Dissertation on

The Study of Time Variation of Cosmic Rays with narrow and wide angle telescopes at Ahmedabad

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by

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SUMMARY

A study of the time variation of meson intensity was made by the author at Ahmedabad ($\lambda = 13.0^{0}$, sea level) with narrow angle telescopes during the period January 1957 to May 1958, and with a wide angle telescope during the period October 1956 to May 1958. The main conclusions of the investigation are presented below.

1. The amplitude of the mean daily variation as well as the daily variation on individual days during the period 1957 and 1958, observed with telescopes of narrow and wide angles of opening in the E-W plane, are not significantly different. During 1954 - 1955, when solar activity was minimum, the situation was different. At low latitudes, telescopes with a narrow angle opening in the E-W plane recorded a daily variation with an amplitude (0.5 to 1.0 %) which was significantly larger than what was observed with wide angle telescopes. Thus the comparative response of narrow and wide angle telescopes, related to the profile of the anisotropy, is different at different periods of time.

2. Telescopes having different zenithangles in the E-W plane do not reveal any difference in the amplitudes of the diurnal and the semidiurnal components of the daily variation during the period 1957 and 1958. However,

the time of maximum of the diurnal variation is found to be later by about 2 hours in wide angle telescopes as compared to narrow angle telescopes. The difference in the time of maximum of the diurnal variation is found to be independent of the level of geomagnetic disturbance. It is shown that this difference cannot arise from a difference in the applicable barometric co-efficient. Nor has it been possible to explain the difference on the basis of the differential geomagnetic bending of the particles coming along different zenith angles in the N-S plane. The result may be due to the effect on the anisotropy of cosmic rays, of beams emitted from the sun in directions inclined to the plane of ecliptic.

3. The long term changes of the daily variation as seen in terms of the form of the daily variation as well as the time of maximum and the amplitude of the diurnal and the semidiurnal component of the daily variation of cosmic ray intensity, measured with both narrow and wide angle telescopes, during the years 1954 to 1958, are presented. The results relating to individual days as well as to the average daily variation are separately examined.

The form of the 12 month mean daily variation measured by a wide angle telescope which exhibits two peaks in 1954-1955, one in the early morning and the other near noon, changes into a curve having a single peak near noon by 1957 - 1958.

The amplitude of the 12 month mean daily variation as well as the daily variation on individual days recorded by a narrow angle telescope show a large decrease from 1954 to 1958 whereas the corresponding amplitudes measured by a wide angle telescope do not reveal any significant difference during the same period. From the changes observed in a narrow angle telescope the author is led to believe that the power of the source has decreased with increase in solar activity. This result would be consistent with the weakening of the polarization of beam of solar plasma with trapped magnetic fields, as the conductivity of the interplanetary space increases with increased solar activity. More experimental confirmation concerning the eleven year change of power of the source of an anisotropy, observed at low latitudes, is required for a confirmation of the interpretation. This is particularly so in the light of conflicting view held by other workers.

4. An examination of the form of the average daily variation on days of low, medium and high geomagnetic disturbance during the years 1954 - 1958 reveals that the early morning maximum, observed during 1954 - 1955, is a feature exclusively associated with days of low and medium geomagnetic disturbance. The days of high geomagnetic disturbance at all times are associated with a noon maximum.

The long term changes of the diurnal time of maximum on groups of days of low, medium and high C_p show that the year to year change is most prominent on low C_p days.

5. A comparison of the changes of the daily mean intensity recorded by a wide angle and narrow angle telescope during cosmic ray storms shows that they are similar during the period 1957 and 1958.

The conclusions are discussed in chapter V of the thesis and a list of references consulted by the author is included at the end of the thesis.

H. Razdan

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C O N T E N T S

CHAPTER I

INTRODUCTION

Some of the most important questions in the field of cosmic ray research are: From where do they come and how have they achieved their enormous energy which is known to extend upwards to as high as 10^{20} ev.

The subject of time variations of cosmic rays has grown in importance with a realization that it will give some clue to the origin of these rays, and of the electromagnetic fields in interplanetary and interstellar space. The close relationship of many of these variations with events occurring on the sun lend to an understanding of solar physics.

The majority of experimental results dealing with the time variations of cosmic rays relate to studies performed on the surface of the earth after the primary cosmic rays have suffered deflection in the geomagnetic field and interacted with matter in the atmosphere. It is, therefore, necessary to make allowance for terrestrial effects before one can interpret the variations in terms of the primary component of the radiation.

Elliot[1], Simpson[2], Sarabhai and Berthier[3], Rose[4] and Singer[5] have reviewed the progress made in time variation studies during its various stages of development. Forman[6] has

treated this subject in great detail in his book "The Variation of Cosmic Rays".

This thesis deals mainly with the comparative study of long and short term variations of hard muons measured with narrow-angle and wide-angle telescopes. The experiments extend from 1964 to 1968 and thus cover a period from sun-spot minimum to sun-spot maximum. In this chapter a survey is made of work relevant to the present investigation.

1. Geomagnetic effects on cosmic rays.

The trajectories of charged particles in the earth's dipole field was first studied by Stormer[7] in an attempt to explain Aurora. His results showed that, at a given geomagnetic latitude, certain directions become inaccessible for charged particles having momentum less than a certain minimum value P^{min}.

The extension of Stormer theory to the cosmic ray physics was made by Lemaitre and Vallarta[8] by applying Liouville's theorm to the assumed isotropic distribution of those rays. By taking into account the earth's shadow effect, they showed that there are directions excluded for certain particles that the simple Stormer theory allows to enter. These results have been summarised by Janossy[9], Johnson[10], Montgomery[11] and Alfvén[12].

In the interpretation of rapid variations such as solar flare effects, where initially the radiation is not isotropic, it is necessary to calculate the individual particle orbits. Schlüter[13], Firor[14], Jory[15], Lust[16], Gall and Lifshitz[17] have approached this problem by combining numerical calculation

for primary energies extending up to 10 Bev for protons and, therefore, to the observing stations in the middle latitudes. Brunberg and Dattner[19], by a spiral terrella experiment, have conducted a comprehensive investigation covering all primary energies greater than 2 Bev for protons and for observing stations situated at different latitudes from equator to the poles. With a well collimated beam of electrons of known variable velocity emitted from a miniature gun mounted on a magnetical model of the earth, they have, at each latitude, determined the asymptotic co-ordinates of the velocity vector of particles of known rigidity which can arrive at specified angles with respect to zenith in the N-S and E-W planes at the observing station. The values of those co-ordinates can be read out from graphs published by these authors covering each 10^{0} of latitude. Brunberg and Dattner's study now forms a most valuable and essential basis for the interpretation of work not dealing with isotropic radiation.

Recent evidences (Rao et al[10], Kodama and Miyazaki[20], Rothwell and Quenby[21], Storm[22], Simpson[23], McDonald[24]) have shown that cut off momenta as predicted by the Stormer theory and the corresponding values derived from intensities of cosmic rays at various latitudes and longitudes are often not in good agreement even when the earth's field is represented by a more appropriate eccentric dipole. Simpson et al[25] have ascribed this to the distortion of the earth's outer magnetic field by highly ionized interplanetary matter. On the other hand, Rothwell and Quenby[21] attribute these to the regional anomalies in the earth's field. Recently Kelley and Schwirtz[26] have theoretically

calculated cut-off rigidities using an approximation to earth's field which includes all moments up to octupole moment and find that results agree fairly well with the observed cosmic ray intensity at various places; thus, ascribing the previous discrepancies to the neglect of higher moments of the real geomagnetic field.

2. Methods of relating secular variations to those of primaries.

Cosmic ray particles incident at the top of the atmosphere undergo complicated interactions before they reach a detector in the lower atmosphere. An observed variation in the secondary component, therefore, has to be connected to the primary variation spectrum through a function named 'yield function' or a 'generating function' or 'multiplicity function' by various authors (Ehlmann[27], Fonger[28], Nagashima[29], Simpson et al[30], Obert[31] and Berman[32]). Basically all authors have made use of the experimental data on latitude effect. The advantage of such a procedure lies in the fact that no assumption need be made regarding the nature of the complicated processes involved in the transformation of primaries into secondaries. At the same time a limitation of this method lies in the fact that it applies to only field sensitive primaries. For higher energies extrapolations have to be made which introduces an element of unreliability.

Following Berman, the total vertical intensity $I^i_{\lambda,f}(h_o)$ of the i^{th} component (Meson, neutron, soft component etc.) observed at latitude λ, longitude f, and at pressure

level h_0 is given by

$$N^{i}_{\lambda,\xi}(h_0) = \int_{E^{min}_{\lambda,\xi}}^{\infty} D(E)\, m^{i}(E, h_0)\, dE \qquad \ldots (1)$$

where $D(E)$ is the energy spectrum of primaries and $m^{i}(E,h_0)$ the multiplicity function, which represents the number of i type particles produced by a single primary particle of energy E at the pressure level h_0 in the atmosphere. $E^{min}_{\lambda,\xi}$ is the geomagnetic cut-off at the observing station.

By varying equation (1) with respect to all parameters, we get the cumulative variation of the observed intensity.

$$\frac{\delta N^{i}_{\lambda,\xi}(h_0)}{N^{i}_{\lambda,\xi}(h_0)} = \delta E^{min}_{\lambda,\xi} \cdot W^{i}_{\lambda,\xi}(E^{min}_{\lambda,\xi}, h_0) + \int_{E^{min}_{\lambda,\xi}}^{\infty} \frac{\delta D(E)}{D(E)} \cdot W^{i}_{\lambda,\xi}(E, h_0)\, dE + \int_{E^{min}_{\lambda,\xi}}^{\infty} \frac{\delta m^{i}(E,h_0)}{m^{i}(E,h_0)} \cdot W^{i}_{\lambda,\xi}(E, h_0)\, dE \qquad \ldots (2)$$

where $W^{i}_{\lambda,\xi}(E, h_0) = \dfrac{D(E)\, m^{i}(E, h_0)}{N^{i}_{\lambda,\xi}(h_0)}$ $\ldots (3)$

The function $W^{i}_{\lambda,\xi}(E, h_0)$ has been named "Coupling co-efficient" by Dorman. It gives an idea of the magnitude of the secondary variation for a particular amount of variation in the primary spectrum.

The first term in equation (3) is the contribution due to the variation in geomagnetic cut-off energy $E^{min}_{\lambda,r}$ of primary particles which, to a first approximation may be neglected. The third term represents the variations due to the variation of 'multiplicity' which, in essence, represents the meteorological effects on the measured secondary. If the data is corrected for such effects, the third term in equation (3) may be neglected. Finally, we are left with the equation

$$\frac{\delta I^{i}_{\lambda,r}(h_0)}{I^{i}_{\lambda,r}(h_0)} = \int_{E^{min}_{\lambda,r}}^{\infty} \frac{\delta D(E)}{D(E)} \cdot W^{i}_{\lambda,r}(E, h_0)\, dE \quad \ldots(3)$$

Equation (3), therefore, represents the variation in the observed intensity of cosmic rays due to variation of primary flux beyond the limits of atmosphere. The relative variation of primary flux $\frac{\delta D(E)}{D(E)}$ may be called the energy spectrum of variations of cosmic rays, or, in short, the primary variations of cosmic rays.

It is clear that with the help of function $W^{i}_{\lambda,r}(E, h_0)$ we can determine the observed variation of type i component from a known value of $\frac{\delta D(E)}{D(E)}$; or, conversely, from the observation data of various secondary variations, having substantially different coupling co-efficients, primary variation of cosmic rays ($\frac{\delta D(E)}{D(E)}$) can be determined. Thus the coupling co-efficients $W^{i}_{\lambda,r}(E, h_0)$ realizes the connection between the primary and the secondary variations of cosmic rays.

2.1. Determination of coupling coefficients from the geomagnetic effects.

By differentiating equation (1) with respect to lower limits of integration we get:

$$\frac{\partial N^{d}_{\lambda,r}(h_0)}{\partial E^{min}_{\lambda,r}} = -D(E^{min}_{\lambda}, z)\, N^{d}(E^{min}_{\lambda,r}, h_0)$$

and substituting the resultant expression in equation (8a), we get:

$$W_{\lambda,r}(E^{min}_{\lambda,r}, h_0) = -\frac{1}{N^{d}_{\lambda,r}(h_0)} \frac{\partial N^{d}_{\lambda,r}(h_0)}{\partial E^{min}_{\lambda,r}} \quad \ldots (9)$$

The right hand side of equation (9) expresses essentially the geomagnetic effect at the given point for the i^{th} component and, thus, coupling co-efficient can be obtained from the results of empirical data on the geomagnetic effects.

Yerman has presented his results in a graphical form from which coupling co-efficients can be read out for total ionizing component, hard component, and neutron intensity at sea level, and total ionizing intensity at 4300 meters altitude for latitudes 0^0, 30^0 and 50^0. For $\lambda = 0^0$ the curves are reproduced in Fig. 1. Direct values have been obtained upto 35 Bev. Beyond that curves have been extrapolated.

In view of the recent proposed changes of cosmic ray geomagnetic co-ordinates, Webber and Quenby [33] have made more accurate calculations of 'Pfotzer's yield functions' taking into

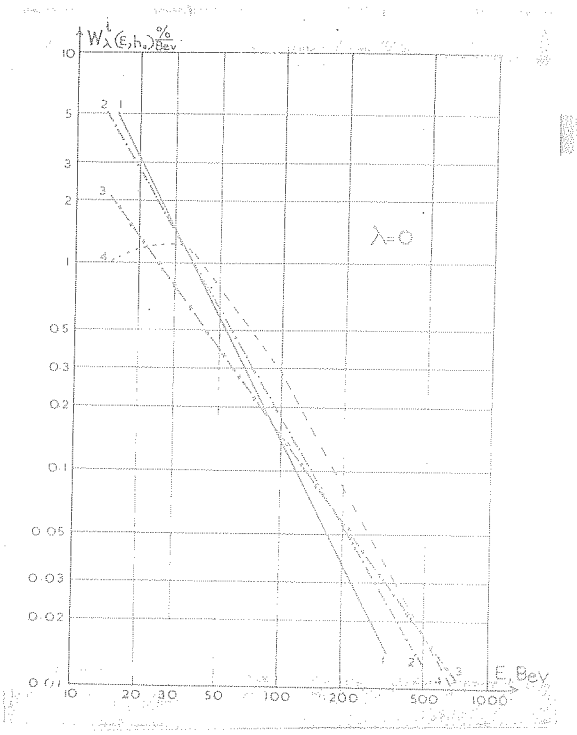

Fig.1 - Coupling coefficients (1) for total intensity, ionising component at high altitude; (2) for sea level neutron intensity; (3) for total intensity at 4300 meters altitude and (4) for hard component at sea level.

account the new cut-off rigidities obtained by considering higher moments of the earth's field as well.

3. Variation of Atmospheric Origin.

Large number of workers such as Duperier[34], Barrot et al Gilbert[36], Kondo and Wada[37], Wada and Kudo[38], Trefall[39,40,41,42], Escholot and Conforto[43], Hayakawa et al[44] and Mathews[45] have made an attempt to understand the cosmic ray variations of atmospheric origin. For the meson intensity in the lower atmosphere the important physical processes are rates of creation and absorption and the survival probability of the unstable π and μ mesons.

Berman and Feinberg[46] have worked out a comprehensive theory of meteorological effects on the same basis as that of Hess and Nedu. The final result has been expressed by Berman in the form

$$\frac{\delta I}{I} = \beta \delta B + \int_0^h W_2(h)\ \delta T(h)\ dh \qquad .. \quad (5)$$

where δB is the change in barometric pressure and β the barometric co-efficient which arises from mass absorption effect. $\delta T(h)$ is the change in temperature of isobaric level of pressure h. The function $W_2(h)$ which is designated as the temperature co-efficient density has been calculated and plotted in his book.

For all practical purposes equation (6) can be written in the form

$$\frac{\delta I}{I} = \beta \delta B + \sum_{i=1}^{11} K_i \cdot \delta T_i \qquad .. \quad (6)$$

K_i is the partial temperature co-efficient for the i^{th} layer obtained by integrating W(h) over the corresponding layer. Berman points out that it is sufficient to sum up the temperature effect over eleven standard atmospheric layers from 1000 mb to 50 mb.

Sarabhai and Nuo[47] have collected all evidences regarding temperature variation in upper atmosphere and find that between 2 Km and 15 Km there is apparently no diurnal variation of temperature of amplitude greater than 1^0C. They, thus, argue that it is sufficient to correct the daily variation of meson intensity for daily variation of atmospheric temperature

upto 2 Km above ground level. Instead of depending upon unreliable radiosonde data for the temperature at 1 Km and 2 Km above ground level (because of the radiation heating of the instrument) they have estimated the temperature at these levels from Roer's relation which has been found by comparison with experimental observations to be quite accurate. According to this relation the temperature variations at 1 Km and 2 Km heights have an amplitude 0.22 and 0.11 times that at the surface with a negligible change of the phase of the daily variation. Using this relation, and following Dorman's formula, they have deduced a temperature co-efficient of 0.0264 %/C°. The temperature correction at Ahmedabad has a maximum amplitude of 0.22 % in the late winter months of February and March and a minimum amplitude of 0.08 % during monsoon months of July and August. The yearly mean correction is 0.15 %. Thus it is clear that whenever amplitude of daily variation of cosmic rays is small temperature correction plays an important role.

The recent work of Thambyahpillai and Quenby[43] shows that by correcting the daily variation of meson intensity for daily variation of atmospheric temperature up to 2 Km above ground level by using Dorman's formula, one at least takes account of 2/3 of the temperature effect.

4. Time Variation of Primary Radiation.

4.1. Long term variation.

A remarkable variation that has been discovered recently is the change of general intensity of cosmic rays and its inverse relation with solar activity. From the study of ion chamber data of Carnegie Institution stations, Gleckova[49] and Forbush[50] find this change of the order of 4 % from sun-spot minimum to sun-spot maximum. The change is present to almost equal degree in all four stations ranging in latitude from equator to 80°N and is found to be present to the same extent for both magnetically quiet and disturbed days.

For the present cycle Fenton et al[51] have made study of meson as well as neutron data of Kenchnie and Ottawa and have shown the existence of a decrease of 20 % in the nucleonic component even after correcting the data for transient decreases. They conclude that the 11 year variation of cosmic ray intensity is not due to cumulative effect of Forbush decreases. Lockwood[52] however argues that the change occurs rather abruptly through sudden drops of the type of Forbush decreases from which there is only a partial recovery.

Evidence of similar changes at high latitudes is provided by balloon experiments conducted by Neher[54,55], Meyer and Simpson[56], Pomerantz[57,58] and others. Corresponding to a change of 4 % in meson at sea level from 1937 to 1954, Neher finds a change of 50 % in total ionising component at 85°N latitude and 70,000 ft. altitude. Neher[59,60] has confirmed this result

from measurements during the present solar cycle. Winckler et al[61,62] find the effect in this cycle more than the change observed during the previous cycle and show that the major part of the change occurs near the peak of the solar activity which indicates a triggering mechanism rather than a proportional relationship with sun-spot numbers. The results of Freier et al[63] and Lohar and Anderson[64] for α flux and heavy nuclei indicate the same result. The question whether there exists a lag between the minimum of cosmic ray intensity and maximum of solar activity is still open.

The only result contrary to the inverse relationship of cosmic ray intensity and solar activity is that of Katsuura[65], who finds an increase in intensity from 1955 to 1957 as measured by a narrow-angle triple coincidence telescope of opening $3^0 \times 3^0$ with 96" of lead in between the trays.

4.2. Change of 'knee' of latitude effect.

The sharp cut off in cosmic ray primary spectrum at an energy of about 8.8 Bev for protons which is derived from the fact that cosmic ray intensity, beyond about 55^0 latitude, does not increase even at highest altitude, presents a difficult problem for interpretation.

In order to understand finer features of this effect Lohar et al[66,67] profiting by experience gained about the appreciable day to day changes in the intensity of cosmic rays, have, since 1951, made simultaneous flights of balloon borne instruments at different latitudes thereby studying the 'knee' independently of general fluctuations in cosmic rays. From the

intensity versus latitude curves for an atmospheric depth of 10 g/cm^2 for the years 1937, 1951 and 1954, they clearly show the shift of 'knee' to higher latitudes from 1937 to 1951.

The low energy cut off for protons at 0.6 Bev, during 1951, is absent during 1954 when a very large intensity of soft particles down to the energy of 0.15 bev for protons is detected. This illustrates a remarkable variability of very low energy primary cosmic rays.

Meyer and Simpson[68] have reported that from 1948 to 1951 the 'knee' of the latitude effect has shifted by 5° from 65° to 58°N. They did not observe such change between 1951 and 1954, but since the results of Meher et al show that the change was restricted to the energy region 0.15 Bev to 0.3 Bev (if particles responsible for it were protons) it is to be expected that these would produce little effect at 80,000 ft. altitude where Simpson's observations were carried out.

Van Allen and Singer[69] have tackled this problem by rocket experiments and compared the intensities up to geomagnetic latitude of 55°N with the Compants'[70] value at 69°. They found there was no appreciable increase in flux in this latitude range and were led to the conclusion that there was absence of protons with energies between 560 bev and 190 Mev. Since these measurements at various latitudes were not simultaneous the results cannot be taken as conclusive because of the uncertainties caused by day to day fluctuations of primary particles.

Van Allen[71] and Meredith et al[72] extended the measurements in rockets up to the pole and found no appreciable increase in

the flux, this allowed one to extend the cut off to as low as 20 Bev for proton. These results have to be taken again with reservation on account of the uncertainties involved in the contribution of the albedo and our rather uncertain knowledge of geomagnetic effects at high latitudes.

Bills et al[70] point out that during 1959 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 on the energy of the primaries which favours a mechanism involving magnetic fields responsible for the cut off.

Meyer's[74] recent measurements show that the 'knee' has reappeared in 1967. Winckler et al[75] and Freier et al[76] at Minnesota show that even in 1957 when the sun was at its peak activity, low energy particles down to 100 Mev/nucleon were still present from which they conclude that the reduction in flux was due to reduction in both high and low energy particles. The major part of reduction occured during 1956 to 1957 which again suggests a trapping mechanism responsible for the change.

It is quite apparent that there is a close relation between changes in 'knee' and the 11 year cycle of intensity change.

4.3. Magnetic Storm effects.

A decrease in cosmic ray intensity accompanying magnetic storms is a frequent phenomena of cosmic ray variations. Its world-wide nature was first shown by Forbush[77] as early as 1937. Since then many workers have studied this phenomena. Some of the

Interesting features that have been noted are:-

(1) A 'Forbush decrease' is a sharp decrease in cosmic ray intensity (of amplitude up to 10 % at times). It is often closely associated with the main phase of magnetic storm, followed by a slow recovery lasting several days.

(2) All magnetic storms are not followed by a cosmic ray storm, and, even when a magnetic storm is effective the ratio of the change of magnetic field strength to the change of cosmic ray intensity does not remain constant from event to event. It suggests that the relation between the two cannot be direct (Sandberg-Hanssen[78]).

(3) There are instances when decrease of intensity occurred considerably earlier than the occurrence of any noticeable geomagnetic disturbance (Chapman[79]).

(4) Magnetic storms of short duration correspond to cosmic ray storms of lower intensity (Krimp[80]).

(5) Magnetic storms with a dominant positive peak and a vanishing small negative peak produce no change in cosmic ray intensity (Brodzi[81]).

(6) Large decreases are always accompanied by magnetic storm with sudden commencement (Kitamura[82]).

(7) Mechnuff[60] at 60 m.v.e. did not record any perceptible change in mean intensity when sea level intensity changed by 5 to 6 % during the storm of January 24, 1949. Thus the particles responsible for the increase are energy dependent.

(8) A small increase of amplitude of cosmic ray storm with increase in geomagnetic latitude exists (Forbush[56], Yoshida and Kamiya[65], Kodama and Miyazaki[66], Brown[67]), but in some storms (March 1946) no latitude effect is observed.

Sobido et al[68] have made an exhaustive study of the relation between cosmic ray storms and magnetic storms and have divided the latter into two classes - S type and R type, according to whether they are effective or non-effective in producing cosmic ray storms. They find that S type storms follow the 11 year cycle of solar activity and are well correlated with the central meridian passage of large sun-spot groups. R type storms do not follow 11 year cycle of solar activity but exhibit a sharp 27 day recurrence tendency. They are associated with the M regions on the sun. The authors conclude that S type storms are caused by wide corpuscular clouds ejected from sunspot groups, but R type storms are caused by narrow corpuscular beams from M regions.

An interesting correlation has been brought forth by Kamiya and Wada[69], who show that every solar radio outburst of type IV is associated with a cosmic ray storm and vice-versa. The radio outburst of type IV is generally believed to be the synchrotron radiation emitted by high energy electrons in a strong

magnetic field extending as far as 2 or 3 solar radii. It is, therefore, plausible to imagine that an appreciable magnetic field may extend or be brought out as far as one or more astronomical units, that is to say, magnetic clouds are emitted in this case.

Because of the better counting instruments run during the I.G.Y. the interest in the study of cosmic ray storms has shifted to finer features. Sarabhai and Pillalore[90] have analysed the storm of February 11, 1958. They find two small increases in intensity; one about four to five hours before the arrival of solar plasma initiated by commencement of the storm and the second essentially during the main phase of the storm, which are observed only at equatorial stations, and not at high latitudes. It thus appears that both these increases are particularly characteristics of the high energy component of primary radiation. In contrast the minimum of 'Forbush decrease' is larger and occurs later for low energy than for high energy primaries.

Fenton et al[91] have made study of onset times of Forbush decreases at four widely spaced stations and have found appreciable differences.

Murakami and Kudo[92] have pointed out that in a cosmic ray storm, low energy cosmic rays (neutrons) have earlier onset time than high energy ones (hard component).

McCracken[93] finds that at the same station the onset of cosmic ray storm does not occur simultaneously in all directions. The intensity in the directions between 30^{0} - 120^{0} East of the

earth-sun line is the first to decrease and is the one that suffers the greatest depression. The intensity from the direction 0^{0} - 90^{0} of the earth-sun line is last to be affected and at the same time suffers the least depression.

4.4. Day to day changes of intensity.

It has been now well demonstrated that day to day changes of cosmic ray intensity are world-wide in nature. Forger[94] has found that changes in the neutron monitor at Climax are similar to simultaneous changes observed in the ion chamber at Freiburg, but on the average are five times greater in amplitude. Heber and Forbush[95] have demonstrated the correlated changes occurring in the ion chambers at Huancayo and Chelteham, the neutron monitor at Climax and the ionization at 70,000 ft. over Bismarck but they show a difference in amplitude of change.

An important type of day to day change of intensity is the one which shows a 27 day recurrence corresponding to the synodic rotation period of sun. Simpson et al[96] showed the association of the cosmic ray increases with the central meridian passage of active solar regions, and particularly of regions of great coronal emission on the sun. These increases were often seen to be followed within two to three days by increased geomagnetic activity. Simpson et al[97] have also shown the close association of CME of unipolar (UM) regions with cosmic ray increases during 1953. These regions as well as the increases of intensity persisted for several solar rotations. The results of Meyer and Simpson[98] and of Van der Hulst[99] show that the recurrence tendency is most pronounced during sun-spot maxima.

Relation between cosmic ray intensity and geomagnetic disturbance has been studied by number of workers. Newton and Thambyahpillai[100] and Simpson[101] and Kane[102] find that the minimum of cosmic ray intensity occurs 3 - 5 days earlier to that of K_p, the index of geomagnetic disturbance. Venkatesan[103] and Krupp[90] and many others have observed that this behaviour is not always followed. Sometimes the minimum in cosmic ray intensity precedes whereas at other times it follows the K_p maxima. Van der Hulst[99] concludes that during the period of solar minimum cosmic ray intensity minimum generally precedes K_p maximum and during solar maximum period it follows K_p maximum after a lag of a day or two.

An exact knowledge of the relationship between cosmic ray intensity change and geomagnetic disturbance is still beyond our present understanding. It is not even certain whether the outstanding feature of the 27 day variation is an increase or a decrease. Van Heerden and Thambyahpillai[100] and Brown[104] interpret it as decreases produced by some sweeping or modulating effect in a manner similar to Forbush decreases, while Kodama[105] adduces evidence for solar emission of low energy particles, at least during the sun-spot minimum, by studying the concurrent diurnal variation.

4.5. Solar flare increase.

A typical flare effect is represented by a rapid rise of intensity followed by a slow decline persisting for a period of many hours. Since for all flares the major part of intensity rise occurs within a few minutes it is most probable that the particles have come from the sun along relatively uncomplicated orbits, and, hence have undergone little scattering.

So far five such major events have been recorded and the main features of these events are:-

(1) The increase in cosmic ray intensity is delayed upto an hour after the visible sighting of the solar flare.

(2) The primary particles responsible for the increase are usually of energy less than 15 Bev, since, even in the last flare of February 23, 1956, no increase was observed at equatorial stations.

(3) The magnitude of increase depends upon the mode of detection, and is a function of latitude, altitude and local time of the station. In other words these particles are strongly energy dependent.

Making a fair assumption that these particles come from the sun, Schlüter[13] and Piron[14] calculated the trajectories of charged particles in the earth's magnetic field. They were able to show that particles arrive in definite 'impact zones'. The most intense maximum is at 90° with respect to the sun-earth line which corresponds to about 9 a.m. local time for positive particles. It is next followed by 'zones' corresponding to local times of 0400 hours and 2000 hours respectively. Their calculation cannot account for polar increases which have been observed during the last two flares.

Webber and Hurnhard[105] find that polar type increases are less steep and decay at a slower rate as compared to middle latitude stations. This suggests that these increases are outside the ingoi

source and are due to particles which do not come directly from the sun but have been redirected and temporarily stored by outer trapping fields. Krimsky[107] attempts to explain the polar increases in terms of deflection by a galactic field and puts an upper limit of 3×10^{-6} gauss for it.

The cosmic ray intensity observations during the flare of February 23, 1956, proves the existence of interplanetary magnetic fields. The development of this event is described by Simpson[108] as follows:-

The first arriving particles come to the earth from a limited source direction in the sky within a time interval of 10-20 minutes. This apparent source is a relatively large area which includes the sun. Initially, the particles arriving are of highest energies in the flare spectrum. Subsequently, the whole sky becomes 'illuminated' with arriving particles extending to lower energies, and for these low energy particles and late arriving high energy particles, there develops a remarkable isotropy in space near the earth, suggesting that particles arrive later as a result of scattering or passage through indirect magnetic channels in the interplanetary magnetic fields. Following the onset of isotropy, the particle intensity gradually diminishes with the flare particle spectrum essentially unchanged over many hours, while the particles escape from the magnetic fields which store them in the solar system. The intensity at the earth is observed to diminish to its pre-flare level within a period of 50 hours. This fact and the fact that no source direction persists for even the highest energy particles strongly support the view that the sun accelerates particles only during

a short interval of time and that these particles are trapped and stored in the interplanetary magnetic fields only to be lost subsequently from the polar cycles or arrive at the earth. This kind of evidence is at present the strongest evidence for the existence of interplanetary magnetic fields.

Meyer et al[109] consider that the isotropic increase observed in the second phase is due to the reflection of the particles from a heliocentric boundary of radius of about 1.2 a.u. With this model the interesting question then arises as to whether solar flares on the remote side of the sun can lead to increases at the earth. Up till now no event of the magnitude of February 1956 flare has been observed under these circumstances. However, Simpson[110] points to a smaller increase ($\sim$ 5 %) on 23 May, 1955 which occurred simultaneously in the neutron monitor at Climax and Sacramento Peak. A search for a solar event at that time has led to a negative result. Two additional but larger increases have been observed in the Antarctic. It is difficult to prove that these increases arise from backside polar flares, but this is a reasonable possibility.

The solar flare of February 23, 1956 has been unique in the sense that it was the most energetic cosmic ray event observed so far and the increase in intensity ($\sim$ 6 %) was registered even at equatorial stations as reported by Forbush[111] and Sarabhai et al[112].

In collaboration with Sarabhai et al the author derived using Brunberg and Hultqvist's results for deflections in the geomagnetic field, that only solar protons in the energy range

30 - 67 Bev could have been responsible for the increase at Indian stations. Thus the upper limit for the energy of particles responsible for flare type increases could be much higher than hitherto believed. A reprint of this paper has been attached at the end of this thesis for further details.

The neutron monitor at Leeds[130] which was in the 0600 hour impact zone registered an increase of 4500 % whereas the neutron monitor at Climax[134] recorded 3000 % increase even though it was far away from any favoured impact zone. Since Sitkha[115] did not observe any increase in extensive air showers, an upper limit of 10^{12} eV for the energy of the emitted particles can be safely assumed.

Winckler[116] found five times the normal intensity at 10 gm/cm^2 over Minneapolis even 17 hours after the occurrence of the flare when cosmic ray intensity at 300 gm/cm^2 had already returned to normal value.

Hurnin et al[127] at Yakutsk ($\lambda = 81^0$N) and Brunberg and Neihart[118] at Stockholm ($\lambda = 49^0$N) found that north pointing telescopes recorded more particles than the south pointing ones. They interpret this as due to solar protons which did not travel in straight lines but were deflected by a weak magnetic field of 6×10^{-6} gauss before reaching the north pointing telescopes.

Ehmert[119] reached a similar conclusion after making a detailed study of the time difference in the onset and the decay of the increases for different stations all over the world. He concluded that high latitude effect and mid-night effect which

cannot be explained on the basis of input zone theory could be satisfactorily explained in terms of deflection of flare particles by the weak interplanetary magnetic field of the order of 3×10^{-5} gauss.

The latitude effect of solar flare increase is considerably steeper than the latitude effect of the normal sea level radiation, but because of difficulties in assigning accurate numerical values to the observed solar flare increases, as pointed out by Sekido and Kaphida[130], it has not been accurately determined. For the flare of February 23, 1956, Meyer et al[100] cite an exponent of 7.

4.6. Effect of small flares.

There have been a few instances when cosmic ray increases have been observed in association with flares of magnitude 1*. Fiore[24] showed an increase of about 1 % in the intensity on days when the Climax neutron monitor was in an appropriate 'input zone' to receive solar particles. Against this he finds no increase associated with small flares when the Climax recorder was not in any one of the input zones. Meyer et al[131] have reported an increase in intensity during flight on July 23, 1951, one hour after the occurrence of a flare of magnitude 1*. Recently Corrigan et al[132] find an increase in intensity ($\sim$ 30 %) at $\lambda = 65^{0}$N at a height of 25,000 ft. during a 1* flare on August 9, 1957.

McCracken[123] has reported an increase of 2 % in the neutron monitor at sea level (Hobart) during the flare of August 31, 1955, which was simultaneously recorded in U.S.A. stations too. Mount Wilson did not however record any increase

5.1. Anisotropy of cosmic rays.

Because of the spinning of the earth, an anisotropy in the distribution of cosmic rays outside the influence of the earth should give rise to a daily variation in cosmic ray intensity.

Early workers like Hogg[124] and Lange et al[125] observed a daily variation of amplitude of about 0.2 per cent but uncertainties due to meteorological corrections did not permit any valid conclusions to be drawn regarding the anisotropy of the radiation. Attempts were made by Bulfore[126] and by Elliot and Dolbear[127] to overcome this difficulty by making studies with directional telescopes inclined equally with respect to the vertical. At middle latitudes ($\sim 45^0$) a north pointing telescope would point to the same direction in the sky, whereas a south pointing one would sweep a plane parallel to the equator. Since the particles entering both telescopes would go through the same atmospheric conditions, the difference between the intensities as measured by the two telescopes would show the effects of primary anisotropy without being disturbed by meteorological conditions. From such a study they concluded that there is a primary anisotropy of cosmic rays.

A recent study of Elliot and Nothall[128] with directional telescopes casts doubt on the view that the daily variation is due to non-isotropic flux of primary particles. They found that a west pointing telescope at London ($\lambda = 45^0$) records a daily variation three times that in east. Considering a mean energy of 3×10^{10} ev, west pointing telescopes record

particles from the north, whereas east pointing telescopes scan the plane of the ecliptic during a 24 hour period. One would, therefore, expect a larger amplitude in east pointing telescope if the cause of the daily variation lies in an anisotropy of the primary radiation.

Parsons[110] comes to a similar conclusion from his directional studies at Newman ($\lambda = 73^{0}$). He finds that a south pointing telescope with zenith a south celestial latitude belt close to and intermediate between those zenithed by the other telescopes show a virtual absence of daily variation Such an observation is again inconsistent with the idea of an anisotropy outside the influence of the geomagnetic field.

Results of Elliot and Bothwell and of Parsons are subject to the criticism that while trying to find the directional response of their telescopes they have taken into consideration the mean energy of the particles whereas it seems necessary to consider the effect over several discrete energy bands. Further their final results have not been corrected for temperature changes in the atmosphere. It is satisfactory to note that when temperature correction is included by Thambyahpillai and Quenby[66], the directional measurements made at Newman by Parsons can be explained in terms of a primary anisotropy without any inconsistencies.

Of late Marshall and Rao[110], from their daily variation studies with east and west pointing telescopes at the low latitude station of Ahmedabad ($\lambda = 14^{0}$), bring forth some interesting results regarding the anisotropy of cosmic rays.

At the equator both east and west pointing telescopes scan in succession the same ecliptic plane. Thus an anisotropy of primary particles in a certain direction in space should reflect itself in the form of a daily variation with a phase difference between east and west pointing telescopes - east being earlier to west by about 6 hours if both telescopes are inclined at 45° to the south. On this basis they find that the daily variation on days of high east-west asymmetry which relate to relatively calm geomagnetic conditions can be attributed to an anisotropy of cosmic rays far away from the earth. On the other hand daily variation on days of low east-west asymmetry which are associated with geomagnetically disturbed conditions is not consistent with external anisotropy and is probably of geocentric origin.

Quite a few experiments (Machumaf[121], Sherman[122], Barrett et al[36], Farley and Storey[123]) have been conducted in order to investigate the energy dependence of the solar daily variation, but the results are unreliable because of poor statistics. Of interest is Hurwitz's[124] recent work, who has made a detailed study of the solar daily variation at surface and at 7,20 and 60 m.w.e. during 1957, 1958. He finds the amplitudes as 0.36 %, 0.25 %, 0.13 % and 0.05 % respectively, i.e. amplitude decreases with increasing depth underground and hence with increasing primary energy.

The anisotropy of heavy primaries has been studied in balloon experiments by Anderson et al[126], McIlwo and Pomerantz[126], Ingve[127], Lord and Schein[128] and Ney and Thon[130]. The anisotropy of the very low energy spectrum has similarly been studied by

Bergstralh and Schroeder[140] and Dutton and Elliot[141]. The experiments are difficult to perform and present even greater difficulties in interpretation. While a daily variation as large as 25 per cent was reported by Ryve, other authors have failed to find a daily variation of amplitude larger than about 1.4 %. Since there is great variability of anisotropy from day to day, as is described later, observations made in balloon flights are not strictly comparable amongst themselves and with results reported from ground level stations which relate to the average of data over a large number of days.

6.2. Dependence of solar daily variation on the geometry of the detector.

The daily variation has generally been determined with instruments measuring intensity from a wide range of directions. Although it helps to reduce the statistical errors the results do not represent the true anisotropy because of averaging effect.

Sekido et al[142] were first to point out that the amplitude of daily variation observed during the period March 1948 - March 1950 increased from 0.19 per cent to 0.24 per cent when the semi-angle of the telescope measuring total intensity was reduced from 40° to 12°. Ehmert and Bithus[143] also showed that during the year 1952 the amplitude of the daily variation measured by counter telescopes of limited directional sensitivity is higher than that recorded by an ion chamber.

At Ahmedabad, Jarabhai et al[144] conducted a detailed study with narrow-angle telescopes in east-west plane and pushed the opening angle to a practical lower limit. They found a

remarkable increase from 0.6 % to 1.0 % in the amplitude of the daily variation with decrease of cone-angle from 15° to 5°. These results correspond to the period August 1954 to July 1955. The author has continued such investigations during the years 1957, 1958 which correspond to the solar maximum of the present cycle and has failed to detect large amplitudes in narrow angle telescopes. These results together with the results of Swarkhal et al are presented and discussed critically by the author in Chapters IV and V.

Recently Krumbeg[165] has calculated in detail the theory of the dependence of amplitude of daily variation on the geometry of the telescope with a basic assumption that the daily variation is caused by an extra-terrestrial anisotropy. He points out that while making measurement of daily variation what we actually measure is the ratio of the source to the background intensity ($\frac{dI}{I}$) and not the source intensity itself. Thus if the source of daily variation were to subtend small solid angle then this ratio ($\frac{dI}{I}$) would be larger for narrow-angle telescopes since they register small background as compared to wide angle telescopes.

Assuming that an infinitesimally small source exists in space with the same source spectrum as that of isotropic background, Krumbeg has numerically calculated the amplitude of daily variation which will be observed by telescopes of different apertures taking only the atmospheric spread into consideration and neglecting the influence of the geomagnetic field. The results are expressed in the form of a graph which is reproduced here in Fig. 2a. It gives for telescopes of

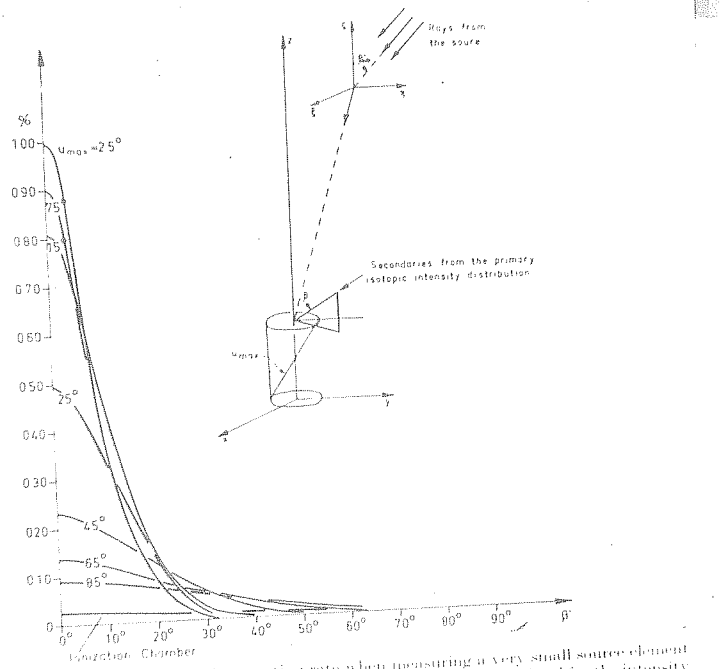

Fig. 31. The percentage increase of the counting rate when measuring a very small source element with telescopes of different apertures. The $\cos^2\theta$ law is assumed to hold at sea level for the intensity distribution of the "background".

Fig. 31 - The percentage increase of the counting rate when measuring a very small source element with telescopes of different apertures.

different apertures the amplitude of daily variation which is expected for cosmic ray particles coming from different zenith angles. The figure reveals that the particles coming along inclined directions will show a small amplitude of the daily variation. But since for a vertical narrow-angle telescope the major contribution to the intensity is due to particles coming along the zenith, the inclined particles will not contribute much to the daily variation. It is further observed that for the particles coming along the zenith, if we assume the ratio between the counting rates of the source and the background intensity to be 1 : 5 the narrow angle telescope of

opening 8.5^{0} measure full 1 % amplitude of the daily variation whereas wide angle telescopes measure much smaller amplitude.

These theoretically calculated amplitudes expected in telescopes of different apertures require to be corrected for the bending of the particles in the geomagnetic field, the effect of which is to smear out the sharpness of the source and thus reduce the amplitude. Krumberg has derived the nature of this correction by calculating the intensities at different local times during the day caused by an infinitesimally small source in the absence of background intensity. The results are shown in Fig. 2b taken from Krumberg's paper.

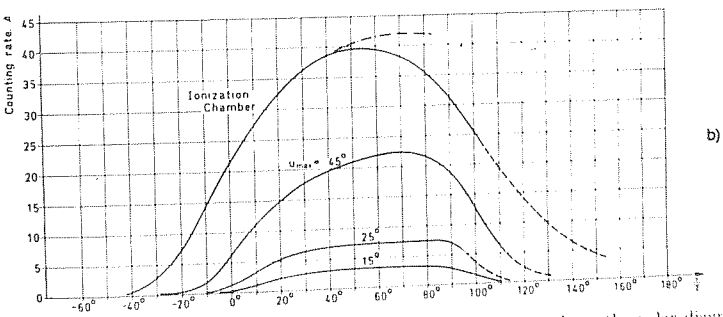

Fig. 33. (*a*) The contributions of different primary momentum intervals to the polar diagram along $\Phi = 0$ of an ionization chamber at sea level in Huancayo. (*b*) The polar diagrams along $\Phi = 0$ for telescopes with different apertures at sea level in Huancayo.

Fig. 2b - The polar diagram along $\Phi = 0$ for telescopes with different apertures at sea level in Huancayo.

Chapman further points out that narrow angle telescopes have better resolving power and higher harmonics of the course of daily variation are more faithfully reproduced in them than in wide angle telescopes.

5.3. Long term changes of daily variation and their world-wide character.

By an examination of Carnegie Institution data from 1927 to 1945 Sarabhai and Sama[146] drew attention to the correlated changes of amplitude and of time of maximum of the diurnal component, at Huancayo, Cheltenham and Christchurch. They pointed out the relationship of these changes with the 11 year cycle of solar activity.

Chamboshpillai and Elliot[147] from an examination of Cheltenham data of various stations from 1932 to 1952 demonstrated the world-wide changes of the time of maximum of the diurnal component and pointed out that the changes probably followed a 22 year cycle of solar activity. Steinmaurer and Obert[148] have also come to the same conclusion by an examination of the Hafelekar ion chamber data for a period of 20 years. They show that the time of maximum of the diurnal component which was about 7 A.M. during the sun-spot minimum in 1933 was comparable with that in 1953-1954 but was earlier than the time of maximum 11 years later in 1944, thus suggesting a 22 year cyclic change. Time of maximum of the diurnal component going to mid-night hours in 1953-1954 has also been reported by Fonseca and Van Heerden[149] from the studies with north and south pointing telescopes at London. Conforto and Simpson[150] confirm this from the examinatio

of both meson and neutron components at various stations.

When the daily variation is considered as a whole instead of in terms of its harmonic components a remarkable sequence of changes is revealed as was shown by Sarabhai et al[157] from Huancayo data (Fig. 3).

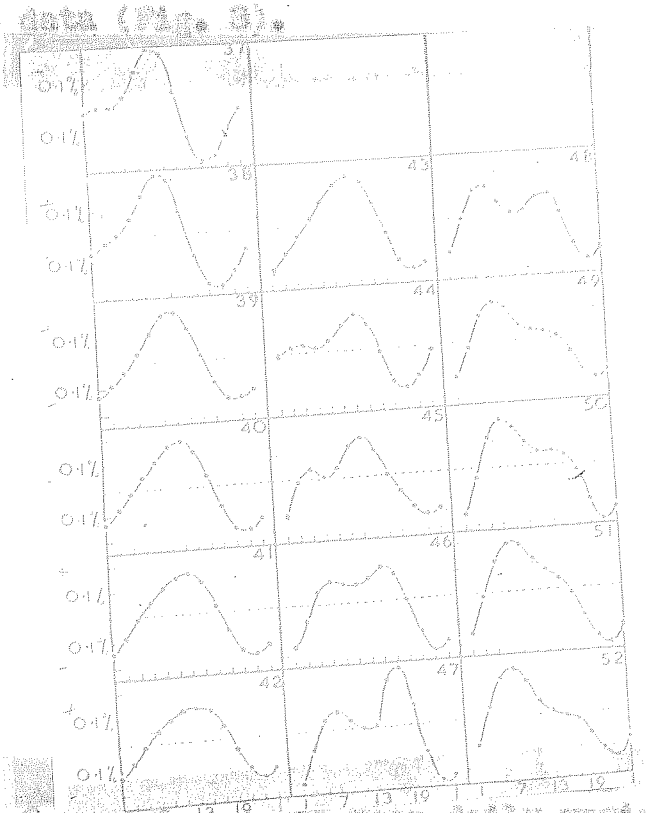

Fig. 3 Seven mean daily variation of meson intensity at Huancayo during different years.

They find that in the daily variation curve there essentially exist two maxima, one in the early morning hours and the second near noon, which was and were from year to year. In 1937, the daily variation curve had mainly a noon maximum whereas in 1947 a noon maximum and an early morning maximum were equally prominent. By 1951 the daily variation curve contained only the early morning maximum. It was suggested by Sarabhai et al that such a sequence of changes in the daily variation curve follows a 22 year cycle of solar activity. They further demonstrated that such changes are not clearly apparent in middle latitudes (Cheltenham), a fact which was also noted by Fulsburg[162].

The author has looked for such changes at Ahmedabad in his data from 1950 to 1958. The changes fit in with the pattern of long term daily variation at Huancayo.

Venkatesan and Pathak[150] find that the changes in the diurnal amplitude follow the changes in geomagnetic activity more closely than the changes in the solar activity. They further observe that whereas the secular changes in the mean annual vector of the diurnal component are world-wide in nature, those of the semi-diurnal component are not. This conclusion does not seem to be warranted as the earlier observations of Sarabhai et al[151] show that the form of the daily variation is different for different latitudes and the daily variation with two types of maxima and with predominant semi-diurnal component is observed mainly at low latitudes. It is further confirmed by Sarabhai et al[154] that the changes in the semi-diurnal component from year to year are similar at the equatorial stations of Kodaikanal and Huancayo. Further, from Huancayo data they observe that the phase changes of the semi-diurnal component follow a 22 year cycle which indicates its relationship with solar activity.

6.4. Day to day changes of the daily variation.

The daily variation of cosmic rays has been found to be highly variable in character. From a study of the nucleonic component, Pfotzer et al[155] first pointed out groups of days with maximum during the day. There were other days when there was no appreciable daily variation whereas there were days when the daily variation appeared to have a maximum in the night. Critchfield

has looked at such changes in ion chamber data and found the tendency for the days of large amplitude with maximum near noon to occur in groups. He found a 27 day recurrence for these groups and remarks that such days did not reveal any association with a significantly different magnetic character figure as compared to the rest of the days. Hoy and Sitting[197] also noticed a great variability of the time of maximum of the diurnal component.

Serebral et al[164] investigated this problem with a narrow angle telescope of 6° in the east-west plane during 1954-1955. On 75 per cent of days they found that daily variation exhibited only one maximum and this maximum had the distinct tendency to occur either at 1200 noon or in the early morning at about 0600 hours local time. The author has studied this problem during 1957, 1958, which corresponds to the solar maximum period, and in conjunction with the 1954 data of Serebral et al, has found some interesting sequence of changes in the day to day changes of daily variation. The results are presented in Chapter IV.

The recurrence tendency of daily variation observed in the ion chamber data of Huancayo has been studied by Yoshida and Kondo[155]. They found a strong recurrence tendency, extending to two solar rotation, which was more marked than the recurrence tendency in either the general cosmic ray intensity or in magnetic character figure during the same period. Nano[103] who examined the data of several stations for the years 1951, 1952 and 1953 finds that the recurrence tendency does not significantly vary from period to period.

The change of daily variation on magnetically disturbed days has been studied extensively and the early work, relating to the period 1907-1931 indicates that on days of high K_p the amplitude of the diurnal component increases and its time of maximum becomes earlier. Sakido and Yodama[150] showed that this effect is more prominent in narrow angle telescopes. Further Sakido and Yoshida[160] demonstrate that the semi-diurnal component which is normally present in quiet day variations gets reduced on magnetically disturbed days. The reduction is shown to be much larger in narrow angle telescopes than in wide angle telescopes. Sanlstrom[161] has made a study of the 12 hour component and the 18 hour component of diurnal variation which, according to Alfven's theory[162] correspond to 'radial flow' and the 'tangential flow' from the sun. He shows that the 12 hour component increases with increasing K_p while the 18 hour component remains constant.

Sakido et al[163] have made an extensive study of the mean storm type vector representing the difference in the diurnal components during geomagnetically disturbed and quiet periods 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.

During the period 1955-1963, dependence of amplitude on geomagnetic character figure (C_p) has been studied by

Satyaprakash[164], Duggal[165], Sastry[166], Ahluwalia[167] and Rao[168] at the equatorial stations of Ahmedabad, Kodaikanal and Trivandrum both in amplitude as well as the mean component. They have not been able to confirm the earlier result of dependence of diurnal amplitude and its time of maximum on the geomagnetic activity. Yoshida[169] explains this difference on the basis of changes in the 'disturbance vector' in step with the 11 year cycle of solar activity. Thus the net change that is observed with high C_p should be dependent on the period of observation related to the phase of solar cycle.

Sarabhai et al.[170] find that on high C_p days associated with a decrease in mean intensity, the daily variation shows an increase in amplitude with an earlier hour of maximum as compared to daily variation of quiet days. They are led to believe that C_p alone is not a meaningful criterion to study daily variation but associated changes of both mean intensity and C_p have to be considered to draw any conclusion regarding the relationship of daily variation and geomagnetic activity.

An exact knowledge of relationship is still far from our present understanding and the whole field needs more attention.

5.5. Correlated changes of daily mean intensity and solar daily variation.

From a study of the horizontal component intensity with narrow angle telescopes at Ahmedabad, during 1954, Sarabhai

and Bhavsar[171] showed that the days corresponding to the daily variation having a night maximum were associated with low daily mean intensity whereas days having a maximum in the day time were associated with a daily mean intensity significantly above the average value for the total period of operation. A detailed study by Sarabhai and Satya Prakash[170] of the hourly intensities of the neutron component at Kodaikanal, during 1957 reveal that there exist correlated changes between the magnitude of hourly intensities centered at particular hours and the daily mean intensity. They showed that the increase of negative deviations at 0600 hours was associated with an increase in the daily mean intensity and an increase of negative deviations at 1800 hours was associated with a decrease in the mean intensity. The world-wide nature of this phenomenon was demonstrated by Sarabhai and Shirvalia[172] by studying the neutron component at the equatorial stations of Ahmedabad, Kodaikanal, Huancayo and Makerere College. It is, therefore, possible to separate days associated with an increase or a decrease of the daily mean intensity by using significant negative deviations at the appropriate hours.

In conclusion, instead of studying the daily variation on the basis of long term averages as has been the case till now, we should make an analysis of day to day characteristics of the daily variation. The essential condition for such a study is the simultaneous operation

of high counting instruments throughout the globe. The I.G.Y. programme is a beginning in this direction.

6.1. Interpretation of Variations.

The major cosmic ray effects which can be associated with events occuring on the sun can be summarised as follows:-

(1) Some large flares on the sun release cosmic ray particles, which in one exceptional case attained an energy upto 50 - 60 Bev ^{132}.

(2) Many short term cosmic ray intensity changes can be related to the central meridian passage of active solar regions such as special types of sun-spot groups, unipolar regions and regions of intense coronal emission of 5303 A^{0} line.

(3) Certain active regions on the sun which persist for several rotations give rise to the characteristic 27 day recurrence tendency in the variation of cosmic rays. The geomagnetic storms associated with type IV radio outbursts produce marked cosmic ray effects.

(4) Cosmic ray intensity as well as the low energy cut off have a relationship with the 11 year cycle of solar activity; the

intensity being maximum and the cut off being about at sun-spot minimum.

(6) The twelve month mean daily variation can be associated with an anisotropy of primary radiation and illustrates changes which are consistent with a cycle of 22 years.

(6) Cosmic ray variations are often associated with geomagnetic disturbances and point to both variations being related to a corpuscular radiation from the sun.

Inspite of the wide range of cosmic ray effects related to solar activity there is, however, general agreement that the sun is not the source of the major part of energetic cosmic rays. Most theories of the variations of cosmic ray intensity, and of isotropy, relate to a modulation of an almost isotropic galactic intensity of cosmic rays. The principal physical processes involved in the modulation relate to screening or scattering by magnetic fields which can be stationary with respect to the earth, or moving with plasma clouds or streams or stretched by an outward wind emitted from the sun. The theories differ with regard to physical features such as the heliocentric or the geocentric character of the magnetic fields and the electromagnetic state of interplanetary space.

6.6. Interpretation of the short term variation.

Many workers have held the view that the short term changes of cosmic ray intensity involve only decreases of intensity. However, Simpson et al[97], Kodama[103] and Sarabhai et al[170,172] point to the existence of increases as well as decreases in the day to day changes of the cosmic ray intensity. Simpson et al relate these increases to the C.M.P. of the unipolar regions, Kodama believes that the increases observed by him are due to actual emission of low energy cosmic rays by the sun at least during the period of solar minima, while Sarabhai and Ahluwalia[173] relate the increases observed by them to the modulation mechanism in solar storms emitted by the sun. Increases of intensity have been observed during Forbush type decreases of cosmic ray intensity as reported by Nagashima and Palmeira[90] and Yoshida and Wada[222]. In proposing a model for explaining the short term changes of cosmic ray intensity one has, therefore, to take proper note of these increases.

Because of close relationship with geomagnetic disturbances, early workers tried to explain the variations in terms of modulation of cosmic ray intensity by changes in the geomagnetic field. But Lange and Forbush's[174] observation of intensity variations at such a high latitude station as Godhavn ($\lambda = 00^{0}$), and Simpson's[101] observation that the variations in neutron intensity at latitudes above

the 'knee' of the latitude curve are similar to those observed at low and middle latitudes, rules out such a possibility.

Nagashima[176] has proposed a static electric field surrounding the earth and assumes changes in it to explain the world-wide nature of day to day changes of intensity variations. Although this model can explain altitude and latitude dependence of variations it cannot explain the large variations which are sometimes observed when there are no magnetic disturbances and presumably no perturbing geoelectric fields. Further, Simpson[101] finds that the latitude dependence of fractional changes in neutron intensity in the range 40^{0}N to 60^{0}N cannot be explained on the basis of this model. He casts doubt on the very existence of the geoelectric field because of the high conductivity of the ionosphere and of interplanetary space.

Alfven[175] has suggested that the emission of corpuscular matter from the sun which is responsible for magnetic storms is also responsible for cosmic ray fluctuations. A neutral beam moving with respect to the earth appears to be electrically polarised when there is a trapped magnetic field carried within it. The acceleration and deceleration of cosmic rays traversing the field may be expected to cause increases or decreases. This model has been considered in greater detail by Brunberg and Dattner[177] to explain the decreases observed

with magnetic storms. They assume the existence of a general though weak magnetic field between the sun and the earth which has the same direction as the field of the earth. This deflects cosmic rays sufficiently to prevent acceleration by the same polarization field.

In order to explain the observed decrease of cosmic ray intensity, Brunberg and Dattner assume that (1) the particles of energy 3×10^{10} ev are involved; (2) the solar magnetic field has a magnitude ~ 10 gauss and (3) it varies with distance as $r^{-2.6}$, so that its value at the earth's orbit would be $\sim 10^{-5}$ gauss. It can be easily shown that the paths of such particles cannot extend to infinity and that those particles must be generated within the solar system. In other words, Brunberg and Dattner's theory of the effects of magnetic storms is substantially related to the hypothesis of solar origin of the cosmic rays which is known to lead to number of serious difficulties of general character (balance of the number of particles, problem of their maintenance, etc.).

Morrison's[178] interesting model for explaining intensity decrease of cosmic rays starts with a cloud of ionized matter emitted from the sun containing a highly turbulent magnetic field. If a field of the order of 10^{-3} gauss is accepted, it will take a few days for the cosmic ray particles to diffuse in the cloud to the normal intensity. So, for this period

of time, cosmic ray intensity within the cloud will be below the normal value; and when such a cloud envelopes the earth one will observe a cosmic ray decrease along with geomagnetic disturbance.

The main difficulty with this picture, however, is the large magnetic fields required to affect cosmic rays of the relevant energies, about 30 Bev. Also, since the diffusion time must depend on the particle energy, this model should lead to a large latitude dependence of Forbush decrease. On the contrary, the observed latitude effect is quite small and the variations observed by neutron monitors are not very much larger than those of ion chamber or meson telescopes at sea level. It is further difficult to explain the long recovery of Forbush decreases unless it is assumed that the magnetic density occurs uniformly throughout much of the solar system and is maintained for a long time.

Morrison's model has been critically discussed by Parker[17], who has added following modifications. He assumes that a turbulent magnetic cloud can be captured and held to the earth by the gravitational field, which, in turn, will modulate galactic cosmic ray particles. Commenting on the merits of this model, Parker points out that the small scale of the model vastly reduces the amount of magnetic gas that is needed, eliminates the necessity of the sun to eject clouds in directions far from its equatorial plane and

reduces the characteristic time to the observed value of a few hours for supporting the barrier and producing a cosmic ray storm. Such a model also attributes low energy cut off in the primary particles to the screening of low energy particles by this geocentric cloud, the duration of which is determined by the decay time of captured magnetic fields which is of the order of a few months. This explains why cut off varies over a period of years with mean level of solar activity.

Since Parker's barrier extends to about 3 earth radii, a verification of this barrier can be made with rocket experiments by testing whether the observed changes of cosmic ray intensity disappear beyond this distance. However, recent evidences[150] obtained from rockets seem to indicate that simultaneously with the occurrence of a Forbush type decrease on the earth, cosmic ray intensity in the interplanetary space at large distances from the earth is also depressed. The modulating plasma responsible for decreases, therefore, may not be of geocentric character.

Parker's[6] comprehensive theory makes use of Alfven's[170] basic concept that cosmic ray variations are caused by the corpuscular streams, emitted from the sun, which carry within them a trapped magnetic field. But in contrast to Alfven's idea of solar generation of cosmic rays his basic postulate is that cosmic rays arrive from the galaxy and suffer modulation in the

corpuscular stream. Parker suggests that apart from the acceleration and deceleration of the particles due to the electric field set up in the stream, the primary cosmic rays are also subjected directly to a strong influence of the magnetic field frozen in stream, which leads to the scattering of low energy primaries. (Importance of this fact was not realised by Alfven). Thus the decreases of cosmic ray intensity during magnetic storm arises from the deflection of low energy primary particles by the streams sweeping the earth whereas the daily variation results from the acceleration or the deceleration of particles, i.e. higher energy particles, by the same streams.

In a recent paper, Parker[101] shows that the individual peculiarities of the variation profile of cosmic ray intensity during magnetic storms is connected, chiefly, with different ways in which the earth enters a corpuscular stream carrying a frozen-in magnetic field. For the relationship between the rate of intensity decline of cosmic radiation and the rate of recovery, the velocity of the corpuscular streams in the vicinity of the earth plays an important part. The inhomogeneity of the frozen-in magnetic field also affects the nature of cosmic ray intensity variations in a variety of ways. From an examination of a number of storms, Parker shows that the frozen-in field is more often inhomogeneous although there are cases when it can be believed to be homogeneous. The most frequent inhomogeneities are:-

(1) The field in the leading side is stronger than in the lagging side.

(2) The field in the front face of the stream is stronger than deep within the stream.

6.3. Interpretation of long term changes of cosmic ray intensity.

Davis[132,133] has discussed the influence of the emission of ionized matter from the sun on solar or galactic magnetic fields within the solar system. He explains that the tendency would be to sweep the magnetic fields away and have a field free cavity of mean radius of about 200 a.u. around the sun. Cosmic rays of energies less than 100 Bev would be trapped within the cavity and their intensity would depend on its volume. He has tried to show that a 1.0 % change of the mean radius of such a cavity with the eleven year solar cycle could explain the 4.0 % change of intensity. However, this mechanism fails to explain the much larger changes of intensity for low energy than for high energy primaries.

The electric conductivity of the interplanetary space may not be infinite. In such a case, as Heiner[134] believes, there is a good likelihood of the emitted matter sweeping the galactic field leaving behind a small residual magnetic field and thus making the cavity dia-magnetic instead of making it field free. His calculations show that the diamagnetic cavity will be an oblated spheroid

of semi-axis 6×10^{15} cm. and 5×10^{14} cm. with a residual magnetic field of intensity 10^{-9} gauss inside it. The cut off in the primaries is explained by considering the trajectories of particles through the diamagnetic spheroid and the trapping of certain particles inside it. A change of 1.6 % in the total corpuscular output of the sun over a sun-spot cycle can explain the 4 % change in the mean intensity. Since the magnetic field H_1, within the diamagnetic spheroid is a function of conductivity of the interplanetary medium and of the regularity of solar ion stream, it is quite variable. By proving that the long term changes in cosmic ray intensity follow the changes in H_1 with a small phase lag of two to three months, Meinor has been able to explain the changes in low energy cut off.

Chandrasekhar has criticised the above models by pointing to the instability of various kinds which will disrupt the cavity walls thereby enabling the trapped particles to escape.

In a later paper, Parker[126] succeeds in explaining the 11 year cycle of cosmic ray intensity on the basis of heliocentric shell of disordered magnetic fields operating at a distance of about 1.2 a.u.

From the observation of comet tails, Biermann inferred that there exists an outward flow of hydrodynamic gas. Parker shows that if such an outward flow of hydrodynamic gas exists it will stretch out the magnetic

lines of force of the solar magnetic field and lead to an essentially radial magnetic field in the inner solar system. Parker estimates that in this radial magnetic field turbulence will set in somewhere in the vicinity of the orbit of the earth, thereby producing a shell of disordered magnetic field of $\sim 10^{-5}$ gauss. The existence of such a shell of disordered field had been inferred earlier from the observation of the solar flare of 23 February, 1956. This heliocentric shell of disordered field will scatter many cosmic ray particles coming from the galaxy (the scatter being more in low energy particles) with the result that intensity inside the shell is less than outside. In addition there will be a reduction of the cosmic ray intensity due to the outward flow of the solar wind itself. During the years of maximum solar activity the solar wind will be stronger and hence the intensity within the heliocentric shell will be less than when the level of solar activity is at its minimum.

6.4. The interpretation of the solar daily variation of cosmic radiation.

It is now clear that on a large number of days the solar daily variation of cosmic ray intensity corrected for meteorological influences is produced by the scanning of an anisotropic primary radiation by a telescope fixed to the spinning earth. It is also clear that there are days on which the solar daily variation is

produced by a source of geocentric origin[128,130]. While the local source has not been adequately studied experimentally and theoretically many attempts have been made to explain the features of daily variation which could be attributed to the anisotropy of the primary radiation.

Explanation of the daily variation of cosmic rays in terms of a solar magnetic field or the variations of a geomagnetic field became untenable quite early, because of the failure to detect the expected large latitude dependance of the variations. Bruber and Datner[126] have pointed out that seen from a fixed co-ordinate 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 polarisation and the solar magnetic field will make charged particles within the solar system partake in a general rotation with the sun so that earth will receive an excess of particles in the 18 hour direction. They thus get a tangential anisotropy. Alfven[127] on the other hand has shown the possibility of an outward radial flow of energy depending on the accelerating process 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 magnetic field of the sun having an intensity of about 10^{-5} gauss at the earth's orbit to account for a diurnal variation whose amplitude was believed to be about 0.2 per cent.

Alfven's[157] idea of deceleration of cosmic ray particles in the solar beam by which he attempted to explain the 'Forbush' decreases in cosmic ray intensity, was taken up by Nagashima[158] to examine its implications on the anisotropy of cosmic rays. He starts with the assumption that the frozen magnetic field in the beam is derived from the solar dipole field. A special feature of his theory is that associated with every beam there is a minimum energy below which no anisotropy would be produced. For higher energies the per cent. anisotropy would progressively decrease with increasing energy. Nagashima has shown that the minimum anisotropy would be produced in the direction pointing towards sun. This agrees with the experimental determination of the storm type vector by Sakido et al[163]. Nagashima's theory also explains the 11 year cycle variation of the storm type anisotropy as being due to a change in the density of the solar streams and of the strength of the trapped magnetic fields during the solar cycle of activity. However, Nagashima's theory does not explain a night type of maximum as observed in the daily variation on groups of days during the solar minimum. Yasuriar[150] has extended Nagashima's work by deriving the trapped magnetic field of the beams not from the general solar dipole field but from the local active regions from which the beams are emitted from the sun. Consequently the components of the trapped magnetic field in the direction perpendicular to the ecliptic, in the radial direction and in the tangential

direction can have different orientations from hour to hour. Considering the component perpendicular to the ecliptic with a direction of the magnetic field parallel or anti-parallel to the sun's dipole field, Parker has demonstrated that there can be anisotropy in the 0600 hour and in the 1800 hour directions for the two conditions. Due to the effect of the gauss-netic field, these anisotropies can produce at low latitudes maximum of intensity in the daily variation at 0600 and 1800 hours respectively in agreement with the observation of Sarabhai et al[144].

Parker[6] has elaborated the above model and tried to assess the effect on diurnal variation of various kinds of beams with different orientations of the trapped magnetic field and for different positions of the beams with respect to the earth.

After analysing the daily variation for different components of cosmic rays measured at different latitudes and longitudes by various types of instruments, Forman and Fokker[42] find that the best fit for the variation of primary spectrum is given by

$$\frac{\delta D(E)}{D(E)} = aE^{-1}, \quad \text{if } E > 6.6 \text{ Bev}$$

$$= 0 \quad , \quad \text{if } E < 6.6 \text{ Bev}$$

This means that there is an average no solar daily variation for particles with energy less than 6.6 Bev. Parker has found that the source of daily

variation is almost at right angles ($82^{\circ} \pm 8^{\circ}$) to the sun-north line and is to the left side of it. He further points out that with an increase in geomagnetic disturbance the angle between the source and sun-north line reduces.

Such a spectrum of daily variation has been derived by Berman from averages over a long period and therefore takes no account of the highly variable nature of daily variation.

From the directional studies at Ahmedabad, during 1957-1958, Sarabhai and Rao[130] find that the spectrum of variation has a form as $R^{-0.6}$, with the source angle equal to $112^{\circ} \pm 10^{\circ}$, which is quite in agreement with Berman's spectrum. However, on geomagnetically disturbed days they find that the daily variation cannot be adequately explained in terms of an external anisotropy. On such days, they believe, that it is caused by modulation of geocentric origin and they cite a spectrum of R^{0} for the primary variation spectrum on such days with a maximum at noon.

Present theories of cosmic ray variations are not able to explain all the existing experimental facts. The very complicated features of these observations suggest that a number of mechanisms work simultaneously and independently at different times to cause the observed effects. A real understanding of the phenomena appears to depend on the ability to sort out the various experimentally observed

effects of different types and to fit models which would explain not only the change of intensity but also the associated changes of isotropy that are observed.

7. Statement of the problem.

The investigation undertaken by the author was directed towards gaining some understanding of the following questions related to the daily variation.

(1) What is the relationship of the form and magnitude of the daily variation of cosmic ray intensity on the opening angle of the telescope in the E-W and the N-S planes? Is this relationship constant or does it vary from period to period? In other words, we would like to know whether the profile and extent of the source of daily variation are constant or do they indicate variability with time?

(2) The power of the source of the daily variation is known to vary from day to day. It is important to know whether there is overall long term change of the power of the source related to the changes in the electromagnetic conditions of interplanetary space with the changes of solar activity. An answer to this question is of particular significance to theories of daily variation which envisage

a trapped magnetic field in streams of solar particles so that with respect to the earth the stream appears to have electric polarization.

(3) What is the relationship between the daily variation and geomagnetic disturbances?

(4) Are long term changes of the daily variation observed on all days or are they characteristic of days with a particular degree of geomagnetic disturbance?

Since narrow angle telescopes were found to exhibit large amplitudes of daily variation ($\sim$ 1.0 % as reported by Marshall et al[144]) it was believed that a more precise information to some of these questions could be sought by making measurements with narrow angle telescopes. The effects were expected to be enhanced in these telescopes and it was expected that one could study some of the finer features of the daily variation standing out over the level of statistical error associated with the counting rate of the measuring instrument. With this view in mind the author set up a 'narrow angle unit' and took observations with it from January 1957 to May 1959. For comparison of the results with a wide angle telescope, the author maintained the 'standard unit' at the Physical Research Laboratory, Ahmedabad, from October 1955 to May 1959. Both these units have been described in the chapter II.

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CHAPTER II

EXPERIMENTAL ARRANGEMENT

The purpose of making a study with narrow angle telescopes has already been discussed in the previous chapter. In this chapter we shall describe in detail, the experimental set up built by the author to study the time variation of cosmic rays.

An ideal experimental unit should have as high a counting rate as possible to enable us to make precise study of the daily variation on individual days. In practice the size of the instrument is determined by the available resources. Since self-quenched Geiger Muller counters have a limited life, failures are not uncommon and duplicate sets of telescopes not only serve to improve the statistical accuracy of the result but also enable us to standardise and normalise the rates when the counting rate is altered in one of the telescopes due to the replacement of a faulty counter by a good one. Thus it is advantageous to have independent duplicate units rather than one instrument of large counting rate.

As the time variation of cosmic rays was to be studied over a period of several years, precautions were taken to ensure the reliable and continuous running of the units. The mains A.C. voltage of 230 volts was fed to the units through a constant voltage transformer. All 'power supplies' were electronically regulated and

were checked from time to time. Periodic checks were made of counters to locate and replace those that did not function properly. Failure of G.M. counters was minimised and their life increased by using external electronic quenching units and pulses from one circuit to another were fed through properly shielded wires to avoid 'pick up'. Counters were maintained in a heat insulated enclosure to restrict the diurnal range of temperature to $\pm 1^{\circ}C$. For the study of the daily variation, in which the author was mainly interested, this arrangement was considered adequate. The enclosure also protected the counters from exposure to outside light, thereby eliminating the photo-electric effect to which the counters were found to be sensitive.

2. Arrangement of the unit.

Since the present work constitutes an extension of the study of Honrahan[164] at the Physical Research Laboratory, Ahmedabad, during 1954, the basic geometrical considerations in the design of the cosmic ray telescopes used earlier was left unaltered; thus four telescopes of semi-angle $8.5^{\circ} \times 10^{\circ}$, three telescopes of semi-angle $5^{\circ} \times 10^{\circ}$ and one telescope of semi-angle $30^{\circ} \times 10^{\circ}$, measuring the intensity of the hard component of cosmic rays in the vertical direction, were provided. The counting rates of the various telescopes are indicated in the table No. 1.

Table 1

Counting rates and the percentage binomial errors of various telescopes in the 'narrow angle unit'.

Type of telescope. (N-W & E-W semi-angles)	Binomial rate per telescope.	Total binomial rate.	Percent standard error for total binomial rate.
$2.5^{\circ} \times 10^{\circ}$	400	1200	$\pm$ 2.8 %
$5^{\circ} \times 10^{\circ}$	2100	6400	$\pm$ 1.3 %
$20^{\circ} \times 10^{\circ}$	12500	12500	$\pm$ 0.9 %

It is important to realise that of the three $5^{\circ} \times 10^{\circ}$ telescopes, the middle telescope (M in Fig.4) records particles about half of which are common to the two end telescopes (A & C in Fig. 4). Thus, even though we do not have completely three independent telescopes the arrangement proves useful to maintain continuity of records during the failures of individual counters.

The experimental arrangement is shown in Fig. 4.

The unit consists of three trays of 16 G.M. counters each, with an absorber of 10 cm. of lead between the middle tray and the bottom tray to filter out low energy particles. The counters are placed with their

axes along the E-W direction. Each counter has a length of 61 cms. and a diameter of 4 cms. The distance between the top tray and the bottom tray is 180 cms. so that any two counters of the top tray combined with the corresponding two counters of each of the other two trays form a triple coincidence telescope having a semi-angle of 2.5° in the E-W plane.

Pairs of counters are connected in parallel to quenching units Q_1, Q_2, Q_3 ..... Q_8. The outputs of Q_1, Q_2, Q_3 and Q_4 are added respectively to the outputs of quenching units Q_5, Q_6, Q_7 and Q_8 through condensers.

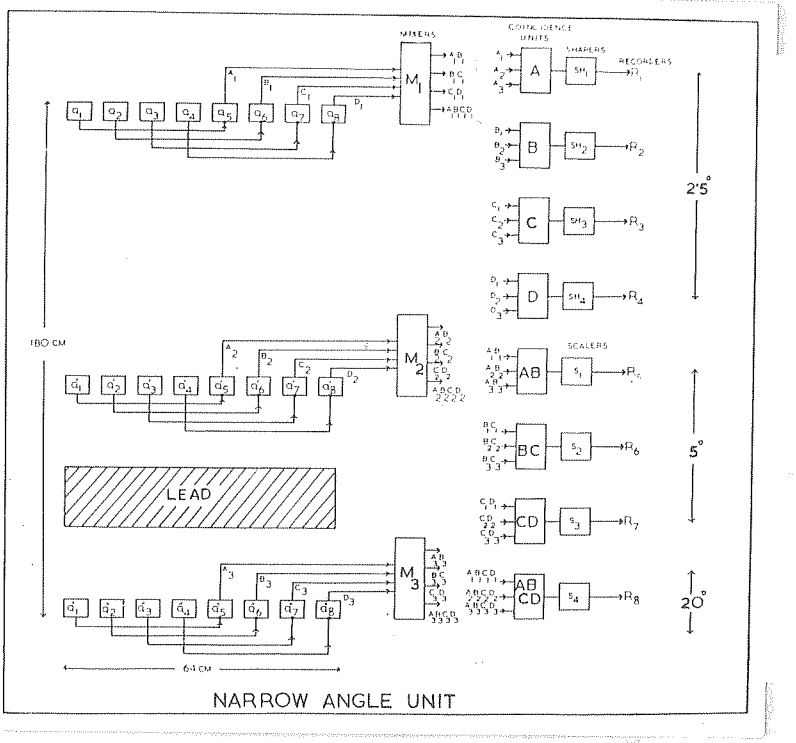

Fig. 4 - A schematic diagram of the arrangement of various telescopes in the 'narrow angle unit'.

Such an arrangement doubles the effective area and hence the counting rate of each of $2.5^0 \times 10^0$ and $5^0 \times 10^0$ telescopes.

The mixed outputs of C_1C_2, C_2C_3, C_3C_4 and C_4C_5, which may be named A_1, B_1, C_1 and D_1 respectively for the sake of convenience, are fed to a diode mixer M_1. The diode mixers are used to get the appropriate combinations of pairs of counters to form telescopes of different openings. Similarly, outputs (A_2, B_2, C_2, D_2) from tray No.2 and (A_3, B_3, C_3, D_3) from tray No. 3 are fed to mixers M_2 and M_3. The following combinations are formed by feeding the pulses from the appropriate pairs of counters:-

(a) A_1, A_2, A_3
B_1, B_2, B_3
C_1, C_2, C_3
D_1, D_2, D_3
} Four 2.5^0 telescopes.

(b) A_1B_1, A_2B_2, A_3B_3
B_1C_1, B_2C_2, B_3C_3
C_1D_1, C_2D_2, C_3D_3
} Three 5^0 telescopes.

(c) $A_1B_1C_1D_1, A_2B_2C_2D_2, A_3B_3C_3D_3$ } One 10^0 telescope.

The output from the coincidence unit of each 2.5^0 telescope is fed to a 'shaper' and then to a mechanical recorder. For the 5^0 telescopes and the 10^0 telescope the outputs are fed through 'pealing units' of 4 and 16

respectively to the mechanical recorders. The purpose of having a 'stepper' or a 'scaling unit' before the recording stage is described later.

Besides the 'narrow-angle unit' the author has made additional observations with a 'standard unit' of this laboratory. Such a unit has been in operation at Ahmedabad from 1951 onwards. The author took charge of its operation in October 1955 and maintained it till May 1959.

The 'standard unit' is made up of four similar telescopes, each having an opening of 82^{0} in the E-W plane and 97^{0} in the N-S plane. The combined counting rate of all four telescopes is 15,000 / hour. The schematic diagram of the unit is given in Fig. 5.

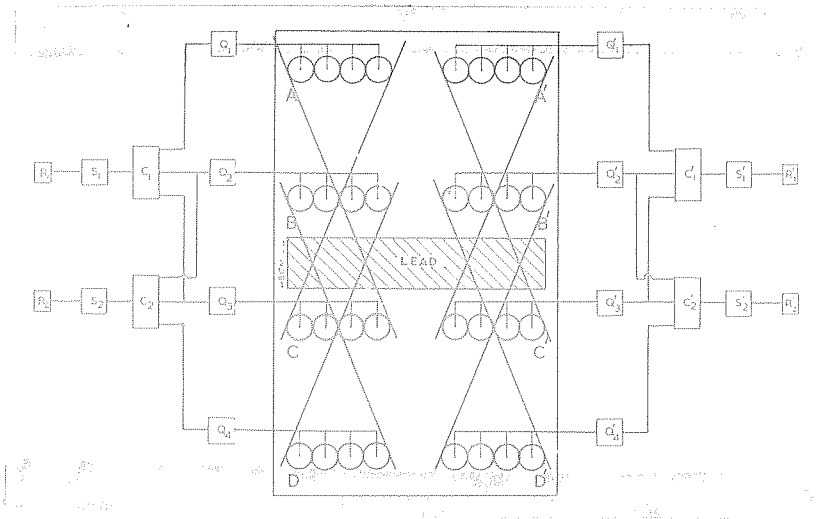

Fig. 5 - Schematic diagram of the 'Standard unit'.

Two identical sets of four trays A, B, C and D and A', B', C' and D' are mounted side by side with a separation of 20 cms. between individual trays of each set. 10 cms. of Pb absorber is included between the second and the third tray of both the sets. The counters used in this unit have a length of 30 cms. and a diameter of 4 cms. and are mounted so that their axes lie along the north-south direction. Each tray consists of four counters which are joined in parallel to a common quenching circuit. Triple coincidence rates ABC, BCD, A'B'C' and B'C'D' are separately recorded. The telescopes one above the other have many common particles and the unit essentially furnishes the vertical intensity measured by a duplicate set of pairs of telescopes. Further details of the components of the total apparatus are given below.

2. Geiger Muller Counters.

A Geiger Muller counter is essentially a diode, filled with some rare gas like argon, and operates in the region of the unstable corona discharge. The passage of a single ionizing particle through it is sufficient to trigger a discharge. The discharge lasts only for a few micro-seconds and finally gets quenched due to the development of positive space charge near the central wire. As a result of production of discharge and its immediate quenching a voltage pulse is developed across the counter which can be suitably amplified and detected. The quenching of the discharge is helped by the addition of a polyatomic vapour

such as ethyl acetate to the counter gas. The decomposition of the quenching vapour following each discharge sets a limitation to the useful life of a counter. Spata[100] has estimated the useful life of a self-quenched counter to be of the order of 10^{10} counts.

The important characteristics of a Geiger counter are its threshold voltage, the length and slope of its plateau, its efficiency, pulse characteristics, temperature dependence and its useful life. No single type of counter exhibits all of the ideal characteristics. The theory of counter discharge has been extensively studied and its complete description is well discussed in literature (Wilkinson[101], Korff[102], Montgomery[103], Stever[104], Curran[105], Friedman[106]).

In the present investigation metal counters were used. Most of them were prepared by the author himself. The method of preparation is described below.

A thin brass tube of 4 cm. diameter is used as a cathode and a tungsten wire of diameter 4 mils. as an anode. The brass tube is fitted at the ends with two well fitting brass discs in the centre of which holes are drilled for attaching glass bushings carrying the central wire. The glass bushings are used for evacuating and filling the counter.

First of all the inside of the brass tube and the end fittings are well polished and then cleaned in succession by petrol and ethyl acetate in order to remove dirt

sticking to the cathode surface which could give rise to spurious counts. The counter parts are next assembled together and a suitable length of 4 mil. diameter tungsten wire is threaded through the capillary of the glass seal.

Metal to metal joints and metal to glass joints are then heated to a temperature of about 300°F and a thermosetting resin, called Ethocyline (Araldite), is applied to the joints to form a leak proof sealing. The entire assembly is allowed to cool till the araldite sets firmly. The thin tungsten wire forming the anode is spot welded at both ends to thicker tungsten wire which protrudes outside the glass necks. These are then soldered to copper wires using an alloy of nickel and silver to provide the external electrical contacts.

The counter is now ready for evacuation. During evacuating its surface is slightly heated to drive away moisture. The central wire is heated to a dull red glow by passing an electrical current through it. This burns off dust and sharp points on it. After evacuation the counters are left as such for 24 hours and then tested for any small leakage. Leak proof counters are filled with 1 cm. of ethyl acetate and 9 cm. of argon. The mixing of these gases is allowed for about three hours and the counter is then tested for a plateau. Counters showing a minimum plateau of 800 volts, having a slope of less than 2 % in 100 volts are sealed at the constriction provided in the glass sleeving. All such counters

are finally 'aged'; that is, they are operated in the middle of the plateau for about a day, and only those counters which retain a good plateau are used in the cosmic ray unit.

3. Quenching Unit.

A quenching unit makes a counter inactive for a short duration immediately after a pulse is developed in it. This restricts the development of any spurious pulses in the counter and adds to its useful life. A quenching circuit also furnishes a uniform sharp output pulse to trigger a coincidence circuit.

Such an external quenching action is attained by a monostable multivibrator (Fig. 6) which when triggered by a counter discharge pulse, produces a rectangular negative pulse of 250 volts and of duration 1000 micro-seconds at the anode of the counter. To make it acceptable

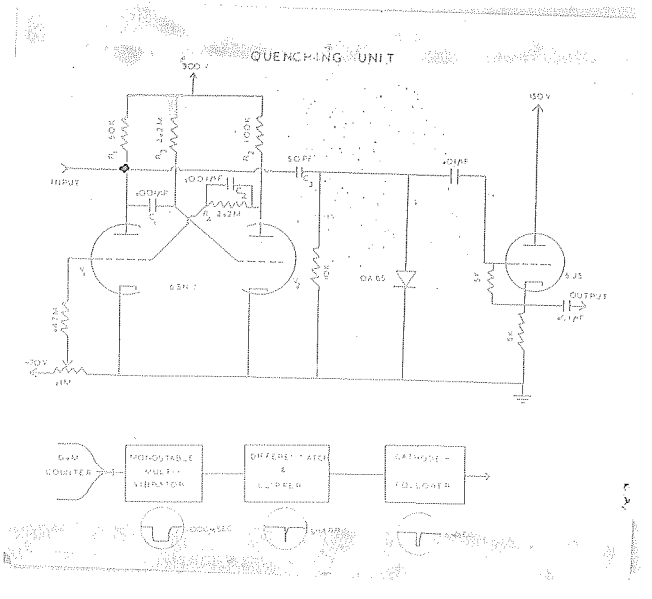

Fig. 6 - Circuit diagram of a quenching unit.

to a fast coincidence circuit it is differentiated by a RC network having a small time constant. The sharp positive pulse generated is by-passed through a crystal diode. Since the negative pulse is to be fed to a number of channels it is preferable to feed it through a cathode follower having a low output impedance which minimises the loss of signal.

4. Mixer Circuit.

The 'mixer' circuit used in the 'narrow-angle' unit to obtain telescopes of different openings is shown in Fig. 7. Ordinary 6H6 diodes have been used as mixer tubes. Inputs A, B, C and D of four 2.5° telescopes are mixed properly to give, in the output, the combinations AB, AC and CD which form three 5° telescopes, and a combination ABCD which forms a 20° telescope.

5. Coincidence Unit.

The coincidence circuit (Fig. 8) used is of the well known Bossi type[17]. The anodes of sharp cut off pentodes (6SJ7) are tied together to a common resistance. The pentodes are normally conducting. But when negative pulses from quenching units arrive simultaneously or within a short duration of a few microseconds at the grids, the pentodes become non-conducting. This gives rise to a large positive pulse at their common anode resistance. The high discrimination between partial and total coincidence is achieved by the use of sharp

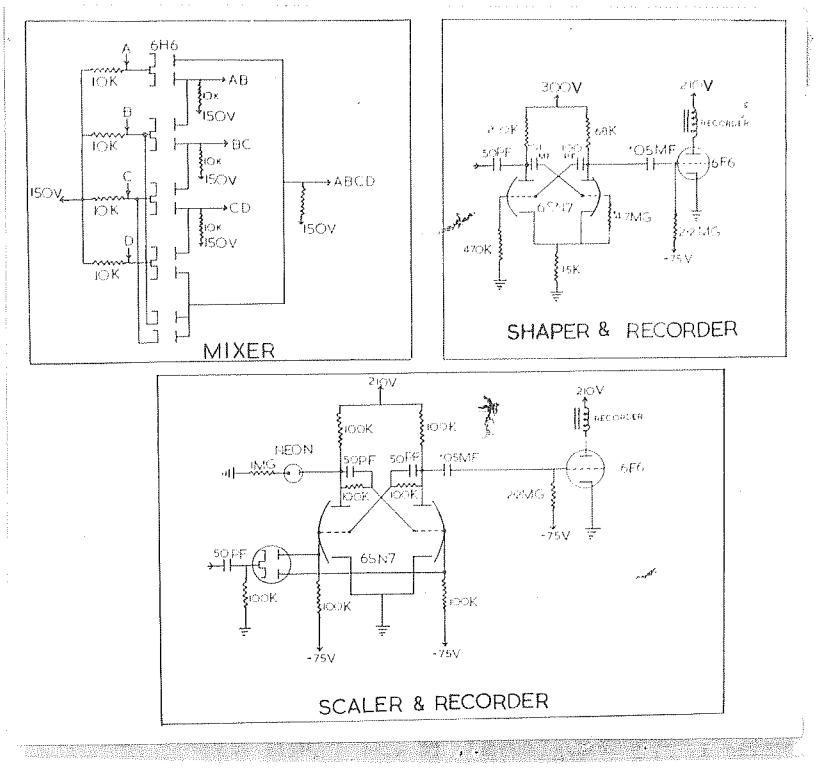

Fig. 7 - Circuit diagram of a 'mixer', 'shaper' and a 'scaler'.

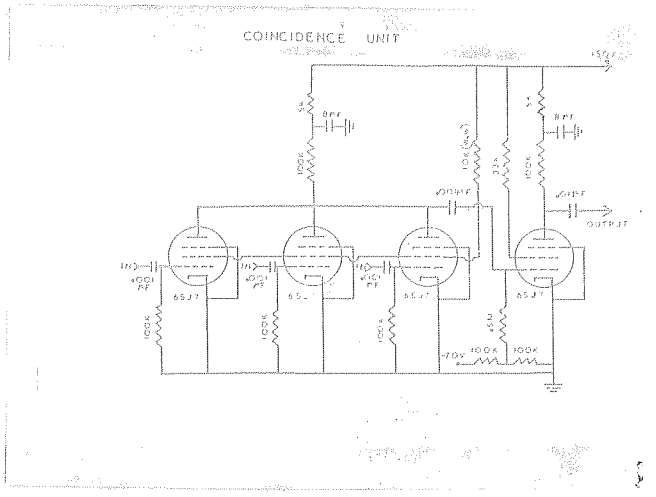

Fig. 8 - Circuit diagram of a triple coincidence unit.

cut off pentodes. The sharp positive pulse derived from a coincidence activates a 'discriminator' pentode which is biased much below cut off to avoid response to partial coincidence pulses. It also reverses the phase of coincidence pulse from positive to negative polarity.

6. Scaler and Recording Unit.

Introduction of a scaling unit before the final recording stage reduces the input rate to the mechanical recorder and at the same time changes the random distribution of pulses into more regularly spaced ones. This eliminates any loss of pulses by a mechanical recorder because of its otherwise poor resolution.

The circuit used as a 'scaler' is a usual bistable multivibrator which has been described in detail by many authors (Freeman[190], Nitchie[199], Fitch[200]).

Fig.7 shows the basic circuit of a scale of two unit any number of which can be put in cascade to increase the scaling factor. For a fast switching action tubes having low input capacitance and high gm are selected. Twin triode 6N8V meets these requirements well.

The final output of the scaler is fed to the grid of a power pentode (6V6) biased beyond cut off. The plate voltage to this tube is applied through the solenoid of a mechanical recorder. A positive pulse appearing at the grid makes the tube conducting to actuate the mechanical recorder.

7. Shaper.

When the counting rate of a telescope is low enough, as in the case of 8.6^{0} telescopes, no 'scaler' is needed, but it is advisable to shape the sharp coincidence output pulses to trigger the power amplifier and the mechanical recorder. A cathode biased monostable multivibrator (Fig. 7) is used for this purpose. This gives a square positive pulse which when fed to the grid of a non-conducting amplifier CV6, makes it conducting for an adequate time to drive the mechanical recorder.

8. Automatic Photographic Unit.

An automatic photographic device is used to obtain hourly records of cosmic ray intensity.

Mechanical recorders of all telescopes together with a clock and a date index are mounted vertically on one side of a light proof box. To the other side is attached a short range open shutter type camera which can be detached easily. The camera holds about 20 feet of 35 mm. Kodak Super XX film which suffices for about 15 days.

To the inside of the light-proof box are fixed two electric lamps which flash every hour for a fraction of a second with the help of a relay arrangement triggered by an electric contact made hourly by a synchronous clock. The exposed film is wound on a spool inside the camera

which is geared to the shaft of a low speed motor. The gearing is adjusted so as to move the film through only one frame after each exposure.

9. Automatic Sequence Control Circuit.

Such a circuit flashes the bulbs momentarily, rolls the exposed film on a spool and then resets to its original condition for the next event. The circuit diagram is shown in Fig. 9.

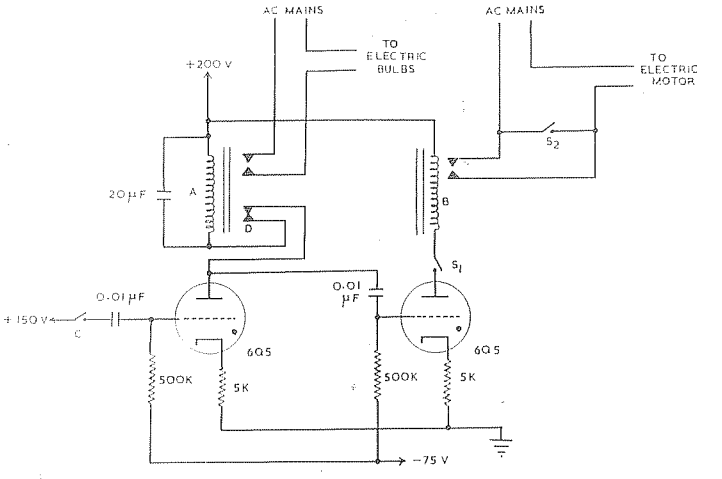

Fig. 9 - Automatic sequence control circuit.

When the clock makes an hourly contact a positive pulse of 150 volts is fed to the grid of a highly biased thyratron T_3, which makes it conducting. A relay contact flashes the bulbs. At the same moment the thyratron T_1 becomes non-conducting due to the opening of the second contact of the relay which switches off the lamps. A momentary positive pulse thus generated at the plate of thyratron T_1 makes the otherwise non-conducting thyratron T_2 conducting. S_1 and S_2 are the press button switches within the motor. Two ebonite plates mounted on the shaft of the motor are so arranged as to press against these switches S_1 and S_2 alternately with the result that when one of them is on, the other remains in the off position and vice versa. Thus when thyratron T_2 conducts, relay contact is made and motor moves. The relay contact continues till S_1 switch is on which is for about 30 seconds. After that S_1 breaks which makes the thyratron T_2 non-conducting. But simultaneously S_2 contact is made and that runs the motor for further 15 seconds. After that S_2 contact breaks and S_1 contact is once again made which brings the whole circuit to its original condition.

10. Power Supplies.

The D.C. voltages that were used in the 'narrow angle unit' and the 'standard unit' are,-

(1) High voltage (~ 1000 V) for counters.

(2) 300 Volts for quenching units.

(3) 200 Volts for 'Scalers', 'Recording Unit' and the automatic camera control unit.

(4) 150 Volts for 'Coincidence', 'Cathode follower' and the 'Mixer' unit.

(5) -75 Volts for the general grid bias for various circuits.

The high voltage power supply for counters and low voltages of 300 and 150 volts were constructed by utilising a degenerative type stabiliser circuit, the complete analysis of which is given by Hunt and Hickman [201] and Oliver [202] and Rutland [203].

The circuit diagram for a unit to provide stabilised supply of 300 volts is given in Fig. 30.

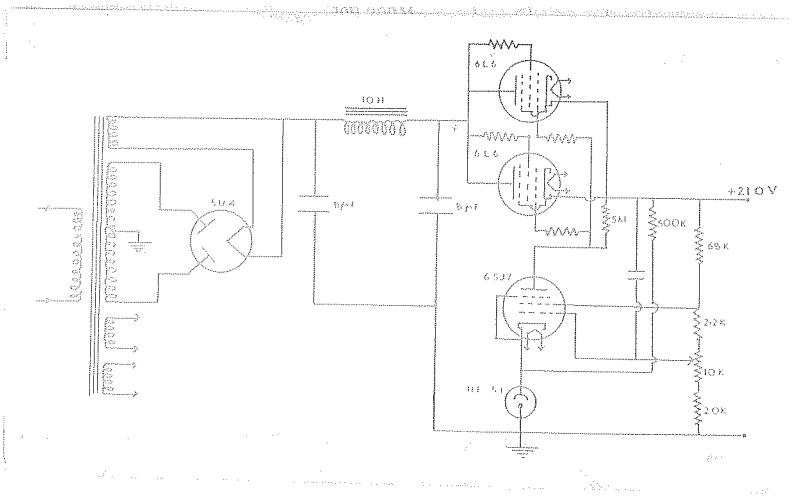

Fig. 30 - Circuit diagram of the electronically regulated power supply of 300 volts.

(1) High voltage (~ 1000 V) for counters.

(2) 300 Volts for quenching units.

(3) 200 Volts for 'Scalers', 'Recording Unit' and the automatic current control unit.

(4) 150 Volts for 'Coincidence', 'Cathode follower' and the 'Mixer' unit.

(5) -75 Volts for the general grid bias for various circuits.

The high voltage power supply for counters and low voltages of 300 and 150 volts were constructed by utilising a degenerative type stabilizer circuit, the complete analysis of which is given by Hunt and Hickman[201] and Olivery and Hatland[202].

The circuit diagram for a unit to provide stabilized supply of 300 volts is given in Fig. 10.

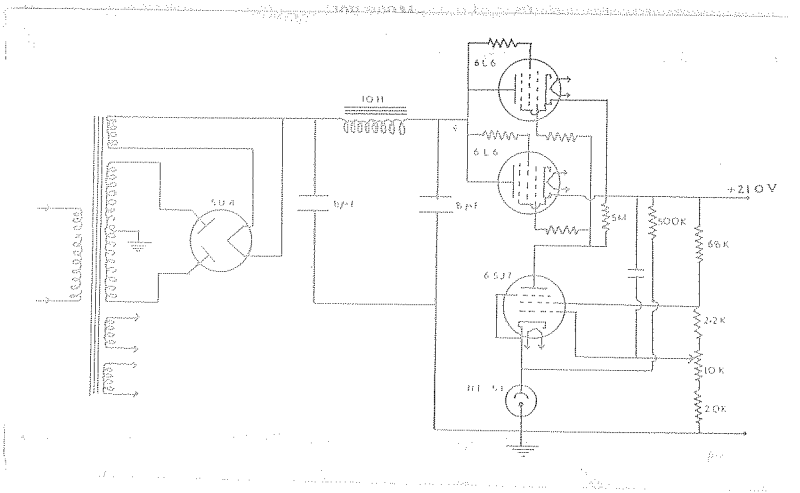

Fig. 10 - Circuit diagram of the electronically regulated power supply of 300 volts.

The 6L6 tube is used as a regulator tube while 6SJ7 tube is used as a feed-back amplifier under 'starved' conditions (low screen voltage and high plate resistance) which improves the per cent regulation considerably (Valkers[309]). Current to the reference tube is fed from the regulated (output) side which ensures more stability and therefore improves regulation.

Fig. 11 gives the circuit diagram of the high voltage power supply. Here 807 tube is used as a regulator tube and 6L6 as a feed-back amplifier. VR90 is used as a reference tube. The output voltage can be varied from 800 volts to 1300 volts.

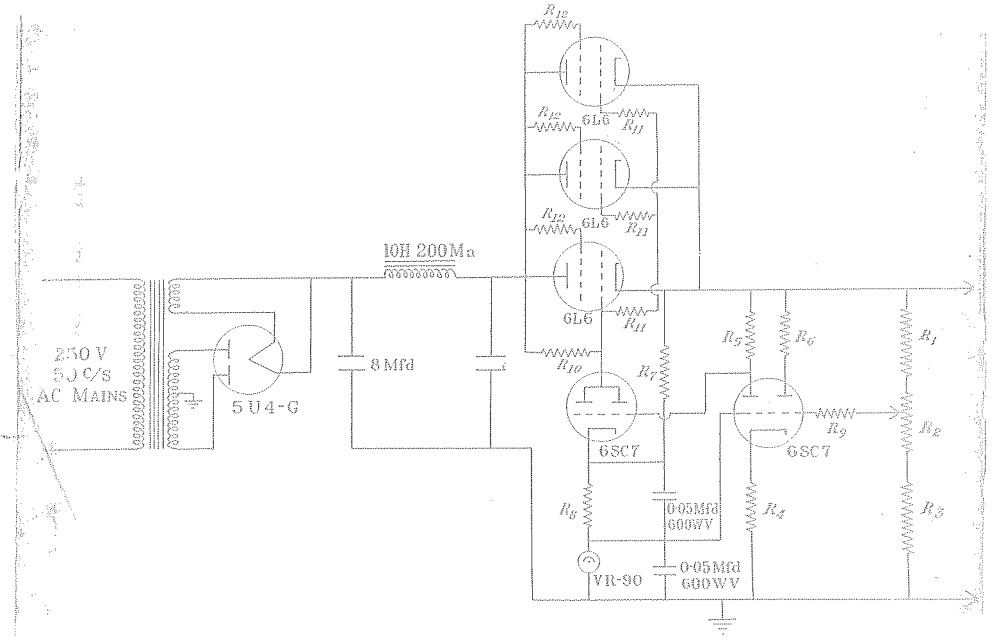

Fig. 11 - Circuit diagram of the electronically regulated high voltage power supply.

D.C. voltage of 300 volts was stabilized by a circuit based on the double triode difference amplifier, described by Elmore and Sands[304]. Both the plates of

6SC7 amplifier are fed approximately 300 volts to obtain symmetrical behaviour with respect to currents and voltages. Standard reference voltage given by VR105 is applied to the grid of one-half of the 6SC7 tube and the other grid is connected to the sampling network. The error voltage amplified by the difference amplifier is further amplified by a second 6SC7 tube before being fed to the grid of the regulating tube 6L6.

Fig. 12 shows the circuit diagram of the difference

CIRCUIT DIAGRAM OF 300 V POWER SUPPLY.

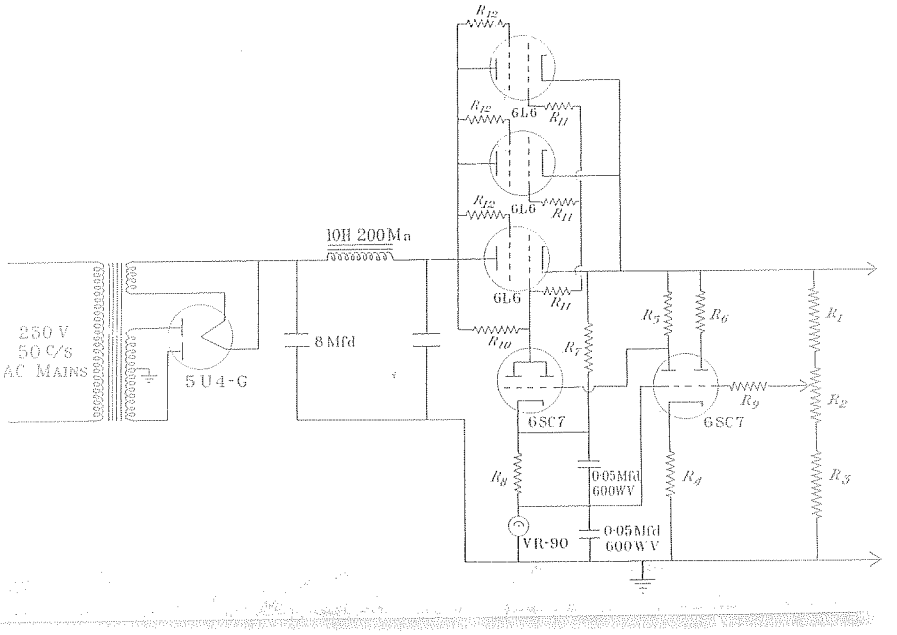

Fig. 12 - circuit diagram of the electronically regulated power supply of 300 volts.

amplifier regulator. The circuit is found to be very stable even for loads up to 300 ma.

+75 voltage is stabilized by using VR75 tube as a stabilizer (Fig. 13).

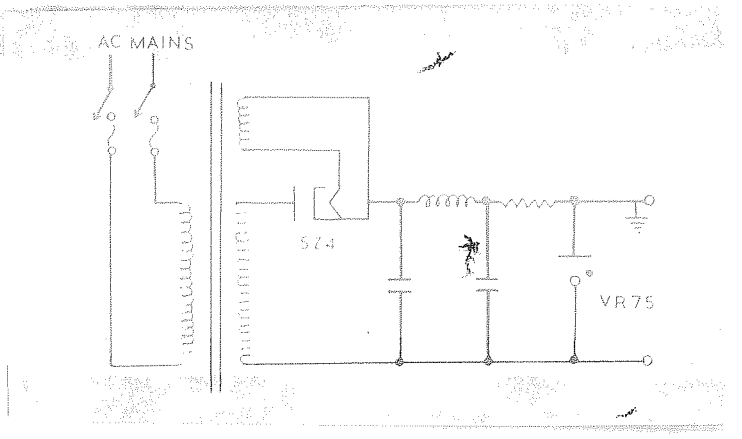

Fig. 13 - Circuit diagram of a stabilized +75 volts.

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CHAPTER III

METHOD OF ANALYSIS.

1. Processing of data.

From the hourly photographs of mechanical recorders, reading at the hours 2300, 0100, 0300, 0500 ..... 2100 I.S.T., are noted down daily. The difference between successive readings gives the hourly intensity of cosmic rays centered at 0000, 0200, 0400, 0600 ..... 2300 hours. The arithmetic mean of these twelve hourly readings gives the cosmic ray hourly mean intensity for the day. All hourly rates are then expressed as deviations from this daily mean.

When more than one telescope of similar geometry exist an intercomparison test is made to check the reliability of data. The telescopes are grouped into two and the difference, Δ, of their hourly counts is found over a certain period. In an ideal case when the telescopes have exactly the same dimensions and the recording sensitivity, the mean of these differences should be zero. However, in practice, it is not possible to have such ideal telescopes and the mean of the differences is always found to have some finite value, $\overline{\Delta}$. It is now checked whether in 95 % of cases the deviations of the difference Δ from the mean $\overline{\Delta}$ of the series remain within 2σ-level, where σ is the standard error of the

difference of the hourly counting rates of the two telescopes and is given by

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2}$$

where σ_1 and σ_2 are the hourly standard errors of the counts recorded by the two telescopes. The various groups of two of similar telescopes are compared in this manner and data from a telescope which is not consistent with the above test is rejected.

After scrutinizing the data in this manner each hourly deviation of similar telescope is added and expressed as percent deviation from the daily mean hourly rate. Correction for the atmospheric pressure changes is then applied to the hourly percent deviations by using a barometric coefficient of -0.72 % per cm Hg, on the grounds discussed by Sarabhai et al [101].

As is discussed in the 'Introduction' (page 10), the temperature correction to the daily variation of cosmic rays is expected to be of the order of 0.15 % at Ahmedabad. Daily variation on individual days is examined only when the amplitudes are significant at the 2 σ-level ($\sim$ 1.0 %) and for such days the application of the temperature correction is not of material importance. But one is often dealing with daily variation averaged over groups of days for which amplitudes of the order of 0.3 to 0.5 % are statistically significant. In such cases an appropriate temperature

correction of 0.0234 % per C^0 has been applied which is derived from the diurnal range of temperature near the surface following the procedure of Carnbhal and Rao[47]. For day to day changes of cosmic ray intensity, when large effects of the type of Forbush decreases are considered, the temperature correction is not important.

After applying correction for barometric pressure the data for each day is punched on a Hollerith card according to the scheme given below:-

Column		Information
1, 2	..	Description of the telescope.
3, 4	..	Year.
5, 6, 7	..	The day of the year.
10, 11	..	C_p index for the day.
14 - 37	..	Pressure corrected 12 hourly values of cosmic ray intensity.
38, 39	..	Sum of 12 hourly values.
41, 42	..	Range of r_1 and r_2 (the 1st and 2nd harmonic components).
47 - 50	..	Mean hourly rate of the day.
51 - 58	..	1st and 2nd harmonic co-efficients (a_1, b_1, a_2, b_2)
60 - 66	..	r_1, r_2, ϕ_1, ϕ_2.
67, 68	..	r_{1/r_2}

2. Normalised mean intensity.

Since we have several similar telescopes, the mean intensity for a day is represented by the sum of mean hourly counts of all telescopes in operation on the day. However, on a particular day not all of them may be working. Under such circumstances an estimate of the mean intensity is made from the rates of properly working telescopes in the following manner.

Let $n_1^j, n_2^j, \ldots\ldots n_x^j$ be the individual mean rates of any number, x, of similar telescopes on the j^{th} day. Then the total intensity for that day will be given by

$$n^j = n_1^j + n_2^j + n_3^j + \ldots\ldots + n_x^j.$$

If the telescope of rate n_1^j is not working on the j^{th} day, then the intensity is normalised by making use of data on the preceding five days and the normalised intensity on that day is given by

$$n^j = \frac{(n_2^j + n_3^j + \ldots\ldots + n_x^j) \sum_{j=1}^{j-5} n^j}{\sum_{j=1}^{j-5} (n_2^j + n_3^j + \ldots\ldots + n_x^j)}$$

If the failure in the telescope is because of break down of an electronic unit then the sensitive area of the telescope does not change and the mean intensity before and after the j^{th} day are directly comparable.

However, in case the failure of the telescope is due to a counter failure, it is difficult to replace it by another counter having exactly the same characteristics. Under such circumstances the total mean rate before and after the counter failure will not be directly comparable and in order to bring the new series of the mean intensity to the previous level it has, therefore, to be multiplied by a factor K, which is derived from the mean intensity of the telescopes five days before and after the j^{th} day and is given by

$$K = \frac{\sum_{j-1}^{j+5} n^j \;\; \sum_{j+1}^{j+5} (n_2^j + n_3^j + \ldots\ldots + n_x^j)}{\sum_{j-1}^{j+5} n^j \;\; \sum_{j-1}^{j-5} (n_2^j + n_3^j + \ldots\ldots + n_x^j)}$$

3. 'Cross' Analysis.

The method of Cross analysis was originally thought of and used by Cross[205] in investigating whether there was association between geomagnetic phenomena and phenomena existing on the sun. Since then the method has been used extensively for finding relationships between any two variables.

Epochs of one of the variables are chosen on the basis of some criterion and the values written down in a row for a number of days prior and later to each epoch, the extent depending upon the nature of the problem

under consideration. The epochs are then super-imposed and the gross effect of the selection criterion is found. For these epochs, values of another variable (the one with which the relation is to be found) are superimposed in a similar manner and the mean effect found. The graphs of the two parameters, then reveals the nature of the relation, if any, between the two parameters. A relationship, if present, can be distinctly seen only when the number of epochs is large.

4.1. Fourier analysis.

For cosmic ray studies it is important to know the nature of periodicities involved in the daily variation and the relationship of these periodicities with known geophysical and astrophysical periodicities. For most geophysical problems the first and the second harmonics have been found to represent the variations almost completely.

The method of resolving a periodic curve into its harmonics have been treated rigorously by various authors such as Whittaker and Robinson[206], Thompson[207], Hanny[208] and Rao[209].

Any time dependent function $f(t)$ can be written as a Fourier series of the type

$$f(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos nt + b_n \sin nt)$$

where $0 < t < 2\pi$.

a_0, a_n, b_n are independent of t and are called 'Fourier co-efficients',

Where the experimental curve can be defined by twelve equally spaced value y_0, y_1 ..... y_{11} corresponding to the times t_0, t_1 ..... t_{11} respectively this analysis determines the co-efficients a_0, a_n and b_n in such a way that the residual values of $\left[y_1 - F(t_1)\right]$ are as small as possible.

Since the twelve values are expressed as deviations from their mean, the co-efficient a_0 becomes zero. The co-efficients a_n and b_n in a twelve ordinate scheme are given by

$$a_n = \sum_{1}^{12} \frac{y_1 \cos n t_1}{6} \quad \text{and}$$

$$b_n = \sum_{1}^{12} \frac{y_1 \sin n t_1}{6}$$

where n represents the order of the particular harmonic component under consideration.

The function f(t) can be rewritten as

$$f(t) = a_0 + \sum_{1}^{\infty} r_n \sin (nt + \psi_n)$$

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 from the relations

$$r_n^2 = a_n^2 + b_n^2 \text{ and } \tan \psi_n = \frac{a_n}{b_n}.$$

Since the set of twelve values is taken over a period of 24 hours r_1 and ψ_1 represent the amplitude and phase of the 1st harmonic having a period of 24 hours. Similarly r_2 and ψ_2 represent the amplitude and phase of the 2nd harmonic.

Conversion from the phase angles ψ_1 and ψ_2 into more convenient times of maxima ϕ_1 and ϕ_2 of the first and second harmonic components respectively are done with the help of the relationship $\phi_1 = 90 - \psi_1$ and $\phi_2 = 90 - \psi_2$.

For the calculation of amplitude and phase of 1st and 2nd harmonics from the daily twelve hourly data scheme a chart designed by Kano[200] has been used in the present investigation.

4.2. Standard error of Fourier co-efficients.

If the standard error in each of the twelve hourly values $u_0, u_1 \ldots\ldots u_{11}$ is q then error in a_0 is $\delta a_0 = \frac{q}{\sqrt{12}}$ and $\delta a_n = \delta b_n = \frac{q}{\sqrt{6}}$.

The error in amplitude of the harmonic component is given by

$$\delta r_n = \sqrt{\left(\frac{\partial r(x)}{\partial a_n}\right)^2 . \delta a_n^2 + \left(\frac{\partial r(x)}{\partial b_n}\right)^2 . \delta b_n^2}$$

$$= \sqrt{\frac{a_n^2}{a_n^2 + b_n^2} \cdot \delta a_n^2 + \frac{b_n^2}{a_n^2 + b_n^2} \cdot \delta b_n^2}$$

$$= \frac{q}{\sqrt{c}}$$

and the error in phase angle ψ is given by

$$= \sqrt{\left(\frac{b_n^2}{a_n^2 + b_n^2}\right)^2 \cdot \frac{1}{b_n^2} \cdot \delta a_n^2 + \left(\frac{b_n^2}{a_n^2 + b_n^2}\right)^2 \cdot \frac{a_n^2}{b_n^4} \cdot \delta b_n^2}$$

$$= \frac{\delta x_n}{\sqrt{a_n^2 + b_n^2}} = \frac{\delta x_n}{x_n}$$

5. Comparison of histograms.

A problem that often arises in statistical analysis of cosmic ray data is to determine whether the samples under consideration belong to the same population or not. In any case of normal distribution or distributions which can be approximated to normal (such as Poisson's distribution) it is sufficient to make comparison of two parameters of the sample; namely, the 'mean' and the 'variance'.

To determine whether the means $\bar{x}_1$, $\bar{x}_2$, of the two samples are significantly different a null hypothesis is made that they are not different and that the difference

observed is due to chance sampling. It can be shown by mathematical analysis that when the population from which the two samples are independently drawn are normal populations, then the sampling distribution of difference of means of these two samples, $\bar{x}_1 - \bar{x}_2$, is also normal, the mean of the distribution being zero and its variance being equal to

$$\sigma^2 = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

where n_1 and n_2 are the number of observations in each sample and σ_1 and σ_2 their variances.

The ratio $t = (\bar{x}_1 - \bar{x}_2)/\sigma$ follows the 't' distribution which tends to a normal distribution for a large sample. A 't' table then gives the probability of obtaining a 't' value as large as one obtained from the sample under consideration on the basis of chance alone. If from the 't' table the t value does not fall within t distribution (or normal distribution when the sample is large) at 5 % level then it can be said that the difference between the means of the two samples is due to inherent difference in the populations from which the samples are derived.

In testing the difference between two sample variances the first step is to set up a null hypothesis that the difference in variance is not due to some specific factor, but is caused by only chance. The statistic that

is used for this problem is the ratio of the two maximum - likelihood estimates of population variance, that is

$$\frac{\hat{\sigma}_1^2 \cdot \frac{n_1}{n_1 - 1}}{\hat{\sigma}_2^2 \cdot \frac{n_2}{n_2 - 1}}$$

where n_1 and n_2 are the number of observations in each sample and $\hat{\sigma}_1^2$ and $\hat{\sigma}_2^2$ their variance.

If the two populations have identical variance, these two estimates will be approximately equal and the above statistic will be close to 1. That is, if pairs of samples are drawn independently from populations with identical variance and if the ratio of the maximum likelihood estimate of variance is calculated from each pair, these ratio will have a frequency distribution that is of the form of 'F' distribution with mean equal to 1.

To test the given hypothesis it is necessary to note whether the above ratio is greater or less than the 0.05 point of 'F' distribution for a certain degrees of freedom n_1 and n_2 given by $n_1 = n_1 - 1$ and $n_2 = n_2 - 1$. In case the ratio falls within the .05 point value then the null hypothesis is not rejected and the difference in variance of the two samples is attributed to chance. Otherwise it is attributed to a real difference in population variance.

By making such a comparison of 'means' and 'variances' of frequency distributions of the diurnal and the semidiurnal components of the daily variation of cosmic rays belonging to different years it can be tested whether the samples differ statistically from year to year.

6. The χ^2 test.

As a measure of compatibility of observed and expected frequencies it is customary to calculate a quantity called χ^2, which is defined by

$$\chi^2 = \frac{\sum (f_o - f_e)^2}{f_e}$$

where f_o and f_e denote the observed and expected frequencies. A value of zero would correspond to exact agreement with expectation whereas increasingly large values of χ^2 may be thought of as corresponding to increasing poor experimental agreement.

χ^2 test can be used in a variety of problems. If the time of maximum of the daily variation of cosmic rays has no preference for any hour then one should expect the frequency of occurrence to be equally distributed among twelve bihourly periods. From the observed frequencies and the expected values one can compute χ^2 and see from the χ^2 table whether it falls within χ^2 distribution at 5 % level. In that case the observed frequency distribution can be taken as random distribution. Thus smaller the value of χ^2 the larger is the variability of the time of maximum and vice versa.

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CHAPTER IV.

EXPERIMENTAL RESULTS.

1. Introduction.

The results that are presented in this chapter relate mainly to the intensity of the hard component at Ahmedabad ($\lambda = 13.0^{\circ}$) measured with the 'standard unit' and with the narrow angle unit which have already been described in Chapter II.

(a) The Standard unit.

Even though the 'standard unit' has been in operation since 1951, the earlier data could not be utilised for analysis on a day to day basis due to frequent interruptions in its operation. The author was responsible for the maintenance of the unit from October 1955 and in this thesis results from the analysis of data for the period June 1954 to May 1960 are presented.

Table 2 shows the number of working days in each month. As is evident from the table, there are two major breaks in the continuity of data, the first one in June 1957 due to renovation of the units, and the second during September and October 1957, when metal counters were replaced by mica counters which, however, did not work satisfactorily.

Table 2.

Number of days in each month for the period July 1954-May 1955 for which daily variation data are available for the standard telescope.

Period	J	F	M	A	M	J	J	A	S	O	N	D
1954							31	27	18	13	30	14
1955	18	23	24	22	26	30	18	28	18	27	29	19
1956	19	20	25	21	27	26	25	19	23	30	28	28
1957	20	21	28	20	20	-	25	27	-	-	23	23
1958	24	25	27	26	25	26	31	29	23	24	29	29
1959	27	25	30	25	28							

Table 3.

Number of days in each month for the period January 1957 to May 1959 for which daily variation data are available for various telescopes in the narrow angle unit.

Type of telescope.	J	F	M	A	M	J	J	A	S	O	N	D
1957												
2.5°	28	9	12	28	27	25	30	29	21	13	19	31
5°	20	9	12	25	25	25	26	23	20	19	17	31
20°	-	-	-	18	23	11	23	19	-	-	-	23
1958												
2.5°	28	26	30	28	26	28	29	29	22	23	22	30
5°	24	27	23	26	26	24	29	30	22	20	28	30
20°	21	18	14	20	21	19	26	22	19	20	19	26
1959												
2.5°	28	28	26	26	26							
5°	26	28	26	27	26							
20°	21	23	17	21	21							

(b) The narrow angle unit.

The data of the 'narrow angle unit' which is discussed in this thesis extends over two continuous periods. For the earlier period, extending from August 1954 to July 1955, it was obtained by Sarabhai and Narurkar[144]. The results indicate a large amplitude of the daily variation observed with narrow angle telescopes during that period. The author rebuilt the narrow angle unit towards the end of 1956 with slight modifications. The details of the unit have already been described in Chapter II. The object was to study the dependence of daily variation on the opening angle of the telescope during the solar maximum period of 1957 and 1958.

Table 3 gives the number of working days of various telescopes during each month for the period it was operated by the author.

2. Scope of the present study.

The daily variation can be studied by examining twelve hourly percent deviations from the mean intensity for the day. If the average daily variation over an extended period of time or few days classified on some criterion is to be considered the average hourly deviations for the group of days is determined. Depending upon the statistical accuracy associated with each hourly deviation and the particular physical causes which are operative, the twelve successive hourly

deviations form a curve which is either smooth or one with a zig zag course. In the latter case, a reasonably satisfactory smooth curve may be fitted by combining a harmonic analysis of the twelve hourly deviations and superposing at least the diurnal and the semidiurnal components of the variation.

The daily variation is often studied by many authors only in terms of the amplitude and the hour of maximum of its diurnal component. However, Kamiat et al have shown that many interesting features of physical importance are missed in such an examination. In the present study we shall first examine the hourly deviations, and the smooth curve fitted to them whenever this is called for, and we shall also follow the traditional approach of examining the diurnal and the semidiurnal components of the daily variation.

Barometric and temperature correction have been applied to the daily variation of cosmic ray intensity as described in Chapter III. The amplitudes and times of maxima of diurnal and the semidiurnal components, after applying meteorological correction, are represented by r_1, ϕ_1 and r_2, ϕ_2 respectively, and their mean values averaged over an extended period of time or for days selected on the basis of some criterion are represented by $\bar{r}_1$, $\bar{\phi}_1$ and $\bar{r}_2$, $\bar{\phi}_2$ respectively.

In this chapter we present the results showing the dependence of short and long term changes of daily

variation on the opening angle of the telescope and their relationship with geomagnetic disturbances. In addition, the dependence of Forbush type decrease on the opening angle of the telescope is also studied.

3.1. Daily variation observed with telescopes of different openings in East-West plane.

Fig. 14a shows the daily variation of intensity measured with telescopes of semiangles of opening $2.5^{\circ} \times 15^{\circ}$, $5^{\circ} \times 15^{\circ}$ and $30^{\circ} \times 15^{\circ}$ averaged for the period 1957 and 1958.

The daily variations reveal one maximum which occurs during the day hour mean. Taking the statistical error into account, the amplitudes of the daily variation observed with these three telescopes, having different openings in the E-W plane, are not significantly different from each other. This result stands in contrast to the observation of Serabhai and Nerurkar[144] who showed that during 1954, the amplitude of the daily variation increases from 0.8 to 1.6 % when the opening angle of the telescope in E-W plane is decreased from 15° to 5°. It, therefore, seems that large amplitude of 12 month mean daily variation associated with narrow angle telescopes during 1954 does not persist during the solar maximum period of 1957 and 1958.

Since the 12 month mean daily variation is determined by the distribution of amplitude and time of

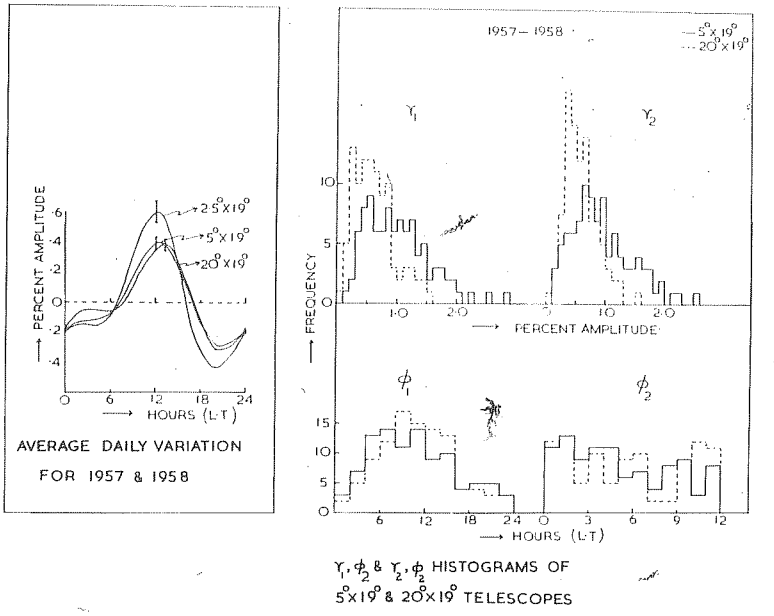

Fig. 34 - (a) Mean daily variation observed with telescopes of opening 2.5^0 x 19^0, 5^0 x 19^0 and 20^0 x 19^0 for the combined period of 1957 and 1958.

(b) Frequency distributions of γ_1, ϕ_1 and γ_2, ϕ_2 on individual days observed with 5^0 x 19^0 and 20^0 x 19^0 telescopes for the combined period of 1957 and 1958.

maximum of the daily variation on individual days, we have examined in the following section the distributions of the parameters related to the daily variation on individual days.

5.8. Comparison of daily variation on individual days studied with telescopes of different openings in the E-W plane.

Since the statistical accuracy of the narrow angle telescope of opening $6.5^{\circ} \times 15^{\circ}$ is extremely poor (hourly standard error = 8.6 %) we have confined our attention to the narrow angle telescope of opening $6^{\circ} \times 15^{\circ}$ which has a hourly standard error of 1.9 %.

Fig. 14b shows the frequency distribution of the diurnal and the semidiurnal components on individual days as observed with $6^{\circ} \times 15^{\circ}$ and $30^{\circ} \times 15^{\circ}$ telescopes, for the combined period of 1957 and 1958. The histograms reveal that the amplitudes of the diurnal and the semidiurnal components on individual days are larger with narrow angle telescopes as compared to wide angle telescopes. This result, however, cannot be taken at its face value since the histograms are not directly comparable because of the difference in the counting rate of the telescopes. The effect of the counting rate of the telescope on the observed amplitude of daily variation is discussed in Chapter V.

The frequency distributions of the time of maximum of the diurnal and the semidiurnal components on days when their amplitudes are significant at the 2 σ level are presented in Fig. 14b, for the telescopes of opening $5^{0} \times 10^{0}$ and $20^{0} \times 10^{0}$.

The χ^2 histograms of both narrow angle and wide angle telescopes reveal a broad maximum whereas the distribution for χ^2_2 is flat for both the telescopes. No apparent difference is observed in the distribution of the narrow angle and the wide angle telescopes.

4.1. Dependence of daily variation on the zenith angle of the telescope in the East-West plane.

The study is made by comparing the daily variation in the following two pairs of telescopes, which have the same N-S angle but different E-W angles:-

(1) $(5^{0} \times 30^{0})$ and $(5^{0} \times 45^{0})$* for the year 1957.
(2) $(20^{0} \times 10^{0})$ and $(22^{0} \times 37^{0})$ for the year 1958.

In table 4 are presented the yearly mean diurnal and the semidiurnal amplitudes and their times of maxima

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* The author is thankful to S.R. Thakare and V.L. Patel for making available the data of $5^{0} \times 45^{0}$ telescope which was operated at Ahmedabad during the year 1957.

Table 4

Yearly mean diurnal and semi-diurnal amplitudes of the daily variation and their times of maxima observed with telescopes of different apertures in the N-S plane during 1957 and 1958.

Period	Telescope opening	F_1(%)	T_1	F_2(%)	T_2	Standard error(%)
1957	$5^0 \times 10^0$	0.29	182^0	0.12	42^0	± .04
	$5^0 \times 45^0$	0.30	204^0	0.13	45^0	± .03
1958	$20^0 \times 10^0$	0.24	184^0	0.08	39^0	± .02
	$22^0 \times 37^0$	0.27	207^0	0.17	39^0	± .02

Table 5

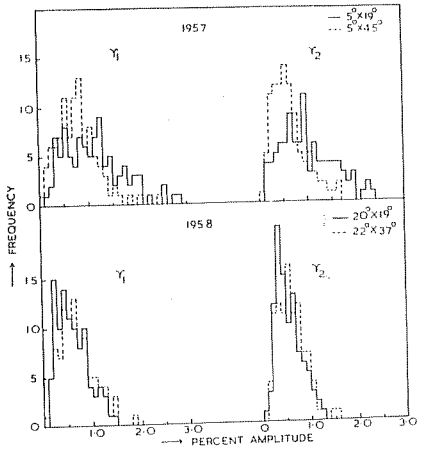
Parameters of the daily variation averaged on common working days of telescopes of different apertures in the N-S plane during 1957 and 1958.

Period	Telescope opening	F_1(%)	T_1	F_2(%)	T_2	Standard error(%)
1957	$5^0 \times 10^0$	0.31	180^0	0.17	42^0	± .04
	$5^0 \times 45^0$	0.33	198^0	0.16	45^0	± .03
1958	$20^0 \times 10^0$	0.26	182^0	0.10	36^0	± .02
	$22^0 \times 37^0$	0.29	204^0	0.18	45^0	± .02

observed with each of these telescopes. It is seen that F_1, F_2 and T_2 are almost the same within statistical error in the narrow angle and the wide angle telescopes but the

yearly mean hour of maximum ($\overline{\gamma}_1$) of the diurnal component is later by about 3 hours in the telescopes with a wider opening in the N-S plane.

The frequency distribution of the diurnal and the semidiurnal components on individual days observed with these telescopes are compared in Fig. 15 for each pair.



γ_1 & γ_2 HISTOGRAMS OF TELESCOPES OF DIFFERENT OPENINGS IN THE N-S PLANE

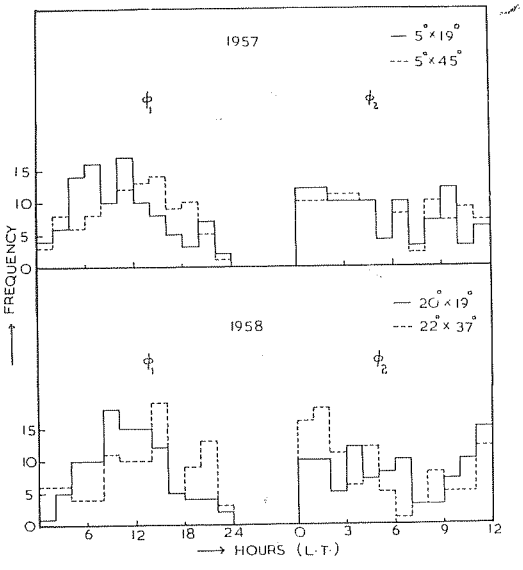
Fig. 15 - Frequency distribution of the diurnal and the semidiurnal amplitudes on individual days observed with telescopes of different openings in the N-S plane during 1957 and 1958.

The telescopes of opening $20^{\circ} \times 10^{\circ}$ and $22^{\circ} \times 37^{\circ}$ do not reveal any difference in the amplitude of r_1 and r_2 on individual days from which it may be concluded that the E-W angle does not play a significant role in determining the amplitude of the daily variation. However, the telescope of opening $6^{\circ} \times 10^{\circ}$ shows larger r_1 and r_2 amplitudes on individual days as compared to the corresponding amplitudes observed with the telescope of opening $6^{\circ} \times 45^{\circ}$. It is interesting to note that the statistical error associated with r_1 and r_2 amplitudes observed with the telescopes of opening $20^{\circ} \times 10^{\circ}$ and $22^{\circ} \times 37^{\circ}$ is roughly the same whereas the telescope of opening $6^{\circ} \times 10^{\circ}$ has a larger error associated with it as compared to the telescope of opening $6^{\circ} \times 45^{\circ}$. This gives an indication that, perhaps, larger amplitudes of the diurnal and the semidiurnal components observed with telescope of opening $6^{\circ} \times 10^{\circ}$ are because of the larger statistical errors associated with them. As already mentioned this is discussed in detail in Chapter V.

The frequency distributions of the time of maximum of the diurnal and the semidiurnal components on days when their amplitudes are significant at the 3σ-level are compared in Fig. 16 for each pair of telescopes.

The f_1 histogram of each telescope reveals a broad maximum which is shifted to later hours in the

telescopes of wider opening in N-S plane as compared to narrow angle telescopes. This difference in ϕ_1 histograms of the narrow angle and the wide angle telescopes is of course in accordance with the observed difference in the yearly mean η_1 as revealed from table 4. The ϕ_2 histograms do not show any difference between the narrow angle and the wide angle telescopes in the N-S plane.



ϕ_1 & ϕ_2 HISTOGRAMS OF TELESCOPES OF DIFFERENT OPENINGS IN N-S PLANE

Fig. 15 - Frequency distribution of times of maxima of the diurnal and the semi-diurnal components observed with telescopes of different openings in the N-S plane during 1957 and 1958.

Keeping in view the day to day variability of the daily variation it is worthwhile seeing whether the difference in hour of maximum of the diurnal component in the telescopes with narrow and wide openings in the N-S plane is observed on days when the telescopes of each pair are working simultaneously during the respective periods.

Table 6 gives the average values of the parameters F_1, Z_1 and F_2, Z_2, describing the mean diurnal and semidiurnal components of daily variation observed with each pair of telescopes on common working days. It is evident that a difference of about 2 to 3 hours in the hour of maximum of the diurnal component observed in the narrow angle and the wide angle telescopes is maintained; the telescopes of wider opening in the N-S plane have a diurnal component with later maximum than the narrow angle telescopes.

This difference in the hour of maximum of the diurnal component becomes striking if the daily variation is averaged on days when the diurnal amplitudes are simultaneously significant at the 2 σ level. Fig. 17a shows that on such common working days a wide angle telescope shows Z_1 about 4 hours later than that in the narrower one.

In order to know whether this difference in the diurnal hour of maximum is a feature of all days or whether it is restricted to geomagnetically quiet or disturbed days,

the daily variation observed with each telescope was averaged for low C_p days ($0 \leq C_p \leq .5$) and for high C_p days ($C_p \geq 1.1$). The average diurnal vector observed with each telescope is compared in Fig. 17b for the two pairs. It is seen that a difference of about 2 hours is maintained in the narrow angle and the wide angle telescopes both on low C_p as well as on high C_p days, thereby revealing that this difference in the hour of maximum of the diurnal component is independent of the level of geomagnetic disturbance.

6.1. Long term change of the form of daily variation.

Fig. 12 shows the 12 month mean daily variation measured with the standard telescope. The curves represent the superposition of 1st and 2nd harmonic components. The 12 month mean daily variations are centered at June and December of each year from 1958 to 1968.

In 1958 the daily variation has mainly an early morning maximum and agrees well with the form of the daily variation observed in an ion chamber at Huancayo (Fig. 3, page 30). By 1964, the daily variation has in almost equal proportion an early morning maximum and a noon maximum. In later years, the early morning maximum diminishes whereas the noon maximum increases in amplitude. By 1967, 1968 the daily variation is almost entirely made up of a noon maximum. These changes are in agreement with the conclusion of Sarabhai et al[151] that long term changes of daily variation measured with wide angle telescopes in low

latitudes can be represented by the waxing and waning of two modes.

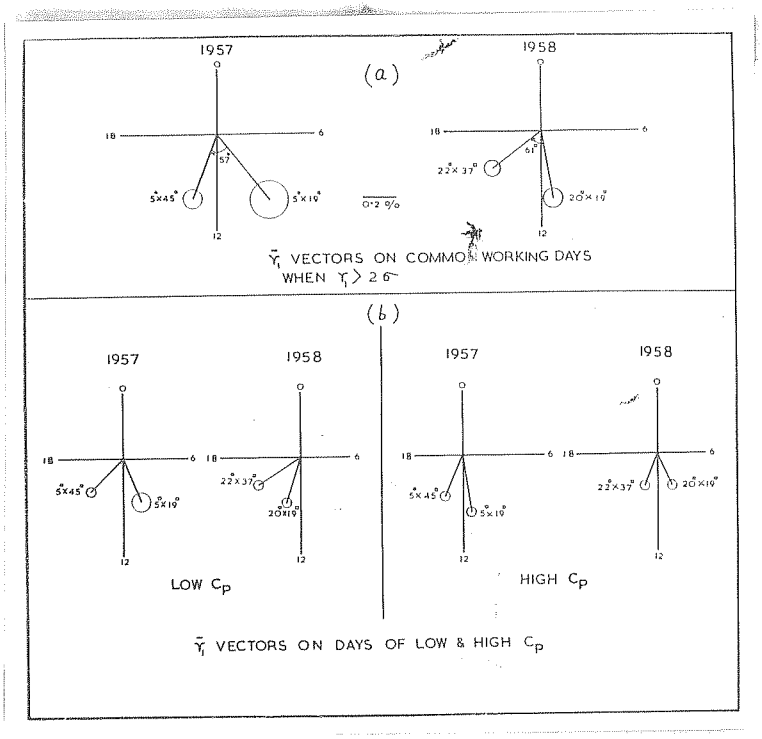
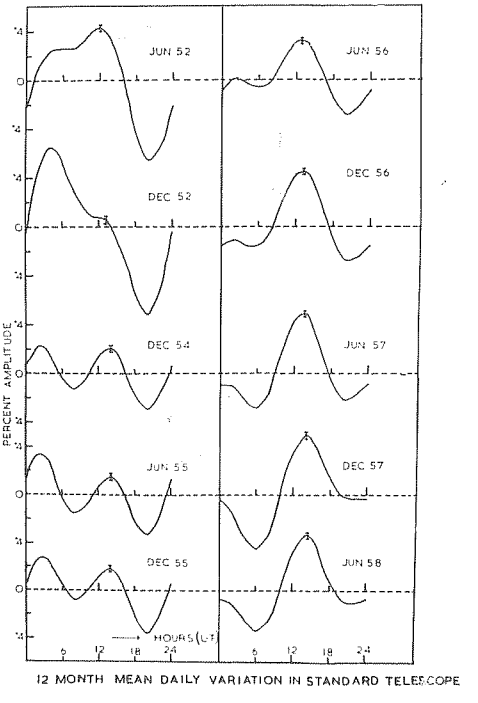


Fig. 17 - (a) Diurnal component of the daily variation averaged on common working days when $Y_1 > 26^-$, observed with telescopes of different openings in the N-S plane during 1957 and 1958.

(b) Average diurnal variation on low and high C_p days observed with telescopes of different openings in the N-S plane during 1957 and 1958.

Similar changes in the form of the daily variation are observed in East and West pointing telescopes at Ahmedabad inclined to the vertical at 45°. The telescopes were run from March 1954 - April 1955 by Ramakrishnan and for the years 1957, 1958 by Rao. The daily variation averaged over each period is presented in Fig. 13b. For the period March 1954 to April 1955 the 12 month mean daily variation in east and west pointing telescopes has an early morning maximum and a maximum near noon. In 1957, 1958 both directions reveal only the later maximum.



12 MONTH MEAN DAILY VARIATION IN STANDARD TELESCOPE

Fig. 13 - 12 month mean daily variation observed with the standard telescope, centered at June and December of each year from 1952 to 1958.

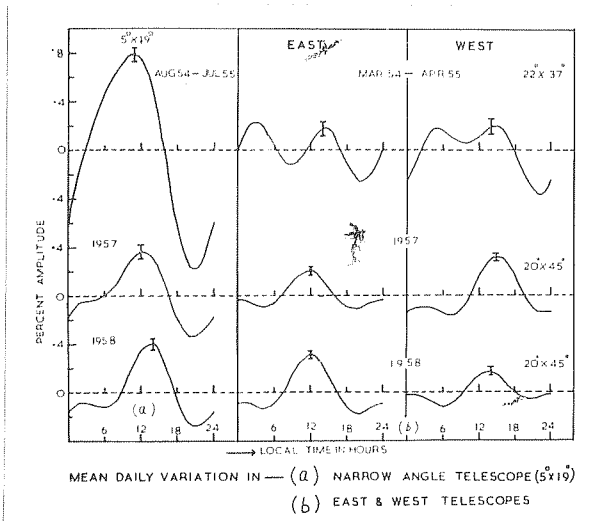


Fig. 10 - 12 month mean daily variation observed with (a) the narrow angle telescope during the periods August 1954 - July 1955, 1957 and 1958 (b) east and west pointing telescopes during the periods March 1954 - April 1955, 1957 and 1958.

The 12 month mean daily variation observed with a narrow angle telescope of opening 5^{0} x 19^{0}, during the periods August 1954 - July 1955, 1957 and 1958 is presented in Fig. 10a. A remarkable aspect is that, with narrow angle telescopes, during 1954, the 12 month mean daily variation does not show two maxima as is observed with a standard telescope at Ahmedabad or the ion chamber

at Huancayo. An understanding of this apparent discrepancy can be found in Ramakar's studies. It has been shown by him that during sun-spot minimum, in 1954, the daily variation measured with a narrow angle telescope has large diurnal amplitude with a maximum which occurs on some days around 0800 hours and on others around 1100 hours. In chapter V, Sec. 8, it is shown that the mean diurnal amplitude, corresponding to days having diurnal time of maximum at about noon, is large as compared to the mean diurnal amplitude corresponding to 0800 hour. Thus, inspite of the fact that both night type and day type maxima occur on individual days, the 12 month mean daily variation has a large amplitude with the time of maximum during forenoon.

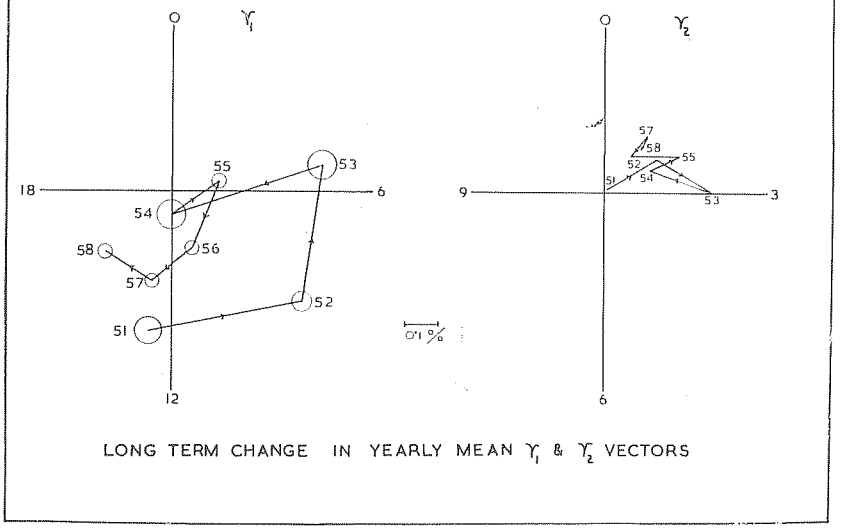
6.2. Long term change of 12 month mean diurnal and semidiurnal components of the daily variation studied with the standard telescope.

Fig. 20 shows the change in 12 month mean diurnal and the semidiurnal vectors from 1951 to 1958. The chief features that are revealed are:-

(1) The 12 month mean diurnal time of maximum $\bar{T}_1$, shifts to earlier hours from 1951 to 1954-1955 and after that it advances to later hours, till, in 1958, $\bar{T}_1$ is almost the same as in 1951.

(2) The 12 month mean diurnal amplitude $\bar{F}_1$, is minimum in 1954 (0.07 ± .04 %) and is not statistically significant.

(9) During the period 1951 to 1958 the time of maximum of the semidiurnal component is always found to occur between 0010 to 0300 hours showing that it remains virtually constant.



LONG TERM CHANGE IN YEARLY MEAN Υ_1 & Υ_2 VECTORS

Fig. 80 - 12 month mean diurnal and semidiurnal components observed with the 'standard toposcope' from 1951 to 1958.

6.3. Long term change of daily variation on individual days.

Fig. 31 shows the frequency distribution of the diurnal component on individual days as observed with the standard telescope as well as the narrow angle telescope of opening $5^{\circ} \times 15^{\circ}$, for various years from 1954 to 1958.

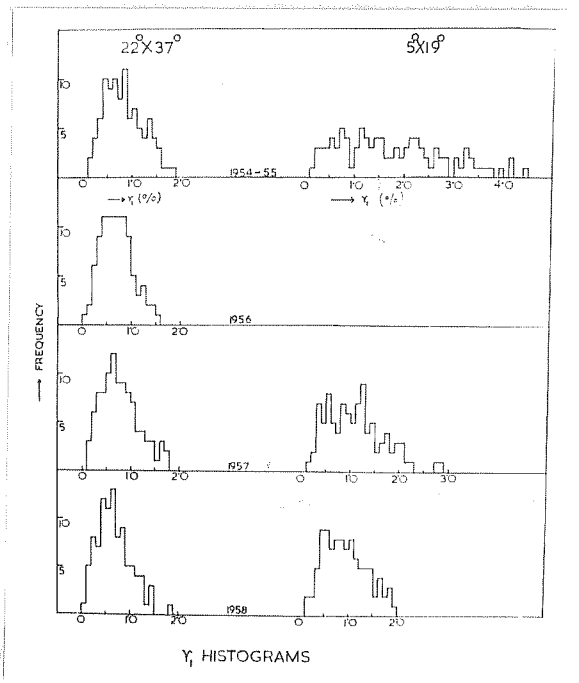
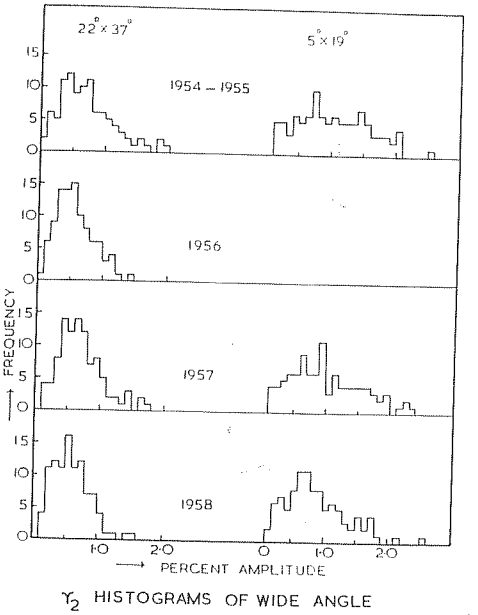


Fig. 31 - Frequency distribution of the diurnal component on individual days observed with the 'standard telescope' and the narrow angle telescope during various periods from 1954 to 1958.

The narrow angle telescope reveals large r_1 amplitudes on individual days during the period August 1954 - July 1955, which vanish by 1957, 1958. On the contrary the daily r_1 amplitudes in the standard telescope have remained the same from 1954 to 1958. Thus the difference in the amplitude of daily variation observed with narrow angle and wide angle telescopes at low latitudes is itself a time dependent characteristic most probably related to the cycle of solar activity.



γ_2 HISTOGRAMS OF WIDE ANGLE & NARROW ANGLE TELESCOPES

Fig. 22 - Frequency distribution of the semi-diurnal component on individual days observed with the 'standard telescope' and the narrow angle telescope during various periods from 1954 to 1958.

In Fig. 22 are presented histograms of the semi-diurnal component of the daily variation on individual days measured with the standard heliscope and the narrow angle heliscope of opening $5^0 \times 19^0$, from 1954 to 1958. No change is observed in the r_2 amplitudes on individual days from 1954 to 1958 in the two types of instrument.

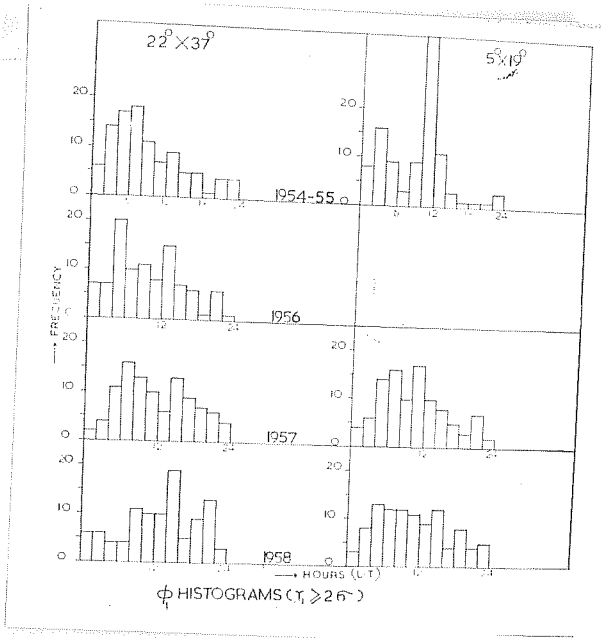
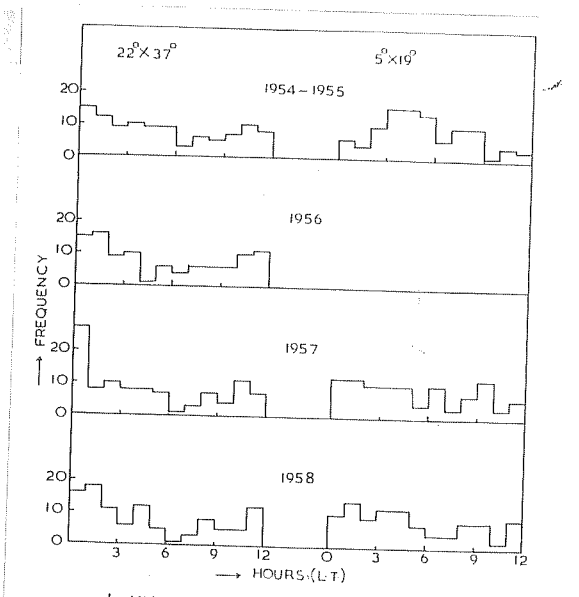


Fig. 22 - Frequency distribution of the diurnal time of maximum on individual days observed with the 'standard heliscope' and the narrow angle heliscope during various periods from 1954 to 1958.

Frequency distributions of the occurrence at each hour of the diurnal time of maximum in standard and narrow angle telescopes when the corresponding diurnal amplitudes are significant at the 3σ level are shown in Fig. 23. The corresponding frequency distributions for the semidiurnal component are also shown in Fig. 24.



ϕ_2 HISTOGRAMS OF NARROW ANGLE & WIDE ANGLE TELESCOPES

Fig. 24 - Frequency distribution of the semi-diurnal time of maximum on individual days observed with the 'standard telescope' and the narrow angle telescope during various periods from 1954 to 1958.

As has been explained earlier, the ϕ_1 histogram of narrow angle telescopes reveals two maxima during the period August 1954 - July 1955; one occurring during the night at about 0300 hours and the other during the day at about 1100 hours. The two peaks merge into a broad maximum by 1958. The distribution for the standard telescope, however, does not reveal two maxima during the period August 1954 - July 1955, or at any other time. It only shows a broad maximum in the morning hours during 1954 and a gradual shift to later hours up to 1958. This result is in accordance with the long term change of the yearly mean diurnal time of maximum described in section 5.2. On the other hand, an examination of the frequency distribution of the time of maximum of the semidiurnal component does not reveal any specific change from 1954 to 1958 either in the standard telescope or in the narrow angle telescope.

6.1. Change of form of daily variation with geomagnetic disturbance.

The daily variation with the standard telescope and the narrow angle telescope of opening $8^{\circ} \times 12^{\circ}$ has been averaged on days of low, medium and high geomagnetic disturbance which are characterised by $(0 \leq C_p \leq .5)$, $(.6 \leq C_p \leq 1.0)$ and $(C_p \geq 1.1)$ respectively.

The mean daily variation for each group during different years from 1954 to 1958 is presented in Fig. 26 for the standard telescope. The mean daily variation for days of high C_p during 1955, exhibits only noon maximum

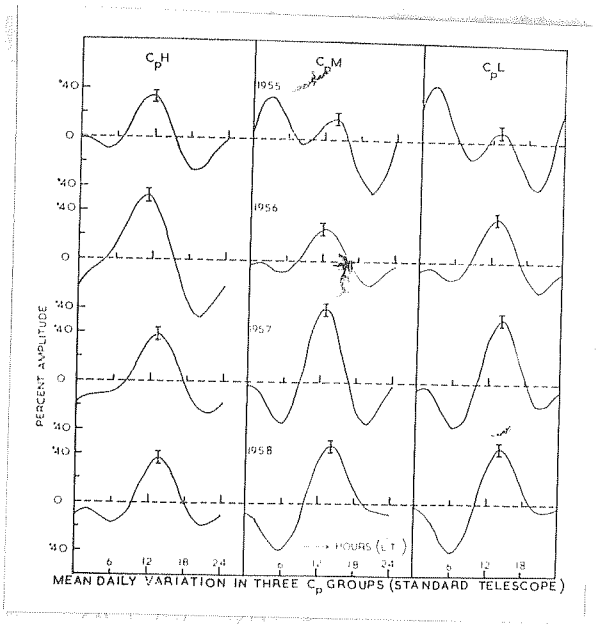


Fig. 26 - Mean daily variation on low, medium and high C_p days during 1955, 1956, 1957 and 1958, observed with the 'standard telescope'.

even though the 12 month mean daily variation during the same period exhibits two maxima, one in the early morning and other at noon (see Fig. 18, page 100). The mean daily variation on medium and low C_p days, however, does show the presence of the early morning maximum along with the noon maximum, it being very prominent on days of low C_p. For the years 1956, 1957 and 1958 when the

yearly mean daily variation has only noon maximum no change is observed in the form of daily variation from high C_p to low C_p days.

Fig. 25 gives the mean daily variation in three C_p groups of each year for the narrow angle telescope.

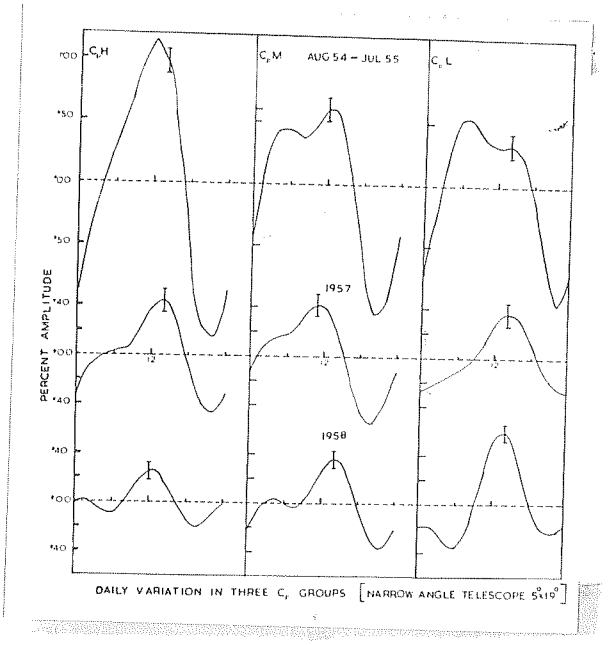


Fig. 25 - Mean daily variation on low, medium and high C_p days observed with the narrow angle telescope during the periods August 1954 - July 1955, 1957 and 1958.

During the period August 1954 - July 1955, although the yearly mean daily variation in the narrow angle telescope

is predominantly diurnal with a maximum at noon, the mean daily variation on low and medium C_p days exhibits an early morning maximum, the amplitude of which is more on low C_p days. During the years 1957 and 1958 the mean daily variations for days of low, medium and high C_p are similar.

It, therefore, seems that an early morning maximum that was present in the 12 month mean daily variation in 1954 and 1955, is essentially a feature of the geomagnetic quiet day daily variation. The geomagnetically disturbed days at all times are associated with a noon maximum. However, during the years of high solar activity (1957, 1958) the relationship with C_p becomes indistinct.

6.2. Changes in the diurnal and the semidiurnal components of the daily variation with geomagnetic disturbance.

Table 6 gives, for the standard telescope the parameters r_1, γ_1 and r_2, γ_2, describing the mean diurnal and semidiurnal components of the daily variation on groups of days when C_p is low, medium or high during the period 1955 to 1958, taken as one.

An examination of the table reveals that the mean amplitude of the diurnal component increases on days of high C_p and its time of maximum shifts to earlier hours as compared to the diurnal variation on days of low C_p. The semidiurnal component, however, is found to be larger

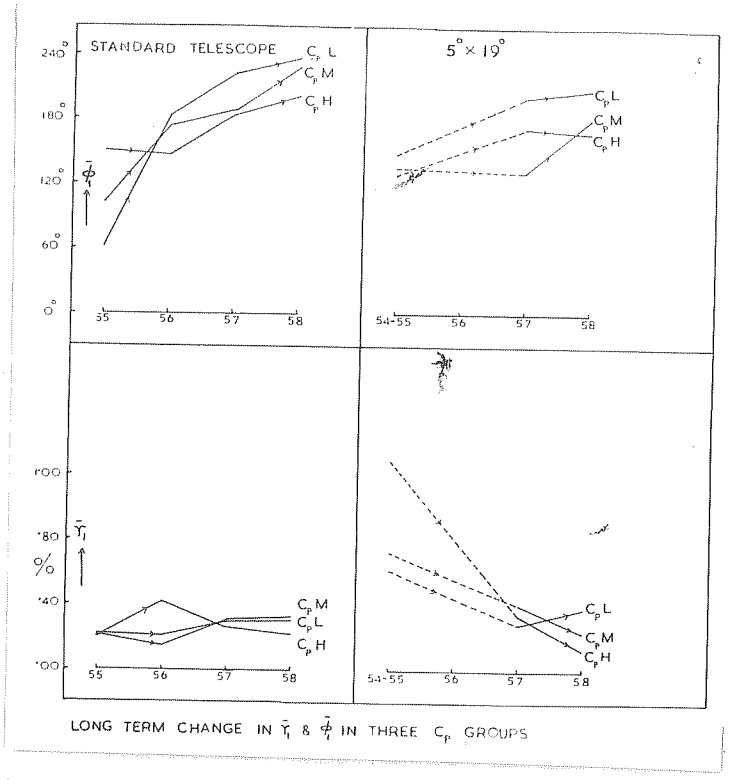
Table 4

The diurnal and the semidiurnal components of the daily variation and their times of maxima averaged on low, medium and high C_p days during the entire period of 1955 to 1958.

C_p group	F_1(%)	Z_1	F_2(%)	Z_2	Standard Error
High	0.36	107°	0.10	22°	± .02
Medium	0.12	134°	0.12	38°	± .02
Low	0.15	208°	0.21	45°	± .02

on low C_p days as compared to high C_p days. These results are in agreement with the observation of Obitsu et al [142] for the period 1949 - 1950.

A closer examination of the mean daily variation on days of low, medium and high C_p for individual years shows that the above relation is not always followed. Fig. 37 shows the variation of F_1 and Z_1 in three C_p groups from 1955 to 1958 with the standard telescope and from the period August 1954 - July 1955 to 1958 with the narrow angle telescope. It can be seen that F_1 is not always larger nor Z_1 earlier on high C_p days as compared to low C_p days. In the standard telescope the amplitude of F_1 is about the same in the three C_p groups during 1955. In 1955 it happens larger on high C_p days whereas in 1958 the



LONG TERM CHANGE IN $\bar{r}_1$ & $\bar{\phi}$ IN THREE C_p GROUPS

Fig. 37 - Year to year change in $\bar{r}_1$ and $\bar{\phi}_1$ in low, medium and high C_p groups, observed with the standard telescope and the narrow angle telescope.

mean r_1 amplitude is more on low C_p days. Narrow angle telescopes show a larger mean amplitude on high C_p days during the period August 1954 - July 1955 which, by 1958 decreases considerably and becomes much less than the amplitude on low C_p days.

The time of maximum, $\bar{\phi}_1$ of the diurnal vector which was earlier on low and medium C_p days when measured

with standard telescope and with the narrow angle telescope during 1956-1963 period, shifts to later hours by 10GE.

Another interesting feature that is revealed from Fig. 27 is that the change in $\bar{I}_1$ from year to year is most prominent on low C_p days. Further, the variation in the amplitude of diurnal component from year to year is more on high C_p days than on low C_p days.

7. A comparative study of the mean intensity observed with narrow angle and wide angle telescopes during a cosmic ray storm.

A common feature of cosmic ray storms is the decrease of intensity of the order of a few percent during the course of a day or two which takes about a week or more to recover to normal. But individual storms differ widely from one another in various features. This has been described in detail in chapter I.

We have compared the average effect of a number of cosmic ray storms to see if any major difference is observed in the mean intensity of narrow angle and wide angle telescopes during a cosmic ray storm.

A selection of cosmic ray storms was made on the basis of decrease of mean intensity of 3 % or greater in the neutron monitor at Mount Norikura. Quite a large number of such events occurred during the period of maximum solar activity for 1957 and 1958. However, only

five storms were found during this period when normalised mean intensity from -15 to +15 days of the epoch was simultaneously available for the standard telescope and the narrow angle telescope of opening $6^{0} \times 10^{0}$. The process of normalisation of the mean intensity has been described in chapter III.

The epochs of the chosen events are:-

(1) 22nd January, 1957.
(2) 20th April, 1957.
(3) 5th August, 1957.
(4) 12th February, 1958.
(5) 5th July, 1958.

Normalised mean intensity for the above five events were superimposed over each other from -15 to +15 days of the epoch and sum of the first ten days of the series was taken as normal intensity prior to the occurrence of the storm. The intensity of each day was then expressed as percent deviation from this mean.

Fig. 33 shows the mean intensity from -15 to +15 days of the epoch as observed in the standard telescope and the narrow angle telescope of opening $6^{0} \times 10^{0}$. For comparison a plot of neutron intensity at Mt. Norikura, the earth's horizontal component H at Kodaikanal, and C_{p}, the index of geomagnetic disturbance, averaged over these five events are also shown in the same figure.

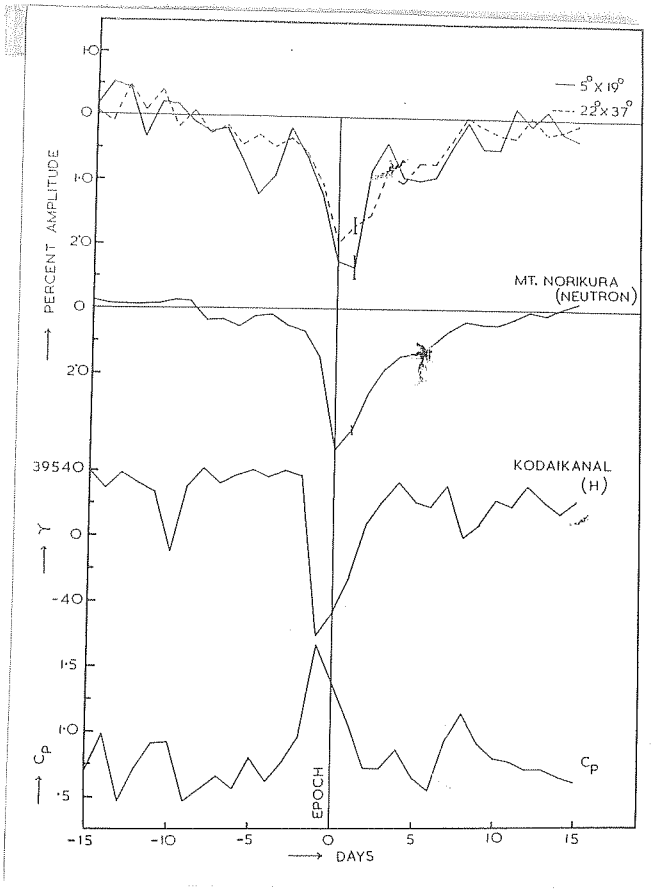


Fig. 28 - Curve analysis of mean intensity observed with the standard telescope and the narrow angle telescope during Forbush type decrease.

Neutron intensity at Mt. Norikura shows a mean decrease of 4.3 % on epoch day. The decrease in H is of the order of 300 γ and C_p attains a maximum value of about 1.6 one day prior to epoch. The mean decrease in mean intensity is of the order of 2 % both

in the standard telescope and the narrow angle telescope. The two telescopes do not reveal any difference during the storm period beyond the statistical accuracy of the instruments. However, as already pointed out, this need not be true about individual storms.

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CHAPTER V

DISCUSSION AND CONCLUSIONS

1. The relationship of the form and magnitude of the daily variation of cosmic ray intensity with the opening angle of the telescope.

The effect of the angle of opening of a telescope can be judged by considering the average daily variation over a group of days or over an extended period, and by an examination of the histograms of the parameters of the diurnal and semidiurnal components of the daily variation on individual days, with narrow and wide angle telescopes. The characteristics of the average daily variation during 1957 and 1958 are indicated in Fig. 14a and table 4 for the telescopes of different openings in the N-S and the E-W planes respectively, whereas the histograms of the parameters of the daily variation on individual days are presented in Figures 14b, 15 and 16. In interpreting histograms of diurnal and semidiurnal amplitudes on individual days it is necessary to consider the effect of the counting rate of an instrument and its associated Poisson standard error. This is discussed in the following section.

4.4. Effect of statistical fluctuations on the observed amplitude of daily variation of cosmic ray intensity.

It is seen from r_1 and r_2 histograms presented in Fig. 14b that $5^0 \times 10^0$ telescope, which has a narrower opening in E-W plane, reveals larger r_1 and r_2 amplitudes on individual days as compared to the wide angle telescope of opening $20^0 \times 10^0$. Similarly, a comparison of r_1 and r_2 histograms of telescopes with different openings in the E-W plane shows that $5^0 \times 10^0$ telescope has larger r_1 and r_2 amplitudes associated with it on individual days as compared to the telescope of opening $5^0 \times 45^0$ (Fig. 16). In both these cases it may be noted that because of its lower counting rate, the statistical error associated with the telescope of opening $5^0 \times 10^0$ is large as compared to the telescopes of opening $20^0 \times 10^0$ and $5^0 \times 45^0$. It is, therefore, important to examine to what extent the large r_1 and r_2 amplitudes on individual days observed with the telescope of opening $5^0 \times 10^0$ are due to larger statistical error associated with it. In this section we describe a statistical method by means of which it can be checked whether the difference in r_1 or r_2 amplitudes on individual days during a certain period, observed with two telescopes of different geometries, is due to the difference in their counting rates or due to the difference in their response characteristics to the source of the daily variation. The method is as follows:-

The diurnal or the semidiurnal amplitude (x) observed on every individual day with two telescopes of different geometries and having different counting rates, can be expressed as

$$x'_j = \zeta'_j + \delta'_j \qquad \ldots \quad (7)$$

and

$$x''_j = \zeta''_j + \delta''_j \qquad \ldots \quad (8)$$

where x'_j and x''_j are the observed amplitudes of any particular harmonic on the j^{th} day, ζ'_j and ζ''_j are the contributions due to Poisson statistical errors, and δ'_j and δ''_j represent the special characteristics of the individual telescopes and are a measure of the response of the individual telescopes to a particular source function. Even though the strength of the source of anisotropy causing the daily amplitude x_j may be the same for both the telescopes the responses δ'_j and δ''_j may not necessarily be the same.

Subtracting equation (8) from equation (7), one obtains for the variance of the difference $x'_j - x''_j$,

$$V(x'_j - x''_j) = V(\zeta'_j - \zeta''_j) + V(\delta'_j - \delta''_j)$$
$$= \sigma'^2 + \sigma''^2 + V(\delta'_j - \delta''_j) \qquad \ldots \quad (9)$$

where σ' and σ'' represent the Poisson standard errors of the two telescopes.

If now, we make a null hypothesis that the response functions δ_j' and δ_j'' are the same for both the telescopes and that the differences in daily amplitudes are only due to the difference in Poisson statistical errors associated with the counting rate of each of them, then

$$V(x_j' - x_j'') = \sigma'^2 + \sigma''^2 \qquad \ldots \quad (10)$$

The left hand side and right hand side of equation (10) then represent the observed and the expected variances respectively on the basis of the assumption that $\delta_j' = \delta_j''$. This assumption can be easily checked by calculating the factor

$$\chi^2 = \frac{(n-1)\ \text{Observed variance}}{\text{Expected variance}} = \frac{(n-1)\ V(x_j' - x_j'')}{\sigma'^2 + \sigma''^2}$$

$$= \frac{(n-1) \sum (d_j - \bar{d})^2 / (n-1)}{\sigma'^2 + \sigma''^2}$$

$$= \frac{\sum (d_j - \bar{d})^2}{\sigma'^2 + \sigma''^2} \qquad \ldots \quad (11)$$

Where d_j is the observed difference between the amplitude on the j^{th} day and $\bar{d}$ the average of the differences (d_j) for the period under consideration.

The χ^2 follows the well known χ^2 distribution with $(n-1)$ degrees of freedom where n is the number of days for which pairs of (x', x'') observations are considered. If the computed value of χ^2 lies within the

theoretical single tail at a 5 % level, we can assume that the observed variance is the same as the expected variance within statistical limits and the assumption $\delta_j' = \delta_j''$ is justified. From this it follows that the differences observed in the x_j' and x_j'' may only be due to the differences in the counting rates of the telescopes. On the other hand, values of χ^2 exceeding the expected value on a 5 % limit are indicative of the difference in δ_j' and δ_j''. Under these circumstances one will have to make assumptions regarding the nature of the functions δ_j' and δ_j''. As an example, one could assume that $\delta_j' = K\delta_j''$, in which case equation (9) can be rewritten as

$$V(x_j' - x_j'') = \sigma^2 + \sigma^2 + \sigma_\zeta^2 + \sigma_\zeta^2$$

$$= \sigma^2 + \sigma^2 + (K-1)^2 \cdot \sigma_\zeta^2 \quad .. \quad (12)$$

and the excess variance $V(x_j' - x_j'') - (\sigma^2 + \sigma^2)$ could be attributed to $(K-1)^2 \sigma_\zeta^2$. It is obvious, however, that this does not give any clue to the constant factor K unless the standard deviation σ_ζ can be evaluated independently. On the other hand, a value of σ_ζ could be estimated if the value of K could be obtained independently, for example, by considering the precise response of the two counters to given types of source functions on the basis of Brunberg's[145] treatment.

It should be noted here that the equations (7) and (8) are true only if the two geometrical arrangements

are independent of each other. In practice, however, it is quite common to design telescope in such a way that narrow angle telescopes are contained within wide angle telescopes with the result that all counts recorded by narrow angle telescope are also a part of the wide angle telescope. Hence, though the physical properties of the narrow angle telescope and the wide angle telescope are still maintained, the observed rates are not drawn from statistically different samples. In fact, for such a situation, the equations (7) and (8) require to be rewritten as

$$x_j' = \zeta_j + \zeta_j'' + \delta_j' \quad \ldots \quad (13)$$

and $$x_j'' = \zeta_j'' + \delta_j'' \quad \ldots \quad (14)$$

where x_j' and x_j'' are the observed amplitudes of the wide angle and the narrow angle telescope respectively, δ_j' and δ_j'' are their geometrical response functions, and ζ_j and ζ_j'' are the Poisson functions for the two independent counting rates N and N'', where N'' is the counting rate of the narrow angle telescope and $N = N_0 - N''$ the difference of counting rates of the wide angle and the narrow angle telescopes. (The function ζ_j refers to the rate $N = N_0 - N''$, i.e. the difference of the rates of the wide angle and the narrow angle telescope). The equation for variance of $x_j' - x_j''$, now turns out to be

$$V(x_j' - x_j'') = \sigma^2 + V(\delta_j' - \delta_j'')$$

and for checking the null hypothesis ($\delta_j' = \delta_j''$) the χ^2 can be calculated as

$$\chi^2 = \frac{(n-1)\, V(x_j' - x_j'')}{\sigma^2} \qquad \ldots \quad (15)$$

where σ refers to the Poisson standard error of the counting rate ($N_0 = N''$) only.

It should be noted here that whether equation (11) or (15) is utilised (depending upon whether the telescopes count independent particles or not) the expected variance has to be calculated from a fixed average counting rate for both the geometries. Even though a set of narrow angle telescopes are in operation, on a particular day not all of them may be working. In each case the percent amplitudes are calculated by averaging the data for all the properly working telescopes, whose number would vary on some days. While applying the above mentioned methods, precaution has to be taken that for any particular geometry, the number of telescopes considered has been maintained the same. Accordingly the data for a particular period may be required to be divided into groups so that for any particular group the average rate for each geometry remains the same.

Table 7 gives the details about the various telescopes that have been employed and analysed by the above methods for various periods.

Table 7

χ^2 values obtained by the comparison of diurnal and semidiurnal amplitudes on individual days observed with telescopes of different counting rates during various periods from 1954 to 1958.

Period	Type of telescope (E-W) x (N-S)	Bihourly rate	No. of days	χ^2	Conclusions
1954 (Group 1)	5° x 19°	4000	35	$\chi^2(r_1) = 97.7$	χ^2 significant at 5 % level.
	22° x 37°	15000		$\chi^2(r_2) = 19.3$	χ^2 not significant.
1954 (Group 2)	5° x 19°	4000	36	$\chi^2(r_1) = 90.20$	χ^2 significant at 5 % level.
	22° x 37°	12000		$\chi^2(r_2) = 31.1$	χ^2 not significant.
1957	5° x 19°	6000	45	$\chi^2(r_1) = 42.6$	χ^2 not significant.
	5° x 45°	12000		$\chi^2(r_2) = 45.6$	χ^2 not significant.
1957-1958*	5° x 19°	5300	277	$\chi^2(r_1) = 233$	χ^2 not significant.
	20° x 19°	13000		$\chi^2(r_2) = 318$	χ^2 not significant.

* The narrow angle telescope is contained within the wide angle telescope so that their counting rates are not completely independent of each other.

It is clear from the table that the observed χ^2 values are non-significantly different from the expected value for r_1 as well as r_2 for the period 1957 - 1958, irrespective of whether the difference in the telescope angles are in the E-W plane or the N-S plane. However, in 1954, which is a period of minimum solar activity, the χ^2 value for the difference in r_1 are significantly large, indicating that the response functions δ_1' and δ_1'' for wide and narrow angle telescopes are not the same for this period.

1.2. Dependence of the daily variation on the pointing angle in the N-S plane and the profile of the ionosphere.

From the study of the average daily variation and the daily variation on individual days, it may be concluded that during 1957-1958, there is no difference in the response characteristics of telescopes with different openings in the E-W plane. On the other hand, in 1954, the year of minimum solar activity, narrow angle telescopes record larger amplitudes than wide angle telescopes. Bramley[145] has treated the problem of response characterisation of narrow and wide angle telescopes exhaustively in his paper "Optics of Cosmic Ray Telescopes". He has shown that if the source of daily variation is a point source, narrow angle telescopes will not only show a better response to it but will measure large amplitudes as well because the ratio

of anisotropy to background intensity will be high. On the other hand, if the source of anisotropy is rather broad, narrow angle telescopes will not have any special advantage over wider angle telescopes. Therefore, the observation that narrow angle telescopes recorded higher amplitudes as compared to wide angle telescopes in 1954 but not in 1957-1958 could be interpreted as indicating that the source of daily variation was fairly sharp in the solar minimum period of 1954 but widened out later when solar activity increased. This effect may be connected with the existence, during the period of minimum solar activity, of relatively few sources which can produce an anisotropy of the primary radiation. At sun-spot maximum, on the other hand, the influence of more than one solar beam in the neighbourhood of the earth on individual days may be observed in the cosmic ray intensity.

It may be mentioned here that for 1954, Elliot's[210] results for narrow angle telescopes operating at London ($\lambda = 48^0$) do not show high amplitudes as compared to wide angle telescopes. On the other hand, during 1948-1950, sekido et al[249] found a difference between the response of narrow angle and wide angle telescopes at 35^0 north latitude. There is indication, therefore, that the enhanced amplitude in narrow angle telescopes during 1954 and earlier years was essentially confined to low latitudes. This emphasises the necessity of simultaneous operation of narrow angle and wide angle

telescopes at various latitudes for getting precise information regarding the nature of the source of anisotropy responsible for daily variation of cosmic ray intensity.

1.3. Dependence of daily variation on the angular angle of telescopes in the N-S plane.

In chapter IV, sec. 4, it has been shown that, during the period 1957-1958, the average daily variation as well as the daily variation on individual days, observed with telescopes of different openings in the N-S plane, reveals a difference in the time of maximum of the diurnal component which is about three hours later in wide angle telescopes. Further it is shown that this difference in the diurnal time of maximum is independent of the level of geomagnetic activity. It is necessary to examine whether this difference in the telescopes of narrow and wide openings in the N-S plane can arise from a difference in the applicable barometric co-efficient.

Elliot and Dolbear[138] have obtained a pressure co-efficient of -0.31 % per mm. Hg from correlation analysis for shielded telescopes inclined to the vertical at 45° east and 45° west, with 25 cm of Pb as absorber. Bachlet and Conforto[42] have also obtained the same pressure co-efficient of -0.34 % per mm. Hg for vertical intensity as well as for the intensity in the direction inclined to the vertical at 30°. Fenton[211] has reviewed the situation

and finds that there does not exist any evidence to show a significant change in pressure co-efficient with inclination. Thus the difference in the diurnal time of maximum observed with narrow angle and wide angle telescopes in the E-W plane cannot arise because of improper pressure correction used for wide angle telescopes which receive particles from more inclined directions.

The following model calculation was performed to examine whether the observed difference in the diurnal time of maximum could arise due to the contribution of additional primary particles coming from the north and south directions, the asymptotic coordinates of which are such that they are able to contribute to the counting rate of the wider angle telescope but not to that of the telescope with narrower angle because of the smaller aperture of the latter in the E-W plane.

From the radiation sensitivity curves corresponding to the configuration of the two sets of telescopes under consideration (Fig. 20), given by Rao and Rao[212] who followed the method of calculation suggested by Parsons[213], we compute the number of secondary particles (as percent of the total counting rate) arriving in the telescope within the angular intervals $0^0 - 8^0$, $8^0 - 16^0$, $16^0 - 24^0$ ....., $32^0 - 40^0$ and $40^0 - 48^0$ with respect to the zenith. Let n_{12}, n_{16}, n_{20}, ..., n_{44} be the number of particles centered at

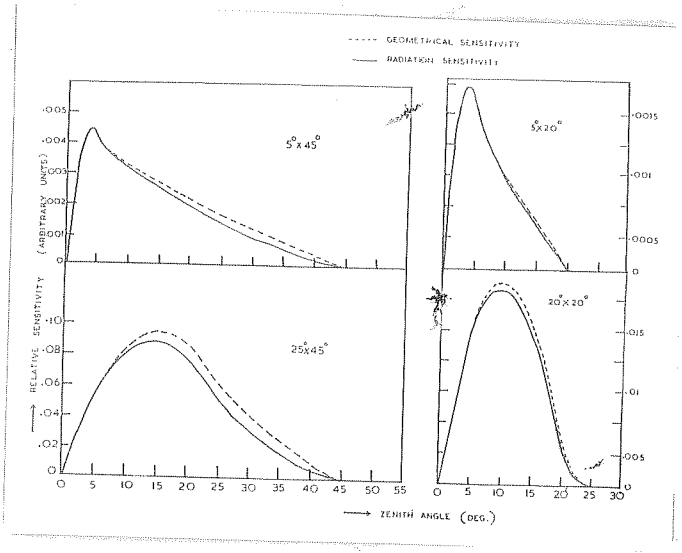


Fig. 32 - Geometrical and the radiation sensitivity of various telescopes with different opening angles.

the middle of the angular intervals given above. These n-values would be used as weights in the counting calculations for determining the effective asymptotic angles for primaries of different energies coming from different zenith angles in the E-W plane which contribute to the counting rate of the various telescopes. The appropriate asymptotic angles γ_E and ϕ_N are then found through interpolation from the curves given by Brunberg and Nathan[18] for the primary particles of energies 15, 20,

25, 30, ..., 100 Bev, coming within the angular intervals $0^0 - 5^0$, $5^0 - 15^0$, ..., $40^0 - 45^0$ with respect to the zenith from north and south directions. Let E_1 be the mean energy corresponding to a particular narrow energy band (width = 5 Bev) and let the pairs of asymptotic angles, appropriate to E_1, and centered at the middle of angular intervals mentioned above be respectively

$$(\psi_E)^N_{\gamma E_1},\ (\psi_E)^N_{\pi E_1},\ (\psi_E)^N_{2e E_1},\ \text{- - - -},\ (\psi_E)^N_{\gamma\gamma E_1}$$

$$(\phi_N)^N_{\gamma E_1},\ (\phi_N)^N_{\pi E_1},\ (\phi_N)^N_{2e E_1},\ \text{- - - -}\ (\phi_N)^N_{\gamma\gamma E_1}$$

and

$$(\psi_E)^S_{\gamma E_1},\ (\psi_E)^S_{\pi E_1},\ (\psi_E)^S_{2e E_1},\ \text{- - - -}\ (\psi_E)^S_{\gamma\gamma E_1}$$

$$(\phi_N)^S_{\gamma E_1},\ (\phi_N)^S_{\pi E_1},\ (\phi_N)^S_{2e E_1},\ \text{- - - -}\ (\phi_N)^S_{\gamma\gamma E_1}$$

Using n_γ, n_{2e}, n_{2e}, ..., $n_{\gamma\gamma}$ as weightage factors we find the weighted values of the asymptotic coordinates for the particles of energy E_1 coming from the north and from the south directions as follows:-

$$(\bar{\psi}_E)^N_{E_1} = \frac{n_\gamma(\psi_E)^N_{\gamma E_1} + n_\pi(\psi_E)^N_{\pi E_1} + \text{- - - -} + n_{\gamma\gamma}(\psi_E)^N_{\gamma\gamma E_1}}{100}$$

with similar expressions for $(\phi_N)^N_{\epsilon_1}$, $(\psi_\epsilon)^S_{\epsilon_1}$ and $(\phi_N)^S_{\epsilon_1}$, $(\psi_\epsilon)^N_{\epsilon_1}$, $(\phi_N)^N_{\epsilon_1}$, $(\psi_\epsilon)^S_{\epsilon_1}$, $(\phi_N)^S_{\epsilon_1}$ are then representative asymptotic coordinates for the particles of energy E_1 entering the telescope from the north and from the south directions respectively. The coordinates are next converted into geographical system using the formulae given by Krumbeg[210]. Let $\psi^N_{\epsilon_1}$, $\phi^N_{\epsilon_1}$; $\psi^S_{\epsilon_1}$, $\phi^S_{\epsilon_1}$ be the effective asymptotic coordinates in geographical system for the particles of energy E_1 entering the telescope from the north and the south direction.

Now if χ is the angle between the direction of the source and the earth-sun line and $t^N_{E_1}$, $t^S_{E_1}$ are the times of arrival (in hours) of particles of energy E_1 entering the telescope from the north and south directions respectively, then following Parman[32]

$$t^N_{E_1} = \frac{\chi - \psi^N_{E_1}}{15} + 180$$

and

$$t^S_{E_1} = \frac{\chi - \psi^S_{E_1}}{15} + 180 \ .$$

To find the percent amplitudes $r^N_{E_1}$ and $r^S_{E_1}$ contributed by the secondaries produced by the primaries of energy E_1 entering the telescope from the north and from the south at different zenith angles, we assume that the variation spectrum of the primaries responsible

for solar diurnal variation at Ahmedabad is given by

$$\frac{\delta_{n(E)}}{D(E)} = a(\phi) E^{-1} \qquad \text{for } E > E_{\lambda}^{min}$$

where E^{min} is the vertical cut off energy due to geomagnetic field, for Ahmedabad $E_{\lambda}^{min} = 14$ Bev. This spectrum has been found by Dorman[32] to hold in case of various experimental data obtained over a decade. We further assume that $a(\phi)$ varies with the angle ϕ made by primaries with the plane of the ecliptic before entering the geomagnetic field in the manner given by Dorman[32]. Thus

$$r_{B_1}^{N} = a(\phi_{B_1}^{N}) E_1^{-1} \cdot W_{\lambda}$$

and

$$r_{B_1}^{S} = a(\phi_{B_1}^{S}) E_1^{-1} \cdot W_{\lambda}$$

where W_{λ} is the coupling coefficient and $a(\phi_{B_1}^{N})$ and $a(\phi_{B_1}^{S})$ are the values of $a(\phi)$ for $\phi = \phi_{B_1}^{N}$ and for $\phi = \phi_{B_1}^{S}$. Strictly speaking, the coupling coefficient $W_{\lambda}(E, h_0)$ may be different for the particles coming from vertical and those coming from the inclined directions for the same instrument. The difference may arise due to the fact that particles coming from the inclined directions traverse greater distances; in fact at the zenith angle θ, they cover $\sec\theta$ times the distance in the vertical direction. But for $\theta = 35^{0}$ within which zenith angle range about 97 % of the particles contributing to the total counting rate of the telescope of largest aperture

(52^{o} x 37^{o}) are confined, the particles would have to travel about 1.3 times the vertical distance.

As can be seen from above, the order of magnitude of the quantities involved are rather small and as such the variation of W_λ in the zenith angle ranges that matter for our calculations would not make significant difference in the values estimated by assuming W_λ to be invariant with respect to zenith angle.

Having calculated the amplitudes and the times of maxima $r^{N}_{E_1}$, $t^{N}_{E_1}$ and $r^{S}_{E_1}$, $t^{S}_{E_1}$ for the particles contributed by the narrow band of primaries of mean energy E_1 which enter the telescope from the north and south directions, we can get the resultant contribution to the gross solar diurnal variation observed by the instrument due to particles of energy E_1 and entering the telescope from the north and south directions. Let r_{E_1}, t_{E_1} be the amplitude and the time of maximum of this resultant contributory curve due to particles of energy E_1. Similarly the resultant curves may be found for particles produced by the primaries of energy E_2, E_3, E_4, ... Later all the vectors defined by r_{E_1}, t_{E_1}; r_{E_2}, t_{E_2}; r_{E_3}, t_{E_3}; ..... can be added up vectorially and the resultant diurnal variation curve found. However, it should be borne in mind that the weightage factors used for calculating the effective values of the asymptotic angles are assumed to be invariant with respect to energy. Now the radiation sensitivity curves, from which these factors have been

derived, are related to the geometrical sensitivity of the telescope as follows:-

Radiation sensitivity = $\cos^{\mu}\theta \times$ Geometrical sensitivity.

Kamo and Rao[212] have taken $\mu = 2$ in calculating radiation sensitivity which corresponds to the well known zenith angle variation of the counting rate of a telescope. It may be argued that $\cos^{2}\theta$ law essentially represents a cumulative effect and that at higher energies μ should be less than 2. This would require the weightage factors to be energy dependent. However, if one looks at the geometrical and radiation sensitivity curves corresponding to the telescopes under consideration (see Fig. 39), it is fairly clear that the two curves overlap for smaller zenith angles (particles coming along which directions contribute most to the total counting rate of the telescope). At higher zenith angles the radiation sensitivity is only slightly less than the geometrical sensitivity. For values of $\mu < 2$, the radiation sensitivity values would lie in between the two extremes. This being the case the energy dependence of the weightage factors will be very feeble indeed to make any significant change in the value of $(\bar{\gamma}_{\varepsilon})^{N}$, $(\bar{\phi}_{\mu})^{N}$ and $(\bar{\gamma}_{\varepsilon})^{S}$, $(\bar{\phi}_{\mu})^{S}$ calculated on the assumption that the weightage factors are independent of energy.

The above represents a simplified theoretical procedure of obtaining the time of maximum of the diurnal variation expected to be observed at Ahmedabad by a particular telescope. There are two unknowns; $a(\phi=0)$, the power of the source in the plane of the ecliptic, and γ the angle which the source makes with the earth-sun line. Various values of γ may be assumed and the one which gives the best fit with the observed time of diurnal maximum may be taken to represent the effective direction of the source. For this value of γ the corresponding value of $a(\phi=0)$ may be derived by comparing the theoretically expected value of the diurnal amplitude with that actually observed. However, since our sole purpose is to see whether on theoretical basis one can account for the difference in the time of diurnal maximum observed with narrow and wide angle telescopes, we can assign any particular value of γ. For simplicity in computations we took $\gamma = 0$ in the above calculations. The resultant values of the diurnal times of maximum so obtained would show up whether one should expect any difference to arise between the diurnal time of maximum observed by two telescopes, one having a narrower aperture and the other having a wider aperture in the N-S plane, due to the contribution of additional particles coming from the north and south directions which are registered only by wider angle telescope. The results

are presented in table 8 for the two sets of telescopes. One can see that there is hardly any difference to be expected on this basis. The situation does not improve by assuming a steeper variation spectrum of the form ω^{-2}. It is, therefore, suggested that the difference in the diurnal time of maximum observed with telescopes of different openings in the E-W plane may be due to an anisotropy present in north and south directions. As Newman[6] points out, such an anisotropy can arise due to the solar beams with trapped magnetic fields emitted from the sun in directions declined to the ecliptic at small angles. It would be interesting to see whether this is so by pointing telescopes in the north and south directions. The plots supplied by Nurnberg[214] reveal that stations like Ahmedabad which are situated at low latitudes are in a favourable position to measure such E-W anisotropy, if it exists, as compared to the high latitude stations.

8. Long term change of 12 month mean daily variation.

It has been shown by Parakal et al[151] that the 12 month mean daily variation of cosmic ray intensity measured at low latitude stations such as Huancayo and Kodaikanal has, during many years, two maxima instead of one. The pattern of change of the two maxima exhibits a period of 22 years in step with the solar cycle.

Table 8

Geomagnetic deflection of particles measured in telescopes of different apertures in the E-W plane, corresponding to the variation spectrum of H^{-1} and dH^{-2}.

Period	Telescope opening	Geomagnetic deflection corresponding to the variation spectrum H^{-1}	Geomagnetic deflection corresponding to the variation spectrum dH^{-2}
1957	$6^0 \times 15^0$	112^0	98^0
	$5^0 \times 45^0$	109^0	95^0
1958	$30^0 \times 10^0$	112^0	98^0
	$32^0 \times 37^0$	106^0	94^0

The daily variation in wide angle telescopes e.g. the standard telescope and the east and west pointing telescopes at Ahmedabad (each having zenith angles of 32^0 and 37^0 in the E-W and the N-S planes respectively) exhibits two maxima in 1954, one in the early morning and the other near noon (see Fig. 10 and 10b). By 1958, the form has changed over to a curve exhibiting only one maximum of enhanced amplitude near noon. In contrast, the daily variation observed with a narrow angle telescope (Fig. 10a) reveals only one maximum in the forenoon, the amplitude of which is quite high ($\sim$ 1.0 %) in 1954 but decreases (to about 0.3 %)

in 1957-1958. This difference in the form of 12 month mean daily variation observed with narrow angle and wide angle telescopes can be understood by studying frequency distributions of ϕ_1 presented in Fig. 23.

In 1954, the histogram for ϕ_1 for the wide angle telescope has only one broad peak in the morning hours while the narrow angle telescope has one major peak at 1100 hours and another subsidiary peak at 0300 hours. The early morning peak is the only common feature of the ϕ_1 histograms of wide angle and narrow angle telescopes for this period. The noon maximum seems to be an exclusive feature of narrow angle telescopes during this period. There is, therefore, a significant difference in the time of maximum and the amplitude of first harmonic of wide angle and narrow angle telescopes in 1954.

Table 9 shows the mean diurnal component for days corresponding to the 0300 hour peak and the 1100 hour peak of the first harmonic of narrow angle telescopes. It will be seen that noon maximum is associated with very high amplitudes. This dominates the 12 month mean daily variation during 1954 which shows a prominent maximum at forenoon and masks the early morning maximum.

Table.9

Parameters of the diurnal variation observed with the narrow angle telescope averaged on days when the time of maximum occurs at 0900 hour or at 1100 hour during the period August 1954 - July 1955.

	r_1(%)	ϕ_1	Standard error
Diurnal variation with time of maximum at 0900 hour.	1.7	45°	± .10 %
Diurnal variation with time of maximum at 1100 hour.	2.7	103°	± .08 %

The waxing and waning of early morning and noon maximum of 12 month mean daily variation observed with wide angle telescopes is similar to the pattern observed by Sarabhai et al[231] in the ion chamber at Huancayo and is consistent with the 22 year cycle of change of these maxima.

9.1. Long term change in time of maximum of 12 month mean diurnal component of the daily variation.

It is now well established that the time of maximum of the diurnal variation of cosmic ray intensity

undergone world-wide changes broadly in step with the 22 year cycle of solar activity.

Monthly mean $\bar{Z}_1$ vector diagrams of an ion chamber and a counter telescope operating respectively at Freiburg and Rome (plotted by Conforto and Simpson[140]) show that the diurnal vector suffered a maximum shift to early morning hours during June - November 1954, and after that started advancing to later hours. A shift of monthly mean diurnal vector to early morning hours during June - November, 1954, is also pointed out by Pounmer and Van Heerden[140] from a study of the hard component at London. It will be seen in Fig. 20 that the time of maximum of the 12 month mean diurnal component observed with the standard telescope at Ahmedabad shifts to early morning hours from 1951 to 1954-1955 and then starts advancing to later hours up to 1958. Since the 12 month mean diurnal amplitude in 1954 is not statistically significant (0.07 ± 0.04 %) one cannot attach meaning to the time of maximum. It is, therefore, not possible to say from this vector diagram whether the time of maximum started advancing to later hours in 1954 or in 1955. However, our results are not in contradiction with the observations of other workers.

$\bar{Z}_1$ in 1958 is almost the same as in 1951 at Ahmedabad. This indicates that there is an eleven year periodic change superimposed on the 22 year cyclic change of $\bar{Z}_1$ which was pointed out by Rumbyrahilland and Elliot[147]. Such a change in $\bar{Z}_1$ which follows an

eleven year cycle is also indicated by Sarabhai and Kane[146] from an examination of the mean component at Huancayo, Cheltenham and Christchurch. On the other hand, for the nucleonic component at Climax, Huancayo, Leeds, Volcano and Uppsala, it is observed by Haraton and Dogan[215] that the direction of anisotropy responsible for the diurnal variation did not change from 1951 to 1958 except during the solar minimum period of 1954. This seems to indicate that large changes in the time of maximum of diurnal variation are essentially confined to the higher energy component of cosmic rays.

The comparison of the change of yearly mean daily variation (Fig. 19) and the diurnal component from 1954 to 1958 (Fig. 20), clearly brings out that a long term change of 12 month mean diurnal time of maximum does not involve the movement of the mean maximum but a gradual disappearance of the morning maximum.

F.2. Long term change in time of maximum of 12 month mean semidiurnal component of the daily variation.

Sarabhai and Pantry[134] have shown that at the equatorial mountain stations of Kodaikanal and Huancayo, the changes of time of maximum of the 12 month mean semidiurnal component, T_2, are similar

and follow a 22 year cycle. Our observations at Ahmedabad do not confirm this for the period 1951 to 1958 since T_2 remains virtually constant.

The mean semidiurnal vector for the period 1956 to 1958, observed with the standard telescope, is presented on a barometric dial in Fig. 30, after correcting it for pressure and temperature changes.

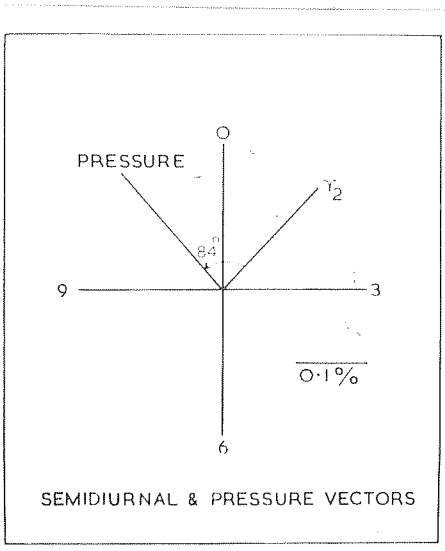


Fig. 30 - Semidiurnal vector of the daily variation of cosmic ray intensity and the corresponding barometric pressure vector averaged for the period 1956 to 1958.

For comparison the average pressure vector for this period is also shown. It will be seen that the two vectors are 90° out of phase which leads to the

conclusion that the r_2 vector of daily variation, after applying correction for various meteorological effects, does not show any relation with the semidiurnal component of the daily variation of atmospheric pressure. Nor can the semidiurnal wave in cosmic ray intensity arise due to temperature effect since the daily variation of temperature is essentially diurnal in character. Katsman and Venkatesan[216] have recently analysed the semidiurnal component at a large number of stations. Even though they find significant amplitudes of the semidiurnal component at equatorial stations they overlook this evidence and conclude that the semidiurnal component arises purely from an imperfect correction of the barometric pressure effect. The evidence presented here taken along with the solar relationship of long term changes of the semidiurnal component demonstrated by Sarabhai and Sastry constitutes, in the opinion of the author, weighty factors against the interpretation of the semidiurnal component at low latitudes as a meteorological effect. The fact that it is large on geomagnetically quiet days, as shown by Sekido et al[142] (and which is also confirmed in the present study as revealed from table 6) shows that it is of extra-terrestrial origin.

5.3. Long term change in the amplitude of the daily variation.

Carmichael and Kane[145] have shown that the long term changes in the amplitude of 12 month mean diurnal variation at different stations are inconsistently correlated at different periods. The correlation is found to be weak during the years 1937-1940 and high during the years 1941-1945.

Rather than studying daily variation in terms of the amplitudes and times of maxima of the diurnal and the semidiurnal components, Carmichael et al[151] looked into the changes of the daily variation in terms of the twelve hourly deviations at Hungaya and Cheltenham and found that changes could be understood in terms of the veering and veering at both stations of an early morning maximum and the noon maximum present in the 12 month mean daily variation. The changes follow a 22 year solar cycle.

From an examination of the data obtained from wide angle instruments at a large number of stations, Norman and Fairberg[217] find that the power of the cosmic goes through a minimum during 1954. Pomerantz and Van Hoerden[149] have observed that during the period June - November, 1954, the mean daily variation studied with neutron monitors operating at London and Manchester decreased to a value which was not statistically different from zero. Glokova's[218] examination of

neutron and meson components at various stations reveals that, after taking proper account of atmospheric effects, the 12 month mean daily variation for a certain period in 1954 (somewhere between June - November 1954) becomes zero in neutron monitors while the meson component still reveals some small but significant amplitude. It is concluded by him that during this period (June - November 1954), there was an absence of disturbing factors of solar origin creating an anisotropy of cosmic rays. Similar conclusions are arrived at by Conforto and Simpson[150] from an examination of neutron and meson component at various stations.

As already mentioned in section 2.1., the 12 month mean diurnal variation in 1954, measured with the standard telescope at Ahmedabad reveals an amplitude which is statistically insignificant and is, therefore, in agreement with other observations referred to above. It must be realised, however, that the results of narrow angle telescopes obtained by Sarabhai and Kenmore[144] at Ahmedabad in 1954 show an amplitude as large as 1.0 % and, hence, are in direct contradiction with all the above mentioned results.

Since the 12 month mean daily variation is dependent on the amplitude and the time of maximum on individual days it is worthwhile examining the

daily variation on individual days to see whether one can reconcile these contradictory results.

In sections 5.1 and 5.2 of chapter IV, we have compared the wide angle and narrow angle results at Ahmedabad for 1954 from the point of view of the mean yearly curves and the histograms of r_1, r_2 and ϕ_1, ϕ_2 for that period. However, since the results of Olakova, and Pomerantz and Van Heerden indicate a negligible amplitude for the mean curves during the period June - November, 1954, it would be interesting to see what happened to the daily r_1, r_2 and ϕ_1, ϕ_2 values for wide angle telescopes for this period. The data utilised for this purpose are derived from the ion chamber at Huancayo and the standard telescope at Ahmedabad for the period from 1953 to 1955 and the mean daily variation as well as the daily variation on individual days is studied for successive six monthly periods. At Ahmedabad only the following three six-monthly periods were available during these years.

(1) July - December, 1954.
(2) January - June, 1955.
(3) July - December, 1955.

We first present in table 10 the mean $\bar{r}_1$, $\bar{\phi}_1$ and $\bar{r}_2$, $\bar{\phi}_2$ for each six-monthly period for which the data are available at the two stations during these years. The period July - December 1954 fairly well

Table 10

Parameters of the mean daily variation observed with ion chamber at Huancayo and the standard telescope at Ahmedabad for successive six-monthly period from 1953 to 1955.

Period.	Huancayo					Ahmedabad				
	$\bar{r}_1$(%)	ϕ_1	$\bar{r}_2$(%)	ϕ_2	Standard error	$\bar{r}_1$(%)	ϕ_1	$\bar{r}_2$(%)	ϕ_2	Standard error
Jan-Jun.'53	0.20	90°	0.09	138°	± .01					
Jul-Dec.'53	0.14	97°	0.07	136°	± .01					
Jan-Jun.'54	0.13	68°	0.06	130°	± .01					
Jul-Dec.'54	0.08	17°	0.10	149°	± .01	0.13	119°	0.11	35°	± .04
Jan-Jun.'55	0.14	101°	0.05	+64°	± .01	0.46	83°	0.20	34°	± .04
Jul-Dec.'55	0.15	166°	0.06	+38°	± .01	0.25	45°	0.31	78°	± .04

Table 11

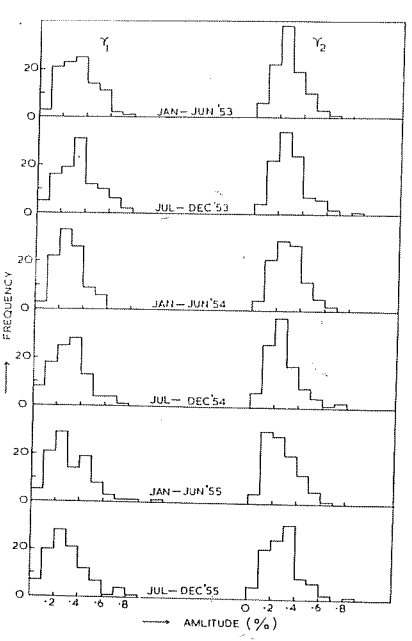
'Mean' and the 'standard deviation' of frequency distributions of the diurnal and the semidiurnal components of daily variation observed at Tucson and Honolulu for various six-monthly periods from 1933 to 1955.

Period	Tucson				Honolulu			
	Mean (δ)		Standard deviation (δ)		Mean (δ)		Standard deviation (δ)	
	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
Jan-Jun, '53	0.27	0.22	0.15	0.12				
Jul-Dec, '53	0.29	0.24	0.15	0.14				
Jan-Jun, '54	0.23	0.23	0.12	0.13				
Jul-Dec, '54	0.25	0.23	0.15	0.14	0.86	0.81	0.47	0.47
Jan-Jun, '55	0.27	0.22	0.17	0.13	0.83	0.75	0.41	0.44
Jul-Dec, '55	0.26	0.25	0.17	0.14	0.77	0.84	0.48	0.35

Note:- Error in the 'mean' of T_1 and T_2 histograms at Tucson is .02 δ while at Honolulu the error is .05 δ.

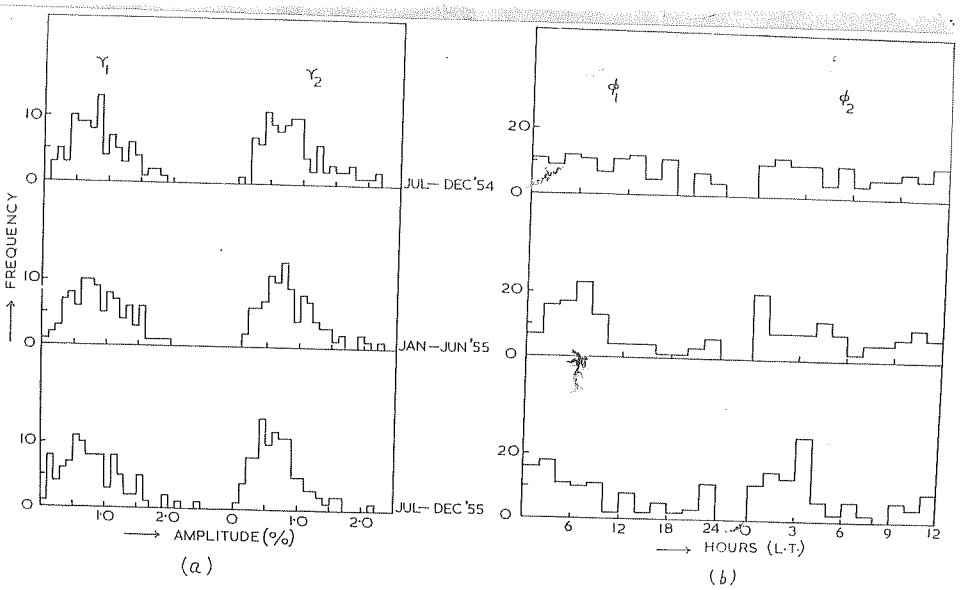
covers the period June - November, 1954, when the mean daily variation is reported to be zero in the neutron monitors at various stations.

It will be seen that F_1 for the period July - December 1954 is minimum at both the places. This agrees with the general conclusion drawn by Dolbova.



Y_1 & Y_2 HISTOGRAMS AT HUANCAYO

Fig. 81 - Frequency distributions of the diurnal and the semidiurnal components of the daily variation observed with ionization chamber at Huancayo for successive six-monthly periods from 1953 to 1955.



γ_1, γ_2 & ϕ_1, ϕ_2 HISTOGRAMS AT AHMEDABAD

Fig. 32 - Frequency distributions of the parameters of daily variation observed with the standard telescope at Ahmedabad for successive six-monthly periods from July 1954 to December 1955.

(a) The diurnal and the semi-diurnal components of the daily variation.

(b) The time of maxima of the diurnal and the semidiurnal components.

In Fig. 32 and 32a are represented frequency distributions of γ_1 and γ_2 amplitudes on individual days observed at the two stations during each of

those periods. The histograms do not differ from period to period. A rigorous comparison of these histograms is made by making a study of two parameters of the histograms, namely the 'mean' and the 'standard deviation'. The statistical comparison of the 'mean' and the 'standard deviation' has been made with the Students' 't' test and the 'F' distribution test respectively, the details of which have been given in chapter III.

Table 11 (see page 156) gives the values of these parameters for the r_1 and r_2 histograms of each period observed at the two places. The two tests reveal that the 'mean' and the 'standard deviation' of r_1 and r_2 histograms for the period July - December, 1964, do not differ significantly from those of other periods. From this it may be concluded that the amplitude of r_1 or r_2 on individual days during this period are not different from other periods.

In Fig. 33 and 32b we present the frequency distributions of times of maxima of the diurnal and the semidiurnal components for each of those six-monthly periods when r_1 and r_2 amplitudes on individual days are significant at the 5% level since only on those days one can attach meaning to ϕ_1 or ϕ_2 values.

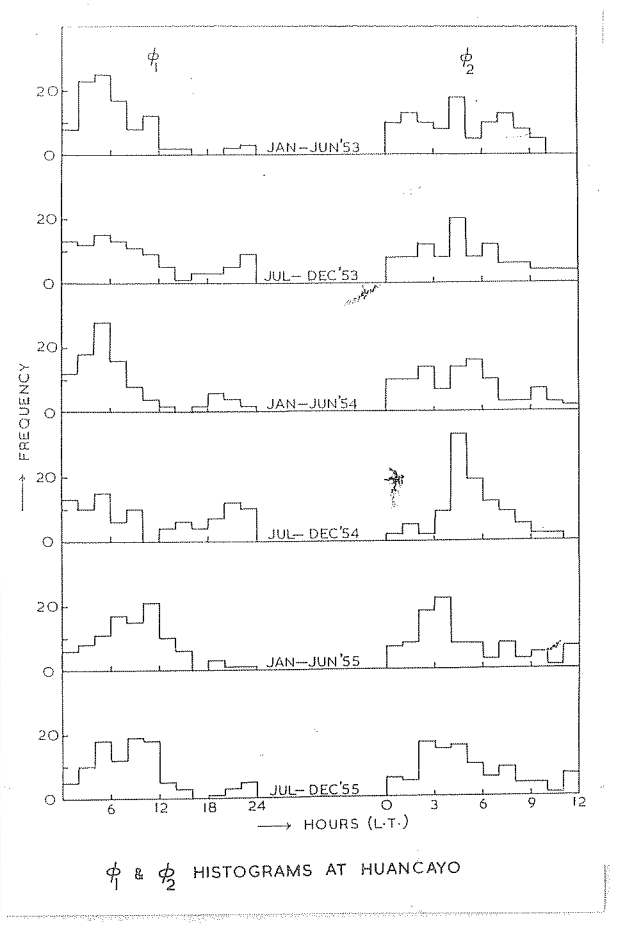


Fig. 33 - Frequency distributions of times of maxima of the diurnal and the semidiurnal components of the daily variation measured with ion chamber at Huancayo during various six-monthly periods from 1953 to 1955.

It will be seen that for the period July - December, 1954, the ϕ_1 histogram reveals a large scatter both in ion chamber at Huancayo and the standard telescope at Ahmedabad. During this period χ^2 value of the histograms which, as already described

in chapter III, represents the inverse measure of the variability of the time of maximum, attains a minimum value (table 12) at both the places. The χ^2 value is insignificant at the 5 % level. Hence A_1 distribution for this period can be taken as a random

Table 12

χ^2 values of the histogram of time of maxima of the diurnal and the semidiurnal components of daily variation observed at Huancayo and Ahmedabad during various six-monthly periods from 1953 to 1955.

Period	χ^2 Huancayo A_1	Huancayo A_2	Ahmedabad A_1	Ahmedabad A_2
Jan - Jun '53	62.1	14.0		
Jul - Dec '53	21.6	13.7		
Jan - Jun '54	45.6	17.0		
Jul - Dec '54	15.6	41.6	10.8	5.8
Jan - Jun '55	42.8	28.0	46.2	15.0
Jul - Dec '55	46.8	28.9	26.5	29.8

distribution with no preference for any particular hour or hours. It is this large scatter of A_1 on individual days rather than an inherently small amplitude of A_1 during the period July - December, 1954, which makes the mean amplitude $\bar{A}_1$ small in wide angle telescopes.

The frequency distributions of the semi-diurnal component at the two places do not seem to show similar behaviour during the period July - December, 1954. The ϕ_2 histogram of ion chamber at Kodaikanal has a peaked structure while the ϕ_2 histogram of the standard telescope at Ahmedabad reveals a wide scatter, similar to the one in ϕ_1 histograms during this period. This discrepancy in the behaviour of ϕ_2 on individual days at the two stations during the period July - December, 1954 is not understood.

The observations with wide angle instruments at the two stations agree in indicating that r_1 and r_2 amplitudes on individual days in the period July - December 1954 were not different from other periods, from 1953 to 1955, and it was only the large scatter of the time of maximum of diurnal component which brought down the mean diurnal amplitude of daily variation to a very low value during 1954. It may, therefore, be concluded that the power of the source of the daily variation viewed by a wide angle telescope did not decrease during the period from 1953 to 1955, and the view held by Dickson, and by Comforto and Simpson that there was an absence of solar daily variation for a certain period in 1954 is not, therefore, borne out by the evidence. On the contrary, the power of the source on individual days as observed with a narrow angle telescope decreases with increasing solar

activity (see Fig. 21).

One can understand the large scatter of diurnal time of maximum on individual days during the period July - December 1964 in terms of the existence of two types of daily variations in that period as revealed by the observations of Sarabhai and Koturkar[144] with narrow angle telescopes. They found that the frequency distribution of diurnal time of maximum for days when F_1 is significant at the 2σ-level, has a tendency to occur either in the night at about 0300 hours or in the day at about 1100 hours from which it may be concluded that in 1964, there were in existence two types of daily variations, one having its time of maximum in the night and the other in the day. Because of poor resolution of wide angle telescopes it is quite likely that no clear distinction is made between these two types of daily variations and what is observed instead is only a broad scatter of the diurnal time of maximum.

3. Relationship of daily variation with C_p.

On geomagnetically disturbed days, the increase of diurnal amplitude and the shift of its time of maximum to earlier hours (a relation which was first pointed out by Ohtaki et al[155]) is not always maintained as is seen from Fig. 17. Many authors,

such as Parsons[220], Venkatesan[221] and Satyanarayanan[164] have reported similar inconsistencies in regard to the dependence of the daily variation or of neon intensity on C_p.

A direct association of geomagnetic activity with some phenomena observable on the sun has been attempted by many authors. Bell and Glaser[219] find that a maximum geomagnetic activity of the recurrent type follows two or three days after CMP of regions of exceptionally low green coronal intensity. On the other hand, CMP of strong coronal emission in the 5303 line is found significantly to inhibit geomagnetic disturbances and are thus associated with C_p minima. Non-recurrent type of geomagnetic activity is found to be associated with sc storms and the central meridian passage of sun-spot groups, which are also found to be sources of emission of solar noise in 1 meter wave length.

It is obvious that high C_p does not correspond to a unique condition of the electromagnetic state in interplanetary space in the neighbourhood of the earth and, therefore, it is not surprising that we got inconsistent results on days selected with only C_p as the criterion. Thus the selection criterion for specifying the electromagnetic state of interplanetary space which is relevant to cosmic ray variations, should be C_p along with some observed characteristics

on the sun such as the intensity of green coronal line or radio outbursts of type IV.

4. Conclusion.

Many features of the daily variation which are ascribed to an anisotropy of the primary radiation can be understood in terms of the ideas developed by Hagenrina[138], Neurlar[139] and Dorman[6], following the basic mechanism proposed by Alfven[137]. These have been described in the introduction. Of particular significance in this connection is the possibility for the existence, under certain conditions, in the neighbourhood of the earth of streams of solar plasma with trapped magnetic fields and presenting an electric polarization as viewed from the stationary earth. In the context of the conductivity of interplanetary space, particularly during a period of maximum solar activity, many workers have doubted the plausibility of the occurrence of a process involving the polarisation of streams at large distances from the sun. Indeed one would expect that the power of the source associated with the trapped magnetic field in beams of solar plasma would be largest during a period of low solar activity when the conductivity of the interplanetary space would be the least.

The conclusions drawn by Rosenow and Van Heerden[140], Gldrova[218], and Comforto and Simpson[150],

which are derived from the daily variation averaged over an extended period, are that the power of the source was minimum during 1954. However, we have shown from the data of wide angle telescopes at Ahmedabad and from Haurwitz-Legnation chamber that, judged from the daily variation on individual days, the power of the source during the sun-spot minimum period of June - November, 1954, was no less than many earlier and later six-month periods. The conclusions of other workers seem to arise from a neglect of the wide scatter of the time of maximum from day to day. Moreover, narrow angle telescopes show that the power of the source was significantly greater during sun-spot minimum than during 1957 and 1958. Because of its great importance in establishing the interpretation, the effect needs further experimental confirmation. Nevertheless, it can be stated that our present evidence is not in contradiction with an interpretation of the daily variation along the lines of the theory developed by Nagashima, Morurkar and Parmar.

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