2 > 0.75$, as well as the daily variation for (n+d+s) days are shown in the figure. A comparison of the mean daily variation for 's' days and (n+d) days illustrates the change of form of the mean daily variation on days for which $r_1/r_2 < 0.75$ with r_2 significant and on days for which $r_1/r_2 > 0.75$ with r_1 significant. It will be noticed that during 1956 on 's' type days ϕ_1 occurs about 4 hours later than on (d+n) days.

Sarabhai & Bhavsar[134] have demonstrated a physical basis for their classification of 'n' and 'd' type days by showing that

(1) On days on which the narrow angle telescopes $5T_A$ have, 'n' or 'd' type characteristics, the wider angle telescopes $22T_A$ have similar characteristics, thus indicating that the effect is not an instrumental one and,

(2) The 'd' and 'n' type days are associated with correlated changes of mean cosmic ray intensity and of Cp.

We can apply similar considerations to elucidate the physical basis of characterisation of data from $5T_K$ telescopes. If the occurrence of 'd', 'n' and 's' type daily variations is related to the state of anisotropy of primary cosmic radiation, we should observe correlated changes of daily variations not

Table 14

Characteristics of the diurnal and semidiurnal components for 'n' type, 'd' type, 's' type days and (n + d) and (n + d + s) days determined by 5_{T_K}, 22_{T_K}, 5_{T_A} & 22_{T_A}.

Tel.	'n'					'd'					(n + d)					's'					(n + d + s)				
	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n
5_{T_K}	1.40	20°	0.05	56°	32	1.70	174°	0.30	-21°	25	0.35	105°	0.16	26°	57	0.16	163°	0.49	74°	51	0.23	114°	0.24	60°	108
22_{T_K}	0.21	152°	0.05	49°	31	0.34	167°	0.15	107°	24	0.23	154°	0.08	π	55	0.22	173°	0.22	35°	49	0.23	165°	0.13	51°	104
5_{T_A}	0.23	162°	0.16	44°	30	0.28	131°	0.13	$\pi+48^\circ$	23	0.24	147°	0.04	38°	53	0.26	$\pi+5^\circ$	0.21	40°	48	0.24	166°	0.10	35°	101
22_{T_A}	0.25	154°	0.06	-19°	23	0.29	142°	0.04	π	19	0.26	148°	0.02	-42°	42	0.23	158°	0.14	32°	41	0.25	153°	0.07	26°	83

only for similar instruments at the same station but also for instruments at different stations operated simultaneously.

During 283 days for which $^{5}T_K$ was in operation at Kodaikanal, we have 25 'd' type days ($r_1 \geqslant 2\sigma$, $r_1/r_2 > 0.75$ and ϕ_1 between 6 hr. and 18 hr.), 32 'n' type days ($r_1 \geqslant 2\sigma$, $r_1/r_2 > 0.75$ and ϕ_1 between 18 hr. and 6 hr.) and 51 's' type days ($r_2 \geqslant 2\sigma$, $r_1/r_2 < 0.75$). The average characteristics of the daily variations on these days and on (n+d) days have been given in Table 14 for $^{5}T_K$. For comparison, characteristics for $^{22}T_K$, $^{5}T_A$ and $^{22}T_A$ on the same days are also given in the Table 14.

It will be observed that 'd' and 'n' type days of $^{5}T_K$ are not associated with daily variations in $^{22}T_K$, $^{5}T_A$ and $^{22}T_A$, which significantly differ for 'd' and 'n' groups in relation to ϕ_1 in the way as they do for $^{5}T_K$. On the other hand 's' type days of $^{5}T_K$ correspond to days of significant semi-diurnal components in $^{22}T_K$, $^{5}T_A$ and $^{22}T_A$. As compared to these, the (d+n) days of $^{5}T_K$ correspond to days in $^{22}T_K$, $^{5}T_A$ and $^{22}T_A$ which have a negligible semi-diurnal component and a more predominent diurnal component than 's' type days. Moreover, the narrow angle telescopes $^{5}T_K$ and $^{5}T_A$ at Kodaikanal and at Ahmedabad respectively have a further common characteristic in that the ϕ_1 for (n+d) days is about 3 to 4 hours earlier than for 's' type days. Thus we can conclude that the 'd' and 'n' characterisation for $^{5}T_K$ data at Kodaikanal on the basis of the value of ϕ_1 on days on which r_1 is significant is by itself not physically meaningful. However for ^5T_K the ratio r_1/r_2 being < 0.75 or ≥ 0.75 is of real interest.

From a recent detailed study of the types of daily variations observed with a neutron monitor, Satya Prakash has come to the conclusion that at Kodaikanal, during 1956-57, merely the ratio r_1/r_2 or the time of maximum ϕ_1 of the diurnal component of the daily variation at Kodaikanal is not enough to pick out days exhibiting different types of anisotropies. Fig.31 taken from Sarabhai & Satya Prakash shows the daily

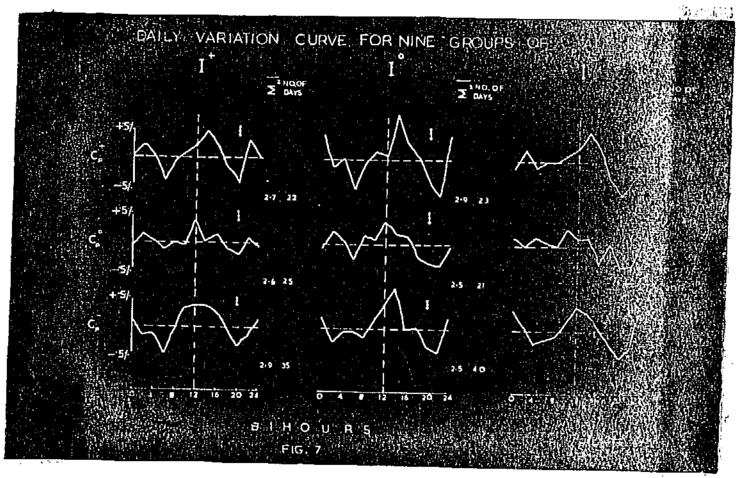


Fig 31.

variation of N_K associated with positive, negative and normal deviations of daily mean intensity and with high, low and medium Cp. It will be observed that the daily variation shows sharp changes of intensity at certain hours. Days of positive deviations of daily mean intensity, associated by Bhavsar[134] at Ahmedabad with 'd' days, have in N_K a large negative deviation of bihourly intensity at 6 hours. Days of negative deviations of daily mean intensity, associated by Bhavsar at Ahmedabad with 'n' type days, have in N_K a large negative bihourly deviation at 22 hours. According to Sarabhai & Satya Prakash[166], the characteristics of the diurnal and semi-diurnal components of the daily variation at Kodaikanal can be used during 1956 to separate 'd' and 'n' type of days, which are associated with correlated changes of mean intensity in the manner observed by Sarabhai & Bhavsar, only for high Cp days. For Cp $\geqslant$ 1, days of positive deviations of mean daily intensity, corresponding to Bhavsar's 'd' days have at Kodaikanal an $r_1/r_2 < 1$ and ϕ_1 later than the ϕ_1 of days with negative deviations of daily mean intensity which have $r_1/r_2 > 1$ and correspond to Bhavsar's 'n' type days. Table 15 shows the characteristics of the mean daily variation of ^5T_K and of $^{22}T_K$ telescopes during 1956 on groups of days sorted according to the following criteria :

Group I has days on which Cp $\geqslant$ 1.0, $r_1/r_2 > 1$,

Group II has days on which Cp $\geqslant$ 1.0, $r_1/r_2 < 1$.

In the table are shown separately the characteristics for each group not only for all days on which data for daily variation is available but also for those days on which both components of the daily variation have an amplitude greater than σ. The latter condition makes the interpretation of the ratio r_1/r_2 more meaningful. For comparison the characteristics of the daily variation observed with a neutron monitor during 1956-57 are also shown.

Table 15

Table showing mean daily variation of 5_{TK}, 22_{TK}, and N_K during 1956 on groups of days sorted according to values of C_p

Telescope	$\{C_p \geq 1,\ r_1/r_2 > 1\}$ $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	$\bar{r}_1/\bar{r}_2$	n	$\{C_p \geq 1,\ r_1/r_2 < 1\}$ $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	$\bar{r}_1/\bar{r}_2$	n
5_{TK}	0.47	112°	0.19	10°	2.5	35	0.17	170°	0.42	4°	0.4	29
5_{TK}*	0.40	109°	0.37	20°	1.1	23	0.44	π+3°	0.56	31°	0.8	16
22_{TK}	0.41	161°	0.09	107°	4.6	57	0.11	π+32°	0.11	-82°	1.0	42
22_{TK}*	0.49	153°	0.11	95°	4.5	36	0.20	π+24°	0.19	-35°	1.2	28
N_K	0.37	178°	0.22	48°	1.6	32	0.10	π+12°	0.34	41°	0.3	38

* includes significant days only.

Table 16

Table showing the characteristics of the daily variation for the groups G_1 & G_2. (page 149).

Telescope	Year	$\{C_p \geqslant 1,\ r_1/r_2 > 1\}$ $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n	$\{C_p \geqslant 1,\ r_1/r_2 < 1\}$ $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	n
5_{TK}	1956	0.47	112°	0.19	10°	35	0.17	170°	0.42	4°	29
22_{TK}	1956	0.41	161°	0.09	107°	57	0.11	132°	0.11	-82°	42
22_{TK}	1955	0.46	107°	0.12	- 4°	37	0.18	129°	0.16	70°	21
22_{TK}	1954	0.47	62°	0.10	-43°	27	0.24	7°	0.13	70°	9

It will be observed that for Group I with $r_1/r_2 \geqslant 1$, the diurnal component of the daily variation in each case has a time of maximum which is from 4 to 6 hours earlier than the time of maximum of the diurnal component for Group II. Moreover $22T_K$ and N_K have for both groups a diurnal variation with a time of maximum ϕ_1 which is later than the time of maximum for $5T_K$ telescopes by about 2 to 3 hours. Thus during 1956 at Kodaikanal, the criterion suggested by Sarabhai & Satya Prakash[166] for differentiation between the daily variation of two types is valid for narrow and wide angle telescopes in addition to a neutron monitor.

It is interesting to apply this criterion to data for $22T_K$ telescopes for the years 1954 and 1955 and to compare with the results for the year 1956. Table 16 shows the characteristics of the daily variation for the two groups. The following are the noteworthy features which emerge from the comparison from year to year.

(1) $\bar{r}_1$ in Group I does not alter significantly from 1954 to 1956. This is in distinction to $\bar{r}_1$ for Group II which gets reduced by almost 50 % from 1954 to 1956.

(2) ϕ_1 shifts to later hours for both groups from 1954 to 1956. But, while the change is by about 6 hours in Group I, it is by almost 12 hours in Group II. Thus though ϕ_1 for Group I is earlier than the ϕ_1 for Group II by almost 4 hours in 1956, the relationship is reverse in 1954 where ϕ_1 for Group I is later than that for Group II by about 4 hours.

(3) The semi-diurnal component for the two groups does not change significantly in amplitude from year to year. However ϕ_2 is not constant from year to year for either group.

(4) The number of days corresponding to Group I and II alter radically from year to year. It is ofcourse to be expected with increasing solar activity that the total of days in both groups, which corresponds to Cp $\geq$ 1, should increase markedly from 1954 to 1956. However, the interesting aspect of the present analysis is that the ratio of days of Group I and Group II which is 3 in 1954 changes to 1.4 in 1956.

The foregoing analysis demonstrates that since the nature of the daily variation is not the same when measured with different types of instruments, with the same type of instrument at different places and at different periods of time, there is difficulty in fixing general criteria for characterisation of anisotropy based only on the characteristics of the diurnal and the semi-diurnal components of the daily variation.

CHAPTER VI

DISCUSSION

Some of the principal questions related to the daily variation of cosmic ray intensity, to which we should like to have answers, can be stated as follows :

(1) Do differences observed in the daily variation represent different states of the primary anisotropy of the cosmic radiation? If they do, what are the solar and terrestrial relationships of these states?

(2) Is the long term change of the 12-month mean daily variation due to a continuous gradual change of the anisotropy or is it due to an alteration of the frequency of occurrence from year to year of anisotropy of two or three definite types?

(3) If there are different types of daily variation corresponding to the different states of the anisotropy, how can we experimentally identify the states from cosmic ray daily variation data?

The investigation made by the author at Kodaikanal, the results of which have been described in earlier chapters, was with the object of throwing some light on these questions. The conclusions from the investigations are now discussed in terms of contemporary studies made elsewhere and views expressed by other workers concerning the same questions.

6.1 The worldwide characteristics of long term changes of 12-month mean daily variation

The majority of studies of the changes of the 12-month mean daily variation relate exclusively to the changes of the diurnal component of the daily variation. In the first chapter, mention has been made of the work of Sarabhai et al[115], of Elliot & Thambyahpillai[116] and others which demonstrated the worldwide character of changes of the time of maximum $\overline{M}_{\phi}^{D}$ of the diurnal component, and during some periods of the solar cycle, of the amplitude $\overline{M}^{D}$ of the diurnal component. In spite of the clear evidence presented by Sarabhai et al[38] of the importance of the semi-diurnal component and of the relationship of the unresolved daily variation with changes of anisotropy, the worldwide character of the changes of the semi-diurnal component have not so far been generally recognised by workers in the field. For instance, in a recent publication Venkatesan & Dattner[122] have concluded as follows :-

"(1) There are essential significant differences in the long term changes of the diurnal and semi-diurnal components of the daily variation. The changes in the diurnal variation are worldwide and are positively correlated at the various stations. The changes in the semi-diurnal variation although observed at various stations, nevertheless do not reveal any common features. The semi-diurnal component at the various stations needs greater consideration in view of the striking dissimilarity amongst the stations and no general conclusions can be drawn about the semi-diurnal component at present. The differences in the changes of the diurnal and semi-diurnal components of the daily variation suggest that it is appropriate to consider the two independently although it is necessary to consider both in order to understand the daily variation completely.

(2) It is possible to determine the direction of the anisotropy uniquely from a study of the diurnal variation corrected for geomagnetic deflection at different stations. The anisotropy tends to earlier hours during years of minimum solar activity........-."

The main reason for reaching the conclusions quoted above appears to be the dissimilarity of the diagrams obtained by putting end to end for successive periods, the semi-diurnal vectors of the daily variation observed at Huancayo, Christchurch, Cheltenham and Tokyo. This representation corresponding to the daily variation at two different stations is visually dissimilar on account of inherent differences in the nature of the daily variation at different stations and with apparatus of different types. Thus comparison of worldwide changes of the daily variation from an examination of these diagrams for different stations is not an easy task. Even so we show in Fig.32 the time series for the diurnal and semi-diurnal vectors for Huancayo, Cheltenham and Kodaikanal arranged end to end for the period 1952 to 1955.

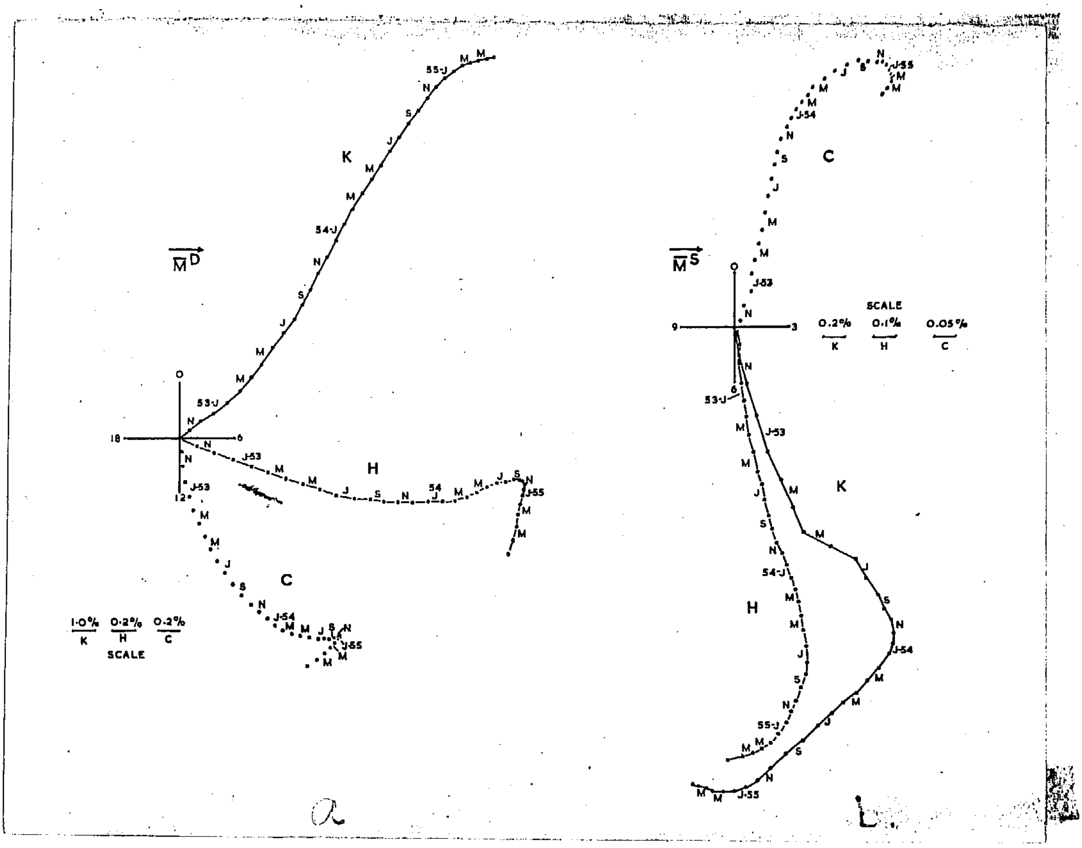


Fig 32

It will be observed that there is intrinsic difference in amplitude and the time of maximum of the diurnal and the semi-diurnal components measured with omnidirectional ion chambers at Huancayo and Cheltenham, and with a directional telescope at Kodaikanal. For the diurnal component, the diagrams are similar for Huancayo and Cheltenham in respect of a sharp change which is observed for the 12-month period centered at January 1955. At Kodaikanal, there is a more gradual change at the same point. For the semi-diurnal component the similarity between Huancayo and Kodaikanal is very striking indeed. Cheltenham like the other two stations also shows a curling over of the diagram starting with January 1954. It has been pointed out by Sarabhai et al[38] that the semi-diurnal variation and changes in it are best observed at an equatorial station such as Huancayo or Kodaikanal, since the semi-diurnal component is not prominent for stations in middle latitudes such as Cheltenham or Christchurch. Venkatesan & Dattner's[122] conclusion is in error because the comparison made by these authors does not relate to two stations at low latitudes where the semi-diurnal component can be studied unambiguously.

The details of the changes occurring in both components of the daily variation and in the daily variation as a whole at Huancayo and Kodaikanal have been discussed in Chapter IV. It is quite clear that changes of both components individually and of the unresolved daily variation have striking worldwide characteristics. The changes are related to the cycle of solar activity and exhibit a periodicity of eleven years as well as 22 years.

We can conclude therefore that for a study of the changes of the anisotropy the examination of only the diurnal component of the daily variation is inadequate. One has to take cognisance of important changes in the semi-diurnal component, particularly for stations in low latitudes. In making use of both the diurnal and semi-diurnal components it is convenient to examine the daily variation produced by the superposition of the two. Directional telescopes permit changes in daily variation to be studied more effectively than omni-directional instruments. Studies at equatorial stations reveal worldwide characteristics of the changes and permit their interpretation in relation to anisotropy of primary cosmic rays, more unambiguously than observations at middle and high latitudes.

6.2 The mechanism of long term change of the daily variation

A detailed comparison of characteristics of the harmonic components of the 12-month mean daily variation with corresponding characteristics of the daily variation on individual days during 1954, 1955 and 1956 has been made in Chapter IV. It reveals that the changes of the harmonic components are of a continuous and progressive nature. For instance, the shift of $\overline{M}_{\phi}^{D}$ by 9 hours between June 1953 to June 1956 occurs progressively between the two epochs and is associated with a total shift of the histograms of ϕ_1 on individual days. With wide angle telescopes we have no evidence during any of the three years for a preferred occurrence of the time of diurnal maximum at more than one epoch during the day. There are however significant aspects which indicate that the mechanism of change is more complex than what would appear at first sight. These may be summarised as follows :

(a) From an examination of the difference between the

12-month mean daily variation from one year to another, it is fairly clear that the changes take place in respect of a maximum shortly after midnight and a maximum near noon. Sarabhai et al's[38] conclusions from a study of the ion chamber data of Huancayo from 1937 to 1952 are therefore confirmed in the later observations at Huancayo and in the data from Kodaikanal for the period 1952 to 1956.

(b) The distribution of the time of maximum ϕ_1 of the diurnal component on individual days which has quite a sharp peak for the bihours 2 and 4 during 1954, becomes gradually broader during 1955 and 1956 with a shift of the peak to later hours. The 12-month mean diurnal amplitude in consequence gets reduced between 1954 and 1956 to a much greater extent than the reduction of the amplitude on individual days.

(c) If attention is confined to the year to year change of the mean amplitude of the diurnal component on groups of days for which the time of maximum of the diurnal component on individual days lies between 0°-90°, 90°-180°, 180°-270° and 270°-360°, it is seen that conditions are different for the four groups. The largest decrease of amplitude $\bar{r}_1$ for 1954 to 1956 is for the group for which ϕ_1 corresponds to a time of maximum shortly after midnight. Almost negligible change of amplitude $\bar{r}_1$ occurs between 1954 to 1956 for the group corresponding to a time of maximum of the diurnal component shortly after noon.

(d) For all three years r_1/r_2 exhibits certain constant features. r_1/r_2 is large for the group for which the time of maximum of the diurnal component is in the early morning and it is small for the group for which the time of maximum of the diurnal component is in the afternoon. The semi-diurnal component is therefore more prominent in the daily variation which has a diurnal component with a maximum in the afternoon than when the maximum is in the early morning.

During 1954-56 the major changes in the daily variation may be looked upon as due to the diminution of amplitude of the diurnal component on individual days with a maximum shortly after midnight, accompanied by a rapid decrease of the frequency of occurrence of such days. There is a corresponding increase during 1954-56 of the frequency of occurrence of days with a diurnal maximum in the afternoon, but the amplitude of the variation remains almost unchanged. In addition to this major change of the 12-month mean daily variation from year to year, there is evidence for a change of form of the daily variation which is correlated with the changes in daily mean intensity. This change occurs with a shift of the time of maximum of the diurnal component by about four hours, and is most prominent on days with high geomagnetic disturbances.

6.3 <u>Identification of types of daily variations with different states of anisotropy of the primary cosmic radiation</u>

The study made at Kodaikanal demonstrates clearly that some of the most interesting and significant aspects of the changes in the 12-month mean daily variation can be identified only by an examination of the daily variation as a whole. These changes occur in a physically meaningful manner and are consistent with a hypothesis proposed by Sarabhai et al[38] that they are due to two states of the anisotropy which are related to the occurrence of a diurnal component with a maximum either in the early morning, or near noon. They have suggested that the changes of the 12-month mean daily variation are primarily due to changes from year to year of frequency of occurrence of days with the two types of anisotropy. While they observed a third type of daily variation which was mainly semi-diurnal in character, they did not link it with either of the first two types.

The present investigation at Kodaikanal with wide angle telescopes, can unfortunately neither confirm nor refute the mechanism of long term change of 12-month mean daily variation postulated above. It suggests however that distinction may exist between only two major types of daily variations, instead of three. The presence of a significant semi-diurnal component on a large number of days at an equatorial mountain station, and its association with days which were designated as "day maximum" and "night maximum" types indicates that a significant semi-diurnal component is involved in both types, particularly the former. If this is so, both types of anisotropies produce at equatorial stations daily variations with two maxima, one in the early morning and the other near noon. The two daily variations differ from each other in the relative magnitudes of the two maxima. The unambiguous identification of these two states using only the characteristics of the harmonic components of the daily variation is not always possible. It has been explained in Chapter V that the identifications is possible under certain conditions. These conditions depend not only on the type of instrument employed but also on the place and period of observation.

6.4 Conclusion

A great deal of further study is required, particularly with directional instruments operated continuously at equatorial stations in order to understand more precisely than hitherto, the relationship of the nature of the daily variation and the different states of the anisotropy of primary cosmic rays. While there are numerous investigations of the relationship of the daily variation with geomagnetic disturbances and changes of intensity occurring with them, the general problem of correlated changes of daily mean intensity and of daily variation at an equatorial station has so far been studied only by Satya Prakash with a neutron monitor at Kodaikanal. An extension of this work and similar study with directional telescopes measuring meson intensity would permit an understanding of the energy dependence of the primary cosmic radiation. Theoretical studies dealing with the interpretation of the daily variation tend strongly towards the view that beams of ionized matter from the sun carrying trapped magnetic fields within them are responsible for some of the variations of cosmic ray intensity as well as the anisotropy of the radiation. In this context the solar and terrestrial relationships of cosmic ray variations and in particular the relationship with geomagnetic disturbances and solar activity in the corona are of great importance. Cosmic Rays have provided the first terrestrially observed effect of the 22-year cycle of the polarity of the magnetic field of sunspots. This is demonstrative of the important role which studies of time variations of cosmic rays can play in the physics of the sun and of the interplanetary space.

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FIGURES

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