Dissertation

on

STUDIES IN COSMIC RAYS

"The Study of Time Variation of Cosmic Rays with Directional Telescopes at Ahmedabad"

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STATEMENT

The mean daily variation of meson intensity at Ahmedabad (Geomag. Lat. 13.9°N, sea level) measured with east and west pointing telescopes inclined to the zenith at 45°, has been studied by the author during the period 1957-1958. The data has been analysed and the conclusions arrived at are listed below. In the study of the average daily variation of meson intensities measured by east and west telescopes it is found appropriate to apply a correction not only for the daily variation of barometric pressure but for the daily variation of temperature of the atmosphere upto an altitude of 2 km from the ground.

1. The 12 month mean and 24 month mean daily variations in east and west directions have almost the same amplitude. The diurnal time of maximum in east, is found to occur 4 to 5 hours earlier to that in west, showing that on an average, the daily variation could be attributed to an anisotropy of primary radiation.

2. (a) The frequency distributions of parameters of diurnal and semidiurnal components of daily variation on individual days have been studied. West pointing telescopes are found to exhibit a larger variability in the diurnal time of maximum as compared to that in east both on individual days and on a monthly basis.

(b) The frequency distribution of large positive and negative bihourly deviations, significant at the 2σ level confirm the larger variability found in west as compared to that in east.

3. (a) Picking the hours when large number of significant positive and negative deviations occur, at least twice as frequently as may be expected by chance alone, we find that they can be broadly grouped into three groups. Group A, corresponds to the days when large number of significant positive deviations occur in west around midnight local time. Group B, corresponds to the occurrence of large number of significant positive deviations near noon in either east or west. Group C, corresponds to the days when large number of significant negative deviations occur at 1600 or 1800 hours in either east or west. The mean daily variation for neutron intensity at different stations are determined for these groups separately.

(b) The daily variation for days of group A, involving a significant and large semidiurnal component on a world wide basis is associated with the occurrence of a sharp maximum of bihourly intensity near midnight local time at low latitudes, affecting mainly the low energy component of primary cosmic radiation. The occurrence is also associated with a relatively disturbed geomagnetic condition throughout the period and a Forbush type of decrease of mean intensity. For groups B and C, the time series of mean intensity do not show any significant changes.

(c) The frequency distributions of significant positive and negative deviations at various stations, separately for days corresponding to groups A, B and C, are examined. It is found that the occurrence of maximum number of positive deviations at equatorial and southern stations on days corresponding to groups B and C, is much earlier (by about 4 hours) to that at northern stations. We believe that this indicates the existence under certain conditions of a hemispherical effect of the source of daily variation which is not symmetrical with respect to the equator.

(d) The diurnal time of maximum for the mean daily variation of neutron intensity at an equatorial station is found to be earliest for all the groups and it gradually becom later as we go either northward or southward towards the poles. This would normally be strongly suggestive of the source of daily variation being an anisotropy outside the influence of the geomagnetic field. However since, on other considerations we find that on geomagnetically disturbed days there is local non-meteorological source of daily variation of geocentric type, we are led to the view that the latter source must itself be produced by charged particle radiation from the sun which in its interaction with the geomagnetic field would be subject to similar effects as the charged primary cosmic rays.

4. (a) Since change in east-west asymmetry denotes either a change in primary spectrum or a change in cut off energy, the mean daily variation in east and west on days of low, normal and high asymmetry is investigated. It is found that

on days of high asymmetry the daily variations in east and west have a high amplitude and a 6 hours phase difference in the time of maximum of the diurnal component in east and west consistent with a source of anisotropy situated outside the influence of the geomagnetic field. Days of high asymmetry are further found to be associated with a low planetary index of geomagnetic disturbance (0.6).

(b) Mean daily variation of neutron intensities at various stations situated in northern, equatorial and southern belts is found on days of low and high asymmetry at Ahmedabad. On days of high asymmetry, the mean daily variation at all the stations exhibits a high amplitude of a predominently diurnal character. On days of low asymmetry, the mean daily variation at stations situated only in the northern hemisphere, show a high amplitude of daily variation. Thus the examination of mean daily variation of neutron intensity at various stations for epochs of low and high asymmetry gives again an indication of the existence of a hemispherical effect of the anisotropic radiation.

5. Mean daily variation of meson intensity in east and west for days of low, medium and high C_p is determined. It is found that on days of high C_p ($C_p \geqslant 1.0$), both east and west intensities show the same time of diurnal maximum. The frequency distributions of diurnal and semidiurnal times of maxima when the appropriate component is significant at the 2σ level on days of low, medium and high C_p are also examined. It is found that on days of high C_p the variability

of diurnal component in west is reduced giving rise to a peaked distribution of diurnal time of maximum, with the peak occuring at the same hour in both east and west. The absence of a phase difference ondays of high C_p in the occurrence of the diurnal time of maximum in east and west is interpreted as an indication of the existence of a geocentric non-meteorological source of modulation being responsible for the daily variation. Elliot et al and Parsons have also reported the need for looking into such a local source to explain the daily variation during some periods. The origin of such a geocentric source of modulation is discussed.

6. With a knowledge of the coupling coefficients and geomagnetic deflections in east and west the energy spectrum of variation has been determined under three different conditions, when the daily variation measured by east and west pointing telescopes shows significant and large amplitudes.

(a) The spectrum of variation consistent with the observed 12 month and 24 month mean daily variation in east and west, is found to be of the form aE^{-r} where $r = 0$ for $E > 20$ Bev and $r = 2$ for $E < 20$ Bev.

(b) On days of high asymmetry, when the daily variation can undoubtedly be related to an anisotropy outside the influence of the geomagnetic field, the spectrum of variation is found to be of the form $aE^{-0.8}$.

(c) On days of high C_p, the best fit for the spectrum of daily variation can be represented as $\delta D(E)/D(E) = aE^0$ where $E > 20$ Bev and $\delta D(E)/D(E) = 0$ where $E < 20$ Bev.

(d) Since the mean daily variation includes daily variation on days of high asymmetry as well as the daily variation on geomagnetically disturbed days, it is remarked that the conclusions derived from the study of mean daily variation over an extended period of time is not very meaningful. It is concluded that there are at least two types of daily variations, one caused by a geocentric source of modulation which is predominent on geomagnetically disturbed days and the other due to an anisotropy situated far outside the influence of the geomagnetic field and which is predominent on other days.

(e) An attempt is made to explain the increase in asymmetry, the spectrum of variation and the high amplitude of daily variation on days of high asymmetry, by invoking the presence of ionised streams of solar matter in the neighbourhood of the earth. It is found that in order to explain the observed results, the increment of energy suffered by particles crossing the beam of width 5×10^{12} cms, should be about 0.1×10^8 eV. Assuming a frozen in magnetic field of the order of 5×10^{-6} gauss, the velocity of such beams is estimated to be of the order of 5×10^7 cm/sec. The values obtained for various characteristics of the beams are found to be of the right order taking into account the various astrophysical and geophysical evidences, which lends strong support to the beam theory.

7. Storm type decreases in east and west, for 6 storms which occurred during the years 1957-1958 and for which we have data for east and west pointing telescopes, are studied. The decreases of neutron intensities at Kodaikanal, Alma-ata and Mawson, all of them situated at almost the same longitude as that of Ahmedabad, are also studied for these storms. It is found that the storms can be broadly classified into two groups.

(a) In group A type of storms, the time interval between Sc storm and intensity minimum is found to be about 20 hours. These storms are accompanied by a sharp fall of nucleonic intensity and are found to have a same onset time at all the stations. The rate of decrease and the amplitude of decrease for low energy component is found to be more than that for high energy component. The low energy component as well as east-west asymmetry continued to be depressed in the later part of the storm, even two days after the minimum is reached.

(b) In storms of group B, the time interval between the commencement of the fall and the occurrence of minimum intensity is found to be about 30 - 35 hours. These storms are characterised by a gradual fall of nucleonic component intensity. The onset time at high latitude stations having a lower mean energy of response is found to be earlier than at low latitude stations. The rate of decrease is found to be same for both low and high energy components. The amplitude of decrease, however, is found to be more for low energy component than for high energy component. These storms are found to be associated with weak or no Sc storms and changes of east-west asymmetry either during the main phase or in the later part of the storm are found to be very small.

It is believed that the storms of group A are caused by the envelopment of the earth by the lateral edge of the second type of streams, as proposed by Dorman. Streams of this type are probably very dense, have a high velocity and strong frozen in magnetic field (10^{-4} - 10^{-5} gauss) and probably originate within the sun's equatorial region.

Storms of group B are believed to be caused by the envelopment of the earth by the lateral edge of the streams of the first kind. Streams of the first kind are rarified streams having a weak frozen in magnetic field (10^{-6} gauss) and are probably connected with some high latitude formation on the sun.

8. A long term change in the diurnal time of maximum from 1955 to 1958 is observed in east, west as well as vertical intensities at Ahmedabad. The diurnal time of maximum in all the cases is found to shift to later hours by about 5 hours from 1955 to 1958. The form of the 12 month mean daily variation curve which was having two peaks in 1954-1955, one in the early morning and the other at noon,

changes into a curve having a single peak at about noon by 1957-1958. These long term changes are consistent with the results obtained by Elliot et al and Sarabhai et al.

These conclusions have been discussed in chapter VI and a list of references consulted by the author has been included at the end of the thesis.

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C O N T E N T S

CHAPTER I

INTRODUCTION

The study of time variations of cosmic rays can be really said to have begun in the middle of 1930's with the continuous recording of μ meson intensity and a systematic study of cosmic ray variations of atmospheric origin. The observed cosmic ray variation which was of the same order of magnitude as the cosmic ray variation of meteorological origin confirmed the then existing belief in the constancy and isotropy of the primary cosmic radiation.

New advancements in experimental techniques and the progress made in the theoretical study and experimental observations of the meteorological effects of μ mesons since 1940, have conclusively proved the existence of a significant variation of extra-terrestrial origin. Mention might be made of the ingenious method of Malmfors[1] and Elliot and Dolbear[2], who in order to overcome the difficulty of correcting for changes of meteorological factors, constructed directional telescopes pointing to two different directions inclined equally with respect to the vertical. From the difference observed in the daily variations in the north and south directions, they could definitely conclude that there was an anisotropy of primary radiation. A growing realisation of the importance of the study of time variation in probing the electromagnetic fields in interplanetary and interstellar space has increased the importance of this fascinating subject in recent years. Since Elliot's[3] review of the subject in 1951, Sarabhai and Nerurkar[4] and Singer[5] have reviewed the progress in the subject upto 1956. Dorman[6] has dealt with the subject in an exhaustive manner in his book "Time Variation of Cosmic Rays". Beside these, individual authors such as Simpson[7], Fortush[8] and Sarabhai et al[9] have reviewed particular aspects of the field with special reference to the work done by their own groups.

The present thesis deals with the daily variation and the variation of mean intensity of cosmic ray muon intensity for east and west directions measured at low latitude during 1957 and 1958. The variations recorded by a detector fixed to the spinning earth and scanning a region of space in which cosmic ray intensity is anisotropic, include variations due to anisotropy, meteorological factors and the variations of the primaries which may be due to a variety of other causes. Nevertheless, an attempt is made to gain some information regarding the anisotropy of cosmic rays and their energy dependence by comparing daily variations in east and west directions.

In this introduction the subject is reviewed in detail only so far as it is of particular significance to the experimental work of the author and the other aspects of the subject are generally just touched upon. Initially we also present a summary of background work related to the geomagnetic effect, the transition effect in the atmosphere and meteorological effects, which is essential to the interpretation of cosmic ray time variation studies.

1.1 Associated topics

1.11 Geomagnetic effects.

Since our earth acts as a magnetic analyser, a knowledge of deflections suffered by cosmic ray primaries of various energies in the geomagnetic field, is essential to locate the source of anisotropy. Considering the earth's field as a dipole, an extensive investigation of the effect of the earth's magnetic field on the motion of charged particles has been done by Stormer[10] and Lemaitre and Vallarta[11,12], the results of which have been admirably summarised by Janossy[13], Johnson[14], Montgomery[15] and Alpher[16]. Recently Quenby and Webber[17] have taken into consideration the dipole as well as nondipole parts of the internal field and deduced the cut off energies at various latitudes.

In order to interpret the anisotropic cosmic radiation and solar flare effects, one is required to calculate the actual trajectories of individual particles. Schluter[18], Firor[19], Jory[20] and many others[21,22,23] have computed the individual orbits of primary particles of energies extending upto 10 Bev. Brunberg and Dattner[24], on the other hand, have tackled the problem in an experimental way. By firing a well collimated beam of electrons of variable velocities from a miniature gun mounted on a magnetised model of the earth, they have determined the asymptotic coordinates of velocity vectors for all primaries of energy greater than 2 Bev which can arrive at specified angles to the zenith in the north-south and east-west plane at various latitudes. The results presented in convenient graphical form have been extremely valuable in the interpretation of effects caused by anisotropic radiation.

1.12 Methods of relating primary cosmic ray intensity changes to secondary intensity changes.

In order to connect the variations of the secondary component in the lower atmosphere to the variations of the primary radiation incident on the top of the atmosphere, it is necessary to relate the primary spectrum through an "yield function" or a "generating function" with the spectrum of secondaries observed at various depths. Even without a knowledge of the intervening physical processes one can calculate the above function for latitude sensitive primaries by knowing the latitude effect of the charged particle component. Utilising the available data for the latitude effect at various altitudes, Treiman[25], Fonger[26], Nagashima[27], Dorman[28] and Olbert[29] have calculated the yield functions at various latitudes and altitudes. Webber and Quenby[30] have done the more accurate calculations of yield function taking into account the new cut off rigidities obtained by considering the dipole as well as the nondipole parts of the internal field of the earth.

Following Dorman, the intensity of the ith component (muons, stars, bursts, soft component etc.) as observed by a station situated at latitude λ, longitude f and level with pressure h_0 and produced by the primaries having an energy spectrum $D(E)$ can be represented by the equation

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

where $m^i(E, h_0)$ is 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. $E^{min}_{\lambda,f}$ is the geomagnetic cut off at the observing station. This formula assumes that $D(E)$ is isotropic beyond the limits of atmosphere and that the secondary particles follow the direction of motion of the parent primary particle. By varying equation (1) with respect to all the available parameters we can get the cumulative variation of the observed intensity.

$$\frac{\delta N^i_{\lambda,f}(h_0)}{N^i_{\lambda,f}(h_0)} = -\delta E^{min}_{\lambda,f}\, W^i_{\lambda,f}(E^{min}_{\lambda,f}, h_0) + \int_{E^{min}_{\lambda,f}}^{\infty} \frac{\delta D(E)}{D(E)}\, W^i_{\lambda,f}(E,h_0)\, dE$$

$$+ \int_{E^{min}_{\lambda,f}}^{\infty} \frac{\delta m^i(E,h_0)}{m^i(E,h_0)}\, W^i_{\lambda,f}(E,h_0)\, dE \qquad (2)$$

where $W^{i}_{\lambda,f}(E,h_0) = \dfrac{D(E)\; m^{i}(E,h_0)}{N^{i}_{\lambda,f}(h_0)}$ is the coupling coefficient which gives an idea of the magnitude of the secondary variation for a particular amount of variation of primary spectrum. The first term in equation (2) is the contribution due to the variation in geomagnetic cut off energy $E^{min}_{\lambda,f}$ of the primary particle which may itself be due to the combined influence of various geomagnetic disturbances. The second term represents the variation in observed intensity of secondary cosmic rays due to the variation of differential energy spectrum of cosmic rays. The third term represents the contribution from the variation in multiplicity function, which may arise as a result of a change in shield thickness above the instrument or due to the changing atmospheric conditions.

Differentiating equation (2) with respect to $E^{min}_{\lambda,f}$ we get

$$\frac{\delta N^{i}_{\lambda,f}(h_0)}{\delta E^{min}_{\lambda,f}} = - D\,(E^{min}_{\lambda,f})\; m^{i}\,(E^{min}_{\lambda,f},\; h_0)$$

By substitution we get

$$W^{i}_{\lambda,f}\,(E^{min}_{\lambda,f},\; h_0) = - \frac{1}{N^{i}_{\lambda,f}(h_0)} \cdot \frac{\delta N^{i}_{\lambda,f}(h_0)}{\delta E^{min}_{\lambda,f}} \qquad (3)$$

From equation (3) it is clear that with a knowledge of the latitude effect we can calculate the coupling coefficients. Dorman has presented his results in a graphical form from which coupling coefficients can be read out for total ionising intensity, hard component intensity and neutron intensity at sea level and total ionising intensity at 4300 meters altitude for latitudes 0°, 30° and 50°. Even though the curves extend upto 1000 Bev, the values upto primaries of energy 30 Bev which are subject to the influence of earth's geomagnetic field are directly obtained and the rest of the values are found by extrapolation knowing the nature of the differential energy flux and the multiplicity function at higher energies. Fig. 1 from Dorman indicates for $\lambda = 0$ the value of the coupling coefficients for total ionising intensity, hard component intensity and neutron intensity at sea level and total intensity at 4300 meters altitude.

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.

There are no published results of coupling coefficients applicable to directions inclined to the zenith. However Johnson[31] et al have measured the cosmic ray intensities with east and west pointing telescopes inclined to the zenith at 45°. Utilising their curves for the latitude effect of cosmic rays in the inclined directions and using Dorman's method we have calculated the coupling coefficients applicable in the inclined directions. A detailed description of the method is given in chapter IV.

In testing whether an assumed model of anisotropic radiation is consistent with experimental results related to the daily variation of secondary intensity, many authors apply the geomagnetic angle of drift corresponding to the mean energy of primary radiation. However the more accurate manner of making a correction for geomagnetic drift should involve integration over a range of energies using the coupling coefficients and the angles of drift appropriate to primaries within narrow bands of energies. Of course when this is applied to telescopes pointing to 45° east and 45° west at stations such as Ahmedabad where the cut off energies in east and west directions are 22.5 and 10.9 Bev respectively, it is necessary to put the different energies as the lower limits of integration. The details of the procedure are explained in chapters V and VI.

1.13 Variations of atmospheric origin.

Since Duperier's presentation of the regression equation

$$100 \frac{\Delta I}{I} = \alpha_p \Delta P + \alpha_H \delta_H + \alpha_T \delta_T$$

connecting the percent change of mean intensity with the change of barometric pressure ΔP, the change in the height of 100 mb level δH, and the change in temperature of the atmosphere δT between 100 mb and 200 mb levels, a number of workers such as Trefall[32,33,34,35], Barret et al[36], Wada and Kudo[37] and others have tried to understand the physical meaning of the coefficients. Realising, that due to the interdependence of pressure and temperature in the atmosphere, the very application of the correlation analysis is often questionable, Olbert[38], Maeda and Wada[39] and Hayakawa et al[40] have considered the problem from a purely theoretical point of view. Maeda and Wada[39] have presented the results on the dependence of the temperature coefficient on energy and altitude in convenient graphical form, from which the negative temperature effect due to the decay of μ mesons and the positive temperature effect due to variation of μ meson production rates can be read out separately. Besides, the partial temperature coefficient used by them incorporates the contribution from temperature changes in separate layers of the atmosphere instead of the average temperature change of the atmosphere as a whole. Hayakawa et al[40] have extended the work of Maeda and Wada[39] by considering the nucleonic effects on the production of μ mesons.

Feinberg and Dorman[41,42,43] have worked out a complete theory of atmospheric effects. Considering the ionisation losses of μ mesons in the atmosphere, they have derived a complex analytical general expression involving several variables such as the ground pressure and density of different isobaric levels from the top of the atmosphere to the ground. A noteworthy point in this theory is that the authors have avoided making any general assumption regarding the structure and distribution of mass of the atmosphere. The only assumptions made by the authors are that (1) μ mesons are generated due to the decay of π mesons and not directly as a result of nuclear collisions and (2) μ mesons are continuously created throughout the atmosphere.

Dorman's results can be summarised by the equation

$$\frac{\delta N_{\mu}}{N_{\mu}} = \beta \delta h_0 + \int_0^{h_0} W(h) \; \delta T(h) \; dh \tag{4}$$

where δN_{μ} is the variation in meson intensity at the pressure level h_0, $\delta T(h)$ is the change of temperature at the level h_0. The function $W(h)$ which is designated as the "temperature coefficient density" has been calculated and plotted. By approximating the above equation to

$$\frac{\delta N_{\mu}}{N_{\mu}} = \beta \delta h_0 + \sum_{i=1}^{n} K_i \; \delta T_i \tag{5}$$

where K_i is the partial temperature coefficient for the ith layer obtained by integrating $W(h)$ over the corresponding layer, we get a ready practical method for the application of temperature correction to the cosmic ray data. As Dorman himself points out, it is sufficient if summation over 11 standard atmospheric layers from 1000 mb to 50 mb is done. The main difficulty in applying this method to correct the daily variation of cosmic ray intensity is the difficulty in the accurate determination of δT_i from radiosonde observations. The principle source of error in measuring the daily variation of temperature in the upper atmosphere arises from imperfect radiation shielding of the instrument. This question will be discussed in detail in chapter V.

Glokova[44], Kuzmin[45] and other Russian workers who have successfully employed the above method for correcting cosmic ray data, find that the seasonal variations of cosmic ray mean intensity and of daily variation vanish if proper temperature correction is applied. The amplitude of the diurnal variation at high latitude is found to be doubled when proper temperature correction is applied. On the other hand Maeda's[46] results indicate an upper limit of 0.05% for the diurnal amplitude with a maximum at 1400 hours which may be caused due to the variation in atmospheric temperature. Recent investigation by Fasoli et al[47] confirms the view that an adequate correction can be applied for all meteorological factors by just knowing the heights of isobars at 50, 100, 200, 300, 500, 700 and 850 mb.

A suggestion by Miyazaki[48] for the application of temperature correction to only low energy portion of cosmic rays consists of comparing the cosmic ray intensities measured by identical instruments at two stations lying almost on the same latitude and longitude but situated at different altitudes. Making the assumption that the temperature variation over a corresponding isobaric level above the two stations are exactly alike, he has shown that the difference in intensity at the two stations corresponding to the low energy component of cosmic rays has only to be corrected for the temperature changes of the mean atmosphere between the two stations.

Almost total absence of decay effects renders the problem of correction of nucleonic data for meteorological factors easier. Simpson et al[49] have proved that the effect of atmospheric temperature variation on the observed neutron intensity is negligible viz. of the order of -0.02 %/°C at equator and even less than -0.006 %/°C at 50° latitude. The barometric coefficient β remains essentially constant throughout the latitude range from the equator to 54° latitude and for all atmospheric depths greater than 600 gm/cm^2. It is gratifying to note that the observations of all the workers[50,51,52] are more or less in agreement with the value of $\beta = -0.94 \pm 0.03\%$ per mm Hg obtained by Simpson et al.

1.14 East-west asymmetry

East-west asymmetry is generally defined as $\frac{2(W - E)}{(W + E)} \times 100$ where W and E are secondary intensities in west and east directions respectively. Johnson[14] has shown that primaries in the energy range between the threshold energies in the two directions can completely explain the asymmetry at low latitudes. The asymmetry is found to increase proportionately with zenith angle upto 60^o, but near the horizon due to the absorption of the low energy field sensitive rays it declines as the zenith angle is increased beyond 60^o. The existence of a small asymmetry of 1% even at high latitudes found by Seidl[53] and others has been explained by Johnson[54] by considering the deflection of secondary mesons in the earth's magnetic field. Due to the presence of the earth's magnetic field the secondary particles will suffer a slight deflection during their passage through the atmosphere and as a result of it the slight excess of secondary positive particles over negative particles will cause a small amount of east-west asymmetry. Using Owen and Wilson's[55] values for the ratio of the positive to negative particles, Burbury and Fenton[56,57] have calculated the expected east-west asymmetry at Hobart which agrees well with the experimental value. The contribution of this process to the east-west asymmetry at low latitudes is however negligibly small.

1.2 Time variations of primary radiation

1.21 Long term variations.

One of the most remarkable long term variation discovered recently is the change of general mean intensity of cosmic radiation with solar activity. The studies of Forbush[58], Glokova[59], Lockwood[60] and Fenton et al[61] reveal a change of about 4 to 5 percent for meson intensity at sea level and about five times that in the intensity of the nucleonic component. This change in mean intensity which is negatively correlated with sunspot numbers is found to remain the same from 0°S (Huancayo) to 80°N Godhavn) and is found to be present to the same extent for both the magnetically quiet as well as disturbed days. Fenton et al[61] have examined meson as well as neutron data of Resolute and Ottawa and have conclusively proved the existence of a decrease of 20% in the nucleonic component and 4% in meson component during this cycle of solar activity, even after correcting for the transient decreases. This clearly proves that the 11 year variation is not due to the cumulative effect of Forbush decreases.

Evidence of similar changes at high altitudes is provided by balloon experiments conducted by Neher[62,63], Meyer and Simpson[64], Pomerantz[65,66] and others. Corresponding to a change of 4% at sea level from 1937 to 1954, Neher finds a change of 50% in total ionisation at 85°N latitude and 70,000 ft. altitude. Neher's[67,68] results for the present solar cycle confirm the above result. Winckler et al[69,70] find the effect in this cycle to be more than the change observed during the previous solar 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 sunspot numbers. The results of Freier et al[71] and Neher and Anderson[72] for α flux and heavy nuclei indicate the same result. The question whether there exists a lag of a few months between the mean intensity and sun's activity still remains unanswered.

The only result which apparently is contradictory, is that of Katzman[73] who finds an increase of 12% in intensity measured by extremely narrow angle telescopes (2^o to 3^o semiangular opening in the east-west plane) at Ottawa from 1955 to 1957. The large statistical error involved does not permit any valid conclusions to be drawn from this stray observation.

1.22 Change of "knee" of latitude effect.

The most interesting fact that emerged out of the early high altitude studies conducted by Neher[74] and Van Allen et al[75] at high latitudes was the absence of low energy cosmic radiation beyond a latitude of about 53 to 55^o, even at the highest altitudes that could be reached by balloons. The sharp cut off of the primary spectrum at 0.8 Bev for protons corresponding to the "knee", has presented a difficult problem for interpretation.

To study the finer naunces of the latitude variation of cosmic ray intensity at high altitudes Neher et al[76,77] have developed a new technique of conducting simultaneous flights of balloon borne instruments at different latitudes by which they can avoid the polluting effect of general fluctuations. The study reveals that the knee was not stationary but shifted to higher latitudes from 1937 to 1951. The low energy cut off for protons which was at 0.8 Bev during 1951 vanished in 1954 when protons of energies down to 0.15 Bev were detected. It reappeared again in 1956.

Recently Meyer and Simpson[64,78] have reported a northward shift of knee for the nucleonic component by 3° from 1948 to 1951. They further estimate that the power law spectrum for the differential primary intensity changed from $j = C(P/Z)^{-2}$ in 1948 to $j = C(P/Z)^{-2.7}$ in 1951, for particles of rigidity 1 to 4 Bev which is accompanied by an increase in the total cosmic ray intensity by 13% during the same period. A close relationship between the shift of knee and 11 year cycle of change of cosmic ray intensity is evident.

Measurements made by Meredith et al[79] with thin walled counters in balloon launched rockets confirmed the absence of low energy particles at high altitudes. The observations of Ellis et al[80] at balloon altitudes showed that the cut off of heavy primaries occurred at almost the same latitude as for protons showing the dependence of cut off on magnetic rigidity rather than on the energy of primaries, which suggests that the physical mechanism responsible for the cut off in the spectra of both protons and heavy nuclei is magnetic in nature.

Recent results by Winckler et al[70] and Freier et al[71] at Minnesota show that even in 1957 when the sun was at its peak activity, low energy particles down to the energy limit imposed by air (150 Mev/nucleon) were still present from which they conclude that the reduction in flux was due to the reduction in intensity of both high and low energy particles. The major part of the reduction occurred during 1956 to 1957 which again suggests a triggering mechanism rather than a proportional relationship with sunspot numbers.

1.23- <u>Change in east-west asymmetry.</u>

Jacklyn and Fenton[81] have reported a decrease in east-west asymmetry from 0.025 in 1950 to 0.011 in 1954 and an increase after 1954 with increasing solar activity. The fact that the intensity of hard component increased with decreasing solar activity, shows that the decrease in asymmetry was caused by a greater increase in intensity arriving from east than intensity arriving from west. A confirmation of this result would be highly useful. The study of the asymmetry over a period of years may prove to be a sensitive method for detecting the energy dependence of the variation of primary spectrum.

1.24 <u>Magnetic storm type changes.</u>

Worldwide decrease of cosmic ray intensity accompanying magnetic storms have been reported by a number of workers[82,83,84]. Well known general features of such events called "Forbush decreases" are a sharp decrease in cosmic ray intensity upto 10% closely associated with the main phase of the storm, followed by a slow recovery lasting several days. Since cosmic ray decreases unaccompanied by magnetic storms and magnetic storms unaccompanied by cosmic ray decreases are both not uncommon (Tandberg-Hanssen[85]) the relation between the two cannot be direct. Where effective storms do take place it is found that the ratio of change of magnetic field strength to the change of cosmic ray intensity does not remain constant from event to event. In large storms of the type which occurred in March 1942, no latitude effect was observed[86] in the magnitude of decrease at different stations. In many storms, as shown by Neher and Forbush[87], the decrease at high altitude is about four times the decrease at sea level. Fonger[26] has reported that the decrease observed by a neutron monitor was five times larger than that observed by an ion chamber at the same place. Chasson[88] has pointed out instances when decrease of intensity occurred considerably earlier than the occurrence of any measurable geomagnetic disturbance. Trefall[89] finds that the magnetic storms with a dominant positive peak and a vanishingly small negative peak produce no change in cosmic ray intensity. Kitamura[90] has shown that large decreases are always accompanied by magnetic storms with sudden commencement. MacAnuff's[91] experiment at 60 M.W.E underground did not record any perceptible change in mean intensity when sea level intensity changed by 5 to 6 %. Trumpy[92,93] who has studied world-wide storms sums up his conclusions as follows.

(1) All worldwide magnetic storms cause only decreases in cosmic ray intensity.

(2) No simple relation between variation of earth's magnetic field and cosmic ray intensity variation exists.

(3) An exact and detailed correlation between the disturbance of the earth's magnetic field and corresponding cosmic ray storm does not exist.

(4) Intensity of cosmic ray storm depends on the mean energy of primary cosmic radiation. Higher the mean energy, the smaller is the amplitude of cosmic ray storm.

(5) A small decrease of amplitude of cosmic ray storm with decreasing geomagnetic latitude exists.

(6) Magnetic storms of short duration correspond to cosmic ray storms of lower intensity.

(7) Cosmic ray storms are associated with a diurnal variation with a maximum at 0 - 2 hour local time.

Sekido et al[94] have made an exhaustive study of the cosmic ray effective and non-effective magnetic storms which they designate as S and M type storms respectively. S type storms follow the 11 year ~~solar~~ cycle of solar activity and are well correlated with the central meridian passage of large sunspot groups. M type storms, which do not follow the 11 year cycle of solar activity, are found to be associated with M regions on the sun and are found to sharply exhibit 27 day recurrence tendency. Venkatesan[95] has analysed the data from Canadian stations from October 1956 to December 1957. He concludes that the observation of recurrences in small as well as large decreases of cosmic ray intensity makes it difficult to distinguish between 27 day variations and Forbush decreases.

Even though it is largely believed that cosmic ray storms are always associated with decreases in cosmic ray intensity, Simpson[96], Sarabhai et al[97], Yoshida et al[98] and McCracken et al[99] have reported a few increases in cosmic ray intensity associated with magnetic storms. Sarabhai et al[97] have analysed the storm of February 11, 1958 and find that there are three remarkable features which can be very prominently seen. The first is an anticipatory increase of intensity observed only at equatorial neutron monitor stations a few hours before the arrival of the solar plasma to a distance at which it interacts significantly with the geomagnetic field. The main Forbush decrease almost coincides with the Sc geomagnetic storm and its minimum is larger and occurs later for low energy than for high energy primaries. A second increase which is more prominent at low latitudes than at high latitudes and with strong east-west and north-south asymmetry occurs about 10 hours after the onset of cosmic ray storm. They believe that the two increases and the main decrease observed with the cosmic ray storm of February 11, 1958 are caused by essentially three types of modulation processes. One is directly associated with the moving plasma, probably related to the magnetic fields in the shock front and gives increases as well as decreases of intensity along with anisotropy. The second gives decreases of cosmic ray intensity and is related to a process which has a sharp onset but a relatively long time constant of recovery. According to them the first is often more effective for high primary energies than low, but the second is much more effective for low than for high energies.

Yoshida and Wada[98] have examined the cosmic ray storms of September 11, 1958 and February 11, 1958 for many stations and find a secondary increase of cosmic rays immediately after the main decrease. The amplitude of the secondary increase is found to be latitude dependent, increasing with latitude upto 50°N, beyond which it decreases rapidly.

1.25 Day to day changes.

Even though 27 day recurrence tendency in hard component has been known for a long time, it was Simpson et al[96,100] who first proved the existence of the close association between cosmic ray increases and the central meridian passage of active solar regions, particularly regions of green coronal emission on sun. These increases were often followed by increased geomagnetic activity with a lag of two or three days.

The worldwide character of day to day changes has also been shown by a number of workers. Fonger[26], for example, has shown that the changes in neutron intensity at

Climax and changes observed in ion chamber at Freiburg were similar and also simultaneous, even though the former was on the average five times larger in amplitude than the latter. Neher and Forbush[87] have demonstrated the simultaneous changes in ion chambers at Huancayo and Cheltenham, the neutron monitor at Climax and the ionisation at 70,000 ft. altitude over Bismarck.

The results of Meyer and Simpson[101], and of Van der Walt[102] show that the recurrence tendency is most pronounced during sunspot maxima. Reordan and Thambyahpillai[51] and Simpson[103] and Kane[104] find that the minimum of cosmic ray intensity occurs five days earlier to that of K_p the index of geomagnetic disturbance. Venkatesan[95], Trumpy[93] and others have observed that this behaviour is not always followed. Sometimes the minimum in cosmic ray intensity precedes and sometimes it follows the K_p maxima. Van der Walt[102] concludes that at the time of minimum solar activity, cosmic ray intensity minima generally precedes K_p maxima and at the time of intense solar activity it follows K_p maxima after a lag of a day or two.

Bell and Glazer[105] have concluded from a statistical study that systematic changes in geomagnetic activity are associated with intensity of green coronal emission line. A maximum in geomagnetic activity of 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 such geomagnetic disturbances and are thus associated with C_p minima. The second type of geomagnetic disturbance which does not exhibit a 27 day recurrence tendency is generally found to be associated with sudden commencement storms and CMP of sunspot groups which are found to be sources of emission of solar radio noise in one meter wavelength. However, as Warwick[106] has pointed out, the relationship between geomagnetic activity and intensity of green coronal line in the period of minimum solar activity during October 1953 to October 1954 was not seen.

Wada and Kamiya[107] find that every solar radio outburst of type IV is associated with a cosmic ray storm and vice versa. It is generally believed that the radio outburst of type IV is the synchrotron radiation emitted by high energy electrons in a strong magnetic field extending so far as 2 - 3 solar radii. The ordered and disordered magnetic fields in the emitted magnetic cloud may produce cosmic ray effects not only through the perturbation of the geomagnetic field but also through other effects of the type described by Alfven.

The difficulty in giving a precise physical interpretation of K_p and absence of one to one relation between K_p and cosmic ray intensity changes, have made the problem of interpretation of behaviour of cosmic ray intensity with K_p difficult. It is increasingly felt that

K_p is not a sufficiently good criterion by which we can separate the cosmic ray effects. Results of Sarabhai and Bhavsar[108] and of Sarabhai and Satya Prakash[109] show that it is important to consider the changes of mean intensity as well as of C_p in drawing conclusions regarding the time variation of cosmic rays. The author has investigated the dependence of intensity variations in east and west directions and their relationships with the geomagnetic disturbance from which he has been able to draw a few conclusio regarding the location of the source of anisotropy.

1.26 Solar flare increases.

1.261 Affect of large flares :- The sudden cosmic ray increases associated with the solar flares provide a direct evidence for the production of cosmic ray particles of energy of several Bev in the sun. The main results can be summarised as follows.

(1) The cosmic ray increases which are associated with intense solar flares reach a maximum about an hour after the onset of the flare.

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

(3) The magnitude of the effects depends on the type of detector, altitude, geomagnetic latitude and local solar time. The effect at mountain elevation is as much as four times the effect at sea level stations and the

increase in neutron intensity is several times larger than the increase in ionising component.

Assuming that the flare effect is caused by the emission of solar particles of cosmic ray energy, Schluter[18] and Firor[19] have calculated the trajectories of charged particles inthe geomagnetic field. They find that particles arrive at earth in distinct impact zones. This theory however, cannot explain polar increases and other peculiarities found in the flare effect. Sekido and Murakami[110] find that the polar type increases are generally less steep and of longer duration which they explain as due to scattering of cosmic rays by a outer trapping field.

The recent giant flare of February 23, 1956 has been observed at more than 40 stations located all over the world. Largest increases were recorded at middle and high latitude stations while Sarabhai et al[111] and Forbush[112] have reported, for the first time, an increase even at equatorial latitudes. Sarabhai et al[111] conclude that particles of energy upto 50-60 Bev were emitted from the sun. Neutron monitor at Leeds[113] which was in the 0400 hours impact zone registered an increase of 4500 % whereas neutron monitor at Climax[114] recorded a 2000 % increase even though it was far away from any favoured impact zone. Since Sitckus et al[115] have not reported any increase in extensive air showers an upper limit of 10^{12} ev for the energy of emitted particles can be safely assumed.

Winckler et al[116] found five times the normal intensity at 10 gm/cm^2 over Minneapolis even ~~after~~ 17 hours after the occurrence of the flare when the cosmic ray intensity at 300 gm/cm^2 had already returned to its normal value. Kuzmin et al[117] ($\lambda = 51^oN$) and Brunberg and Eckhartt[118] ($\lambda = 58^oN$) find that a north pointing telescope recorded a relatively greater increase compared to a south pointing telescope, from which they conclude that the flare particles must have suffered a deflection in a mean magnetic field of the order of 6×10^{-6} gauss before reaching the north pointing telescope. Australian workers[119] at Hobart have observed a higher relative increase in 45^oW than in the vertical direction, inspite of the atmospheric attenuation being larger in the inclined direction.

Meyer et al[120] have proposed a model which assumes a field free spherical cavity of the type proposed by Davis[121,122] ($B < 10^{-6}$ gauss) centered round the sun and having a radius of 1.4 a.u. Tangled magnetic fields of finite thickness ($B = 10^{-5}$ gauss) surrounding the cavity scatter the cosmic ray particles into the field free region. The slow decline of intensity after reaching a maximum is explained as due to the escape of cosmic ray particles into the galaxy. By comparing the data from different stations they conclude that the flare radiation had a sharp momentum spectrum (power law with exponent $n \simeq 7$) and it declined with time roughly as $t^{-3/2}$.

An interesting feature of this flare was that it occurred during a broad Forbush decrease. Brown[123] has recently proposed a model to explain the flare effect super imposed on Forbush decreases. The new model is essentially the same as that of Simpson[120] and differs from it only in geometry and hence is subject to the same criticism that the mean free path required to explain the increases is too long to give the slow diffusion essential to explain the preflare decrease.

Ehmert[124] has made a special study of the delay in onset times and of the decay pattern at various stations. He concludes that the main features of cosmic ray flare effects, particularly the midnight effect and high latitude effect can be satisfactorily explained in terms of deflection of flare particle trajectories in the inter-planetary magnetic field of the order of 3×10^{-6} gauss.

Eckhartt[125] has pointed out that Hobart, which lay outside Firor's impact zone at the beginning of the flare, had an early onset time. He has suggested that the cosmic ray particles which caused an earlier onset time came from direction towards the solar beam which produced the magnetic storm two days after the flare.

Lust and Simpson[126] have discussed the different onset times of this flare at different places. They find that for this flare 20 hour impact zone was as important as 0900 and 0300 hour impact zones. They believe that the high energy particles were the earliest to arrive at the earth and the time delay caused by the back scattering from the irregularities of the disordered magnetic fields enveloping the sun to be an inverse function of energy. Successive scatterings lead to a more or less isotropic distribution of particles. The impact zones were seen to be dominant in the initial nine minutes after which isotropy set in, probably due to a storage mechanism.

McCracken[127] has examined the cosmic ray data at many stations for all the important flares and concludes that only very energetic flares (white light flares) accompanied by continuous visible spectrum of sufficient intensity to be observable against the photospheric background, give rise to cosmic ray increases. He finds that even a 3^+ intense white light flare will not produce cosmic ray increases if it is situated in the east limb of the sun.

1.262 Effect of small flares : - Firor[19] was the first to report a small increase of cosmic ray intensity during small flares of magnitude +1. McCracken[128] has recently reported the results of the study of the intense flare at 1226 U.T. on August 31, 1956. Slight increases in neutron intensity were recorded 20 minutes after the occurrence of the visual flare, almost simultaneously at stations in Australia and U.S.A. Meson telescopes however did not record any increase. Corrigan et al[129] have found similar evidence of increases in intensity at balloon altitudes at $\lambda = 55^{0}$N on August 9, 1957 which was associated with a solar flare of magnitude +1.

1.3 Anisotropy of primary cosmic radiation

Even though many of the early workers[130,131] observed a daily variation with an amplitude of 0.2%, uncertainity with regard to the meteorological corrections did not permit any valid conclusions to be drawn from the above observations regarding the anisotropy of cosmic radiation. To circumvent this difficulty Kolhorster[132], and Alfven and Malmfors[133] experimented with directional telescopes pointing to two different directions equally inclined to the zenith, thereby elliminating the atmospheric effect which would be same for both. The difference in the daily variations measured by two telescopes will not contain any contribution due to the meteorological changes and hence can be attributed to the anisotropy of primary radiation. Their experiment showed the existence of a significant difference between the daily variations in north and south directions which they attributed to the anisotropy of the high energy part of the spectrum which suffers little deflection in the geomagnetic field.

The above conclusions were soon confirmed by Elliot and Dolbear[2,134] who found a larger semidiurnal component in the daily variation measured with south pointing telescopes as compared to that measured by north pointing telescopes and a seasonal variation of considerable amplitude in only south pointing telescopes. They found the amplitude of the daily variation in east to be 1.3 $\pm$ 0.05 times that in west.

Ehmert and Sittkus[135] showed a difference in amplitude between the daily variations measured simultaneously by an ion chamber of omnidirectional sensitivity and by a vertical counter telescope. Sekido et al[136] observed that the daily variation increased from 0.19% to 0.24% when the semiangle of the measuring telescope in the east-west plane was reduced from 40° to 12°. Sarabhai et al[9] found that the 12 monthly mean daily variation of meson intensity measured at Ahmedabad with telescopes having a semiangular opening of 22° in the east-west plane, were different for different periods of observation and the values varied from 0.3% to 0.8% which could not be accounted by meteorological factors. Sarabhai and Nerurkar[137] tried to investigate the effect of opening angle on observed daily variation and found that with the decrease of the opening angle in the east-west plane the amplitude increased enourmously from 0.6% to 1.2% in agreement with the observation of Japanese workers[136]. However Elliot[138] et al have failed to observed this change at middle latitudes.

In the case of the nucleonic component due to the absence of ambiguity in regard to the correction to be applied for the meteorological factors, the interpretation of daily variation becomes easier. Firor et al[139] who made an extensive investigation of daily variation with neutron monitor at different latitudes found for groups of days a daily variation with peak to peak amplitude of about 1%, which is comparable with the amplitude observed by meson telescopes with moderate apertures at low latitudes. They did not find any latitude dependence of the daily variation.

With regards to the solar anisotropy of high energy primary particles made at great depths under ground[36,91], no conclusion can yet be drawn due to the poor statistical significance of the observations. The observations of the anisotropy of heavy primaries made by balloon borne instruments have also given very conflicting results. While Yngve[140] has reported a daily variation of amplitude as large as 25 ± 8.5% many others[141,142] have failed to detect any daily variation higher than the experimental error. The balloon flights made at different places at different times cannot be compared with each other or with other ground measurements. This makes the interpretation of various results a difficult problem. With the added evidence of the recent measurements by Ney and Thon[143] and by Lord and Schein[144], one can only conclude that there is a strong indication for the existence of diurnal variation of heavy primaries which, however, probably is just of the order of the experimental error.

The results of a few experiments conducted of late, are very interesting. Elliot and Rothwell[145] and more recently Parsons have cast doubt on the view that the daily variation is due to non-isotropic flux of primary particles entering the earth's magnetic field. In the experiments conducted at London (λ = 50°N) with two identical sets of counter telescopes one pointing 45°E and the other pointing 45°W, Elliot and Rothwell[145] find that the daily variation measured by west pointing telescope is three times that measured by east pointing one. Considering a mean energy of 3×10^{10} ev., one would expect the east pointing telescope to register a larger daily variation. This is because the west pointing telescope at $\lambda = 50^{o}$N and inclined at 45^{o} to the zenith points nearly to the same direction in space throughout the day and night while east pointing telescope inclined to the zenith by the same amount scans the plane of the ecliptic in the course of a day. Comparing with Possener and Heerdan's[146] observations they find that there is a change in the hour of maximum from 0300 hours in June-November 1954 to 1000 hours in December 1954-March 1955 in the daily variation measured by vertical telescopes. But this is not reflected in the daily variation measured by inclined telescopes which evidently means that the change observed in the vertical telescopes was not due to a real change of anisotropy. They conclude that all these observations are not consistent with a view that the daily variation is produced by an anisotropy of primary flux located at a large distance from the earth. However Sandstrom[147] at Stockholm and Stensland[148] at Kiruna find that the phase shift of diurnal variation of 2 hours per year is seen in vertical as well as inclined telescopes during the period 1947 to 1950. This evidently means that the descrepancies observed by Elliot et al are found under only certain conditions during some periods of observation.

Parsons[149,150] has reported similar anomalies in the directional dependence of the daily variation. Examining the data of vertical telescopes and telescopes inclined at 45° to the zenith in each of north, east, west and south directions, he finds that the south pointing telescope which actually scans the celestial latitude belt close to and intermediate between those scanned by other telescopes, shows a virtual absence of daily variation from which he surmises that the daily variation is probably caused by modulation of primary cosmic ray intensity within the influence of earth's magnetic field. Eventhough all these results can be criticised as they have utilised the mean energy of response in their calculations rather than the effect over an extended range of energies, they nevertheless raise a serious problem of interpretation of the solar daily variation under certain conditions.

The author has examined the data of directional telescopes built by him, with special reference to this point of controversy. The east-west instrument situated at Ahmedabād has an advantage as both the east and west pointing telescopes successively scan almost the same portion of the celestial sphere. Hence the presence or absence of a phase difference between the daily variations measured by east and west pointing telescopes is an indication of the presence or absence of an anisotropy of primary radiation located far away in space. The results which are discussed later, show very interesting features. The author has discussed the conditions under which the anisotropy is located far away and also conditions when the source of the daily variation is probably of geocentric origin.

1.4 Changes of solar anisotropy

1.41 Long term changes of daily variation and their worldwide characteristics.

Sarabhai and Kane[151] examined the data of Lange and Forbush[130] and found that the solar anisotropy as characterised by the amplitude and phase of the 12 month mean daily variation of meson intensity, underwent significant long term changes of worldwide character having 11 year cycle of periodicity. Thambyahpillai and Elliot[152], from an examination of cosmic ray data from 1932 to 1952 of various stations, demonstrated the worldwide changes of time of maximum of diurnal component and pointed out that this may have a 22 year cycle of periodicity.

Recent observations by Steinmaurer and Ghori[153] also indicate a 22 year cycle of periodicity. An examination of Hafelekar ion chamber data for over 23 years, shows a maximum at about 0700 hours during the sunspot minimum in 1933 and 20 years later during 1953-1954, whereas in 1944 it was considerably earlier. Similar phase changes of diurnal variation have also been reported by Fosaher and Heerdan[146]. They observed that the hour of maximum of daily variation measured by north and south pointing telescopes showed an anomalous shift to midnight hours during a few months in 1953. During the same period no such phase shift was observed in the nucleonic component but the observed amplitude of the daily variation of neutrons for that period was negligibly small. Conforto and Simpson[154] have demonstrated a progressive phase shift to earlier hours during 1954 in the daily variation measured by both nucleonic component and charged particle detectors.

Sandstrom[147] at Stockholm and Stensland[148] at Kiruna have reported a phase shift in the diurnal variation for vertical and directional telescopes. Sandstrom finds a phase shift of 2 hour per year from 1947-1950 which is independent of the direction of measurement of particles. Sarabhai et al[9] have compared the data from vertical telescopes at Ahmedabad with ion chamber data from Huancayo. They find that changes in both are well correlated, even though changes observed in counter telescopes are in general about 2.5 times greater than the changes observed in ion chamber. Opening angle of the instrument seems to have a considerable amount of influence on the amplitude of variation and its long term changes. Sarabhai et al have further shown that in addition to long term changes of the diurnal component, significant changes do occur in the semidiurnal component also. When the daily curve composed of both the first and the second harmonics is considered, a remarkable sequence of changes is observed from year to year. At Huancayo, the 12 month mean daily variation which exhibits one maximum near noon from 1937-1943, changes over by 1952 to a variation exhibiting one maximum in the early morning. In the intervening period a clear evidence of the progressive increase of early morning maximum accompanied by a decrease in noon maximum is seen. During 1945-1950 the daily variation exhibits two maxima instead of one. The sequence of changes indicate a 22 year cycle of periodicity. Sarabhai et al[9] have thus demonstrated that particularly for observations at low latitudes, it is important to consider the daily variation unresolved into its harmonic components.

Sarabhai et al[9] have suggested that the changes in the daily variation could be considered as due to the contribution from two distinct types of variations - 'd' type having a noon maximum and the other 'n' type having a maximum at 0300 hours, both of which being prominently seen at particulrly equatorial latitudes. The observed sequence of changes from year to year at Huancayo and Cheltenham can be explained by assuming that the relative changes of day and night contributions of daily variation from year to year are worldwide in character and are closely related to the solar cycle of activity. Just preceding sunspot minimum, a brief period when only day component is active appears which is immediately followed by an equally brief period when only the night component is active. The pattern of addition and attenuation of individual contributions appears to be reversed after 11 years.

Venkatesan and Dattner[155] have studied data from four stations at different latitudes and find that the changes in the diurnal amplitude follow the changes in geomagnetic activity more closely than the changes in the solar activity. By plotting mean yearly vectors for diurnal and semidiurnal variations separately end to end, they observe significant differences in the behaviour of diurnal and semidiurnal variations. The changes in the diurnal variation are found to be worldwide and positively correlated at various stations, whereas the semidiurnal component does not follow a particular pattern. This conclusion does not seem warranted as the earlier observations of Sarabhai et al[9] show that the form of the daily variation is different for different latitudes and the daily variation with two types of maxima and with a predominant semidiurnal component is observed mainly at low latitudes.

On the other hand Sastry[156] has pointed out that only at low latitudes, the semidiurnal component can be studied without any ambiguity. He finds that the changes in the semidiurnal component at Kodaikanal and Huancayo from year to year are very similar, from which he concludes that changes in the semidiurnal component are also worldwide. Further, he finds that the hour of maximum of the semidiurnal component at Huancayo has changed by 10 hours in 19 years from 1936 to 1955 and appears to follow a 22 year cycle.

Sastry[156] and Parsons[157] have also reported a decrease in the amplitude of the diurnal variation from 1954 to 1957. Sastry finds that this is caused by the combined effect of the decrease in amplitude on individual days and the increased scatter of the hour of maximum from day to day.

1.42 Day to day changes of anisotropy.

Day to day changes in the anisotropy of primary radiation has been a subject of interesting study. Firor et al[139] first drew attention to the extreme variable character of the daily variation of the nucleonic component measured by a neutron monitor. Firor et al[139] and Remy and Sittkus[158] found that there were groups of days on which the daily variation had a maximum at night and groups on which maximum occurred at day time. Sittkus[159] has examined the daily variation measured by an ion chamber on individual days and has noticed the tendency for variations of large amplitude to occur in groups of days with a maximum near noon. This phenomenon showed a marked tendency to repeat itself after 27 days but it was not found to be associated with significantly different magnetic character figure than the rest of the days. Sarabhai and Nerurkar[160] who have studied the daily variation with narrow angle telescopes, find that on nearly 75 percent of days the diurnal variation exhibits only a single maximum either at 1200 noon ('d' type) or in the early morning hours at 0300 hour local time ('n' type). The results indicate the existence of at least two preferred orientations of anisotropy. 'd' type days are usually found to occur in groups and are found to exhibit a marked 27 day recurrence tendency.

Yoshida and Kondo[161] have studied the recurrence tendency of anisotropy observed by ion chamber data of

Huancayo. They observed a strong recurrence tendency much stronger than the one seen in either the mean intensity of cosmic rays or in the magnetic character figure in the same period. Kane[104] who examined the data of several stations for the years 1951-1953, finds that the recurrence tendency does not significantly vary from period to period.

The first significant evidence suggesting a connection between the mean intensity and the nature of anisotropy has been put forward by Sarabhai and Bhavsar[108] who find that, in general, the days having a night maximum are associated with a mean intensity significantly below normal and days having day time maximum are associated with mean intensity significantly above normal.

As pointed out by Sarabhai et al[9] and Dorman[6], fluctuations of daily variation observed in middle latitudes do not resemble the fluctuations near equator, and the existence of two components of daily variation, 'd' and 'n', are not quite clearly defined in middle latitudes, although a shift in the time of maximum of total diurnal variation towards the morning hours is sometimes observed.

The change of daily variation on magnetically disturbed days has been extensively studied by a number of workers. The results of earlier work indicated that on days of high K_p, the amplitude of the diurnal component increases and its time of maximum becomes earlier. Sekido and Kodama[18] have shown that this effect is more prominently seen in narrow angle telescopes than in wide angle instruments. Sekido and Yoshida[163] have further demonstrated that the semidiurnal component which is normally present in quiet day variation gets reduced on magnetically disturbed days. Sekido et al[163] have found that, in general, the time of maximum follows the trend of the mean intensity I and not of the horizontal component of the earth's magnetic field H, and the increase in amplitude ΔA follows the decrease in mean intensity $-\Delta I$ more closely than the change in horizontal component of the earth's magnetic field. Sandstrom[164] finds that the 12 hour component which can be attributed to the radial flow of particles from the sun is well correlated with the geomagnetic activity. It is non-existent are reversed in sign when the geomagnetic activity as characterised by K_p is low but increases with K_p.

Sekido et al[165] have studied the behaviour of the mean storm type vector representing the difference in the diurnal component of daily variation of disturbed and quiet days separately during each year of a solar cycle of activity. The disturbance vector representing a storm type anisotropy, points on the average towards the radially outward direction from the sun and unlike the quiet day anisotropy, undergoes a long term change from year to year in step with the 11 year cycle of solar activity. They suggest that the 22 year cycle of periodicity found by Elliot[152] and others may be due to the secular variation of quiet day anisotropy. Yoshida[166] has made an extensive investigation of storm type anisotropy and concludes that storm type changes are caused by anisotropic flow of cosmic rays produced by the acceleration of cosmic rays in the solar stream. From an examination of Kodaikanal neutron monitor data Satya Prakash[107] finds that daily variation on high C_p days shows a sharp maximum near noon as compared to daily variation on low C_p days which exhibits quite a broad maximum at the same time. The time of maximum of the diurnal component for the two groups remains almost unchanged while the amplitude of the diurnal component is smaller for days of high C_p. Similar results have been observed by Sastry[156] for daily variation of meson intensity at Kodaikanal. Sarabhai et al[109] also find that the daily variation on high C_p days associated with a decrease in mean intensity, shows an increase in amplitude with an earlier hour of maximum as compared to the daily variation on quiet days. This clearly indicates that associated changes of both mean intensity and C_p have to be considered to draw any conclusions regarding the relationship of daily variation with C_p. The apparent contradiction of this result with that of Sandstrom[164] can be understood if one considers that Sandstrom has taken storm type days when the mean intensity is low.

Yoshida[166] has pointed out another important consideration to explain the difference between the results relating to 1947-1950 and 1956-1957. She finds that the disturbance vector which displaces the vector representing the quiet period diurnal variation, has itself an 11 year period of change in the amplitude as well as time of maximum. Thus the net change that is observed with high C_p should be dependent on the period of observation relative to the phase of the solar cycle of activity.

This problem is by no means conclusive. The author has examined the relationship between the daily variation and C_p for the data of the inclined telescopes, and has discussed the location of anisotropy on geomagnetically disturbed and quiet days.

1.5 Interpretation of variations

The major cosmic ray effects which can be associated with events occurring on the sun can be listed as follows.

(1) When giant flares occur on the sun, sun emits cosmic ray particles which in exceptional cases may even attain an energy upto 50-60 Bev.

(2) Many short term cosmic ray intensity changes and some fluctuations of anisotropy can be directly associated with the central meridian passage of active solar regions such as sunspot groups, unipolar regions, and regions of intense coronal emission of 5303Å 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.

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

solar activity. Probably changes in east-west asymmetry at middle latitudes follows the solar cycle.

(5) It is very interesting to note that the 12 month mean solar anisotropy exhibits a 22 year periodicity in step with the activity of some of the interesting features on the sun amongst which the following may be mentioned[168].

(a) The state of magnetic polarity of bipolar sunspot groups.
(b) Alternating character of successive sunspot cycles.
(c) Frequency of prominences.
(d) Probable variation of solar diameter.
(e) The diverging motion of forming sunspot groups.
(f) The proper motion of spots in latitude.

(6) The close relation existing between cosmic ray variation and geomagnetic activity points out to a common source of solar activity through particle radiation from the sun.

The inverse relationship between the solar activity and changes in mean intensity and geomagnetic cut off of cosmic rays and the fact that magnetic storms are mainly accompanied by only decreases in cosmic ray intensity and not increases, suggest that the mechanism responsible may be modulation by solar controlled screening of the earth probably by magnetised clouds of interplanetary matter which may become temporarily inactive at sunspot minimum and admit low energy particles to enter the atmosphere.

1.51 Geoelectric and Heliocentric models.

Davis[121,122] has discussed a model in which a field-free cavity of diameter 200 A.U. around the sun is created by the transportation of galactic fields by the highly conducting ion streams from the sun. The size of the cavity is obtained by equating the momentum flux of diverging corpuscular emission to the material pressure. This cavity can trap cosmic ray particles of energies less than 100 Bev. for periods very long compared to a sunspot cycle. Davis has shown that a change of 1% in the mean radius of the cavity with 11 year of solar activity can cause a change of 4% in the mean intensity of cosmic rays. Since the travel time required for corpuscules to travel from the sun to the cavity wall is one year as compared to one day required by cosmic rays to travel the same distance, rapid fluctuations of cosmic ray intensity cannot be explained by this theory.

The electrical conductivity of the interplanetary space may not be infinite. In such a case, as Beiser[169] believes, there is a good likelihood of the emitted matter sweeping the galactic fields leaving behind a small residual magnetic field and thus making the cavity diamagnetic instead of making it field-free. His calculations show that the diamagnetic cavity will be an oblate spheriod of semiaxis 5×10^{15} cm and 5×10^{14} cm with a residual magnetic field of intensity 10^{-9} gauss inside it. The cut off in the primary rigidity is explained by considering the trajectories of particles through the diamagnetic spheriod and the trapping of certain particles inside it. Integral spectrum of protons, α particles and heavy nuclei predicted by this model agree well with the experimental observations. A change of 1.6% in the total corpuscular output of sun over a sunspot cycle can explain the 4% change in mean intensity. Since the magnetic field within the diamagnetic spheriod H_1 is a function of conductivity of interplanetary medium and of the regularity of solar ion streams, it is quite variable. By proving that the changes in cosmic ray intensity follow the changes in H_1 with a small phase lag of two to three months, Beiser 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.

Nagashima[170] has tried to explain the changes in intensity through changes in the state of geoelectric fields. His model is able to explain the observed altitude and latitude dependence of variations in a satisfactory manner. However, it cannot explain the large variations which are some times observed on magnetically quiet days, when most probably no perturbing geoelectric fields are present. Further Simpson's[103] observations of latitude dependence of fractional changes, in neutron intensity between $\lambda = 45^{o}N$ to $60^{o}N$ do not agree with the theoretical estimates calculated by assuming axially symmetric geoelectric fields, at different distances from the earth. After a critical examination, Simpson[103] concludes that the variation mechanism must be of extra-terrestrial origin and its association with solar phenomena is independent of the earth's system. He has cast doubt on the very existence of geoelectric field because of the high electrical conductivity of ionosphere and inter-planetary space.

Morrison[171] has proposed a heliocentric model which assumes the existance of a highly turbulent magnetic field in the ionised matter emitted from the sun. The ionised matter moving outwards from the sun engulf the earth and shield it from galactic cosmic ray particles. The outward motion of the ionised matter will sweep back the low rigidity cosmic ray particles and cause a decrease in cosmic ray intensity which will slowly recover to its normal value when the intensity builds up within the cloud due to the diffusion of galactic cosmic ray particles into it.

Parker[172] has raised a number of objections against this qualitative model, principal amongst which are as follows.

(1) The number of outgoing clouds required will result in a loss of solar mass to the tune of 10^{14} gm/sec.

which is very much in excess than the present estimate of 5×10^{10} gm/sec., obtained from a study of dynamics of comet tails.

(2) In order to screen the earth from all the directions, uniform ejection of matter in all directions from the sun is necessary whereas we do not have any evidence of violent activity in the polar regions of the sun with which are associated the ejection of matter.

(3) Since the outward rushing clouds have a characteristic time of one day, it is rather difficult to explain the absence of marked cosmic ray variations associated with the appearance of active solar regions on sun's disc.

(4) The short time taken by flare particles to reach the earth suggests that the space inside the earth's orbit is remarkably free from scattering magnetic clouds which is opposite of the assumption of the existence of enough outward moving clouds required to produce Forbush decreases.

(5) It is difficult to explain the rapid Forbush decreases and slow recovery observed in cosmic ray intensity. The high velocity and field strength of clouds required to explain the sudden worldwide decreases have to be maintained for weeks together to explain the slow recovery of cosmic ray intensity.

To overcome these objections Parker[172] has proposed a mechanism which operates within a few earth radii.

interplanetary magnetic gas clouds are captured by the terrestrial gravitational field forming a nebulous geocentric barrier which modulates the galactic cosmic ray particles. Even though the solar bursts are quite irregular, the long life of the disordered magnetic fields of geocentric clouds built up from bits of captured interplanetary matter, will produce an uniform effect on the cosmic ray intensity. He has shown that the geomagnetic field is sufficiently dense to support the weight of the nebula. Parker's geocentric model is able to explain many of the important features observed in cosmic rays.

Low energy cut off :- The low energy cut off can be explained as due to the scattering from the disordered magnetic fields in the captured interplanetary material. Forbush decrease occurs whenever a magnetic gas from a cosmic cloud is captured by the terrestrial gravitational field. The fraction of cosmic ray decrease will be equal to the fraction by which the geocentric magnetic cloud is augmented. The length of time over which the decrease takes place will be more than the time required for the gravitational capture of magnetic clouds. Forbush decreases which take a time of the order of 3 to 4 hours will correspond to a free fall of magnetic clouds from a distance of about five times the earth's radius. The recovery of cosmic ray intensity which will depend on the decay of captured fields, may take several months.

Geomagnetic effect :- The weight of magnetic clouds forming the geocentric barrier compresses the geomagnetic field below the clouds causing an increase in the geomagnetic field on the surface of the earth. On the other hand the presence of nonmagnetic gas clouds may have just the opposite effect. Ideally suitable combination of these two effects, while the earth is capturing new interplanetary material, can produce both a cosmic ray decrease and a magnetic storm. The proportion of magnetic and nonmagnetic gas in the captured interplanetary material determines the extent to which the cosmic ray decrease will be accompanied by the magnetic storm and vice versa.

Even though this theory has many attractive features, the existence of the geocentric barrier has not yet been experimentally proved. The detection of a narrow absorption line of the barrier clouds in the solar spectrum taken by rocket borne spectrographs can establish the existence of geocentric barrier.

In a recent paper Parker[173] has succeeded in explaining the 11 year cycle of cosmic ray intensity by the hydrodynamic outflow of gas from the sun. By stretching the magnetic lines of force of the solar magnetic field, the hydrodynamic gas will make the magnetic field in the inner solar system essentially radial. Such an outward flow of hydrodynamic gas has also been inferred by Biermann from observations of comet tails. A heliocentric shell of disordered field of 10^{-5} gauss is formed when turbulence sets in at a distance from the sun. Such a shell was inferred from the observations of the last solar flare. This model can explain the inverse relationship between the cosmic ray changes and solar activity and also give a proper cosmic ray energy spectrum which is in agreement with the observed spectrum. Parker[173] has suggested that the Forbush type decreases are local geocentric phenomena produced by the interaction of the outflowing gas from the sun to the earth. His model however, does not explain the changes in the solar daily variation and its relationship with solar and geomagnetic activity.

1.52 Modulation in interplanetary space.

Alfven[174,175] has attempted to explain the cosmic ray variation with the help of solar beams of ionised gas. The frozen in magnetic fields carried by the moving ionised material of the beam will give rise to an electric field for an observer situated in a fixed frame of reference. The increases and decreases of cosmic rays can be explained by the acceleration and deceleration of cosmic rays traversing the field. Brunberg and Dattner[176] have greatly extended this model to explain the solar daily variation of cosmic rays. According to them the rotating sun would be strongly polarised as seen from a fixed coordinate system so that a voltage difference of the order of 10^9 volts will be developed across the poles and the solar equator. The combined action of the electric field produced by polarisation, and the solar magnetic field is to make the charged particles partake in the general solar rotation thus causing an anisotropy at 1800 hours. Sandstrom[164] has resolved the diurnal variation into two components and claims that (1) the first is the 1800 hour component due to the particle wind of cosmic rays as a result of the sun overtaking the earth in its orbit and (2) the second is the 1200 hour component which is due to the radial flow of particles from the sun consisting of a general outward diffusion of particles as well as the direct flow of particles inside corpuscular beams associated with active sunspot regions and solar flares. The 1200 hour component which imparts the radial anisotropy will change the 11 year cycle of solar activity whereas the 1800 hour component will remain fairly constant except perhaps during very heavy magnetic storms. These deductions require a magnetic field of the order of 10^{-5} gauss at the earth's orbit to explain the diurnal variation of amplitude of approximately 0.2%.

Nagashima[177] has qualitatively examined the trajectories of the cosmic ray particles passing through the beam under the combined influence of the frozen magnetic field within the beam and an electric field inside the beam as seen from a fixed observer. He has shown that, associated with every beam, anisotropy exhibits a sharp maximum at a particular energy, below which it does not exist and above which it progressively decreases as the energy is increased. The change in the density of solar stream and the strength of the magnetic field during the cycle of solar activity causes the 11 year cycle of cosmic ray variation. According to this theory the maximum anisotropy would be produced in the direction pointing towards the sun, which agrees well with the experimental observations of storm type vector by Sekido et al[165]. For the purpose of daily variation the most important component of the frozen field is one perpendicular to the plane of ecliptic. Nerurkar has suggested the possibility of the frozen field in beams being derived from the high local sunspot field rather than the dipole field of the sun. Consequently, the field perpendicular to the plane of ecliptic would have accompanied which is either parallel to the solar dipole field or opposite to it. Using primary spectrum given by Neher and multiplicity function derived by Nagashima, Nerurkar[178] has shown that the above theory can explain the night maximum found at low latitudes.

Dorman[6] has attempted to explain the observed cosmic ray effects by the modulation of anisotropic primary intensity through changes in electromagnetic state of interplanetary space. He has worked out the expected cosmic ray effect due to different orientations of the frozen magnetic field and for different positions of beams with respect to the earth. He cannot however explain the secular or day to day changes of daily variation which are seen prominently at low latitude.

Dorman and Feinberg[43], after examining the daily variation for different components of cosmic rays measured at different latitudes and longitudes by various types of instruments, have come to the conclusion that the best fit for all types of components is given by the spectrum

$$\frac{\delta D(E)}{D(E)} = a E^{-1} \text{ if } E > E_1$$
$$= 0 \text{ if } E < E_1$$

where $a = 0.14$ and $E_1 = 6.6$ Bev. This means that the daily variation of particles of energy less than 6.6 Bev is virtually absent. 'a' has been called by Dorman as the "power of source". He has found out that the source of daily variation is almost at right angles ($82^{\circ} \pm 8^{\circ}$) to the sun-earth line and is to the left side of it. He further points out that the increase of geomagnetic planetary index has the effect of reducing the angle between the sun-earth line and the position of the source. A serious drawback of his method, as he himself points out, is that he has neglected to take into consideration of the highly changing form of the daily variation.

None of the existing theories is able to explain all the experimentally observed complicated features of cosmic ray variations. The task of formulating a theory accomodating all the observed facts is formidable. Any acceptable theory has to explain a minimum of the following important features observed in cosmic ray variations.

(1) The 12 month mean daily variation often

exhibits two significant maxima, particularly at low latitudes, which indicates that the daily variation cannot be adequately explained by the diurnal component alone.

(2) The principal maximum of daily variation has shifted by as much as 10 to 12 hours over a period of years.

(3) The very existence of a permanent anisotropy has not been proved beyond any doubt. Even if such an anisotropy is present it is completely masked by large and highly variable day to day anisotropies.

(4) The change of the amplitude of daily variation with the semiangle of opening of the telescope at low latitudes is much larger than can normally be expected.

(5) The connection between the mean intensity and the changes of daily variation and their relationship with the geomagnetic disturbance is not clear.

(6) The energy dependence of daily variation seems to be very complicated as at times variation in some energy bands unaccompanied by corresponding variations in other energy bands or accompanied by opposite type of variations in other energy bands have been observed.

(7) Experimental evidences point out that at least under certain conditions, the daily variation is caused by a source of geocentric origin.

Further progress in the subject depends upon conducting the experiments at different latitudes and longitudes and in different periods of solar cycle and comparing the results of these investigations with various

1.6 Statement of the problem

The study of cosmic ray time variations has assumed great importance on account of the light it throws on the origin processes of modulation of cosmic radiation. The study is moreover, very helpful in understanding the electromagnetic state of interplanetary space.

In view of the highly variable character of the daily variation, importance has recently shifted to the study of changes of daily variation rather than a mere study of the mean daily variation over an extended period of time. Some important questions on which we would like to gain information can be listed as follows.

(1) After applying correction for variations of meteorological origin, is the daily variation caused solely by an anisotropy of primary radiation or is there a different source of daily variation which operates on some days? Is there, for instance, a local source of nonmeteorological origin?

(2) Is there any source of daily variation which may be considered to be constant over a period of about a year or longer in addition to the source or sources which are responsible for the daily variation of highly variable character on a day to day basis?

(3) What is the energy dependence of the source of anisotropy?

(4) What is the relationship between mean intensity, daily variation and C_p, the index of geomagnetic disturbance ?

(5) What are the changes occurring in east-west asymmetry and what is their relationship with C_p and the daily variation ?

In seeking to answer some of these questions, the directional study of cosmic ray intensity can be very helpful. Kolhorster[132], Malmfors[1,133], and Elliot and Dolbear[2], demonstrated almost ten years ago, the importance of directional telescopes in the study of cosmic ray variations. Later on emphasis shifted to other techniques particularly the measurement with neutron monitors and this was reflected in the nonadoption of a standardised instrument for making directional studies during I.G.Y. Nevertheless, isolated investigations at middle latitudes have demonstrated the very great significance of continuing and extending directional studies. Recent studies of Elliot et al[145] and of Parsons[149,150] using directional telescopes, suggest that the source of daily variation, at least at certain times, may be situated within the influence of the geomagnetic field. These results have raised an important problem of interpretation of solar daily variation.

Because of the complex trajectories and the large geomagnetic deflections of low energy primaries which contribute to the intensity at middle latitudes, inclined directional telescopes pointing to different azimuths respond to primaries which do not originate in the same part of the celestial sphere. The study with directional telescopes can be conducted with greater advantage at equatorial latitudes where both east and west pointing telescopes successively scan the same part of the celestial sphere. The presence or absence of phase difference in the time of maximum between east and west at equatorial latitudes can indicate more unambiguously than from studies at middle latitudes, the presence or absence of an anisotropy outside the influence of the geomagnetic field. Further, since at Ahmedabad, the cut off energies in east and west are 22.5 and 10.9 Bev respectively, the energy dependence as well as location of the source of anisotropy can be studied by comparing the daily variationsof mean intensity in east and west.

Except for Nerurkar's[179] study with east-west telescopes at Ahmedabad for a year during 1954 to 1955, cosmic ray measurements with directional telescopes at equatorial latitudes have been completely lacking. The author, under the guidance of Prof. V.Sarabhai, designed and constructed an east-west instrument consisting of telescopes of various angles of opening in the east-west plane and inclined at 45° to the zenith. All the telescopes subtend a semiangle of 45° in the north-south plane. Earlier studies at Ahmedabad[137] and in Japan[136] had indicated the influence of the angle of opening of the telescopes on the nature of daily variation that is observed and one of the objects of the present experiment was to investigate the extent of this effect in the inclined directions. The instrument was operated at Ahmedabad (geomag. latitude 13.9°N, geogr. longitude 72°30'E, sea level) during 1957 and 1958 with 12 cm of iron as absorber and the data collected during this period have been analysed.

The results of the 12 month mean daily variation for meson intensity in east and west during 1957 and 1958 are compared with Kerurkar's results for east and west pointing telescopes at Ahmedabad for the years 1954 and 1955, to examine the long term changes of anisotropy. The results of mean daily variation of directional intensities are also compared with the mean daily variation for vertical meson intensity at Ahmedabad, for the same periods.

The nature of the 12 month mean daily variation as well as of the daily variation on individual days of cosmic ray meson intensities in east and west are compared with each other and location and energy dependence of the source of anisotropy under different conditions are discussed. The relationship of the changes in asymmetry with daily variation in east and west and Cp, the index of geomagnetic disturbance, is investigated. The behaviour of daily variation and of mean intensities in east and west on geomagnetically quiet and disturbed days, is discussed and the possible significance of the absence of phase difference in the diurnal hour of maximum between east and west on geomagnetically disturbed days is pointed out. It is suggested that there is evidence for at least two principal sources of daily variation of cosmic ray intensity, in addition to meteorological sources. The conditions under which anisotropy located at a distance from the earth outside the influence of the geomagnetic field produces daily variation of cosmic ray intensity are discussed and conditions when the source of anisotropy may be of geocentric origin are pointed out. An attempt has been made to determine the energy spectrum of the source of the daily variation on days of high and low asymmetry and of 12 month mean daily variation and it is shown that the spectrum of variation is different for different types of variations.

Daily variations of neutron intensity at various stations are examined on days of low and high asymmetry as well as on days when east or west pointing telescopes show maximum number of significant positive and negative bihourly deviations. The results are discussed in the light of the conclusions drawn from the results of east and west pointing telescopes on such days.

An attempt has been made to understand the particular model or models which were operating under different conditions and which produced the observed changes of daily variation in

CHAPTER II

EXPERIMENTAL TECHNIQUE

The significance of making measurements with directional telescopes at low latitudes with different angles of opening has been discussed in the earlier chapter. In this chapter, we describe, in detail, the experimental set up built by the author to study the time variation of cosmic ray intensity in the inclined directions.

An ideal experimental unit should give statistically significant bihourly counts to enable us to study the daily variation on individual days and the day to day variation. The limitations imposed by the available facilities and difficulty in running a large equipment successfully, may not allow us to realise this ideal in practice. The geometry and the number of counters are chosen according to our resources and the units are duplicated as much as possible to get the maximum counting rate and improve the statistical significance. Since self-quenched counters have limited life, counter 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.

In conducting directional studies it is desirable to provide for the telescopes on successive days to be turned round 180° in azimuth around the vertical axis. This can ensure the determination of long term characteristics free from differences of instrumental sensitivity. However the procedure has no special significance in relation to the measurement of day to day changes. Satisfactory operation of the unit can be judged by intercomparison between duplicate independent units in the same direction, as discussed in chapter III.

In a study of the behaviour of long term changes of cosmic ray intensity, the long term stability of the unit is essential. This necessitates the regulation of all A.C. and D.C. voltages. The counter failures can be minimised and their life increased by using external electronic quenching units. Proper shielding, wherever necessary, is done to avoid all pick up of electrical interference and properly earthed cables of short length are used as leads to feed pulses from one unit to another. All output terminals of power supplies are decoupled to avoid undesirable interfeeding. Counters are maintained in a constant temperature enclosure throughout the period of experimentation.

2.1 <u>The apparatus</u>

To study the variation of cosmic ray intensity in the inclined directions the author has designed and constructed an experimental arrangement to measure the daily variation of cosmic rays with narrow angle telescopes inclined to the zenith at an angle of 45^{o}. Fig. 2 shows the experimental set up of the unit.

Fig. 2 - Arrangement of the unit.

The unit consists of two sets of telescopes one pointing east and the other pointing west. Each set consists of three trays of eight counters each with an absorber of 12 cm of iron plates interposed between the middle and the bottom trays. To increase the rate of counting long counters of length 96 cm and diameter 4.2 cm are used. The distance between two successive trays is 45 cm. The geometry is such that any two counters of top tray combined with the corresponding two counters each of other trays form a triple coincidence telescope having a semiangle of 5^{o} in the east-west plane.

In each tray, pairs of adjoining counters are connected in parallel to separate quenching units Q_1', Q_2', Q_3', Q_4' and so on. As is obvious from the figure, in each direction the following combinations will give the required telescopes.

A. (1) Q_1', Q_1'', Q_1'''
(2) Q_2', Q_2'', Q_2'''
(3) Q_3', Q_3'', Q_3'''
(4) Q_4', Q_4'', Q_4'''
} Four 5° telescopes (5T)

B. (1) $(Q_1' + Q_2')$, $(Q_1'' + Q_2'')$, $(Q_1''' + Q_2''')$
(2) $(Q_3' + Q_4')$, $(Q_3'' + Q_4'')$, $(Q_3''' + Q_4''')$
} Two 10° telescopes (10T)

C. $(Q_1' + Q_2' + Q_3')$, $(Q_1'' + Q_2'' + Q_3'')$, $(Q_1''' + Q_2''' + Q_3''')$ - One 15° telescope (15T)

D. $(Q_1' + Q_2' + Q_3' + Q_4')$, $(Q_1'' + Q_2'' + Q_3'' + Q_4'')$, $(Q_1''' + Q_2''' + Q_3''' + Q_4''')$ - One 20° telescope (20T)

Thus in each direction we have triple coincidences from four independent telescopes having semiangle of 5°, from two telescopes having semiangle of 10° and one telescope each with semiangles of 15° and 20° in the east-west plane. All the telescopes have a semiangle of 45° in the north-south plane. A schematic diagram of the unit showing the various telescopes and the associated electronic units is given in Fig. 3.

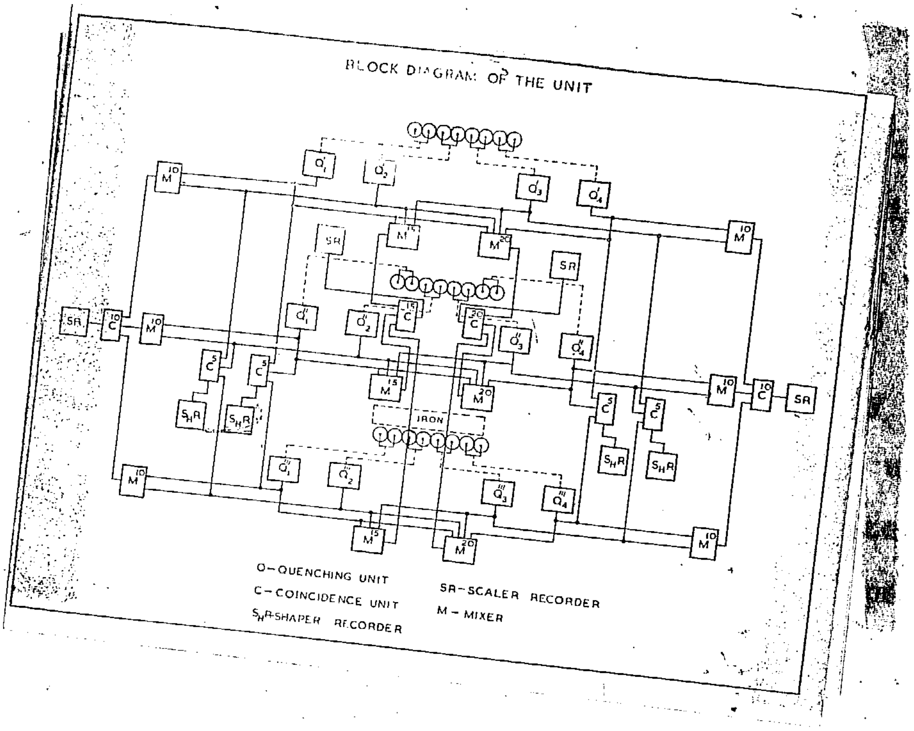

Fig. 3 - A schematic diagram of the arrangement of the various telescopes.

2.2 Geiger-Muller counter

A Geiger-Muller counter is essentially a high gain gas filled diode operated below its continuous discharge voltage. The theory of the counter discharge is extensively studied and its complete description is well discussed in literature,(130, 131, 132, 133, 134).

An ionising particle passing through a counter produces a few ion pairs in the sensitive volume of the counter. An important property of Geiger discharge is that the magnitude, duration and general character of the discharge are independent of the specific ionising power of the initial particle. 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 the counter. Spatz[185] has estimated the useful life of a self-quenched counter to be of the order of 10^{10} counts. The useful life can be considerably increased by working the counter at low over voltages and in combination with an external quenching unit which will limit the extent of discharge in the counter. The most important operational characteristics desirable in a Geiger counter can be summarised as follows.

(a) Low operating voltage.
(b) Long and good plateau.
(c) High efficiency.
(d) Long useful life.

Even though some of the features are mutually exclusive, a workable compromise can always be evolved and a good counter accomodating all the features to an optimum extent can be prepared.

2.21 Preparation of G.M. counter.

Since a metal counter, unlike a glass counter, has the advantage of having a uniform geometry and sturdier construction, metal counters of diameter 4.2 cm and length

96 cm are used in the present investigation. Brass tubes of required dimension, free from depressions and minor grooves running parallel to the length of the tube, are taken. The inside of these tubes is well polished successively with three grades of emery paper, the last one being of No. 1 grade. Discs cut out of a brass rod of the same diameter are turned on lathes and well polished to provide well fitting end pieces to the selected tubes. Holes are drilled in the centre of each end piece for attaching glass bushings carrying the central wire. The glass bushings are used for evacuating and filling the counter.

Inner surface of the counter and end pieces are cleaned with petrol and ethyl acetate to remove dirt sticking to the cathode surface which otherwise may become the centre of strong local fields and by distorting the main field, may give rise to spurious counts[186]. All parts are assembled and thin uniform tungsten wire of diameter 4 mil is threaded to the glass bushing. Metal to metal and metal to glass joints are then warmed to 280°F to 300°F and a thermosetting resin called Ethoxyline (Araldite) is applied to joints to form an uniform leakproof coating. The entire assembly is allowed to cool till the Araldite sets in firmly. The thin tungsten wire forming the anode is spot welded at each end to thicker tungsten wires which protrude outside the glass necks. These are then soldered to copper wires using an alloy of nickel and silver to provide the external electrical contacts. Fig. 4 shows a typical metal counter prepared at the laboratory.

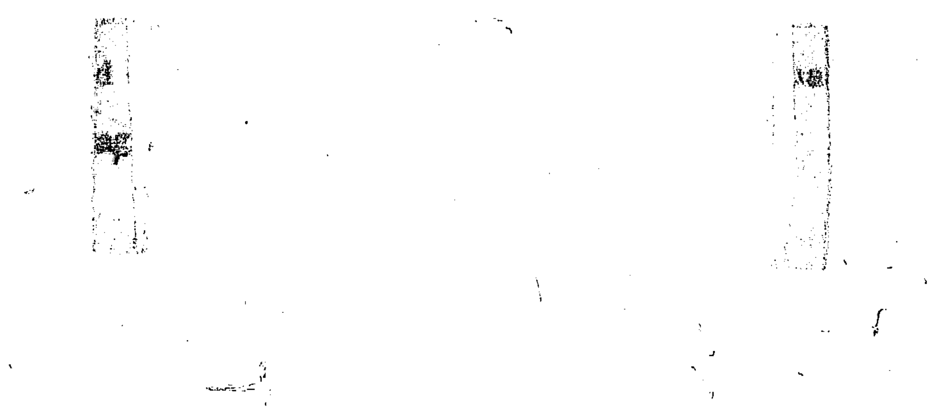

Fig. 4 - Metal counter.

The counters thus prepared are connected to a vacuum system and evacuated. While evacuating, counters are warmed slightly to drive away any moisture and the central wire is electrically heated to a dull red glow to burn out dust and sharp points on it. The vacuum is tested for air leakage for 24 hours and the counters found satisfactory are filled with 1 cm ethyl acetate and 9 cm of argon to a total pressure of 10 cm of Hg. The choice of argon is made because it has a large cross-section for ionisation, a sufficiently high ionising potential to allow electron transfer to polyatomic molecules, does not form negative ions and is cheaply available to the required degree of purity. Ethyl acetate is a good quenching agent as its band absorption spectrum blankets the region (between 1070 and 790Å) of emission of excited argon atoms.

The plateau of individual counters is tested after allowing the mixture of gases to mix at least for 3 to 4 hrs.

Satisfactory counters showing 200 volts long plateau and having a slope of less than 2% in 100 volts are sealed at the constriction provided in the glass sleeving. They are aged or operated in the middle of their plateau for a day and those which retain their plateau characteristics after aging are used in the unit.

2.3 Electronic units.

2.31 Quenching unit.

The deterioration of quenching action with time and the development of spurious pulses in a self-quenched counter can be improved[187] to a great extent by the usage of an external quenching unit. Application of a quenching pulse of a well defined duration and magnitude to the central wire, limits the spread of the discharge besides quenching it. Limiting the spread of discharge results in minimising the number of dissociating ethyl acetate molecules and improving the useful life[188] of the counter.

The circuit consists of a monostable multivibrator (189,190,191) which when triggered by a counter discharge pulse, produces a rectangular negative pulse of 250 volts and of duration 1000 microseconds at the anode of the counter. To make the pulse acceptable for fast coincidence work, it is differentiated by using a fast differentiating network and the sharp negative index pulse generated by the leading edge of the pulse is used.

The working of the circuit is described by a number of authors. Fig. 5 gives the circuit diagram of the quenching unit.

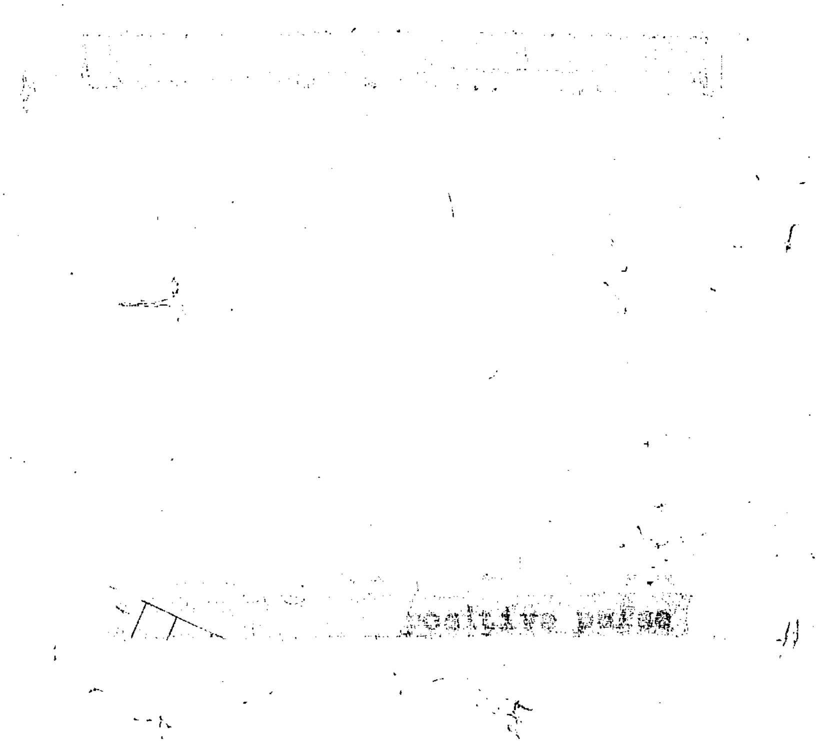

Fig. 5 - Circuit diagram of a quenching unit.

2.32 Coincidence unit.

Well known Rossi[192] type of coincidence circuit (Fig. 6) using sharp cut off pentodes 6SJ7 with low internal resistance is employed. The pulses from individual trays are fed to the control grid of 6SJ7 tubes, whose plates are tied together to a common resistance R. When negative pulses arrive in all the channels simultaneously or within a short interval of time of the order of 5 microseconds, the tubes are driven beyond cut

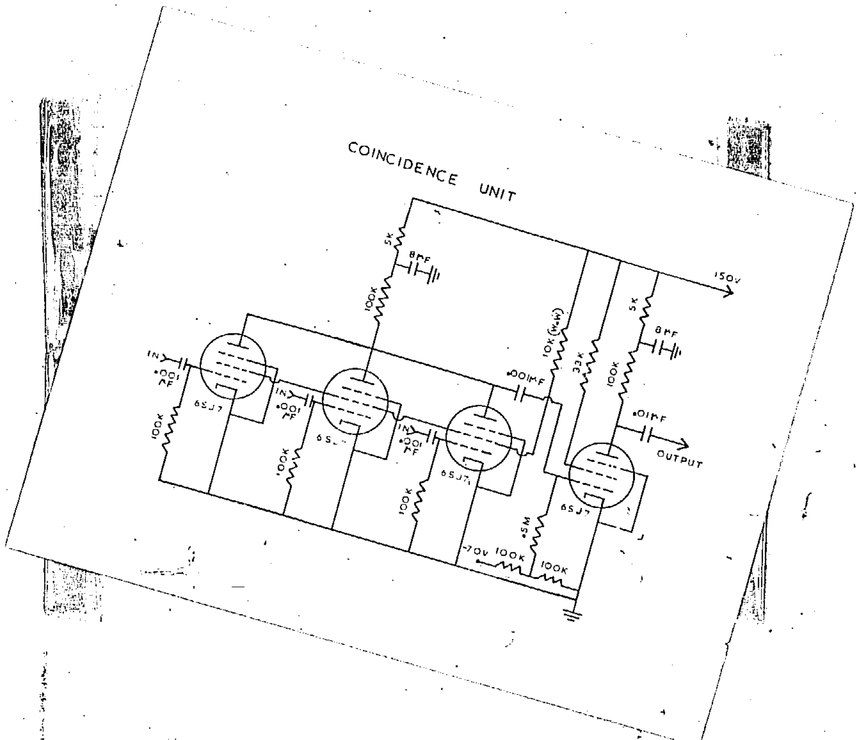

Fig. 6 - Circuit diagram of a triple coincidence unit.

off, resulting in a large positive pulse at their plate. The high discrimination between partial and total coincidence is achieved by the use of a sharp cut off pentode. A discriminator pentode biased much below cut off is made to respond only to the large coincidence pulses. The tube also reverses the phase of the coincidence pulse from positive to negative polarity.

2.33 Scaling and recording unit.

To keep the counting loss of random pulses less than 1%, it can be shown that a mechanical recorder having a resolving time of 1/10 of a second, should be fed less than 6 pulses per minute. This neccessitates the scaling down of high counting rates. Besides decreasing the frequency of pulses, a scaling circuit also smoothens out the randomness (193, 194) due to the averaging out of extreme short and long intervals between the pulses.

The circuit employed for scaling uses a bistable multivibrator of the usual type described by many authors (195, 196, 197). Fig. 7 shows the basic scale of two circuit used. Any number of stages can be used in cascade

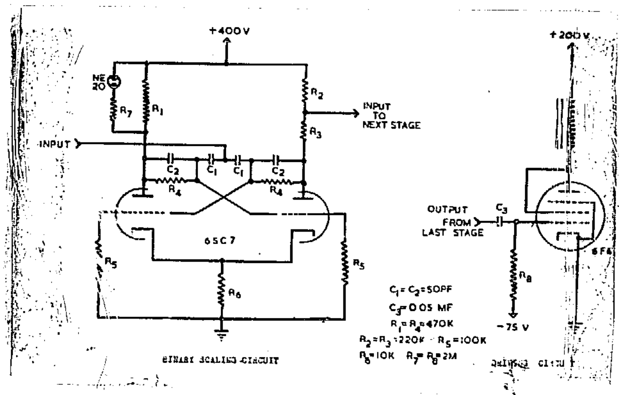

Fig. 7 - Circuit diagram of a scaler and recording unit.

to get the required scaling factor. The counting rates of 10° telescopes, 15° telescope and 20° telescope are scaled down by factors of 4, 8 and 16 respectively. The final output of the scaler is fed to the grid of a power pentode (6F6) biased beyond cut off. The plate voltage is applied to this tube through the solenoid of a mechanical recorder. A positive pulse appearing at the grid of the tube will make it conduct and actuate the mechanical recorder.

2.34 Shaper.

When as in the case of 5° telescopes the counting rate is low enough and need not be scaled down, it is advisable to shape the sharp coincidence output pulses to actuate the power amplifier and recorder circuit. A cathode biased monostable multivibrator is used (Fig. 8) to give a square positive pulse which when fed to the grid of the nonconducting aplifier 6F6, makes it conducting for an adequate time and thus actuates the mechanical recorder.

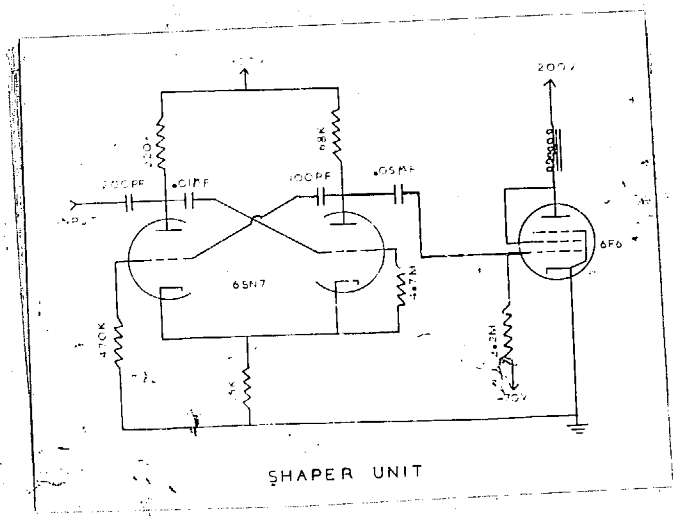

Fig. 8 - Circuit diagram of a shaper and recorder unit.

2.35 Mixer circuit

In order to mix the pulses of various channels to get the appropriate combinations of telescopes, germanium diode mixers are used. The circuit diagram of the mixer circuit is given in Fig. 9.

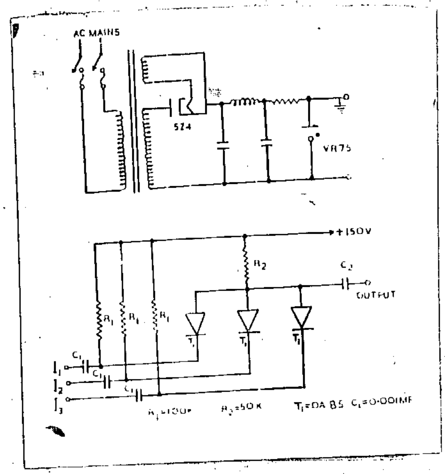

Fig. 9.- Circuit diagram of a mixer.

2.36 Automatic photographic unit.

An automatic photographic device is employed to obtain the hourly cosmic ray records. All the mechanical recorders, a clock and a date index are mounted at one end of a light tight box. The other end of it is fitted with an easily detachable open shutter type camera having a short focus lens of very good quality. The camera can be loaded with 20 ft. of 35 mm Kodak Super XX film, which will suffice for a couple of weeks. Fig. 10 shows the arrangement of the camera unit.

E_1 and E_2, are two electric bulbs which can flush at predetermined intervals. The spool S_2 in the camera which winds the exposed part of the film is geared to the shaft of a low speed motor which is adjusted so as to roll the film through only one frame after each exposure. The moment the minute hand of the clock makes the expected

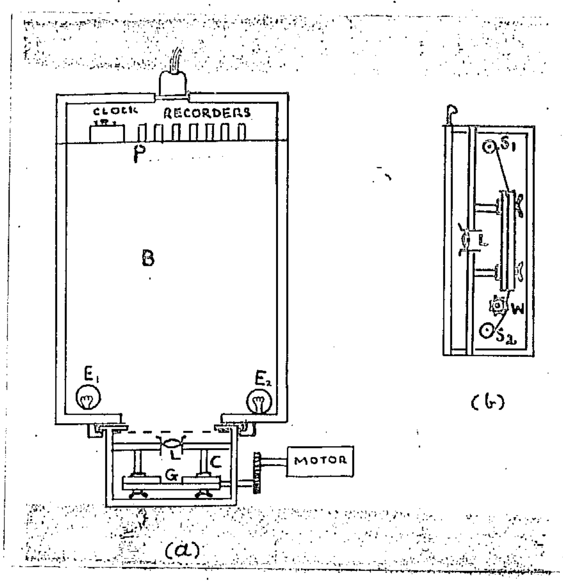

Fig. 10 - The camera unit.

electrical contact at hourly intervals, the bulbs inside the camera flash momentarily enabling the camera to photograph the registration of pulses as indicated by the mechanical recorders. The motor then starts and rolls the exposed film to prepare the camera for the next exposure.

The photographic sequence control unit consisting of two thyratrons, gets automatically reset after 30 seconds of each exposure. Fig. 11 shows the circuit diagram of the automatic sequence control unit. The first thyratron controls the flashing of the bulbs and the second operates the motor. When the minute hand makes the hourly contact, a positive pulse of 200 volts is fed to the grid of the highly biased thyratron T_1 which makes it conducting. The current passing through T_1 closes the relay R_1 resulting in a momentary flash of the bulbs. At the same instant the

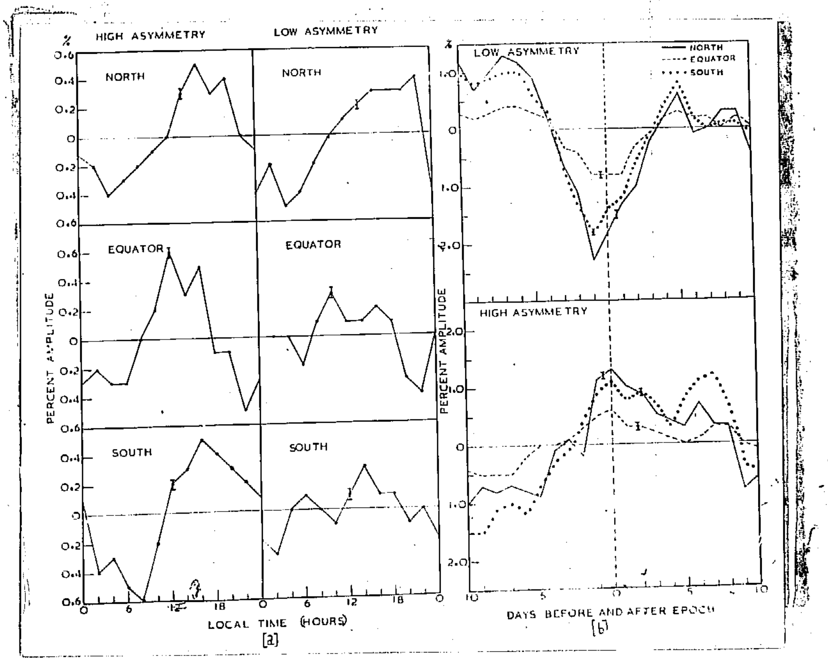

Fig. 11 - Automatic sequence control circuit.

plate circuit of T_1 becomes open, resetting it to its original nonconducting condition which opens the relay R_1 and switches off the lamp circuit. The positive pulse from the plate of T_1 is fed to the grid of the second thyratron T_2 which starts conducting and operates the relay R_2. The motor gets the mains voltage as its circuit is complete and the main shaft starts rotating. Two ebonite pieces mounted on the shaft are so arranged as to press against the switches S_1 and S_2 alternately such that when S_1 is on, S_2 is off and vice versa. It is evident from the figure that the motor circuit can be put on either when relay R_2 is closed, or when switch S_2 is closed. When S_1 becomes open due to the action of the ebonite piece, the thyratron circuit is broken. However, when S_1 is off and S_2 is on, the motor continues to rotate till the main shaft rotates through 180° and the ebonite piece under S_2 switches it off. The gearing is so adjusted as to move the film by one frame when the shaft completes half a revolution.

2.37 Power supplies.

Voltage fluctuations of the A.C. mains supply are very rare at Ahmedabad. However a good 3 KW constant voltage transformer giving a stabilised output of 230 volts A.C. within ± 1% for an input variation from 180 to 250 volts was used to stabilise mains voltage. It is desirable to stabilise the D.C. voltage also against mains fluctuations and load variations. Hunt and Hickman[198] have treated the subject of voltage regulation in a thorough fashion and have recommended the following three methods.

(1) Transconductance bridge circuit.
(2) Amplification factor bridge circuit.
(3) Degenerative amplifier circuit.

In the present investigation advantage has been taken of the simplicity and elegance of the widely used degenerative amplifier circuit to stabilise the various D.C. voltages.

2.371 High voltage power supply : - Basically one requires a sampling circuit which develops the error voltage function. The error voltage function is compared with a standard reference voltage and the difference is fed to the control element which compensates for the change that develops in the error voltage function. Normally a resistance network is used as a sampling element. A part of the output voltage tapped from the bleeder is compared with the reference voltage either from a neon glow tube or from a standard voltage regulator glow gap tube like VR75 or VR150. High gain D.C. amplifier tube is used as the comparison circuit. Since the voltage stability depends on the voltage gain of the amplifier, 6SJ7 is used in the starvation condition. Volkers[199] has shown that when a pentode with low screen voltage and high plate resistance is used as a starvation amplifier, very high gain upto 2500 can be achieved.

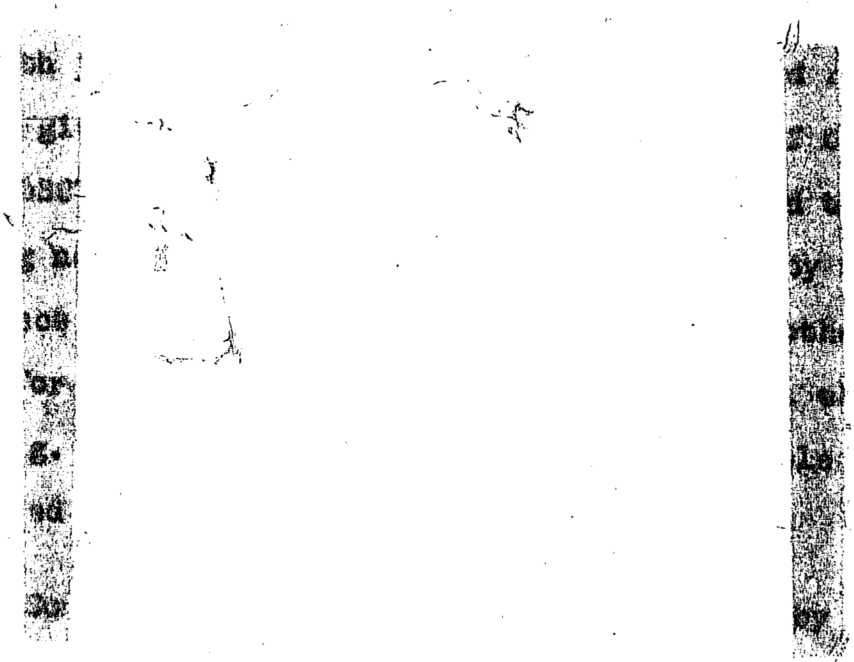

Fig. 12 - Circuit diagram of the electronically regulated high voltage power supply.

The amplified error voltage which is fed to the grid of 807 tube which acts as control element changes its bias such that the output voltage remains unaffected. Greater stability is ensured by feeding the current to the reference tube from the regulated side. The regulation obtained by this circuit is of the order of ± 2 volts at 1300 volts for an input variation from 180 to 240 volts. The power supply is adjusted to give voltages from 800 volts to 1300 volts in steps of 50 volts by using a bleeder.

2.372 <u>Low voltage power supply</u> :- The circuit used is based on the double triode difference amplifier described by Elmore and Sands[190]. Both the plates of 6SC7 amplifier are fed approximately 200 volts to obtain symmetrical behaviour with respect to currents and voltages from both the halves of the amplifier. 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 another 6SC7 tube before being fed to the grid of the control element 6L6. Fig. 13 shows the circuit diagram of the electronically stabilised power supply giving 300 volts.

Comparison voltage will not be effected by changes caused by varying current through the VR tube since the current for the VR tube is obtained from the output side of the power supply. Another important factor is that the plate resistance of the second amplifier is returned to

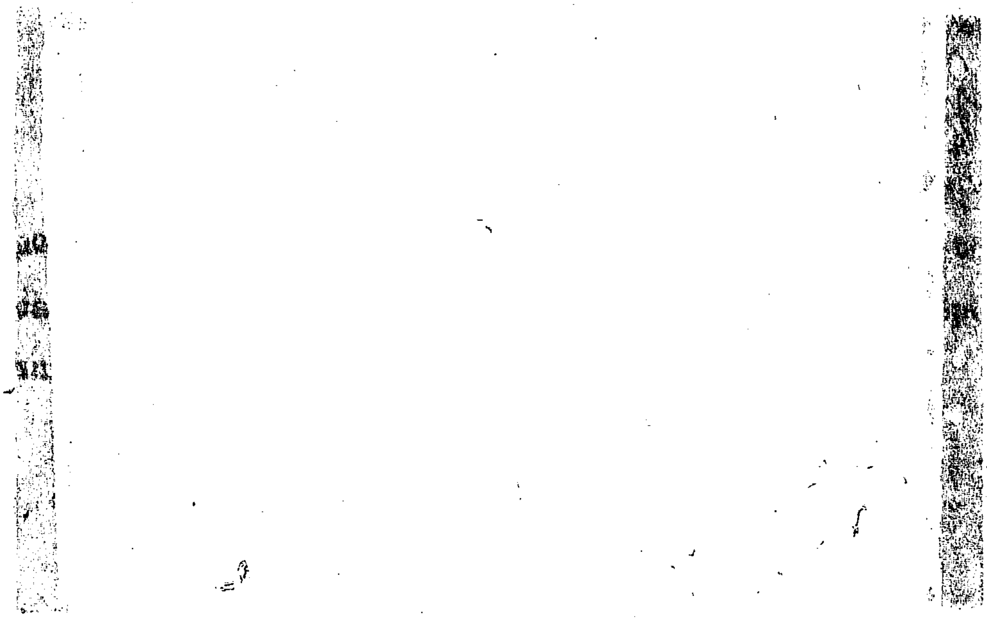

Fig. 13 - Circuit diagram of an electronically regulated power supply giving 300V.

the unstabilised side of the power supply which enables the grid potential of the series triode to approach its cathode potential without causing the current through the amplifier stage to become very small and thus avoiding the reduction in gain. The circuit is found to be very stable even for loads upto 300 ma.

2.4 Maintenance procedure.

The following routine check ups of the instrument, which ensure the proper running of the instrument, are conducted every day.

(1) High and low voltages which are applied to the various electronic units are checked for their constancy.

(2) Rates of groups of counters in trays are examined every day.

From these checks and an examination of hourly readings of the various telescopes, it is possible to locate a faulty telescope easily. Data of only properly running telescopes are used in the analysis.

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CHAPTER III

METHODS OF ANALYSIS

3.1 Cosmic ray data

From the hourly photographic records of the mechanical counters, the readings corresponding to odd hours namely 2300, 0100, 0300.... 2100 I.S.T. are noted down. The difference between the successive bihourly readings of each telescope gives 12 bihourly counting rates m_0^i, m_1^i, ...m_{11}^i centred at 0000, 0200, ...2200 hours I.S.T. respectively. All bihourly counting rates are expressed as deviations Δm_0^i, Δm_1^i, ... Δm_{11}^i from the daily mean

$$\bar{m}^i = \frac{m_0^i + m_1^i + \ldots\ldots + m_{11}^i}{12} \text{ on each day.}$$

3.11 Selection and processing of data.

Where more than one telescope of identical dimension exist, the deviations of bihourly counting rates from their respective daily means are tabulated side by side and examined to see whether they are similar within the limits of statistical errors. Telescopes which do not confirm to the general behaviour are rejected. In case only two telescopes are running, the data for both the telescopes are rejected on a day when their bihourly deviations from their respective means show dissimilar changes. The daily mean intensities are also checked for their parallel behaviour, and the deviation of same bihourly interval as well as the daily mean on each day for all the properly running telescopes are added together. The resultant data of each day comprising of 12 values $\sum \Delta m_0^i$, $\sum \Delta m_1^i$, ... $\sum \Delta m_{11}^i$ centred at 0000, 0200, ... 2200 hours I.S.T. are finally expressed as percent deviations ΔM_0, ... ΔM_r, ... ΔM_{11}

$$\text{where} \quad \Delta M_r = \frac{\sum_{i=1}^{n} \Delta m_r^i}{\sum_{i=1}^{n} \bar{M}} \times 100$$

where n denotes the total number of telescopes working properly.

Daily barometric pressure readings for even hours namely 0000, 0200,.....2200 hours I.S.T. are obtained from an accurate microbarograph. Readings of ground temperature for these hours are obtained from the Meteorological Office, Ahmedabad. The ground temperature and pressure are expressed as deviations from their respective daily means and tabulated alongside the cosmic ray data to facilitate easy application of meteorological correction. Barometric coefficient of -0.22% per mm Hg. is used for correcting for variations in pressure, on grounds discussed in chapter V. Correction for variation of atmospheric temperature is also discussed in chapter V.

3.12 <u>Normalisation of mean intensity.</u>

Loss of data can be due to two types of failures in the unit. One is due to power failure or breakdown of electronic unit and the other is due to the failure of Geiger counters. In the first case the sensitive area of each tray of the telescopes remains unaltered and an estimate of the rate of the telescope on the day of failure can be made from the rate of the telescope which functions, using a normalising factor derived from the ratio of the counting rates of the individual telescopes on days preceding the day of failure. Thus if two identical telescopes have for their daily mean, N_1^1 and N_2^1 on the first day and N_1^2 and N_2^2 on the second day and so on, the sum of the two for any day r is $N_1^r + N_2^r = N^r$. If on a particular day x, one of the telescopes is not in operation and only N_2^x is available, the total rate had both the telescopes been working, can be calculated by using the formula

$$N^x = \frac{N_2^x \sum_{x-1}^{x-5} N}{\sum_{x-1}^{x-5} N_2} .$$

When a counter failure occurs, it is hardly possible to replace a bad counter with a good one of identical characteristics. Therefore the total mean counting rate of telescopes before and after replacing a bad counter are not directly comparable. In this event normalisation can be undertaken in the following manner. If N_1, N_2 etc., are the total daily rates of the two telescopes before counter failure in the first telescope on the x^{th} day and N^{x+1}, N^{x+2} ..... are the total rates after counter failure, the latter series after the break on the x^{th} day has to be multiplied by a factor K,

$$\text{where} \quad K = \frac{\sum_{x-1}^{x-5} N \quad \sum_{x+1}^{x+5} N_2}{\sum_{x+1}^{x+5} N \quad \sum_{x-1}^{x-5} N_2}$$

3.13 Fourier analysis.

In geophysical problems it is often advantageous to resolve periodic variation into its fundamental and higher harmonics. An elegant and easy treatment of fourier analysis and labour saving procedures for evaluating harmonic coefficients have been described by various authors such as Thompson[200], Wittaker and Robinson[201], Henney[202] and Kane[203]. For most geophysical problems of interest, it is found that only the first and the second harmonics are adequate.

Any observed time dependent function can be expressed in terms of a Fourier series of the type

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

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

a_0, a_1 ..... b_1, b_2 .... are independent of t and are called "Fourier coefficients". Where the experimental curve can be defined by 12 equally spaced values u_0, u_1.....u_{11} corresponding to the times t_0, t_1, ...t_{11} respectively, we have just to determine the coefficients a_0, a_n and b_n such that $\{u_i - F(t_i)\}$ is as small as possible. The coefficients a_n and b_n in a twelve ordinate scheme are given by

$$a_n = \sum_{1}^{12} \frac{u_i \cos nt_i}{6} \quad \text{and} \quad b_n = \sum_{1}^{12} \frac{u_i \sin nt_i}{6}$$

where n represents the number of the particular harmonic under consideration.

We can rewrite $F(t) = a_0 + \sum_{1}^{\infty} r_n \sin(nt + \psi_n)$ where $a_n = r_n \sin \psi_n$ and $b_n = r_n \cos \psi_n$. r_n and ψ_n are designated as amplitude and phase of the n^{th} harmonic.

Using the simple relationships $r_n^2 = a_n^2 + b_n^2$ and $\psi_n = \tan^{-1} \frac{a_n}{b_n}$, the magnitudes of r_n and ψ_n can be calculated.

In the solar daily variation, since 12 ordinates cover the complete solar day, r_1 and ψ_1 represent the amplitude and the phase of the first harmonic wave having a period of 24 hours and r_2 and ψ_2 represent the amplitude and phase of the second harmonic wave having a period of 12 hours. 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 the second harmonic components are done with the help of the relationships, $\phi_1 = 90 - \psi_1$ and $\phi_2 = 90 - \psi_2$.

3.14 The harmonic dial.

A convenient method of representation of the harmonic coefficients is by a harmonic dial. Fourier coefficients a_n and b_n can be considered as the components of the vector r_n on mutually perpendicular axes as shown in Fig. 14. First harmonic can be represented on a circular time scale of 24 hours equal to 360° measured in

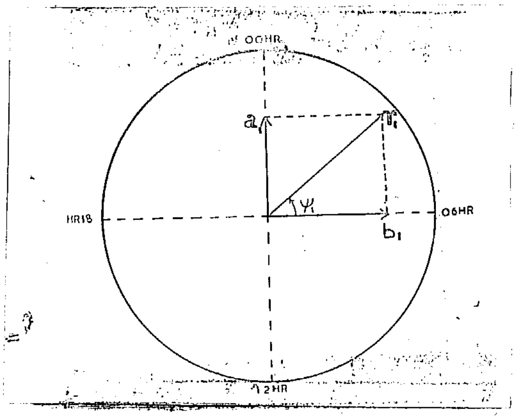

Fig. 14 - The harmonic dial.

a clockwise direction from the "b" axis and second harmonic can be represented on a similar circular time scale where 12 hours equal to 360°.

3.15 Standard error of Fourier coefficients.

From a knowledge of the standard error of the data consisting of 12 equally spaced values u_0, u_1,....u_{11}, it is possible to determine the standard errors of Fourier coefficients a_0, a_1,....b_1..etc. if E is a linear function of u_0, u_1,....u_{11} of the type $K_0u_0 + K_1u_1 + ... + K_{11}u_{11}$, the standard error in E is given by $(K_0^2 + K_1^2 + ... + K_{11}^2)^{\frac{1}{2}}.q$ where q is the standard error of each of the quantities u_0, u_1, ...u_{11}.

In a 12 ordinate scheme, since $12a_0 = (u_0 + u_1 + .. + u_{11})$ the standard error of a_0 is given by $q/\sqrt{12}$. Similarly one can show that the standard errors of a_1, b_1, a_2 and b_2 are all given by $\sigma/\sqrt{6} = \beta$. Standard errors of r and ψ can be easily calculated knowing the standard errors of a and b. Since $\delta r = \frac{a\,\delta a + b\,\delta b}{\sqrt{(a^2 + b^2)}}$, the standard error in r is the same as the standard error in a or b. Similarly since $\delta\psi = \frac{b\,\delta a - a\,\delta b}{\sqrt{(a^2 + b^2)}}$, standard error in ψ is given by $\beta / \sqrt{a^2 + b^2}$.

It is customary to show the error by a circle at the end point of the vector on the harmonic dial. The size of the error circle in relation to the magnitude of the vector itself determines the significance of the particular harmonic component.

3.2 "Chree" analysis.

The method of analysis originally developed by Chree[204] and hence named after him, is very useful in the investigation of any quasi-periodic phenomena such as 27 day recurrence tendency of cosmic ray intensity. The method, which is free from any preconceived ideas about length and significance of recurrence tendency, has been extensively used in finding out the recurrence tendency of geophysical and solar phenomena.

Chree analysis is essentially superposition of a number of similar type of events, which gives the results so obtained a good statistical weightage. The values, for example of cosmic ray intensity, all belonging to a similar type of event are written one below the other in column zero. This is called the epoch day. The cosmic ray intensities for times prior and later to each epoch are likewise arranged one below the other in columns -1, -2,... etc. and +1, +2, ... etc. The extent or the length of the series preceding and following the epoch is to be fixed according to the convenience and the nature of the problem. The mean value of the intensity for each column is then found and plotted on a graph against the corresponding column number. The curves so drawn, at once reveal the recurrence tendency of any effect and its magnitude and periodicity.

3.3 Punch-card system for tabulation and analysis of data.

In cosmic ray time variation one is often required to sort the data according to different criteria and find out the daily variation for each group of days so obtained. By putting the data and all the necessary parameters on a punch card and using a sorter and a tabulator for analysis, one can save quite a good amount of labour.

Each card is so designed as to contain the full information of one day namely the harmonic components of daily variation, mean intensity and the harmonic components of pressure. In the present investigation Hollerith cards having a maximum capacity of ten rows of eighty columns have been used for tabulating the primary data. The following is the scheme of the punch card.

Punch card tabulation of data

Column	Description
1, 2	Year.
3	Month
4, 5	Date
6, 7	C_p index for the day.
8 - 15	a_1, b_1, a_2 and b_2 the Fourier coefficients of daily variation in east, uncorrected for variations of atmospheric pressure.
16 - 23	r_1, ϕ_1, r_2 and ϕ_2 for daily variation in east, corrected for variations of atmospheric pressure.
24	Blank
25 - 27	Daily mean intensity in east.
28, 29	r_1/r_2 in east.
30, 31	Range in which r_1 and r_2 in east lie.
32 - 39	a_1, b_1, a_2 and b_2 the Fourier coefficients of daily variation in west, uncorrected for variations of atmospheric pressure.
40 - 47	r_1, ϕ_1, r_2 and ϕ_2 for daily variation in west, corrected for variations of atmospheric pressure.
48	Blank.
49 - 51	Daily mean intensity in west.
52, 53	r_1/r_2 in west.
54, 55	Range in which r_1 and r_2 in west lie.
56 - 58	Mean (W - E) intensity for the day.
59	Blank.
60 - 67	a_1, b_1, a_2 and b_2 the Fourier coefficients of daily variation of pressure.
68, 69	S_E, daily mean intensity in East corrected for long term variations.

Column	Description
70	Range in which E* lies.
71, 72	W*, daily mean intensity in west corrected for long term variations.
73	Range in which W* lies.
74, 75	(W* - E*)
76	Range in which (W* - E*) lies.
77 - 80	Blank.

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CHAPTER IV

RESPONSE CHARACTERISTICS OF TELESCOPES

In order to relate the daily variation of the measured μ meson intensity with variations and anisotropy of primary cosmic ray intensity, it is essential to know the response characteristics of counter telescopes for background radiation and for anisotropic radiation and the coupling coefficients. In this chapter we discuss these three matters in relationship to the experimental arrangement used by the author.

4.1 Response characteristics of counter telescopes for background radiation.

In order to calculate the response characteristics of a telescope in any direction, one has to calculate the sensitive area of the telescope for the particles coming from that direction and multiply it by the intensity in that direction. The sensitive area of the telescope is maximum for particles coming in a direction perpendicular to the plane of the counter tray. A vertical meson telescope for example, has a maximum sensitive area for particles coming in the vertical direction. A simple geometrical consideration shows that the solid angle available for particles coming in inclined directions is greater than the one available for those coming in vertical direction. Taking into account both these factors one can calculate the geometrical sensitivity G.S(θ) of any telescope arrangement for different values of the inclination θ, which the incoming cosmic ray trajectories make with the vertical. Parsons[205] has obtained an expression for the same for a meson telescope of cubical symmetry. The author, in collaboration with Dr.Kane[206] has extended Parsons' method and has obtained an expression for the geometrical sensitivity of vertical counter telescopes having any rectangular dimensions.

The author has also calculated the radiation sensitivity and cumulative sensitivity assuming a zenith angle attenuation of the form $I_\theta = I_0 \cos^2\theta$ where I_0 and I_θ are cosmic ray intensities in the vertical direction and in a direction inclined to the vertical at an angle θ respectively. The plots of cumulative sensitivity reveal that the bulk of the radiation is confined to comparatively small zenith angles inspite of large opening of the telescope. Thus, for a telescope having semiangles as large as 60° in both east-west and north-south planes, above 70% of the radiation is confined to zenith angles less than about 35°. The bias towards smaller zenith angles is increased still further if one of the semiangles of the telescope is small. A reprint of the above paper is attached at the end of the chapter.

In the case of inclined telescopes, the calculation of response characteristics is rendered complicated. No annular ring around the axis of the telescope corresponding to a particular value of θ , the angle of inclination of the incoming particle with respect to the zenith, will have uniform intensity airound. However, considering the problem only in the east-west plane in which the angular opening of the telescopes is narrow, we have determined the response of inclined telescopes for different values of θ . The approximation involved, if applied to a vertical telescope having semiangles of opening of 20° and 45° in the east-west and north-south planes respectively, does not cause an error greater than $\pm 0.5^{\circ}$ in the calculation of the angle of maximum response of the telescopes. Further the angle of maximum response calculated for Parsons' inclined telescopes with this method agrees exactly with his calculations.

Consider a geometrical arrangement in which the top and bottom trays are represented by XY and AB respectively. Let the breadth AB = XY = d and the length of the telescope in the north-south plane be "l". Let the seperation between the two trays be BY = AX = a . The telescope is inclined to the vertical at 45°.

Case I :- Consider cosmic rays incident along a zenith angle θ , where $\theta \leq 45^{\circ}$. In order to calculate the response, we have to calculate the area perpendicular to the path of the particle in each direction and multiply it by the intensity in that direction. From the Fig. 15

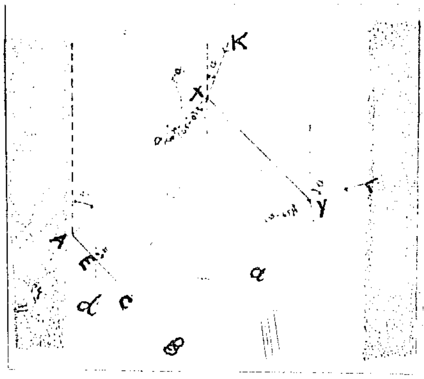

Fig. 15

We see that $AC/AX = \tan(45 - \theta)$ (6)

or $AC = AX \tan(45 - \theta) = a \tan(45 - \theta)$

$\therefore \quad BC = AB - AC = d - a \tan(45 - \theta)$ (7)

Projection of BC perpendicular to the ray KC is $= BC \sin(45 + \theta)$

$$= \left\{d - a \tan(45 - \theta)\right\} \sin(45 + \theta) \qquad (8)$$

Area perpendicular to the path of the particle is

$$= l \left\{d - a \tan(45 - \theta)\right\} \sin(45 + \theta) \qquad (9)$$

When $\theta = 45^{\circ}$, the expression for the area reduces to $l \times d$ and when $\theta = (45 - \tan^{-1}\frac{d}{a})$ the area becomes zero, thus satisfying the boundary conditions. Sensitivity in the direction of the particle is $= I_o l \cos^2\theta \times \left\{d - a \tan(45 - \theta)\right\}$ $\sin(45 + \theta)$ where I_o is the intensity in the vertical direction which falls off with the zenith angle according to $\cos^2 \theta$ law.

Case II : - Now let us take the case when the particles are coming in the direction LY and making an angle ϕ with the vertical so that $\phi \geqslant 45^{\circ}$. From the Fig. 15 we see that

$$BE/BY = \tan(\phi - 45) \qquad (10)$$

or

$$BE = BY \tan(\phi - 45) = a \tan(\phi - 45) \qquad (11)$$

$$\therefore \quad AE = AB - BE = d - a \tan(\phi - 45) \qquad (12)$$

Projection of AE perpendicular to the direction YE of the particle is AE sin AED = AE sin $\left[180 - \overline{\phi + 45}\right]$ = AE sin$(\phi + 45)$

$$= \left\{d - a \tan(\phi - 45)\right\} \sin(\phi + 45) \quad ..13$$

Area perpendicular to the direction of the particle is

$$= l \left\{d - a \tan(\phi - 45)\right\} \sin(\phi + 45) \quad ..(14)$$

The area, as in the previous case, reduces to $l \times d$ when $\phi = 45^{\circ}$ and reduces to zero when $\phi = (45 + \tan^{-1}\frac{d}{a})$.

Intensity in the direction of the particle is $= I_o l \cos^2\phi \times \left\{d - a \tan \overline{\phi - 45}\right\} \sin(\phi + 45) \quad ..(15)$

Intensity is calculated for each value of θ and the curves showing the relation between intensity and the zenith angle as well as the curves showing the relationship between cumulative sensitivity and zenith angle are drawn for telescopes having 10° and 20° semiangles of opening in the east-west plane and inclined to the vertical at 45°. (Fig. 16)

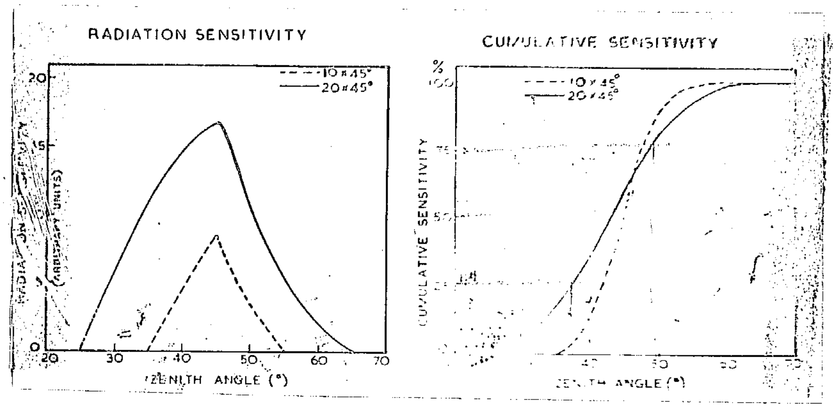

Fig. 16 - Curves showing zenith angle sensitivity and cumulative sensitivity of cosmic radiation for east and west pointing telescopes inclined to the zenith at 45°.

We find that for telescopes having semiangle of 20° in the east-west plane, the mean inclination of all radiation recorded is at 42.5° and that 50% of the recorded radiation is incident within a cone of approximately 5.5° of this mean value. For telescopes having a semiangle of 10° in the east-west plane and 45° in the north-south plane, the mean inclination is at 44.5° and 50% of the recorded radiation is incident within a cone of 3° of this mean value. Thus we find that there is not much difference between the response characteristics for background radiation for telescopes having 10° and 20° semiangle of opening in the east-west plane.

4.2 Response characteristics of counter telescopes for anisotropic radiation

Brunberg[207] has worked out an expression for the total counting rate of a telescope for different angular positions of source element corresponding to a solid angle $\Delta\Omega$ on the sphere of asymptotic directions, and assuming a certain momentum spectrum. Each portion of the element gives a certain counting rate in the telescope for a given momentum interval. Marking a distance in radial direction proportional to the counting rate contributed by each source element at various positions $\Delta\Omega$, a curved surface above the global surface is obtained, the height of which varies continuously over the globe. This mountain is called the "polar diagram" of the telescope in the given momentum interval. To get the total counting rate, one has to calculate the counting rate for a number of angular position of the source element within the total solid angle and add similar contributions from all momentum intervals. Due to the spreading in the atmosphere, even a parallel beam of primary particles gradually gets converted into a more or less divergent beam of secondaries before being finally recorded by the telescope.

The final expression for the total counting rate of particles dn_μ arriving at a telescope of semiangular opening u_{max} and of area of cross-section 'a' perpendicular to the zenith, is given by the expression

$$dn_\mu = \int^{2\pi} \int_{\beta=0}^{u_{max}} a \cos\beta \sin\beta \cdot G(\beta)\, d\alpha\, d\beta \;.\; I(P)\,dP\, M\, \Delta\Omega \int_0^{\infty} K\,dZ \quad ..(16)$$

where I(P) represents the number of particles per cm^2/sec./sterad.momentum interval and M is the magnification of the beam which represents the ratio of the infinitely small solid angle of the telescope dW to its projection angle dW_{∞} on the asymptotic direction.

$I(P)dp\, M \Delta\Omega \int_0^{\infty} K dZ$ represents the number of μ mesons arriving at the telescope from the direction α, β (azimuthal and zenith angle of the telescope respectively), and produced by primary particles coming from α', β'. The factor K is given by R.J.D. where R represents the production rate of μ mesons (from π or primary particles) while D represents the decrease in meson intensity due to decay and J gives the absorption rate of μ mesons.

Assuming a source of anisotropy varying sinusoidally in the equatorial plane, Brunberg has shown that the amplitudes of the extraterrestrial intensity as measured by ion chamber at Huancayo get reduced in the first, second and third harmonic components of daily variation by factors 0.72, 0.32 and 0.05 respectively. Even if the source is considered to have a sinusoidal intensity distribution along a meridian also, the results will not change considerably. The corresponding reduction factors at equator for vertical counter telescopes of various openings are given below.

Semivertical angle in the east-west plane	Reduction factor (X) and the expected hour of maximum (ψ) in					
	1st harmonic		2nd harmonic		3rd harmonic	
	X	ψ	X	ψ	X	ψ
Ion chamber	0.72	56°	0.32	105°	0.05	124°
45°	0.86	57°	0.53	116°	0.20	185°
25°	0.89	58°	0.62	119°	0.29	187°
15°	0.91	56°	0.63	114°	0.29	173°

From the above table we can conclude that reduction factors for telescopes with semiangles of 20° and 10° in the east-west plane are almost the same. Further it is evident that narrow angle telescopes have great advantage over ion chambers or wide angle telescopes as the former observe a much higher amplitude particularly in relation to the 2nd and 3rd harmonics.

From the above table one can also see that the hour of maximum is not dependent on the angle of opening of the telescope. The experimental results of Sarabhai et al[137], however, show that during 1953-1954, the amplitude of daily variation measured by narrow angle telescopes was about 1.2% as compared to the amplitude of daily variation of omni-directional intensity which was 0.25%. Similarly the maximum of the diurnal component for omnidirectional intensity was at 0500 hours as compared to that for narrow angle telescopes which was at 0900 hours. Sekido et al[136] observed similar behaviour in narrow angle telescopes during the same period. The cause of this is not understood. It is therefore important to further examine the dependence of measured daily variation on the angle of opening of the telescope. The instrument constructed by the author has a number of telescopes having different angles of opening in the east-west plane, by means of which one can study the dependence of daily variation of directional intensities on the angle of opening of the telescope.

4.3 Coupling coefficients for cosmic ray intensities measured in inclined directions.

Trieman[25], Fonger[26], Nagashima[27], Dorman[28] and more recently Quenby and Webber[30] have calculated the coupling coefficients for vertical intensity. A summary of the results has been given in chapter I. However, there are no published results of coupling coefficients applicable to directions inclined to the zenith. Since the latitude effect for small inclinations upto 20° does not differ appreciably from the latitude effect for vertical intensity, Dorman[6] has suggested that the coupling coefficients for the vertical direction can be adopted in such cases. For large inclination, however, one has to calculate the coupling coefficients.

As described in chapter I, coupling coefficients are calculated by knowing the latitude effect. Johnson et al[31] have given the experimental curves for the latitude effect of total ionisation measured by east and west pointing telescopes inclined to the zenith at 45°. They find the latitude effect in east to be 12% and that in west to be 4%. Law, McKenzie and Rathgeber[208] have shown that the latitude effects of the total vertical radiation and of the vertical radiation filtered by 10 cm of lead differed from each other by less than 1%. Hence we can utilise the latitude effect curves given by Johnson et al to calculate the coupling coefficients for hard component at sea level, in east and west.

The slope of the latitude curve will give us coupling coefficients only upto the cut off energy in each direction. For higher energies, Dorman[6] has shown that the coupling coefficient can be represented by

$$W^{i}_{\lambda,f}(E,h_o)_{E > E_o} = K\left(\frac{E}{E_o}\right)^{-a + \frac{b}{\sqrt{E/E_o}}} \quad (17)$$

where E_o is the cut off energy at equator and K, a, b are constants. Values of K, a and b are to be determined from the conditions of normalisation of the density of the coupling constant and from the conditions of the tie-in between the extrapolated curve and the curve calculated from the data of the geomagnetic effects.

Following Dorman we choose $W^{i}_{\lambda,f}(E, h_o)$ such that

$$\int_{E^{min}_{\lambda,f}}^{\infty} W^{i}_{\lambda,f}(E, h_o)\, dE = 100\% \quad (18)$$

The condition for normalisation of equation (17) may be written as

$$\int_{0}^{\infty} K\left(\frac{E}{E_o}\right)^{-a + \frac{b}{E/E_o}} dE = 100 - S_o \quad (19)$$

$$\text{where} \qquad S_0 = \int_{E^{min}_{\lambda,f}}^{E_0} W^i_{\lambda,f}(E,\ h_0)\ dE \qquad (20)$$

i.e. $100 - S_0$ represents the ordinate of the corresponding curve of the latitude effect of the type i component at $E = E_0$.

The function $W^i_{\lambda,f}(E,\ h_0)$ calculated from the data of the geomagnetic effects at $E \to E_0$ (where $E < E_0$) can be represented as

$$W^i_{\lambda,f}(E,\ h_0)\Big|_{E\to E_0} = m\left(\frac{E}{E_0}\right)^l \qquad (21)$$

where $m = W^i_{\lambda,f}(E_0, h_0)$ or the condition of equality of this function at the tie-in point is

$$K = m \quad \text{and} \quad l = -a + b \qquad (22)$$

To calculate the integral of equation (19), we substitute $E/E_0 = e^t$ and expand the integral so obtained into a series.

$$m\int_{E_0}^{\infty} \left(\frac{E}{E_0}\right)^{-a + \frac{b}{E/E_0}} dE = mE_0 \int_0^{\infty} e^{t(1-a)}\ e^{tb\,e^{-t}}\ dt$$

$$= mE_0 \int_0^{\infty} e^{t(1-a)} \left[1 + \frac{bt\,e^{-t}}{1!} + \frac{b^2t^2\,e^{-2t}}{2!} + \dots\right] dt$$

$$= mE_0 \left\{\frac{1}{a-1} + \frac{b}{a^2} + \frac{b^2}{(a+1)^3} + \dots\right\} \qquad (23).$$

Substituting the value of l from equation (22), we can show that the equation (23) reduces to

$$\sum_{\gamma=0}^{\infty} \frac{(l+a)^{\gamma}}{(a+\gamma-1)^{\gamma+1}} = \frac{100 - S_0}{mE_0} \qquad (24)$$

From equation (24) value of 'a' may be found by the method of successive approximation. From equation (24), taking one summand at $\nu = 0$ we get

$$\frac{1}{a-1} = \frac{100 - S_0}{mE_0} \text{ or } a_0 = 1 + \left[\frac{100 - S_0}{mE_0}\right]^{-1} \qquad \ldots (25)$$

Substituting the value of a_0 in the right hand side of equation (24), we can find the value of 'a' taking two summands.

$$\frac{1}{a - 1} = \frac{100 - S_0}{mE_0} - \frac{1 + a_0}{a_0^2}$$

$$\text{or} \quad a_1 = 1 + \left[\frac{100 - S_0}{mE_0} - \frac{1 + a_0}{a_0^2}\right]^{-1} \qquad \ldots (26)$$

Similarly substituting the value of a_1 in equation (24) with three summands we get

$$\frac{1}{a_2 - 1} = \frac{100 - S_0}{mE_0} - \frac{1 + a_1}{a_1^2} - \frac{(1 + a_1)^2}{(a_1 + 1)^3} \qquad \ldots (27)$$

Since the left hand side of equation (24) converges rapidly, in practice, it is sufficient to take account of only a few terms of the sequency a_0, a_1, a_2. Using the value of 'a' so obtained we can calculate the coupling coefficients at higher energies from the equation

$$W^{4}_{\lambda,f}(E,h_0)\Big|_{E > E_0} = m\left(\frac{E}{E_0}\right)^{-a + \frac{a + 1}{E/E_0}} \qquad \ldots (28)$$

Using the above method of extrapolation, and utilising Johnson's[31] experimental curves for the latitude effect in inclined directions, the author has calculated the coupling coefficients applicable to the hard component measured by east and west pointing telescopes at Ahmedabad. Fig. 17 shows the coupling coefficients for hard component at sea level measured by east and west pointing telescopes.

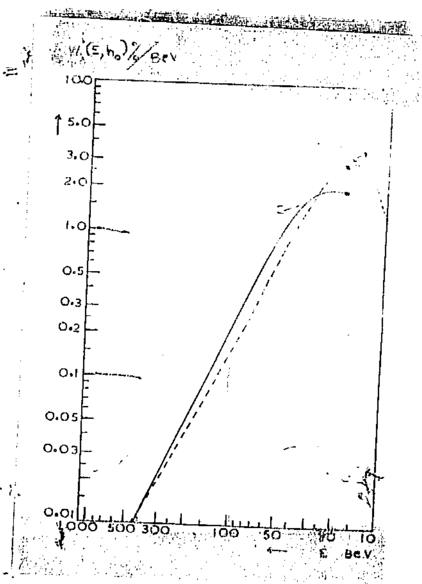

Fig. 17 - Coupling coefficients for hard component at Ahmedabad, measured by east and west pointing telescopes inclined to the zenith at 45°.

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ZENITH ANGLE RESPONSE OF A VERTICAL MESON TELESCOPE

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ABSTRACT

Expressions have been obtained for the Geometrical Sensitivity as a function of the zenith angle of a cosmic ray telescope comprising of counter trays of rectangular dimensions. The Radiation Sensitivity and Cumulative Sensitivity have also been calculated, assuming a zenith angle attenuation of the form $I_\theta = I_0 . \cos^2\theta$ for cosmic ray intensity.

I. INTRODUCTION

MEASUREMENTS of cosmic ray intensity in the vertical direction are mostly carried out by Geiger counter telescopes which comprise of a series of counter trays of rectangular dimensions situated one above the other. All counters in the same tray are connected in parallel and the pulses from the various trays are fed to a coincidence unit which gives a sizable pulse in the output only if pulses are fed to all its inputs within a small time interval, termed as the "resolving time" of the coincidence unit. The coincidence output rate corresponds to single charged particles passing through all the counter trays except for (1) a contribution due to showers where different trays could be triggered by different particles all belonging to the same shower and hence arriving almost simultaneously and (2) a contribution due to chance coincidences where different trays could be triggered by different particles apparently unrelated to each other. For coincidence units with resolving times of the order of a few microseconds as is usually the case and for more than two counter trays in coincidence, the contribution of chance coincidences is negligible. The contribution of side showers depends on the material in the near environment of the telescope and on the separation of the trays. Under optimum conditions this does not exceed about 7% for triple coincidence telescopes, as investigated by Greisen and Nereson.[1] Thus the vast majority of counts registered by such a counter telescope are due to cosmic radiation incident in the cone within which a single particle can cross all the trays.

A vertical meson telescope is characterised by (*a*) its dimensions which may be given as length, breadth and separation of the end trays, or, alternatively, the semi-angles subtended by the telescope in two mutually perpendicular planes and the separation of the end trays, (*b*) the amount of absorber used in between the top and bottom trays. Once these characteristics are known it is possible to evaluate the expected counting rate of the telescope from known values of the vertical flux of cosmic ray intensity at the place of observation and the zenith angle dependence of the same.

A vertical meson telescope offers a maximum sensitive area for particles coming in the vertical direction. A simple geometrical consideration shows, however, that the solid angle available for particles coming in inclined directions is greater than the one available for those coming in a vertical direction. Taking into account both these factors one can calculate the Geometrical Sensitivity G.S. (θ) of any telescope arrangement for different values of the inclination θ which the incoming cosmic ray trajectories make with the vertical. Parsons[2] has obtained an expression for the same in case of a meson telescope of cubical symmetry which is recommended as standard equipment for the current International Geophysical Year. His method can, however, be extended to counter telescopes of any dimensions. We have attempted here to get a general expression for telescopes of any given dimensions.

II. GEOMETRICAL SENSITIVITY OF A VERTICAL MESON TELESCOPE

Consider a geometrical arrangement (Fig. 1) in which the top and bottom trays are represented by ABCD and A'B'C'D' respectively. Let the length AB = A'B' = CD = C'D' = l and breadth BC = AD = B'C' = A'D' = d. The separation between the two trays is AA' = BB' = CC' = DD' = a.

If the ratios l/a and d/a are denoted by Δ and δ respectively, the semi-angles of the telescope in the two vertical planes one along the length and the other perpendicular to it are $\tan^{-1}(\Delta)$ and $\tan^{-1}(\delta)$ respectively. The most inclined direction the telescope can record has a zenith angle $\theta = \tan^{-1} \sqrt{l^2 + d^2}/a = \tan^{-1}\sqrt{\Delta^2 + \delta^2}$ and corresponds to rays parallel to the diagonals AC', BD', CA' or DB'.

Consider cosmic rays incident along a zenith angle θ and an azimuth α, where $\alpha = 0$ for a direction parallel to the breadth 'd' of the counter trays. The beam will then be incident on the rectangular area OXD'Y of the lower tray where

$$OX = (l - a . \tan\theta . \sin\alpha) \text{ and}$$
$$OY = (d - a . \tan\theta . \cos\alpha) \quad (1)$$

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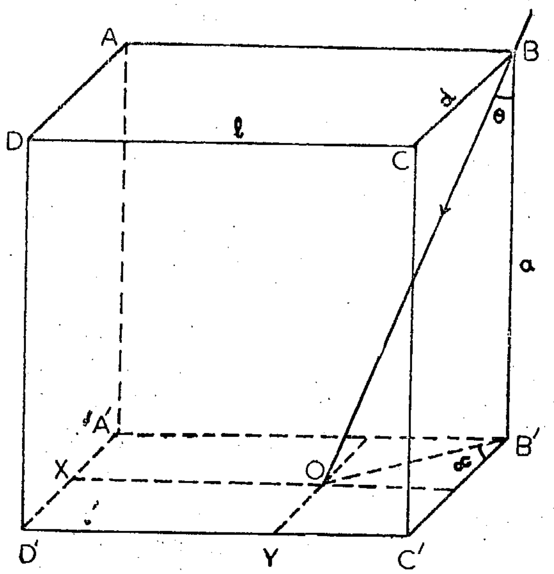

FIG. 1

The effective cross-sectional area of the telescope normal to the beam would be

$$A = \cos\theta\cdot(l - a.\tan\theta\cdot\sin\alpha)\cdot(d - a\cdot\tan\theta\cdot\cos\alpha). \quad (2)$$

Consider the shaded area (Fig. 2) normal to the direction of incidence of a beam which has a zenith angle ranging from θ to $(\theta + d\theta)$ and azimuth

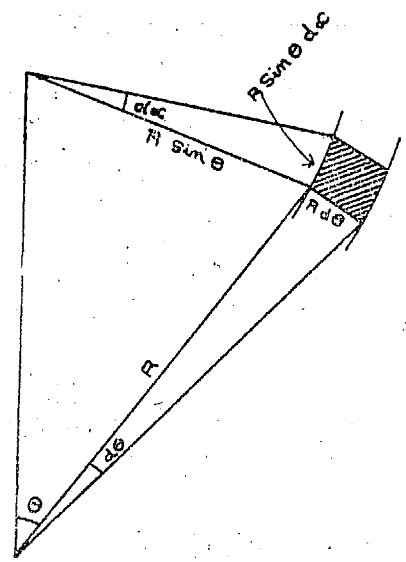

FIG. 2

from α to $(\alpha + d\alpha)$. The solid angle subtended by this beam at the centre of the telescope is given by

$$dw = \frac{(\mathrm{R}\cdot\sin\theta\cdot d\alpha)\cdot \mathrm{R}d\theta}{\mathrm{R}^2}$$

$$= \sin\theta\cdot d\theta\cdot d\alpha \quad (3)$$

The relative Geometrical Sensitivity of the telescope for directions confined to zenith angles between θ and $(\theta + d\theta)$ and azimuth between α and $(\alpha + d\alpha)$ is given by

$$\text{G.S.}(\theta)\cdot d\theta\cdot d\alpha = \mathrm{A}.\sin\theta\cdot d\theta\cdot d\alpha \quad (4)$$

The total relative Geometrical Sensitivity of the telescope corresponding to a zenith angle θ is

$$\text{G.S.}(\theta) = \int_{\alpha_1}^{\alpha_2} \mathrm{A}.\sin\theta.d\alpha$$

$$= \sin\theta.\cos\theta\,[l\,d\cdot(\alpha_2 - \alpha_1) - a\cdot\tan\theta.l.(\sin\alpha_2 - \sin\alpha_1) + a\cdot\tan\theta.d.(\cos\alpha_2 - \cos\alpha_1) - (a^2/4)\cdot\tan^2\theta\cdot(\cos 2\alpha_2 - \cos 2\alpha_1)] \quad (5)$$

Putting $(d/a) = \delta$ and $(l/a) = \Delta$,

$$\frac{\text{G.S.}(\theta)}{a^2} = \sin\theta.\cos\theta\,[\Delta.\delta.(\alpha_2 - \alpha_1) - \Delta\cdot\tan\theta\cdot(\sin\alpha_2 - \sin\alpha_1) + \delta.\tan\theta.(\cos\alpha_2 - \cos\alpha_1) - (\tan^2\theta/4)\cdot(\cos 2\alpha_2 - \cos 2\alpha_1)] \quad (6)$$

where α_1 to α_2 is the range of azimuth for which the effective cross-sectional area A has positive values.

Assuming that the breadth 'd' is less than the length 'l', the zenith angle θ can be grouped into three ranges for each of which a set of values of α_1 and α_2 would be effective.

Case 1.—$0 < \theta \leqslant \tan^{-1}(\delta)$. For this range, the azimuth values range from 0 to 2π. Since, however, all the quadrants are symmetrical, it is sufficient to integrate from 0 to $\pi/2$. Thus $\alpha_1 = 0$ and $\alpha_2 = \pi/2$.

Case 2.—$\tan^{-1}(\delta) < \theta \leqslant \tan^{-1}(\Delta)$. For values of θ in this range (*see* Fig. 3) the particle would miss the telescope for azimuth $\alpha = 0$. The cross-sectional area A will first become positive for values of azimuth given by

$$\cos \alpha_1 = \frac{d}{D} = \frac{d/a}{D/a} = (d/a).\cot\theta = \delta.\cot\theta$$

Thus the lower limit is $\alpha_1 = \cos^{-1}(\delta.\cot\theta)$. The upper limit for integration is still $\pi/2$ as in case 1.

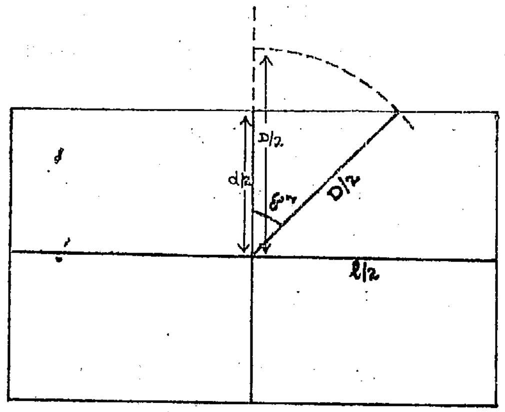

FIG. 3

Case 3.—$\tan^{-1}(\Delta) < \theta \leqslant \tan^{-1}\sqrt{\Delta^2+\delta^2}$. For this region (*see* Fig. 4) the particles will have a positive cross-sectional area for values of α between α_1 and α_2, where

$$\alpha_1 = \cos^{-1}(\delta.\cot\theta) \text{ and } \alpha_2 = \pi/2 - \cos^{-1}(\Delta.\cot\theta).$$

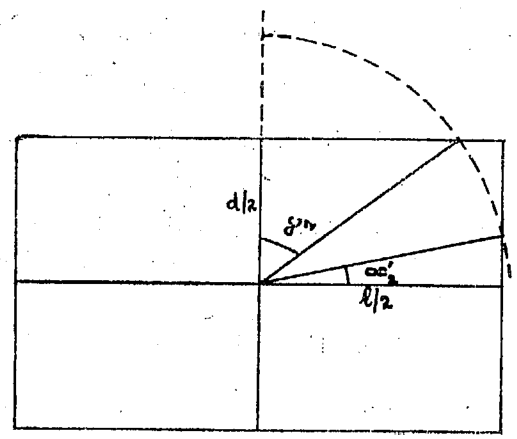

FIG. 4

For isotropic radiation incident upon the telescope, G.S. (θ) is directly proportional to the number of particles coming at a zenith θ. If, however, there is a zenith angle dependence of the cosmic radiation of the form

$$I_\theta = I_0.\cos^\lambda\theta \quad (7)$$

the Radiation Sensitivity R.S. (θ) is given by

$$\text{R.S.}(\theta) = \cos^\lambda\theta.\text{G.S.}(\theta). \quad (8)$$

III. RESULTS

In Figs. 5, 6 and 7, the relative Geometrical Sensitivity and Radiation Sensitivity for various values of the semi-angles $\tan^{-1}(\delta)$ and $\tan^{-1}(\Delta)$ of a telescope are plotted. The value chosen for λ is 2.

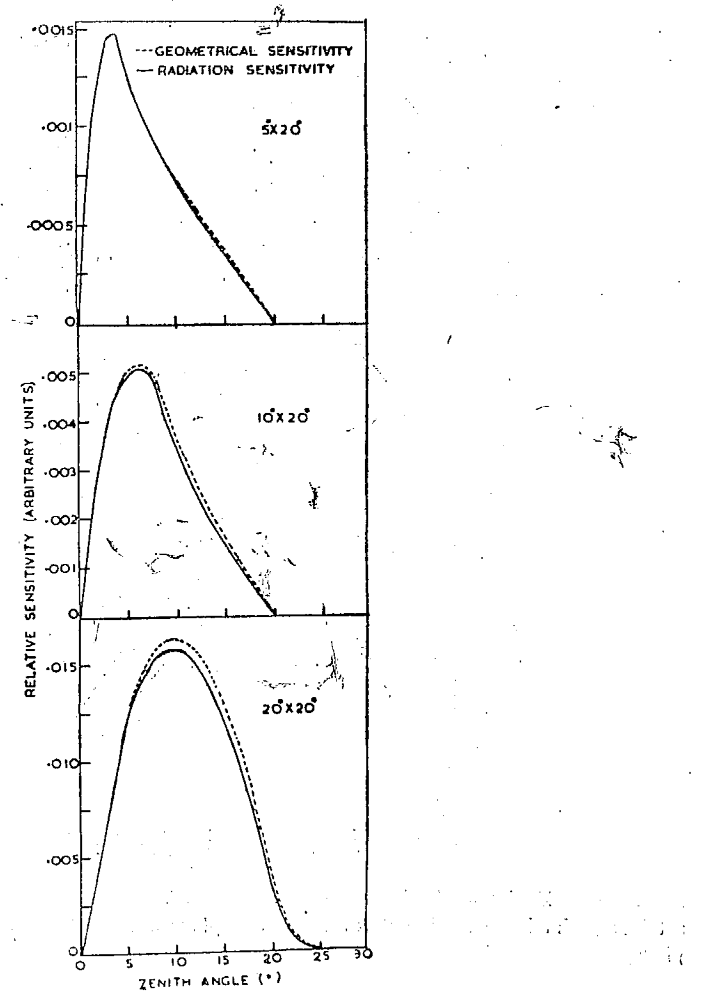

FIG. 5. Zenith angle dependence of Geometrical Sensitivity and Radiation Sensitivity for a telescope having a semi-angle of 20° in one plane and 5°, 10° and 20° in a perpendicular plane,

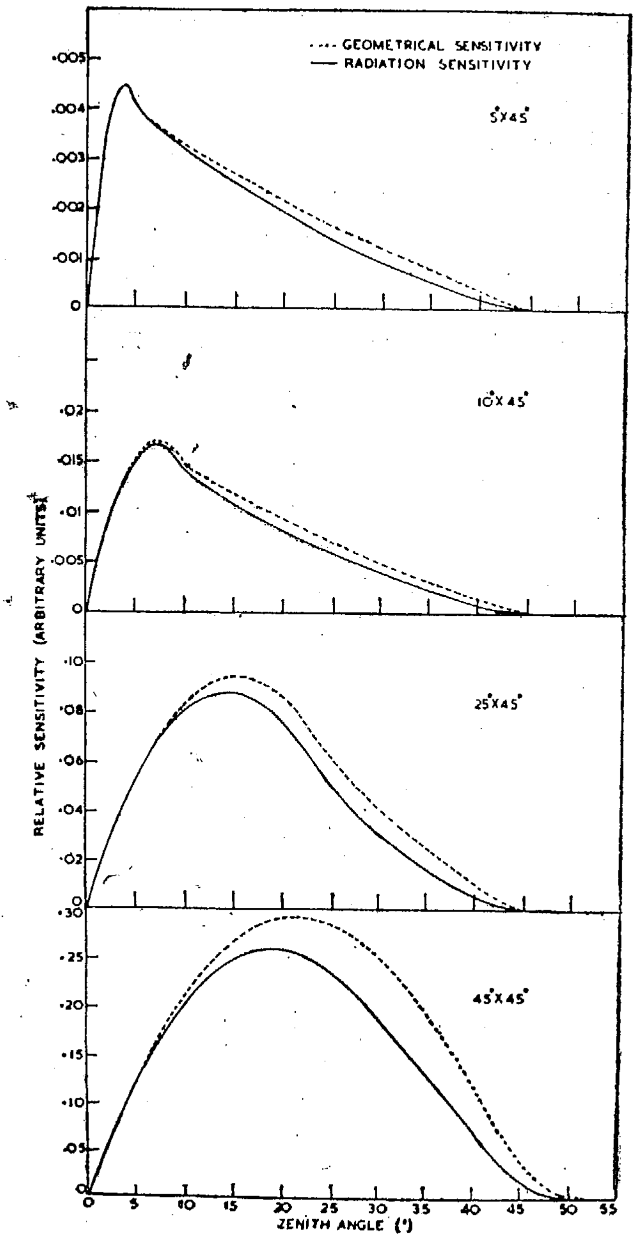

FIG. 6. **Zenith angle dependence of Geometrical Sensitivity and Radiation Sensitivity for a telescope having a semi-angle of 45° in one plane and 5°, 10°, 25° and 45° in a perpendicular plane.**

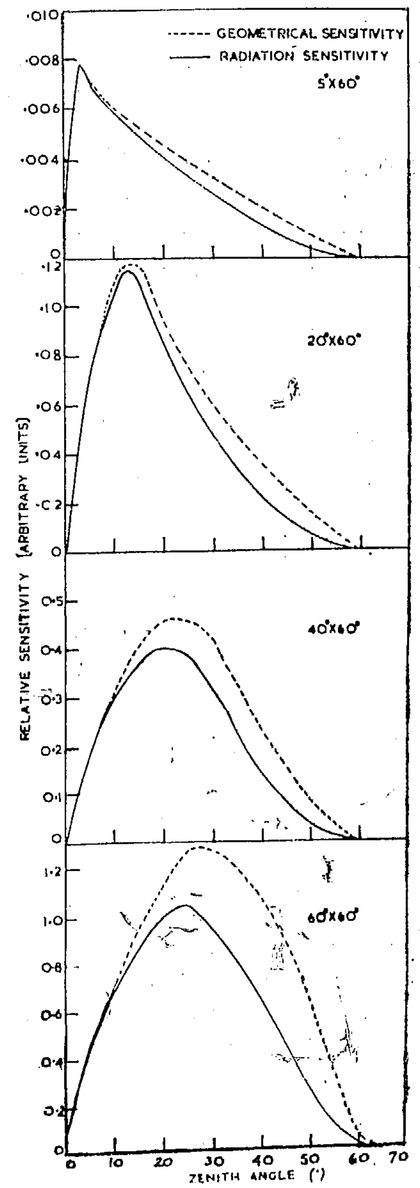

FIG. 7. **Zenith angle dependence of Geometrical Sensitivity and Radiation Sensitivity for a telescope having a semi-angle of 60° in one plane and 5°, 20°, 40° and 60° in a perpendicular plane.**

The total counting rate of a telescope is given by

$$N = 4I_0 \cdot \int_0^{\tan^{-1}\sqrt{\Delta^2 + \delta^2}} \text{R.S.}\,(\theta)\cdot d\theta \qquad (9)$$

The percentage contribution to the total rate of particles confined to the zenith angles between 0 and any value θ_0 is given by the Cumulative Sensitivity C.S. as

$$\text{C.S.} = \left[100 \cdot \int_0^{\theta_0} \text{R.S. } (\theta)\cdot d\theta\right] \div \left[\int_0^{\tan^{-1}\sqrt{\Delta^2+\delta^2}} \text{R.S. } (\theta)\cdot d\theta\right] \tag{10}$$

The Cumulative Sensitivity for various zenith angles and for various values of $\tan^{-1}(\delta)$ and $\tan^{-1}(\Delta)$ is shown in Figs. 8, 9 and 10.

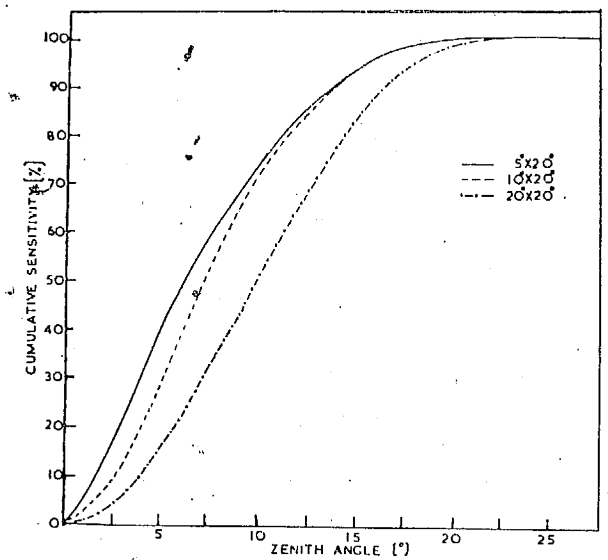

FIG. 8. Percentage Cumulative Sensitivity of a telescope having a semi-angle of 20° in one plane and 5°, 10° and 20° in a perpendicular plane.

A striking feature revealed by the plots of Cumulative Sensitivity is that the bulk of the radiation is confined to comparatively small zenith angles in spite of large opening of the telescope. Thus, for a telescope having semi-angles as large as 60° in both the East-West and North-South planes, about 70% of the radiation is confined to zenith angles less than about 35°. The bias towards smaller zenith angles is increased still further if one of the semi-angles of the telescope is small. For example, a telescope having semi-angles 20° and 60°, counts 70% of its counting rate within zenith angles of 0 to 25°.

In designing a telescope for a particular investigation, the research worker is interested in the directional sensitivity of his instrument. The present work enables the investigator to decide the shape of a counter tray which would satisfy requirements of directional sensitivity in the most appropriate

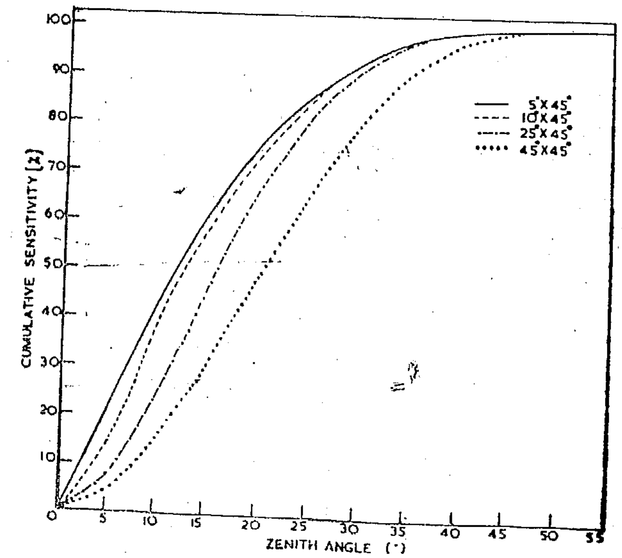

FIG. 9. Percentage Cumulative Sensitivity of a telescope having a semi-angle of 45° in one plane and 5°, 10°, 25° and 45° in a perpendicular plane.

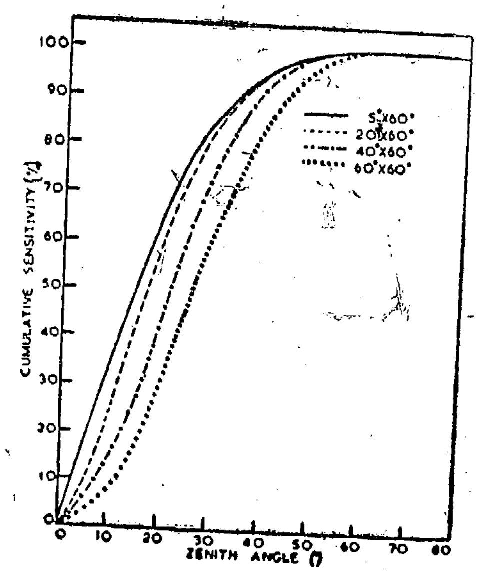

FIG. 10. Percentage Cumulative Sensitivity of a telescope having a semi-angle of 60° in one plane and 5°, 20°, 40° and 60° in a perpendicular plane.

way. If, for example, the requirements specify an 80% response due to particles within 10° inclination with zenith, irrespective of azimuth of direction of arrival, a counter tray of square geometry obviously provides the optimum solution. If, however, we are interested in a narrow angle of 5° in the E.-W. plane, a rectangular tray of dimensions 1 : 4 in the E.-W. and N.-S. planes would still provide an 80% response restricted to 10° with zenith.

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CHAPTER V

EXPERIMENTAL RESULTS

5.1 Introduction

As described in chapter II, the author has operated at Ahmedabad, directional telescopes in east and west directions inclined at 45° to the zenith. The apparatus has for each direction four 5T telescopes, two 10T telescopes, one 15T and one 20T telescope having semiangles of opening in the east-west plane of 5°, 10°, 15° and 20° respectively. All telescopes have a semiangle of opening of 45° in the north-south plane. The instrument was operated during the years 1957 and 1958 and the data collected were put on Hollerith punch cards and analysed as described in Chapter III.

Table 1 shows the number of days in each month in the years 1957 and 1958 for which data of daily variation is available for the various telescopes. The column "total working days" denotes the number of days on which at least one or more telescopes of a particular type are working. The subscripts E and W are used to distinguish telescopes pointing to the east and to the west directions respectively.

Table 1

Number of days in each month of the years 1957 and 1958 for which daily variation data for inclined telescopes at Ahmedabad are available.

Type of telescope	1957 J	F	M	A	M	J	J	A	S	O	N	D	Total working days
$5T_E$	27	21	30	30	27	25	26	31	22	26	24	31	320
$10T_E$	22	21	30	30	26	25	26	31	22	23	21	30	307
$15T_E$*	-	-	26	24	21	23	25	27	22	21	20	26	235
$20T_E$	13	17	27	24	20	23	22	27	21	12	17	28	248
$5T_W$	30	21	30	30	28	25	26	31	22	23	24	31	321
$10T_W$	30	20	30	30	28	25	26	28	22	19	23	31	312
$15T_W$*	-	-	30	28	23	23	25	20	22	17	24	29	241
$20T_W$	27	18	30	28	27	23	25	24	22	17	24	29	294

Type of telescope	1958 J	F	M	A	M	J	J	A	S	O	N	D	Total working days
$5T_E$	26	26	30	27	23	27	30	30	20	25	29	30	323
$10T_E$	26	26	28	27	23	27	30	30	20	25	29	30	321
$15T_E$	25	15	27	23	18	24	28	25	18	20	28	28	279
$20T_E$	26	23	24	24	18	22	29	25	18	21	28	28	286
$5T_W$	26	28	30	27	23	27	30	30	20	25	29	30	327
$10T_W$	26	28	30	27	24	26	30	29	20	25	29	30	324
$15T_W$	26	26	29	23	17	23	27	26	15	17	23	25	277
$20T_W$	26	25	28	23	21	24	28	26	15	19	22	25	282

* 15T telescopes were not in operation during January and February 1957.

5.2 Correction for meteorological factors

5.21 Barometric correction : - In chapter I we have discussed the meteorological corrections which should be applied to cosmic ray data. For vertical telescopes at Ahmedabad, a pressure coefficient of -2.2% per cm.Hg. has been used to correct the bihourly cosmic ray intensity. In an inclined direction we have to consider the contributions from two compensating factors. The variation of mass in the vertical direction will correspond to a greater increase of mass in the inclined direction, the effect of which would be to increase the pressure coefficient in the inclined direction approximately by a factor of sec.θ, where θ is the angle of inclination with the vertical. This arises because we use barometric pressure which corresponds to the total mass above the apparatus to correct the intensity in the inclined direction, even though the change of mass in inclined direction is greater than the change in the vertical direction. However, the higher energy mesons recorded in the inclined directions have also to pass through a greater amount of air mass which is equivalent to increasing the shield thickness. The effect of this is to reduce the pressure coefficient. Dorman[6] has considered theoretically the problem of meteorological correction in inclined directions and concludes that the pressure coefficient, on the whole, decreases with increasing zenith angle and depth of observation. From the curves drawn by him we find that for the hard component at sea level the barometric coefficient varies from -0.27% per mm.Hg. in the vertical direction to -0.23% per mm.Hg. in a direction inclined to the vertical at 45°.

It is essential to determine whether the same pressure coefficient can be used to correct east and west intensities in view of the fact that at equatorial latitudes cut off energies and mean energies of response in east and west are different. The cut off energies at 45°E and 45°W are 22.5 and 10.9 Bev respectively. Olbert[209] has shown that the production spectrum of μ mesons does not vary appreciably from 50°N to equator corresponding to cut off energies of 2.5 and 15 Bev respectively. Further there is no evidence to show the existence of latitude variation of pressure coefficient which indicates that for small difference in cut off energies one can apply a constant pressure coefficient to correct the cosmic ray bihourly intensities.

Experimental results bear out the validity of the above mentioned conclusion. Elliot and Dolbear[2,134] have obtained a pressure coefficient of -0.27% per mm.Hg. from correlation analysis for unshielded telescopes inclined to the vertical at 45°N and 45°S. Elliot and Rothwell[145] obtained the same coefficient for telescopes inclined to the vertical at 45°E and 45°W. For shielded telescopes in inclined directions with 35 cm of lead as absorber, they have used a pressure coefficient of -0.21% per mm.Hg. which was also obtained from correlation analysis.

The pressure coefficient obtained by Murayama et al[210] for intensity of high energy μ mesons measured by alti-azimuth telescopes inclined to the vertical at 30°, serves as the lowermost limit for the value of the pressure coefficient to be used for correcting cosmic ray intensity in inclined direction. They obtained a pressure coefficient of -0.10% per mm.Hg.

Fenton[211] has reviewed the situation and finds that there does not exist any evidence to show a significant change in pressure coefficient with inclination. Hence Parsons[149,150] has used the same coefficient of -0.23% per mm.Hg. for correcting the vertical intensity as well as intensity in directions inclined to the vertical at 45°. Sachlet and Conforto[212] have also obtained the same pressure coefficient of -0.24% per mm.Hg. for vertical intensity as well as for intensity in the directions inclined to the vertical at 30°. Nerurkar[179] at Ahmedabad has corrected the intensities inclined to the vertical at 45° by using a pressure coefficient of -0.25% per mm.Hg.

From all the theoretical as well as experimental considerations presented above, we conclude that we are justified in correcting the cosmic ray intensities in east and west directions for variations of pressure using a barometric coefficient of -0.22% per mm.Hg. which is the same as that used for correcting vertical intensity. However, to know the maximum extent to which the results may vary due to the inaccuracy in the applied pressure coefficient we have corrected one of the 12 month mean curves by using extreme values for the pressure coefficient namely -0.17% per mm.Hg. and -0.27% per mm.Hg. Fig. 18 shows the 12 month mean curves in east and west for the year 1957 corrected with different pressure coefficients.

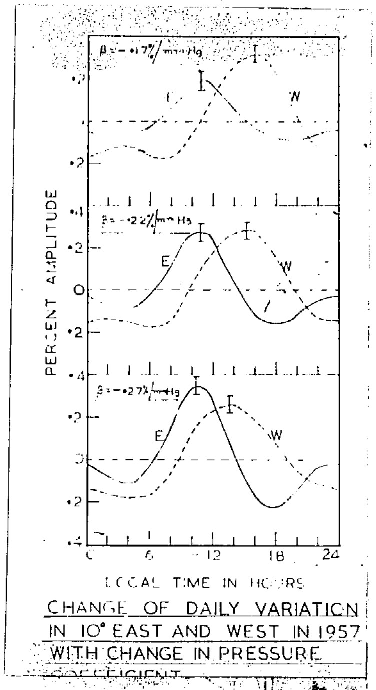

Fig. 18 - Curves showing the mean daily variation in east and west for the year 1957 corrected for variation of pressure using pressure coefficients of (a) -0.17% per mm.Hg. (b) -0.22% per mm.Hg. (c) -0.27% per mm.Hg.

Even in the case of 12 month mean curves having small amplitudes of the order of 0.2%, the main features of the daily variation in east and west remain unaltered when pressure coefficients of -0.17% per mm.Hg. and -0.27% per mm.Hg. are applied. The daily variation on individual days can be considered only when amplitudes of variation on individual days exceed 1.0%, since the standard error in daily variation on each day is of the order of 0.5%. In such cases where large amplitudes are considered, the effect of the variation of pressure coefficient on the results will be negligible. When we consider the difference curves obtained by subtracting the daily variation curve in east from the daily variation in west, any ambiguity about the pressure coefficient can of course play no part as the contribution due to change in pressure will be same in both the directions.

5.22 Temperature correction :- For the correction of cosmic ray μ meson data for variation of the atmospheric temperature, Maeda and Wada[39] and Dorman and Feinberg[43] have developed elegant practical methods using temperature changes at different levels in the atmosphere. For applying these methods to correct the daily variation of meson intensity a knowledge of the daily variation of temperature at various levels from the ground upto the 50 mb level is required.

It is found that the diurnal variation in temperature decreases rapidly with altitude and its time of maximum gets retarded. In summer, the diurnal variation has a greater amplitude than in winter. Haurwitz[213] has theoretically shown that the diurnal variation falls to 1/e (0.37) of surface value at a height of 500 meters and to $1/e^3$ (0.05) at a height of 1500 meters, which are in close agreement with the experimental observations at Lindenberg[214]. At a height of 2 km over Lindenberg the diurnal variation of temperature has a value equal to 0.06 of the surface value.

Many workers such as Barkow[214], Dines[215] and Bemmelan[216] have shown that there is no diurnal variation of temperature beyond 2.5 km in winter months. In summer it is found that the diurnal variation of temperature over Lindenberg[214,217] has an amplitude of 0.5° even at a height of 4 km above the ground. One has to however remember that an inaccuracy of this magnitude is possible due to the direct heating of the instrument by sun.

Expressing daily variation of temperature as

$$T = A_0 + A_1 \sin(15t + \alpha_1) + A_2 \sin(30t + \alpha_2) \qquad (29)$$

in terms of harmonic components, Napier Shaw[218] concludes that beyond 2km, the amplitude of the first harmonic with which we are chiefly concerned becomes negligible, and beyond that height there is no evidence showing a regular dependence of temperature on the time of the day.

The results of 14000 ascents made in two years at five stations in England have been summarised by Kay[219]. He finds that the diurnal variation of temperature at 150 mb level is of the order of about 2°K which changes with seasons. He has also pointed out that this result may be due to the inherent errors in radiosonde instruments mainly due to imperfect radiation shielding of the instrument. Desai and Venkateswaran[220] have studied daily variation in temperature in upper atmosphere over Ahmedabad. They confirm the absence of daily variation of temperature with amplitude larger than 1°C above 2 km.

Sarabhai et al[221] have discussed the significance of various causes which can produce a daily variation of temperature in the upper atmosphere. Reviewing the available experimental and theoretical evidence, they conclude that the daily variation of temperature which gets rapidly attenuated upto a height of 2 km above ground level becomes important once again only in the ultraviolet absorption region of ozone, which however, is well above the level of meson production. We are therefore justified in assuming that no significant daily variation of temperature exists above 2 km above ground level. Comparing the curves for the density of temperature coefficients given by Dorman[6] for vertical meson intensity and meson intensity recorded by telescope inclined to the zenith at 45°, we find that the difference in the coefficients for vertical and directional intensities arises only at higher levels above 0.3 atmosphere. If therefore we assume that no significant diurnal variation of temperature exists above 2 km, the temperature coefficient densities to be used for vertical and directional intensities will be practically identical.

With the evidence presented above we feel that we are justified in correcting the east and west intensities for variations of ground temperature and variations of temperature upto 2 km by using global temperature coefficients given by Dorman[6]. Dorman's equation for applying temperature correction to μ meson data can be approximated to the following summation,

$$\frac{\delta N_\mu}{N_\mu} = \sum_{i=1}^{11} K_i \, \delta T_i$$ where $\frac{\delta N_\mu}{N_\mu}$ is relative

variation in the muon intensity due to variations in the air temperature at various layers and K is the partial temperature coefficient for the i^{th} layer obtained by integrating W(h) the temperature coefficient density for the corresponding layer. Dorman and Feinberg have pointed out that summation over 11 standard atmospheric levels from 1000 mb to 50 mb is sufficiently accurate. Dorman has given the following values for K_i at various levels.

No.	1	2	3	4	5	6	7	8	9	10	11
H(mb)	1000	900	800	700	600	500	400	300	200	100	50
K_i%	0.020	0.021	0.022	0.024	0.025	0.026	0.028	0.033	0.038	0.031	0.023

Knowing δT_i, the temperature variation of the i^{th} standard level and K_i the partial temperature coefficient corresponding to that level, one can easily apply the temperature correction.

Since we are assuming that no significant temperature variations exist above 2 km, which approximately corresponds to 800 mb level, we have to correct the cosmic ray intensity for temperature variations at ground level and at 900 and 800 mb levels. Instead depending upon radiosonde data for the temperatures at 900 and 800 mb levels, we have estimated the time of maximum and amplitude of diurnal variation at these levels from Beers'[222] relation. According to Beers' experimental results the temperature variations at 1 km and 2 km above the ground have an amplitude equal to 0.22 and 0.11 times its surface value respectively. By using the above results we have corrected the cosmic ray bihourly intensities in east and west directions for temperature variations at 1 km and at 2 km.

Table 2

Table showing the harmonic components of the mean monthly variation of ground temperature and the harmonic components of the temperature correction curve for each month in the year 1957.

Month	Ground temp. (°C)				Temp. correction curve (%)			
	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$
Jan.	6.7	$\pi+54^\circ$	1.8	61°	0.17	$\pi+54^\circ$	0.05	61°
Feb.	8.1	$\pi+55^\circ$	2.0	60°	0.21	$\pi+55^\circ$	0.05	60°
Mar.	6.9	$\pi+57^\circ$	1.3	58°	0.18	$\pi+57^\circ$	0.04	58°
Apr.	6.5	$\pi+59^\circ$	1.2	42°	0.17	$\pi+59^\circ$	0.03	42°
May	5.8	$\pi+63^\circ$	1.0	53°	0.15	$\pi+63^\circ$	0.03	53°
Jun.	4.5	$\pi+64^\circ$	0.9	96°	0.12	$\pi+64^\circ$	0.02	96°
Jul.	2.5	$\pi+59^\circ$	0.6	72°	0.07	$\pi+59^\circ$	0.02	72°
Aug.	2.8	$\pi+58^\circ$	0.6	81°	0.07	$\pi+58^\circ$	0.02	81°
Sept.	4.5	$\pi+61^\circ$	0.9	63°	0.12	$\pi+61^\circ$	0.02	63°
Oct.	6.4	$\pi+51^\circ$	1.5	48°	0.17	$\pi+51^\circ$	0.04	48°
Nov.	6.3	$\pi+49^\circ$	1.7	52°	0.17	$\pi+49^\circ$	0.04	52°
Dec.	6.8	$\pi+53^\circ$	1.7	54°	0.18	$\pi+53^\circ$	0.04	54°

Table 2 gives the harmonic components of the monthly mean daily variation of temperature at ground for the various months in the year 1957. The pattern of change in monthly mean daily variation of temperature from month to month in the year 1958 is very similar to that in the year 1957. We find that the daily variation of temperature has a maximum amplitude in late winter months, February and March, and a minimum in the monsoon months, July and August. In monsoon months the sky is overcast with clouds which absorb and radiate effectively as a black body. The net result is to reduce the rise of surface temperature during the day and diminish the net loss of it by the ground during the night. In monsoon months, therefore, the daily variation of temperature has a minimum amplitude. Table 2 also gives the harmonic components of the temperature correction curve. The temperature correction has a maximum amplitude of 0.22% in February and March and has a minimum amplitude of 0.06% in July and August, the annual mean amplitude being 0.15%. In Table 3 the amplitudes and times

Table 3

Amplitudes and times of maxima of 12 month mean daily variation in 1957 for 10E and 10W telescopes before and after temperature correction.

Tel.	Before temperature correction				After temperature correction			
	r_1%	ϕ_1	r_2%	ϕ_2	r_1%	ϕ_1	r_2%	ϕ_2
10E	0.20±0.03	102°	0.12±0.03	-48°	0.14±0.03	146°	0.12±0.03	-31°
10W	0.08±0.03	π+20°	0.04±0.03	90°	0.22±0.03	π+43°	0.07±0.03	74°

of maxima of diurnal and semidiurnal components of 12 month mean daily variation in east and west for the year 1957, before and after applying temperature correction, are given separately.

5.3 An examination of the form of daily variation and changes occurring in it.

5.31 Form of 12 month mean curve :- The 12 month mean daily variations in east and west directions for telescopes having different angles of opening in the east-west plane are shown in Fig. 19, for the years 1957 and 1958

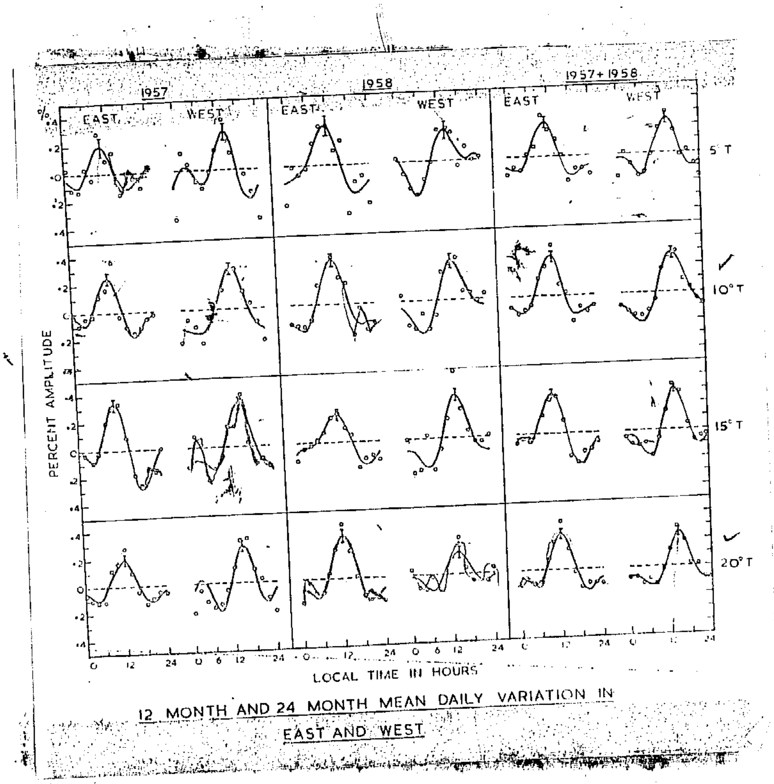

Fig. 19 - 12 month mean and 24 month mean daily variations in east and west during 1957-1958 at Ahmedabad.

separately. The curves obtained by superimposing the diurnal and the semidiurnal components as well as the curves

Table 4

Table showing the values of $\bar{r}_1$, $\bar{\phi}_1$, $\bar{r}_2$, $\bar{\phi}_2$ describing the diurnal and the semidiurnal components of the 12 month mean and 24 month mean daily variations in east and west directions at Ahmedabad, for the years 1957 and 1958. The values are corrected for both the pressure and temperature variations in the atmosphere.

Tel.	1957 $\bar{r}_1$	1957 $\bar{\phi}_1$	1957 $\bar{r}_2$	1957 $\bar{\phi}_2$	1958 $\bar{r}_1$	1958 $\bar{\phi}_1$	1958 $\bar{r}_2$	1958 $\bar{\phi}_2$	1957 + 1958 $\bar{r}_1$	1957 + 1958 $\bar{\phi}_1$	1957 + 1958 $\bar{r}_2$	1957 + 1958 $\bar{\phi}_2$
$5T_E$	0.11±0.05	158°	0.09±0.05	-36°	0.22±0.05	158°	0.08±0.05	0°	0.16±0.03	158°	0.08±0.03	-21°
$10T_E$	0.14±0.03	146°	0.12±0.03	-31°	0.23±0.03	π+2°	0.09±0.03	- 6°	0.18±0.03	167°	0.11±0.03	-22°
$15T_E$	0.21±0.03	137°	0.16±0.03	-22°	0.16±0.03	153°	0.06±0.03	9°	0.18±0.02	144°	0.11±0.02	-15°
$20T_E$	0.12±0.03	171°	0.08±0.03	- 7°	0.20±0.03	177°	0.11±0.03	5°	0.16±0.02	173°	0.10±0.02	0°
$5T_W$	0.13±0.04	π+13°	0.15±0.04	86°	0.17±0.04	π+65°	0.10±0.04	17°	0.14±0.03	π+43°	0.11±0.03	56°
$10T_W$	0.22±0.03	π+43°	0.07±0.03	74°	0.22±0.03	π+65°	0.09±0.03	55°	0.21±0.02	π+52°	0.08±0.02	61°
$15T_W$	0.13±0.03	π+51°	0.15±0.03	75°	0.21±0.03	π+48°	0.10±0.03	61°	0.17±0.02	π+49°	0.13±0.02	67°
$20T_W$	0.21±0.02	π+46°	0.11±0.02	90°	0.10±0.02	π+37°	0.07±0.02	34°	0.16±0.02	π+45°	0.08±0.02	69°

formed from the average bihourly deviations are drawn. Table 4 gives the amplitudes and times of maxima of the diurnal and semidiurnal components of the 12 month mean daily variation in east and west for the years 1957 and 1958.

Since there is no significant change in the form of daily variation from 1957 to 1958, we have combined the curves for 1957 and 1958 and 24 month mean curves covering the years 1957 and 1958 are also shown in Fig. 19.

On examining the mean daily variation in east and west, the following observations can be made.

(1) The peak to peak amplitude of the variation in east and in west is comparable. The diurnal and the semidiurnal amplitudes in east and west are similarly comparable.

(2) In general we find that the diurnal time of maximum in east occurs about 4 hours earlier to that in west.

If no correction is applied for variation in temperature, the amplitude of the diurnal variation in west is found to be very small, being only about half the amplitude of the diurnal variation in east. The four hours difference between the times of diurnal maximum in east and west remains unaltered. By applying the correction for variations of atmospheric temperature, the amplitude of the diurnal variation in west increases since its time of diurnal maximum is approximately at 1600 hours.

5.32 <u>Form of daily variation on individual days</u> :-

Frequency distributions of the occurrence at each bihour of the diurnal time of maximum in east and west when the corresponding diurnal amplitudes are significant at the 2σ level are shown in Fig. 20. The distributions related to the semidiurnal component are also shown in the figure. Since only amplitudes greater than about 1.2% are considered, the temperature correction which has a magnitude of the order of about 0.15% can be neglected. The histogram for

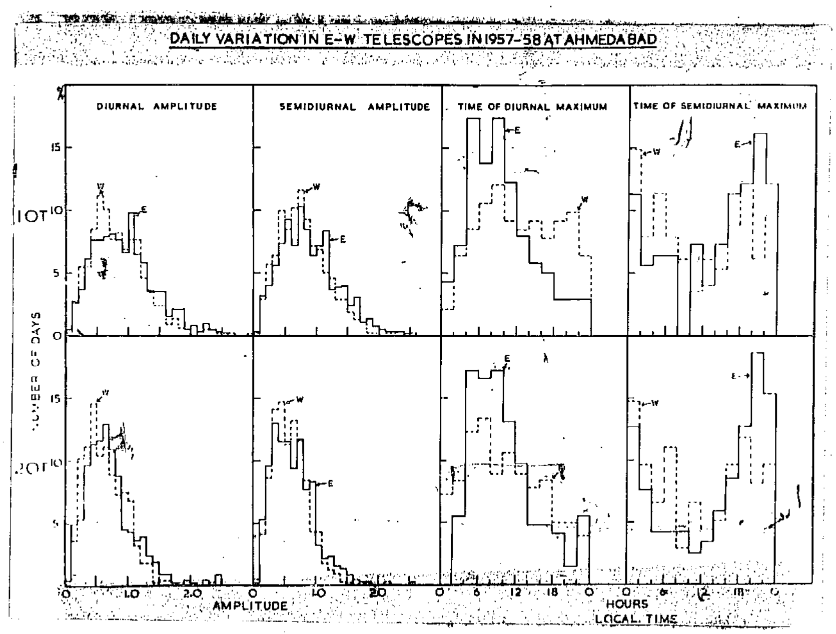

Fig. 20 - Frequency distributions of the amplitudes and times of maxima of diurnal and semi-diurnal components of the daily variation of cosmic ray intensities in east and west on individual days during 1957 and 1958.

east shows a desicisive preference for the occurrence of diurnal maximum at 10 or 12 hours whereas the histogram in west shows a large scatter in the occurrence of the diurnal maximum. The histogram for semidiurnal hour of maximum for east and west show almost the same amount of scatter even though the occurrence of maximum in west is shifted to later hours by two or three hours as compared to that in east.

The histograms of diurnal and semidiurnal amplitudes for east and west are also shown in figure 20. Since the harmonic components on individual days are not corrected for temperature variations in the atmosphere, we shall only examine the frequency distribution of amplitudes higher than 1.0% which are not appreciably affected by temperature correction. We find that the frequency distribution of diurnal as well as semidiurnal amplitudes both in east and west are roughly similar.

5.33 <u>Monthly mean daily variation</u> :- Table 5 gives the values of monthly mean diurnal and semidiurnal components of daily variation in east and west for various months in the years 1957 and 1958. When monthly mean diurnal and semidiurnal components are plotted on a harmonic dial as shown in Fig. 21, we find the large scatter in the diurnal time of maximum in west from month to month whereas in east the scatter is less. The harmonic dial of the semidiurnal component for east and west show that the scatter of the semidiurnal time of maximum from month to month in east and west is roughly similar. If v_1, v_2, v_3.....are deviations

Table 5

Table showing $\bar{r}_1$, $\bar{\varphi}_1$, $\bar{r}_2$, $\bar{\varphi}_2$ describing the diurnal and the semidiurnal components of the monthly mean daily variation of east and west intensities at Ahmedabad, for each month during the years 1957 and 1958. All the values are corrected for the variations of atmospheric temperature and pressure.

Month	$10T_E$				$20T_E$				$10T_W$				$20T_W$			
	$\bar{r}_1$	$\bar{\varphi}_1$	$\bar{r}_2$	$\bar{\varphi}_2$	$\bar{r}_1$	$\bar{\varphi}_1$	$\bar{r}_2$	$\bar{\varphi}_2$	$\bar{r}_1$	$\bar{\varphi}_1$	$\bar{r}_2$	$\bar{\varphi}_2$	$\bar{r}_1$	$\bar{\varphi}_1$	$\bar{r}_2$	$\bar{\varphi}_2$
1957																
Jan.	0.08	105°	0.23	π+19°	0.12	109°	0.27	179°	0.37	−31°	0.12	132°	0.24	π+75°	0.11	74°
Feb.	0.12	150°	0.21	π+58°	0.25	π+73°	0.15	π+74°	0.32	π+61°	0.25	77°	0.34	π+52°	0.22	121°
Mar.	0.34	148°	0.24	18°	0.28	π+ 1°	0.21	37°	0.25	π+31°	0.15	102°	0.28	π+52°	0.09	103°
Apr.	0.03	71°	0.25	6°	0.21	172°	0.19	11°	0.28	171°	0.09	118°	0.29	π+11°	0.18	94°
May	0.15	161°	0.23	−17°	0.14	172°	0.18	−47°	0.19	−30°	0.13	−22°	0.22	−36°	0.17	20°
Jun.	0.23	86°	0.05	128°	0.27	114°	0.03	−63°	0.19	172°	0.08	121°	0.10	175°	0.23	84°
Jul.	0.06	−8°	0.13	−16°	0.17	83°	0.18	−70°	0.06	130°	0.24	−34°	0.16	160°	0.16	0°
Aug.	0.16	102°	0.27	−25°	0.16	125°	0.21	−31°	0.28	π+73°	0.19	100°	0.11	π+56°	0.13	142°
Sept.	0.23	π+9°	0.31	−48°	0.25	169°	0.28	−30°	0.39	π+31°	0.05	−97°	0.39	π+37°	0.14	π+20°
Oct.	0.16	164°	0.15	−49°	0.30	−90°	0.09	103°	0.40	154°	0.14	−53°	0.21	170°	0.03	−44°
Nov.	0.34	169°	0.10	−10°	0.27	174°	0.26	−35°	0.59	π+56°	0.20	124°	0.45	π+78°	0.25	95°
Dec.	0.25	172°	0.05	−21°	0.08	π+39°	0.08	39°	0.21	π+42°	0.09	90°	0.24	π+70°	0.14	107°

Table 5 cont.....

Table 5 ..cont.....

Month	10T_S $\bar{r}_1$	10T_S $\bar{\phi}_1$	10T_S $\bar{r}_2$	10T_S $\bar{\phi}_2$	20T_S $\bar{r}_1$	20T_S $\bar{\phi}_1$	20T_S $\bar{r}_2$	20T_S $\bar{\phi}_2$	10T_W $\bar{r}_1$	10T_W $\bar{\phi}_1$	10T_W $\bar{r}_2$	10T_W $\bar{\phi}_2$	20T_W $\bar{r}_1$	20T_W $\bar{\phi}_1$	20T_W $\bar{r}_2$	20T_W $\bar{\phi}_2$
1 9 5 3																
Jan.	0.25	π+25°	0.32	68°	0.31	π+37°	0.18	46°	0.24	-70°	0.17	61°	0.22	π+53°	0.04	90°
Feb.	0.64	π+47°	0.12	54°	0.30	π+27°	0.19	5°	0.22	π+72°	0.22	121°	0.28	π+62°	0.15	58°
Mar.	0.26	180°	0.32	- 6°	0.24	171°	0.25	- 2°	0.09	-62°	0.15	-31°	0.15	63°	0.11	6°
Apr.	0.00	0°	0.02	-90°	0.14	53°	0.10	-44°	0.21	- 4°	0.09	111°	0.22	68°	0.12	122°
May	0.25	157°	0.10	π+73°	0.34	151°	0.15	-31°	0.42	π+31°	0.10	164°	0.11	180°	0.09	-40°
Jun.	0.28	π+12°	0.15	π+57°	0.30	π+ 4°	0.06	100°	0.37	π+86°	0.14	24°	0.34	-83°	0.11	- 4°
Jul.	0.42	143°	0.17	π+72°	0.33	146°	0.02	0°	0.34	176°	0.05	π+52°	0.13	142°	0.07	-22°
Aug.	0.17	π+ 2°	0.10	-10°	0.15	139°	0.18	49°	0.17	-72°	0.28	0°	0.18	19°	0.18	-21°
Sept.	0.14	π+ 3°	0.18	86°	0.16	π+26°	0.13	π+57°	0.29	π+87°	0.02	π+26°	0.07	180°	0.08	π+35°
Oct.	0.29	179°	0.34	-33°	0.26	176°	0.20	-17°	0.38	π+35°	0.11	- 4°	0.27	π+14°	0.07	π+73°
Nov.	0.29	152°	0.17	-52°	0.25	π+11°	0.13	-8°	0.32	π+76°	0.22	92°	0.30	π+53°	0.16	68°
Dec.	0.17	171°	0.28	29°	0.07	154°	0.24	54°	0.38	π+31°	0.28	49°	0.38	π+24°	0.33	61°
Std. error	±0.11		±0.11		±0.08		±0.08		±0.10		±0.10		±0.07		±0.07	

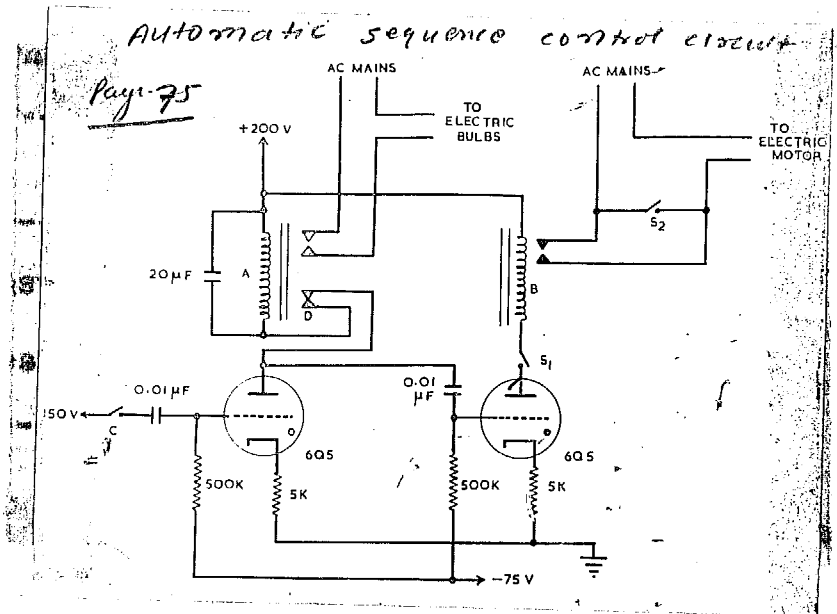

Fig. 21 - Monthly and 12 month mean diurnal and semidiurnal components of daily variation in east and west plotted on harmonic dials for various months during 1957-1958.

of individual vectors V_1, V_2, V_3......etc. from their mean value $\overline{V}$, the standard vector deviation which is a measure of the scatter of the individual vectors around the mean can be expressed as[223] $\sigma = \sqrt{(\Sigma v^2/N)}$ where N is the total number of vectors. Instead of calculating the vectorial difference between each vector and the mean, the above expression can be reduced to $\sigma^2 = \Sigma \frac{V^2}{N} - \overline{V}^2$. Table 6 gives the value of σ^2 for the distribution of monthly mean diurnal and semidiurnal components in east and west separately. The results show a larger scatter for the diurnal component in west from month to month as compared to that in east. σ^2 for the diurnal component in west is about 1.5 times that in east. The result bears out the conditions existing on a

Table 6

Table showing the value of σ^2, the square of the standard vector deviation, for the distribution of monthly mean diurnal and semi-diurnal components in east and west.

	ϕ_1 distribution		ϕ_2 distribution	
	10T	20T	10T	20T
East	0.033	0.029	0.030	0.017
West	0.052	0.045	0.022	0.022

day to day basis. Thus on a monthly mean basis as well as on a day to day basis, the variability of the time of occurrence of the maximum of the diurnal component is greater for the west direction than for east.

5.34 <u>Occurrence of significant diurnal and semi-diurnal components of the daily variation on individual days</u> :- Table 7 gives the number of days in 1957 and in 1958, having significant diurnal and semidiurnal amplitudes r_1 and r_2 for east and west intensities separately. In general, we find that there are as many days on which r_1 is significant as the number of days on which r_2 is significant. Probably the implication of this is that when one considers large amplitudes, the number of days on which r_1 and r_2 can be significant is not different. On a fair proportion of days, roughly a quarter of the total number of significant days, each side has both r_1 and r_2 significant on the same day.

Table 7

Table showing the number of significant days in east and west for various telescopes, when diurnal and semidiurnal components individually and together are significant at the 2 sigma level during the years 1957 and 1958.

Telescope	East r_1	East r_2	East r_1&r_2	West r_1	West r_2	West r_1&r_2	East & West r_1	East & West r_2	East & West r_1 & r_2
10T	138	124	39	141	114	29	35	22	4
20T	145	118	35	179	136	53	44	25	6
10T or 20T	228	200	82	249	196	73	92	51	10
10T & 20T	55	42	8	71	54	9	9	4	2

5.35 Histograms of occurrence of significant bihourly deviations :- Fig. 22 shows the histograms of the occurrence of bihourly positive and negative deviations, for east and west intensities for the period 1957-1958, which are significant at the 2 σ level. From statistical considerations, we know that on approximately 95.4% of the days, all the values should lie within the 2 σ level. Hence one can get deviations above 2 σ level on 4.6% of the days, by chance alone. Since deviations can be either positive or negative, the probability of either positive or negative deviations to exceed 2 σ level through chance alone is 2.3%. We consider the total number of positive or negative deviations significant at 2 σ level and occurring at any bihour as meriting some consideration when the number exceeds 2.0 times the number of significant deviations which can

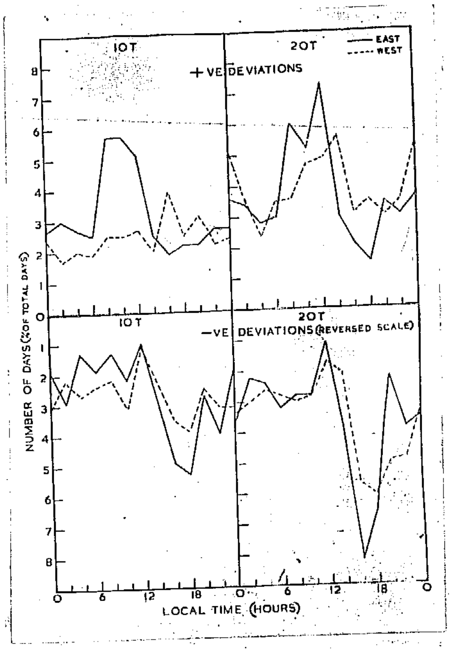

Fig. 22 - Histograms of occurrence of positive and negative bihourly deviations at each bihour, significant at the 2σ level for 10T and 20T telescopes in east and west during 1957-1958.

occur through chance alone. It is realised that this does not set a stringent enough selection criterion to draw conclusions unambiguously and for this reason the results of this section can only be taken tentatively and require further experimental consideration with an instrument of higher counting rate than the present one.

We find that for east pointing telescopes important bihours for significant positive deviations exceeding twice the value expected by chance are 0800, 1000 and 1200 hours, while for west pointing telescopes they are 1000, 1200 and 1400 hours and 0000 hours. In west, this phenomenon is seen only for 20° telescopes, where the statistical error in the bihourly counts is smaller than for 10° telescopes. The important bihours for significant negative deviations to occur in 10° and 20° telescopes in east as well as for 20° telescope in west are 1600 and 1800 hours. It is very interesting to note that the shift to later hours seen in the occurrence of large positive deviations in west as compared to that in east, is absent for negative deviations. The peaks of maxima and minima in the histograms in east are sharp and pronounced whereas the peaks in west are broad and less conspicuous. The results confirm the features of histograms (vide page 121) of the occurrence of the diurnal times of maxima in east and west pointing telescopes for days on which the diurnal amplitudes are significant at the 2 σ level.

From an examination of the histograms, it is obvious that there are three groups, one corresponding to positive deviations at 0000 hours in west (A), the second corresponding to positive deviations near noon in either east or west (B) and the third corresponding to negative deviations at 1600 and 1800 hours in either east or west (C). We designate these groups as A, B and C respectively.

A - Positive deviation at 0000 hours in west.

B - Positive deviations at 1000, 1200 or 1400 hours in west or positive deviations at 0800, 1000 or 1200 hours in east.

C - Negative deviations at 1600 or 1800 hours in either east or west.

When one selects on a criterion such as the one indicated above, a bias is introduced in the daily variation of the data on which the selection is based. Keeping this in mind, we have looked at only the diurnal and the semidiurnal components of the daily variation in east and west for each of these groups and in addition we have examined the mean daily variation of neutron intensity at Ottawa, Churchill, Huancayo, Mt.Wellington and Mawson for the three groups separately.

5.351 <u>Mean daily variation of neutron intensity at various stations for days corresponding to groups A,B and C</u>:- Fig. 23 shows the mean daily variation of nucleonic component at Churchill, Ottawa, Huancayo, Mt.Wellington and Mawson for groups A, B and C seperately . Table 8 describes the harmonic components of mean daily variation of nucleonic component at these stations and of east and west intensities at Ahmedabad, for all the groups separately.

In all these stations, we find that only for group A, the semidiurnal component is prominent. On these days we find that the semidiurnal component in west also to be very prominent. In all the three groups A, B and C we find that the diurnal maximum at an equatorial station such as Huancayo, occurs much earlier as compared to the diurnal maximum in stations situated in northern and southern hemispheres. This suggests that the daily variation is either caused by an anisotropy outside the influence of the geomagnetic field or if it is caused by a geocentric source of modulation, then that source itself is produced by charged particle radiation

Table 8

Table showing the harmonic components of mean daily variation of east and west intensities at Ahmedabad and of neutron intensities at various stations for days corresponding to groups A, B and C

Station.	A (21 days) $\overline{r}_1$	$\overline{\varphi}_1$	$\overline{r}_2$	$\overline{\varphi}_2$	B (120 days) $\overline{r}_1$	$\overline{\varphi}_1$	$\overline{r}_2$	$\overline{\varphi}_2$	C (100 days) $\overline{r}_1$	$\overline{\varphi}_1$	$\overline{r}_2$	$\overline{\varphi}_2$
East	0.09 ± 0.08	130°	0.27 ± 0.08	9°	0.46 ± 0.04	142°	0.19 ± 0.04	-46°	0.38 ± 0.04	104°	0.33 ± 0.04	-35°
West	0.33 ± 0.07	-17°	0.58 ± 0.07	11°	0.32 ± 0.03	$\pi+13^\circ$	0.18 ± 0.03	36°	0.14 ± 0.03	108°	0.18 ± 0.03	2°
ur- ill.	0.55 ± 0.03	$\pi+79^\circ$	0.05 ± 0.03	44°	0.39 ± 0.02	$\pi+67^\circ$	0.09 ± 0.02	7°	0.41 ± 0.02	$\pi+71^\circ$	0.03 ± 0.02	113°
tawa	0.39 ± 0.03	$\pi+23^\circ$	0.14 ± 0.03	-84°	0.33 ± 0.02	$\pi+39^\circ$	0.05 ± 0.02	$\pi+86^\circ$	0.34 ± 0.02	$\pi+26^\circ$	0.02 ± 0.02	146°
an- yo	0.23 ± 0.03	180°	0.12 ± 0.02	-77°	0.28 ± 0.01	$\pi+5^\circ$	0.06 ± 0.01	19°	0.29 ± 0.01	179°	0.05 ± 0.01	4°
. Wel- ngton	0.27 ± 0.03	$\pi+54^\circ$	0.26 ± 0.03	51°	0.39 ± 0.02	$\pi+42^\circ$	0.14 ± 0.02	75°	0.25 ± 0.02	$\pi+40^\circ$	0.08 ± 0.02	80°
wson	0.25 ± 0.03	$\pi+71^\circ$	0.10 ± 0.03	18°	0.25 ± 0.02	$\pi+48^\circ$	0.01 ± 0.02	$\pi+50^\circ$	0.17 ± 0.02	$\pi+72^\circ$	0.03 ± 0.02	$\pi+65^\circ$

from the sun in which case the interaction between the charged particles and the geomagnetic field would be subject to similar effects as the cosmic ray component itself.

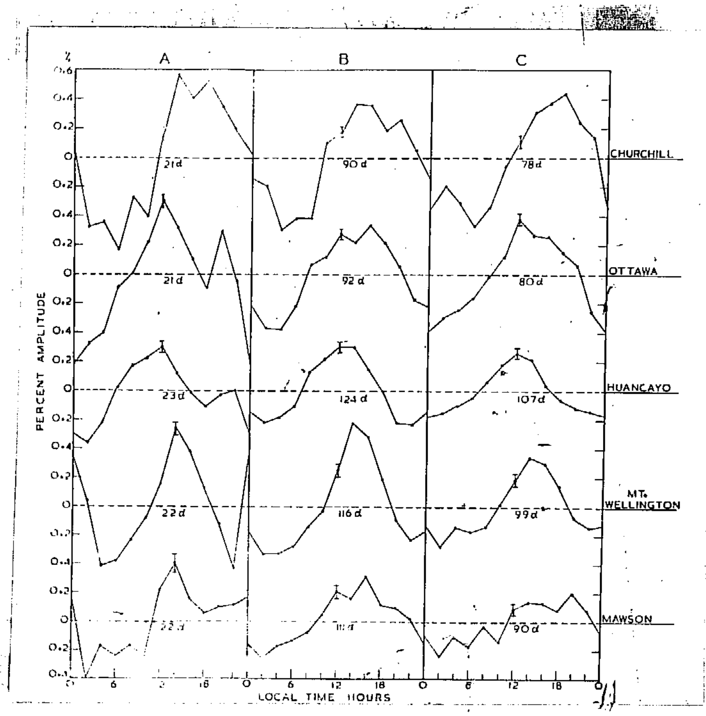

Fig. 23 - Mean daily variation of nucleonic intensity at various stations on days corresponding to groups A, B and C.

5.332 <u>Histograms of significant bihourly deviations of neutron intensity at various stations for days corresponding to groups A, B and C</u> :- Fig. 24 shows separately for three groups, the histograms of significant positive and negative bihourly deviations for neutron intensities measured by stations situated in the northern, southern and equatorial belts. We have selected Churchill and Ottawa in the northern hemisphere, Lae and Huancayo in the equatorial belt and Mt.Wellington and Mawson in the southern hemisphere. For

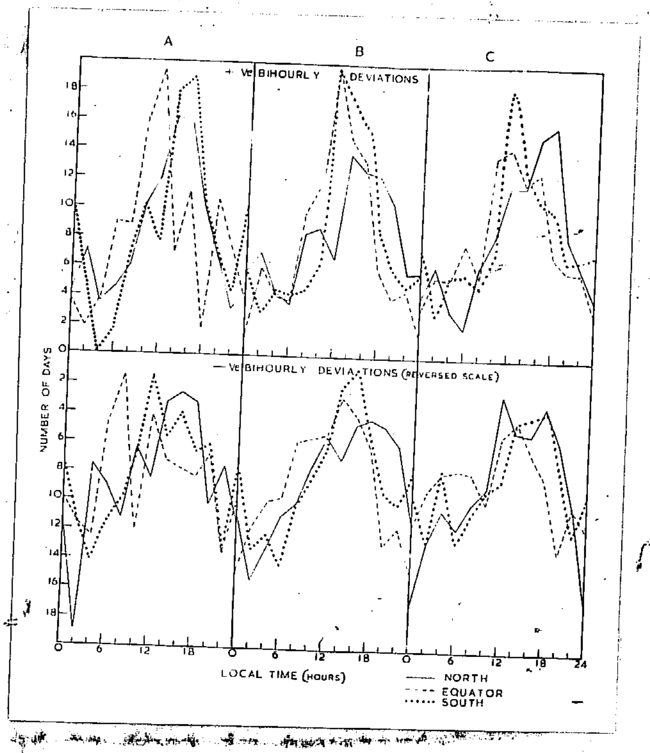

Fig. 24 - Histograms of significant positive and negative bihourly deviations of neutron intensities at stations situated in equatorial, northern and southern belts on days corresponding to groups A, B and C.

neutron intensities at Huancayo, Mt. Wellington and Mawson, deviations significant at the 3σ level are considered. In the case of Ottawa, Churchill and Lae all deviations exceeding 2σ are considered, as the bihourly statistical errors of neutron intensities at these stations are large.

In group A, we find that the maximum number of bihourly positive deviations at equatorial stations occur at 1200 hours, much earlier than in either southern or northern stations. In groups B and C, maximum number of significant positive deviations at equatorial as well as southern stations occur at the same time namely 1200 hours whereas for northern stations, the maximum number of significant positive deviations occur later at 1400 hours and 1800 hours for groups B and C respectively. Histograms of significant negative deviations, however, do not clearly reveal this phase lag in the occurrence of maximum number of significant negative deviations in different hemispheres, even though an indication of the maximum number of negative deviations occurring slightly earlier at equatorial stations can be seen. On the whole, there are many instances when similarities in the behaviour of southern and equatorial stations are seen whereas in northern stations many of the important features seem to always occur with a lag of a few hours as compared to that in equatorial and southern stations.

5.353 Chree analysis of mean intensities of neutrons at various stations for groups A, B and C :- Chree analysis of daily mean intensities at Ottawa, Huancayo and Mt.Wellington for epochs corresponding to groups A, B and C have been carried out by the method of superposed epochs which are presented in Fig. 25. A sharp fall of mean intensity on epoch days is seen for group A. However, even though in Ottawa and Mt.Wellington mean intensity falls from 0.7±0.04% to -0.7±0.04%, at Huancayo the fall is much less from 0.5±0.01% to -0.3±0.01%. The change in mean intensity in group A is further characterised by a fairly high value of $C_p \approx 1.1$, throughout the period. Even though the mean intensities before and after epochs for groups B and C do not show such striking features, one can easily see that the magnitude of small falls and rises of mean intensity are much less at equatorial stations as compared to that at either Ottawa or Mt.Wellington.

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Fig. 25 - Chree analysis of mean i
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5.4 Location of the sour origin from primaries having

as lyin the range from +6 to -7°.

In order to locat east and w pointing telescopes knowledge of the bendin same equatorial belt of the celestial in the geomagnetic fiel earth's field as a si urse of a day.

energies in 45°E ondning the geomagnetic bending, the usual 13°N, geographic loed by various workers has been to determine 10.3 Bev respectiof response of a telescope. By knowing the past few years icients one can easily calculate the mean Kodama et al response in east and west, which work out to be of cosmic ray intensity cannot be accounted for by a simple dipole field. Quenby and Webber[17] have recently deduced the cut off rigidities taking into account both the dipole and the nondipole parts of the internal field. Using their method, the cut off energies in east and west are found to be 22.5 and 10.9 Bev respectively. In other words, whereas, the east pointing telescopes respond to all primaries down to 22.5 Bev, the west pointing telescopes respond to primary particles down to 10.9 Bev.

To draw any conclusions regarding the energy dependence and location of anisotropy we have to determine the asymptotic directions of primary particles to which the telescope responds. From Brunberg's curves one can determine the asymptotic latitude ϕ_N for particles of different energies measured by east and west pointing telescopes. Primaries of all particles measured by east pointing telescopes have their ϕ_N between +12 and -2^{o}, whereas all particles measured by west pointing telescopes originate from primaries having their asymptotic directions lying in the range from +6 to -7^{o}. Thus we find that both east and west pointing telescopes successively scan the same equatorial belt of the celestial sphere during the course of a day.

For determining the geomagnetic bending, the usual method often adopted by various workers has been to determine the mean energy of response of a telescope. By knowing the coupling coefficients one can easily calculate the mean energies of response in east and west, which work out to be

52.5 and 32.5 Bev respectively. Geomagnetic deflection for particles in east and west having the above energies are 98° and 14° respectively, the difference between the two being 84° or nearly 6 hours, which is almost the same as the geometrical difference between the axis of the two telescopes. This method however, has a serious drawback as it does not consider the contribution from each energy band and varying energy dependence of the spectrum of variation. It is important to examine the extent to which this might lead us into error.

A better method of calculating the bending would be, to find out the bending of particles in various energy bands and determine the mean deflection. Particles having energies very near the cut off suffer very large deflections and at present it is not possible to make any precise calculation of the bending suffered by such particles. Since however, the percentage of such particles is very small, about 4%, the degree of inaccuracy caused due to the lack of precision in the calculation of their bending is small. Table 9 shows the percent of particles in each energy band and their deflections in the geomagnetic field.

The value of the mean deflection will naturally depend on the form of the spectrum of anisotropic radiation. The energy spectrum of anisotropic radiation is not yet established under different conditions. It is possible to determine the energy dependence of the spectrum of primary variation indirectly by the aid of experimental data on the

Table 9

Table showing percent of primary particles in different energy bands to which east and west pointing telescopes at Ahmedabad respond and deflections suffered by these particles in the geomagnetic field.

Energy (Bev)	WEST Particles (%)	WEST Deflection (°)	EAST Particles (%)	EAST Deflection (°)
10.9-11.5	1.15	150	-	-
11.5-12.0	1.00	113	-	-
12-13	3.03	95	-	-
13-15	5.18	80	-	-
15-20	13.65	58	-	-
20-22	4.90	43	-	-
22-23	2.40	39	2.14	220
23-25	4.71	34	4.53	185
25-30	9.41	25	10.87	150
30-35	7.06	15	9.63	128
35-40	5.51	5	8.21	112
40-45	4.33	- 1	7.13	104
45-50	3.53	- 6	5.95	97
50-60	5.18	-11.5	9.40	89
60-70	3.77	-17.0	6.91	82
70-80	2.64	-21.0	5.21	77
80-90	2.07	-23.5	4.08	73
90-100	1.69	-25.5	3.17	69
100-150	4.71	-28.0	8.49	64
150-200	2.35	-34.0	3.96	59
200-400	3.96	-38.0	5.55	54
400-1000	2.90	-42.0	2.99	50

observed variation of different components at various latitudes and elevations above sea level. Even though the daily variation changes substantially with time, Dorman has attempted a derivation of the spectrum of variation for time averaged data. From the experimental data collected during 1937-1951 from many stations all over the world, Dorman[6] concludes that a source of the diurnal variation yields an energy spectrum of primary variation which may be approximately represented in the form

$$\frac{\delta D(E)}{D(E)} = 0.14\ E^{-1} \text{ if } E > E_1$$
$$= 0 \text{ if } E < E_1 \quad \text{where } E_1 = 6.6 \text{ Bev.}$$

McCracken[228] has also examined neutron data from a number of records and finds that the energy dependence of variation can be represented by $K(1 + E)^{-\gamma}$ where $\gamma = 0.6$ or 0.8 in the case of short time variations and $\gamma = 1.2$ in the case of long term variations. Kuzmin[229], on the other hand, reports that a spectrum of the type $aE^{-0.7}$ can explain short as well as long term variations. One has, however to remember, that at certain times, such as at the time of giant flare which occurred on February 23, 1956, the spectrum of anisotropic radiation may become as steep as aE^{-7}.

Knowing the time of maximum of diurnal variation $t^{i}_{max,\lambda}$ one can use the calculated angles of drift ψ^{i}_{λ} to determine the direction of motion of additional cosmic radiation responsible for the diurnal variation of cosmic rays. Neglecting the influence of the general magnetic field of the sun on the trajectories of the particles, which obviously is very small, Dorman[6] has calculated the angle χ between the direction of additional cosmic rays and the sun-earth line using the formula $\chi = \psi_{\lambda}^{i} + 15(t^{d}_{max,\lambda} - 12)$. He finds that χ has a mean value of $22 \pm 8^{\circ}$.

The following table gives the outline of the method adopted, for finding out the contribution to the total variation from primaries of various energy bands.

Table 9(a)

Table showing the method of numerical integration for estimating the daily variation at a particular station due to a source of anisotropy.

Energy in Bev	ψ	Groups according to deflection (hours).	$W^{d}_{\lambda,f}(E,h_0)$ coupling coefficient.	amplitude expected with spectrum E^{-n}	$W^{d}_{\lambda,f}\cdot\frac{\partial D(E)}{D(E)}$
E_1	A_1^0	ϕ_1	W_1	K_1	W_1K_1
E_2	A_2^0				
E_3	A_3^0	ϕ_2	W_2	K_2	W_2K_2
E_4	A_4^0				
E_5	A_5^0				
⋮	⋮	⋮	⋮	⋮	⋮
E_{n-3}	A_{n-3}^0	ϕ_{n-1}	W_{n-1}	K_{n-1}	$W_{n-1}K_{n-1}$
E_{n-2}	A_{n-2}^0				
E_{n-1}	A_{n-1}^0	ϕ_n	W_n	K_n	W_nK_n
E_n	A_n^0				
I	II	III	IV	V	VI

In column I of this table the primary spectrum has been divided into a number of energy bands from the geomagnetic cut off energy to the highest energy of primaries. Near the geomagnetic cut off energy the geomagnetic deflections are very large and hence the bandwidth of energy chosen is narrower. Column II gives the geomagnetic deflections of particles of different energies read from Brunberg's curves. Deflections very near cut off are obtained by extrapolation. Brunberg's globe for Ahmedabad has been used to determine the asymptotic longitudinal angle for primaries of different energies. Even if ψ_E is used, since the conversion from geomagnetic to geographic angles of drift involves a correction of less than 2^o at Ahmedabad even for low energies such as 10 Bev and since we are grouping various energies according to their deflections in hours, it will not matter in our calculations. In column III the energy bands are grouped together such that the particles in each group have deflections within 15^o of the mean of the group. Column IV represents the coupling coefficient $W^{1}_{\lambda,f}$ (E,h_o) of each group multiplied by the energy bandwidth of the group or ratio of primary particles in the group to the total number of particles recorded expressed as a percentage. In column V, the amplitude of various energy bands calculated for the mean energy of the group assuming certain variation spectrum is given. Column VI which is the product of columns IV and V gives the actual contribution of each energy band to the total amplitude of variation. Daily variation is calculated by vector summation of column VI taking into account the differential banding of primary particles of different energies.

If the energy spectrum of the variation is of the form aE^0 where E is the energy of the primary particle, mean deflection of particles recorded by east and west pointing telescopes are found to be 16° and 92° respectively. The difference between the geomagnetic deflection in east and west is found to be 76° or nearly 5 hours. Table 10 gives the ratio of the calculated diurnal amplitude in west to that in east and the phase difference between the times of maxima in east and west, assuming different types of spectra for the energy dependence of the anisotropic radiation. It can be seen that, even with a steep spectrum, the difference in the times of maxima between east and west remains almost the same. This can be easily understood by a close study of Brunberg's curves. If the east curve is shifted by 90° we find that the difference curve between east and west is negligible upto 50 Bev and contains only a small contribution from 22.5 to 50 Bev due to differential bending in east and west besides the contribution of nearly 14% of particles having energy between 10.9 and 22.5 Bev, to which only the west pointing telescope responds. Any change in the form of spectrum of variation changes the daily variation curves in east and west in the same way and the phase difference

Table 10

Table showing the calculated ratio of percent amplitude in west to that in east and the phase difference between the times of maxima in east and west for different types of spectra of variation.

Spectrum of variation	$\psi_W - \psi_E$	A_W/A_E
aE^{0}	76°	0.96
aE^{0} upto 20 Bev and aE^{-2} below 20 Bev.	70°	1.01
aE^{0} upto 20 Bev and aE^{-4} below 20 Bev.	49°	1.19
aE^{-1}	75°	1.73
aE^{-1} upto 20 Bev and aE^{-2} below 20 Bev.	68°	1.91
aE^{-1} upto 20 Bev and aE^{-4} below 20 Bev.	50°	2.73
aE^{-2}	70°	2.87
aE^{-4}	67°	9.78
aE^{-6}	78°	39.23

between east and west will not be substantially altered. Ratio of amplitude in west to that in east will however steadily increase as the spectrum of variation becomes steeper. Since the 12 month and 24 month mean curves show that east and west intensities have almost the same amplitude of variation and the diurnal time of maximum in east occurs about 4 hours earlier to that in west, the spectrum aE^{-n} for the anisotropic radiation where n = 0 for E > 20 Bev and n = 2 for E $<$ 20 Bev, gives the best fit. Since the error in the harmonic components of 24 month mean daily variation is less than 0.02%, the error in the exponent is negligible. Mean value of χ the angle between the direction of additional cosmic rays and the direction from the earth to the sun is found to be 73 ± 4^{0}.

From the above discussion it is clear that east-west telescopes at equatorial latitudes afford an unique device to determine the location of the source of anisotropy. If anisotropy is of geocentric origin and takes part in the isorotation of the earth, we should not expect any difference in the diurnal time of maximum between east and west. If on the other hand, the anisotropy is located far outside the influence of the geomagnetic field, as the earth spins on its axis from west to east, east pointing telescopes will scan any point in the celestial sphere about 6 hours earlier than the west pointing telescopes and hence we should expect the characteristic difference of 6 hours in the times of maxima between east and west pointing telescopes.

Now we shall re-examine the 12 month mean daily variation curves in east and west in the light of above discussion. Both the histograms as well as the 12 month and 24 month mean curves show that the diurnal time of maximum in east occurs approximately 4 to 5 hours earlier to that in west. From this we can conclude, that on an average, daily variation is produced by an anisotropy located far outside in space. In the following pages we examine whether this state is present on all days. We shall also examine the conditions under which there is an indication of the existence of a geocentric source of daily variation.

5.5 East-west asymmetry

East-west asymmetry is defined as 2(W-E)/(W+E)x100 where W and E are mean intensities in west and east directions respectively. The mean asymmetry at Ahmedabad is found to have a value of approximately 15%.

It is well known that the energy spectrum of primary cosmic radiation, especially of the low energy portion of cosmic rays, fluctuates considerably from day to day. Simpson et al[73] and Neher[74] have shown that low energy cosmic rays attained their highest exponent for power law spectrum and the low energy cut off reached a minimum value at the time of minimum solar activity. Besides long term fluctuations, short time fluctuations of both the primary cut off ~~rigidity~~ as well as of the primary spectrum are reported by Neher[77] and McCracken[228]. McCracken believes that the mechanism responsible for short and long term variations may be different. His conclusion is based on the fact that he gets different values of 0.6 and 1.2 for the exponent of the differential energy spectrum in the case of short and long term variations respectively, both of which may be represented by the formula $K(1+E)^{-\gamma}$. Since asymmetry can change with a change of the cut off energy as well as with change of the spectrum of primary cosmic radiation, it will also fluctuate considerably over its normal value.

Since the mean intensity of cosmic radiation increases with decreasing solar activity, one expects the asymmetry to increase with the decrease in solar activity. However, Jacklyn et al[31] have reported a decrease in east-west asymmetry at Hobart with a decrease in solar activity during 1947-1954. Taking into account the fact that east-west asymmetry at Hobart arises due to the effect of the earth's magnetic field on the secondary mesons and not due to the difference in primary cut off energies in east and west directions (see chapter I) and considering the actual polar diagrams, one might be able to explain the above apparent contradiction. At equatorial latitudes, on the other hand, where the cut off energies in east and west are vastly different and the trajectories of primary particles are less complicated, one can relate the change in east-west asymmetry to the changes in the spectrum of primary radiation and the changes in cut off energies.

Since the upper air radiosonde data at Ahmedabad is not available, mean intensity on each day could not be corrected for variations in atmospheric temperature. As we have used the normalised mean intensities in east and west only to calculate the east-west asymmetry, which is not appreciably affected by variations of atmospheric temperature, neglect of correction of mean intensity for variations of atmospheric temperature does not alter the situation significantly. Days of high asymmetry and of low asymmetry i.e. days on which asymmetry shows a deviation above or below 2σ level over its normal value, are separated and mean daily variation for east and west intensities on these days is determined. We have also done the chree analysis of mean intensities in east and west, of asymmetry and of C_p for ten days prior and later to epochs corresponding to days of low and high asymmetry.

Fig. 26 shows the average daily variation in east and west for days of high, normal and low asymmetry. In Table 11 we have given the corresponding harmonic components

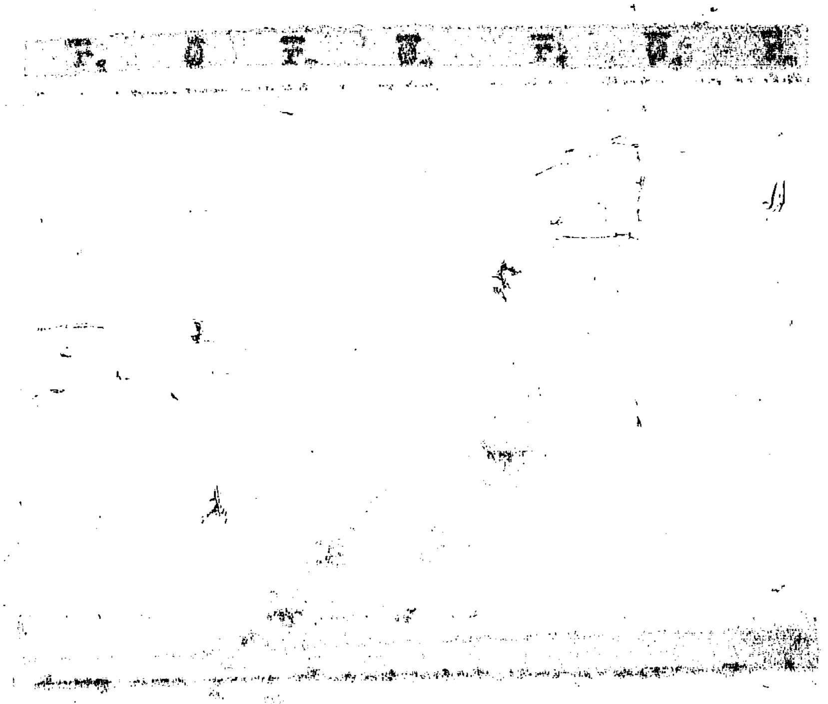


Fig. 26 - The mean daily variation in east and west pointing telescopes during 1957-1958 for groups of days with low, medium and high asymmetry. Results of chree analysis of the daily mean intensities in east and west, east-west asymmetry and C_p for epochs of high and low asymmetry are also shown.

of daily variation. Corresponding to high asymmetry epochs we find a large daily variation of significant amplitude in east and west with the difference in their time of diurnal maximum consistent with an external source of anisotropy. On days of low asymmetry the average amplitude of variation in west is small due to large scatter of the time of maximum on individual days. But east pointing telescope shows a high

<u>Table 11</u>

Table showing $\bar{r}_1$, $\bar{\phi}_1$, $\bar{r}_2$, $\bar{\phi}_2$ describing mean diurnal and semidiurnal components of daily variation in east and west for 10F telescopes, on groups of days having low, normal and high asymmetry.

	No. of days.	$\bar{C}_p$	EAST $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	WEST $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$
Low A	24	0.8	0.09± 0.12	122°	0.63± 0.12	15°	0.09± 0.11	-58°	0.12± 0.11	π+35°
Med. A	491	0.8	0.20± 0.03	π+3°	0.07± 0.03	-16°	0.24± 0.03	π+51°	0.09± 0.03	72°
High A	28	0.6	0.35± 0.12	167°	0.26± 0.12	-20°	0.46± 0.11	π+76°	0.32± 0.11	175°

average amplitude of variation which is predominently semidiurnal in character. Further we find that the high asymmetry days are associated with comparatively low index of geomagnetic disturbance, as can be seen from the chree analysis of C_p shown in the figure.

5.51 <u>Histograms of occurrence of diurnal and semi-diurnal times of maxima on days of low, normal and high asymmetry</u> :- Fig. 27 shows the frequency distribution of

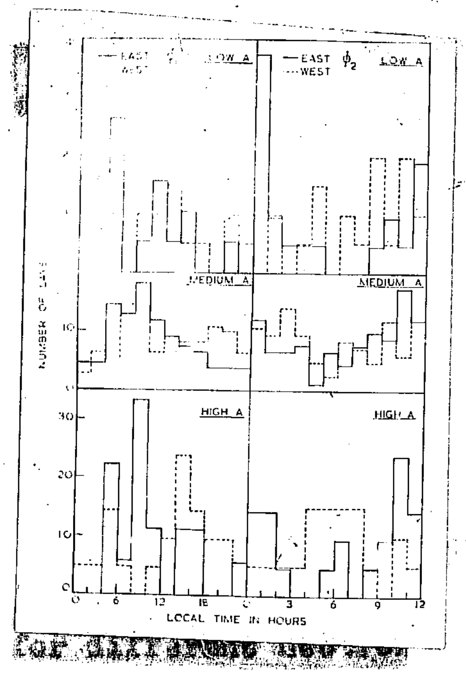


Fig. 27 - Histograms of ϕ_1 and ϕ_2 of mean daily variation in east and west on days of low, normal and high asymmetry.

diurnal and semidiurnal times of maxima on days of low, normal and high asymmetry. In case of normal asymmetry having 491 days, all amplitudes significant at the 2σ-level (1.1%) are considered. Since the total number of days of high and low asymmetry are only 28 and 26 respectively, a lower level of significance corresponding to all amplitudes above σ = 0.5% are considered for determining the frequency distributions of diurnal and semidiurnal times of maxima. Neglect of correction for variation of atmospheric temperature is not serious, as the correction is small of the order of 0.15% in comparison with the amplitudes of 0.5% which are considered. From the figure we see that on high asymmetry days the diurnal time of maximum in both east and west shows a peaked distribution, the maximum in east occurring about 6 hours earlier to that in west. On days of low asymmetry only the semidiurnal time of maximum in east shows a peaked distribution. The results confirm that on low asymmetry days west intensity shows a larger scatter in its time of maximum which is absent on high asymmetry days.

5.52 <u>Daily variation of neutrons at different stations on days of high and low asymmetry</u> :- To test whether high and low asymmetry epochs correspond to different states of interplanetary space, we have examined the mean daily variations for different neutron monitor stations for these groups of days. Combining the various stations into three groups namely northern, southern and equatorial stations the mean daily variations of neutron intensity are found for all these groups separately which is shown in Fig.28.

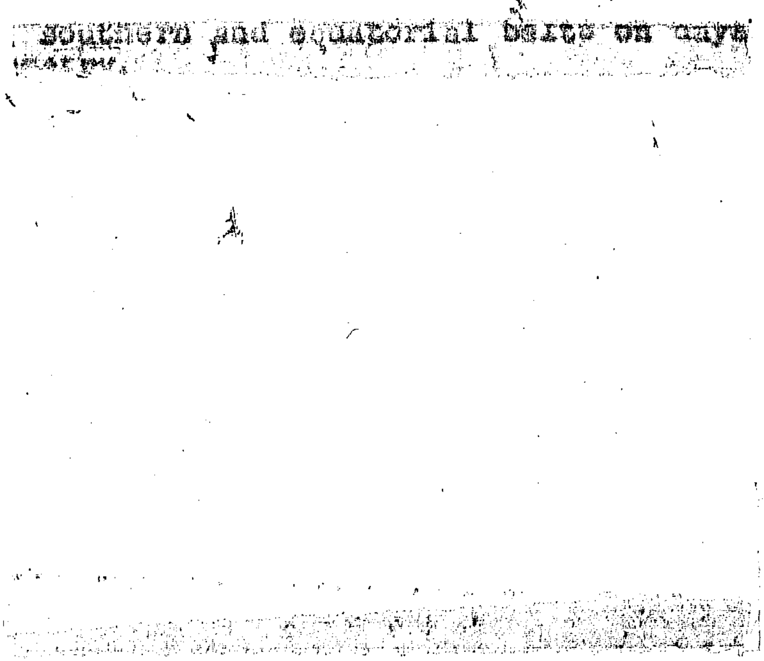


Fig. 28 - Mean daily variation and chree analysis of daily mean of neutron intensity at various stations situated in northern, southern and equatorial belts on days of low and high

Northern stations exhibit the same type of daily variation on high as well as on low asymmetry days. But southern and equatorial stations show a much higher amplitude of variation with predominently diurnal character on days of high asymmetry as compared to the daily variation on low asymmetry epochs. Thus we find that on days of high asymmetry equatorial, northern as well as southern stations show a large amplitude of daily variation with a predominently diurnal character whereas on days of low asymmetry, only northern stations show a large amplitude of daily variation. Table 12 shows the amplitudes and times of maxima of diurnal and semidiurnal components of daily variation for northern, southern and equatorial stations on days of high and low asymmetry.

Table 12

Table showing harmonic components for the mean daily variation of neutron intensities at stations situated in northern, southern and equatorial belts on days of low and high asymmetry.

Station	High asymmetry				Low asymmetry			
	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	$\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$
Northern	0.40 ± 0.02	$\pi+76^\circ$	0.05 ± 0.02	153°	0.40 ± 0.02	$\pi+71^\circ$	0.10 ± 0.02	-84°
Equator	0.42 ± 0.02	$\pi+11^\circ$	0.20 ± 0.02	58°	0.20 ± 0.02	166°	0.12 ± 0.02	76°
Southern	0.49 ± 0.03	$\pi+84^\circ$	0.09 ± 0.03	42°	0.17 ± 0.03	$\pi+30^\circ$	0.08 ± 0.03	140°

Location of these stations in terms of their geographic and geomagnetic coordinates and of elevations is indicated in Table 13. It is interesting to note that similar north-south

Table 13

Table showing location of various stations, the data of which has been used in the analysis.

Station	Altitude. meters	Geo. Coordinates		Geomag. Coordinates.	
Northern stations					
Churchill	39	N58°45'	W94°05'	69°.7	322°.9
Ottawa	101	N45°24'	W75°54'	56°.8	351°.1
Murchisonbay	S.L	N80°03'	E18°15'	72°.2	137°.2
Resolute	17	N74°41'	W94°54'	82°.9	289°.3
Equatorial stations					
Ahmedabad	S.L	N23°01'	E72°36'	13°.9	143°.9
Huancayo	3400	S12°02'	W75°20'	-0°.6	353°.8
Kodaikanal	2343	N10°14'	E77°28'	0°.6	147°.1
Lae	S.L	S 6°44'	E147°0'	-16°.0	217°.4
Mekere College	1196	N 0°20'	E32°34'	- 2°.0	101°.4
Southern stations					
Mawson	S.L	S67°36'	E62°53'	-73°.1	103°.8
Mt.Wellington	725	S42°55'	E147°14'	-51°.5	224°.5

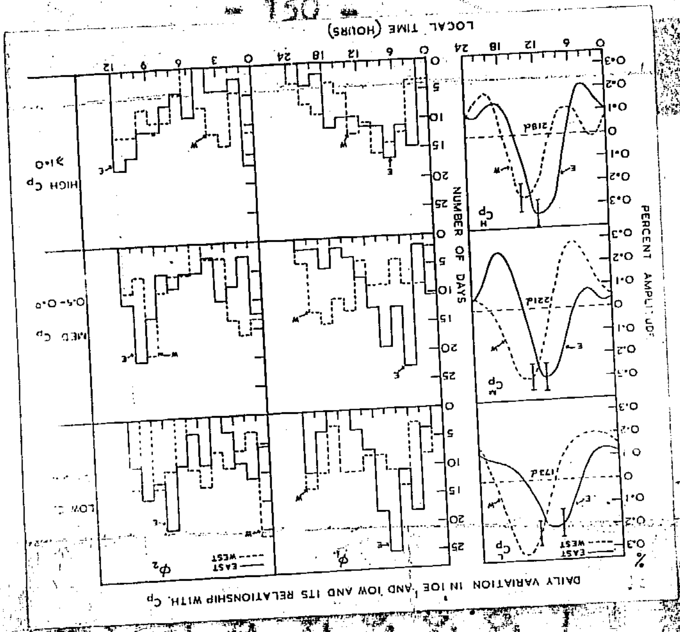
asymmetry of anisotropic radiation has been reported by Sarabhai et al[97] for the storm type variation on February 11, 1958.

5.53 Conclusions :- We conclude that the daily variation on days of high asymmetry is associated with lower geomagnetic activity and a predominently high diurnal variation, and is probably caused by an anisotropy located far outside the influence of the geomagnetic field. The scatter in the occurrence of the time of diurnal maximum becomes less in both east and west on days of high asymmetry. On days of low asymmetry, only the semidiurnal component of the daily variation in east seems to be important. Further an examination of neutron intensity at various stations for epochs of low and high asymmetry shows a strong indication of the existance of a hemispherical effect of the anisotropic radiation.[78]

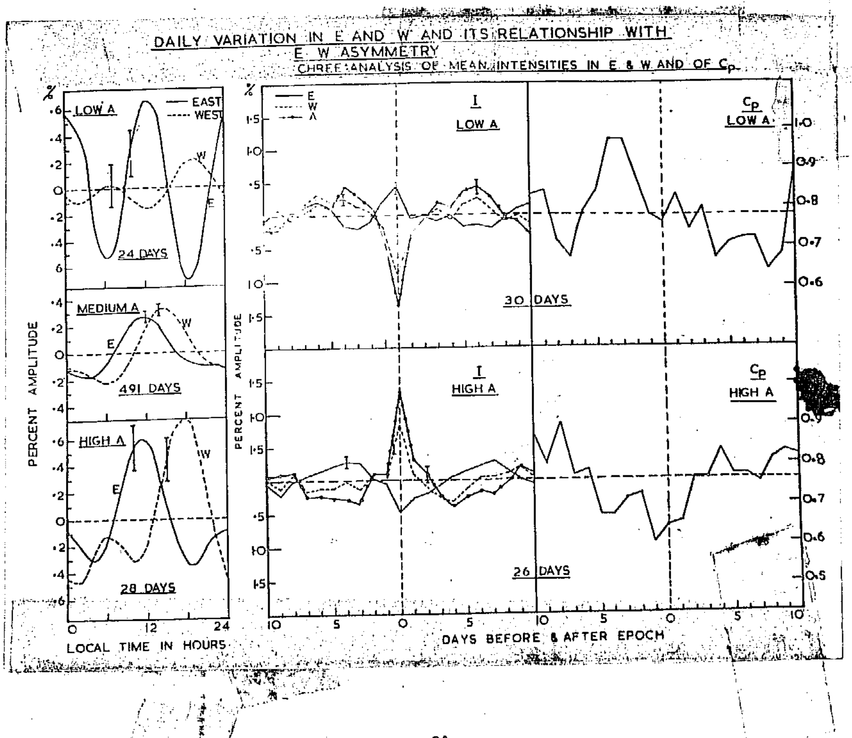
5.6 Daily variation and its relationship with the index of geomagnetic disturbance.

Average daily variation on days having low geomagnetic disturbance as indicated by the index of geomagnetic disturbance C_p having a value less than 0.4, and average daily variation on days having medium C_p ($0.9 \geqslant C_p \geqslant 0.5$) and on days of high C_p ($C_p \geqslant 1.0$) are determined. Fig. 29 shows the mean daily variation in east and west on days of low, medium and high C_p. Table 14 gives the amplitudes and times of maxima of diurnal and semidiurnal components in east and west on days of low, medium and high C_p.

On low and medium C_p days the diurnal time of maximum in east occurs about 5 to 6 hours earlier to that in west, indicating that the anisotropy is of external origin. But on high C_p days both east and west have almost the same time of diurnal maximum, indicating that on geomagnetically disturbed days the modulation responsible for the diurnal



2.



29 (b)

Fig. 29 - Mean daily variation in east and west on days of low, medium and high C_p (a) for 10° telescopes (b) for 20° telescopes. Histograms of significant ϕ_1 and ϕ_2 are also shown for these

Table 14

Table showing the mean diurnal and semidiurnal components of daily variation in east and west intensities on groups of days having low, medium and high C_p during the years 1957-1958.

C_p	$\bar{C}_p$	Tele-scope	No. of days	EAST $\bar{r}_1$	EAST $\bar{\phi}_1$	EAST $\bar{r}_2$	EAST $\bar{\phi}_2$	WEST $\bar{r}_1$	WEST $\bar{\phi}_1$	WEST $\bar{r}_2$	WEST $\bar{\phi}_2$
C_p	0.25	10T	173	0.16±0.04	173°	0.05±0.04	-59°	0.24±0.04	π+63°	0.05±0.04	149°
0.4		20T	132	0.16±0.03	173°	0.08±0.03	-21°	0.21±0.03	π+55°	0.05±0.03	112°
um C_p	0.69	10T	221	0.19±0.04	150°	0.13±0.04	- 4°	0.25±0.04	π+63°	0.10±0.04	53°
$\geqslant C_p \geqslant 0.5$		20T	172	0.17±0.03	170°	0.13±0.04	45°	0.18±0.03	π+45°	0.11±0.03	56°
C_p	1.32	10T	218	0.22±0.04	177°	0.13±0.04	-28°	0.14±0.04	π+15°	0.13±0.04	61°
1.0		20T	176	0.18±0.03	150°	0.14±0.03	-12°	0.12±0.03	π+ 8°	0.10±0.03	73°

variation is of geocentric origin. The amplitudes in east and west for all C_p groups remain almost the same.

5.61 <u>Chree analysis of mean intensities in east and west on days of low and high C_p</u> :- Fig. 30 shows chree analysis of mean intensities in east and west on days having $C_p \geqslant 1.5$ and on days having $C_p \leqslant 1.5$. Only on very high C_p days i.e. on days having $C_p \geqslant 1.5$, chree analysis of mean intensities reveals some interesting features. The mean intensity in west shows a minimum one day after epoch agreeing well with Van Der Walt's[102] observation of neutron intensity for the same period. But the mean intensity in east shows a minimum 1 to 2 days before the epoch. Peak to peak amplitude of mean intensity variation in east and west is about 0.4%.

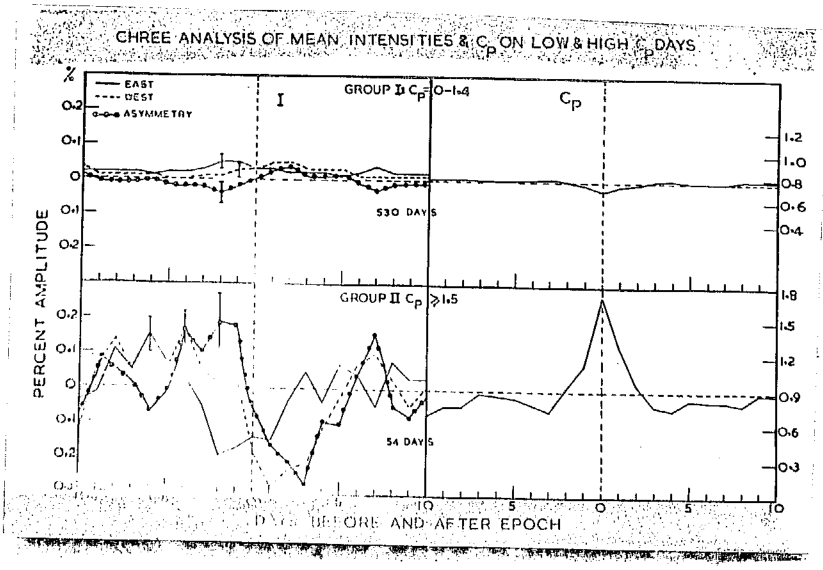


Fig. 30 - Chree analysis of mean intensities in east and west on days having $C_p \geqslant 1.5$ and on days having $C_p \leqslant 1.5$.

Many workers such as Elliot et al and Beerdan et al have shown that minimum of cosmic ray intensity precedes maximum of K_p by several days. However, Venkatesan[95], Trumpy[93] and others find that this effect is not always exhibited. They find that cosmic ray intensity minima some times precede and at other times follow C_p maxima. Van Der Walt[102] concludes that at the time of minimum solar activity during 1952 and 1953 the cosmic ray minima preceded K_p maxima whereas in the period of intense solar activity it follows K_p maxima. In the present case we find that the mean intensity shows a very slight dependence on geomagnetic activity only when C_p is ≥ 1.5. For other days three analysis of mean intensity does not show any significant changes before and after epoch. But even though the minimum in west intensity follows one day after the K_p maximum, minimum in east precedes K_p maximum by two days and hence Van Der Walt's conclusions do not seem to be generally applicable.

5.62 <u>Histograms of ϕ_1 and ϕ_2 in east and west on days of low, medium and high C_p</u> :- Histograms of diurnal and semidiurnal times of maxima when the appropriate component is significant at the 2σ level are shown in Fig. 29 for groups of days having low, medium and high C_p. ϕ_1 histograms for east pointing telescopes show a similar type of distribution on low, medium and high C_p days. But in the case of west pointing telescopes, the scatter in the diurnal time of maximum is large only on days of low, and medium C_p. On days of high C_p, ϕ_1 distribution in west resembles exactly that in east, which is to be expected if the source of daily variation on high C_p days is of geocentric origin. ϕ_2 histograms for all the C_p groups in both east and west are almost similar.

5.63 Conclusions :- We conclude that on geomagnetically disturbed days, since the phase difference between the times of maxima of the diurnal components in east and west vanishes the results are compatible with the idea of the daily variation being produced by a source of daily variation having a geocentric origin.

5.7 Study of cosmic ray intensities in east and west during cosmic ray storms.

Solar corpuscular streams are regarded as an important cause of many terrestrial effects, observed in geomagnetism, in the aurora, in the ionosphere and in cosmic rays. Many workers, principally Alfven[175], Elliot[2], Nagashima[177], Nerurkar[178] and Dorman[6] have tried to understand the effects which may be expected in cosmic ray intensity by corpuscular streams carrying frozen magnetic fields from the sun. It is well known that all magnetic storms do not give rise to cosmic ray decreases. Sekido et al[94] conclude that S type of storms which are cosmic ray effective storms, are well correlated with CMP of large sunspot groups and M type of storms which are cosmic ray noneffective storms, have a well defined recurrence tendency. They have suggested that M storms might be associated with the M regions on the sun.

Dorman[6] has classified ~~storms~~ streams into two kinds.

streams probably connected with faculae or with high latitude formation on the sun, which do not cause an appreciable amount of decrease in cosmic ray intensity. Such streams are likely to cause cosmic ray storms with gradual onset and longer duration with a marked recurrence tendency. Streams of the second kind are very dense ones. They probably originate within the sun's equatorial region and are most probably intimately connected with spots. They are likely to cause large sudden commencement cosmic ray storms of short duration which show a weak or no recurrence tendency. In Table 15 we have summarised the properties of the two types of streams as suggested by Dorman. Dorman finds that about 80% of great storms and only 8% of moderate magnetic storms exert an influence on cosmic rays. He concludes that streams of great density causing large cosmic ray storms carry strong magnetic fields ($H \sim 10^{-4}$ gauss) unlike the streams of the first kind which carry weak magnetic fields ($H < 10^{-5}$ gauss).

The experimental results are not found to be always consistent with the above theory. Venkatesan[95] finds that the absence of recurrence is not limited only to large cosmic ray decreases of about 4%, but is also seen in small decreases of about 1%. However it is evident that a study of cosmic ray storms can give us some understanding of the nature of the beams. In the following pages, we discuss the behaviour of east and west intensities during some of these storms and compare our results with those obtained by other authors. Since cut off energies in east and west are

Table 15

	Streams of I kind	Streams of II kind
1. Place of origin	Probably connected with faculae or with some high latitude formation.	Probably originate within the sun's equatorial region and are intimately associated with sunspots.
2. Velocity of the stream	Probably lower than 10^{8} cm/sec.	Greater than 10^{8} cm/sec.
3. Density at $R_{\oplus}$	3 corpuscules/cm^3	2×10^2 corpuscules/cm^3
4. $H_{\oplus}$	$< 10^{-5}$ gauss	$\sim 10^{-4}$ gauss
5. Dependence on solar activity	Weak	Strong
6. Onset of ~~cosmic ray~~ [magnetic] storms caused.	Indefinite, in the course of several hours.	Definite and sharp.
7. End of the storm.	Very indefinite, during a course of half a day or longer.	Definite but sometimes during one or several hours.
8. Duration of the storm.	Ranging from 36 hrs. to weeks or longer.	24 to 36 hours.
9. Course in time.	Slow and smooth variation of magnetic field.	Rapid oscillations of the magnetic field, which are most pronounced in the horizontal component.
10. 27 day recurrence tendency of ~~cosmic ray~~ [magnetic] storms caused.	Well marked especially during the period of minimum solar activity.	Weak or no recurrence tendency.

different, such a study can give us an idea of the energy dependence of the storm type decreases of cosmic ray intensity. Further, since asymmetry is intimately connected with the changes in the spectrum of primary radiation, a study of asymmetry during these storms can be very helpful.

5.71 <u>Criteria of selection</u> :- Large cosmic ray storms when the neutron intensity decreased by more than 3% in 24 hours have been selected for the study. During the period 1957-1958, 11 such large storms occurred out of which the data for east and west pointing telescopes, on the epoch day and three days prior to and after the epoch day, are available for only 6 events. There were three very large storms in August-October 1957 during which the east-west instrument was unfortunately not in continuous operation.

Since the statistical error in the bihourly intensities in east and west are high, we have examined the 6 hourly mean intensity instead of examining the intensity at each bihour. Fig. 31 shows for various storms, the 6 hourly mean intensities in east and west on storm days as well as on three days prior to and following the storm days. The time sequence of east-west asymmetry for different storms is also plotted in the same figure. We have also plotted the bihourly as well as 6 hourly mean intensities of neutrons at the three stations Kodaikanal, Alma-ata and Dawson. Since Sarabhai et al[97] have found longitudinal differences in storm type decreases, the above stations are selected as they lie on almost the same longitude as that of Ahmedabad. The geographic and geomagnetic coordinates of these stations are given in table 13. The mean energies of response for neutron intensities at Kodaikanal, Alma-ata and Dawson are about 30, 22 and 10 Bev respectively. Thus we find that neutron monitors at Alma-ata and Mawson measure much lower energy component of cosmic radiation as compared to that of Kodaikanal.

5.72 Study of individual events :- The following are the individual events in a chronological order, for which we have east-west data. Here, we also narrate, in brief, the results of the study of other workers for the corresponding storms.

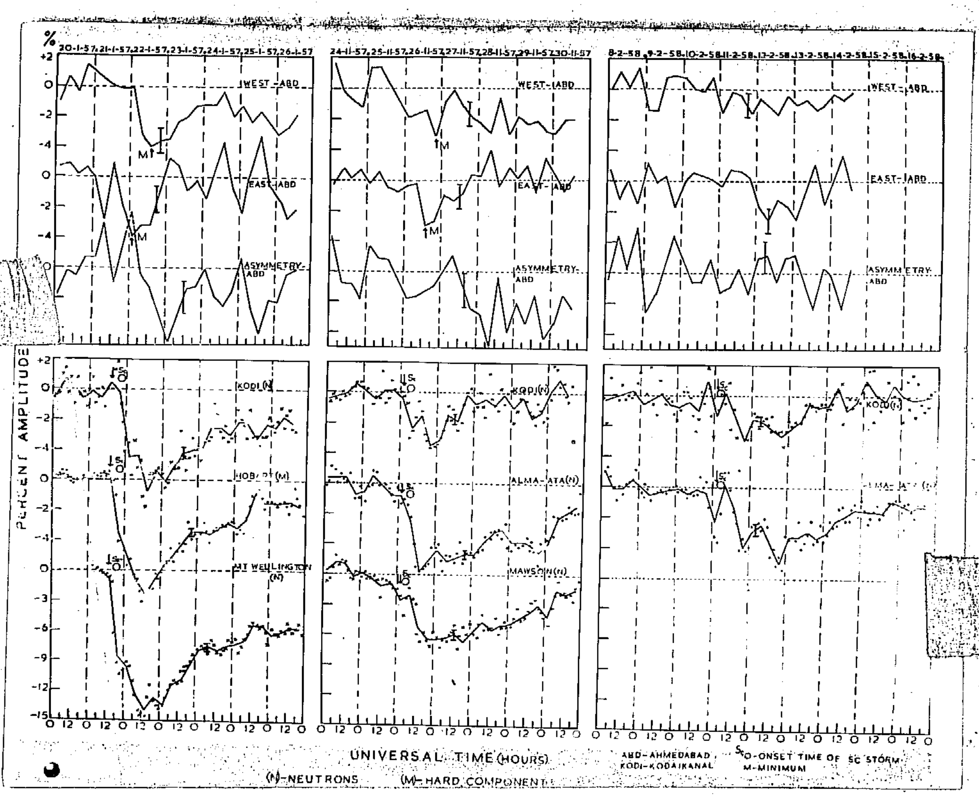
(1) January 21, 1957 :- This large non-recurring storm has been extensively studied by Fenton et al[230], Trumpy[93], Lockwood[231], and Venkatesan[95]. This storm, caused a fall of 13-19% in neutrons and of about 6% in mesons at various stations such as Ottawa, Churchill, Resolute and Hobart. Trumpy found that the hard component measured by inclined telescopes pointing south, north, east and west (inclined at 34^{o} to the vertical) showed a decrease of about 7% in all of them.

(2) August 2, 1957 :- We do not have any published result for this storm.

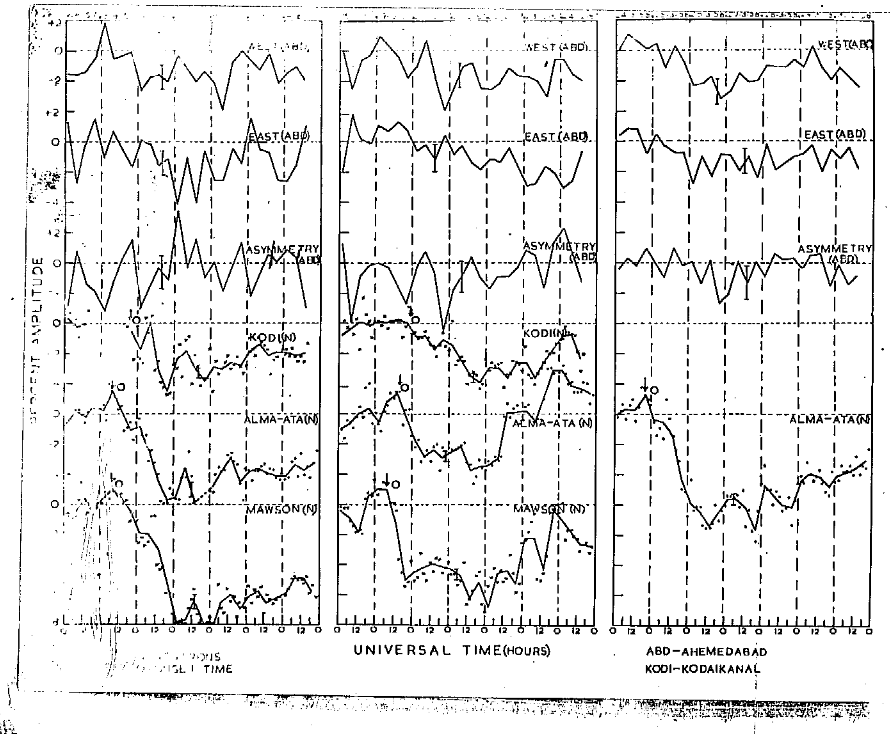
(3) November 26, 1957 :- -do-

(4) December 21, 1957 :- -do-

(5) February 11, 1958 :- The storm has been extensively studied by Sarabhai et al[97], Yoshida et al[98] and Lockwood[231]. A flare of magnitude 2^{+} occurred at 21.08 UT on February 9.



31(a)



31(b)

Fig. 31 - Decreases of meson intensities in east and west at Ahmedabad and of neutron intensities at Kodaikanal, Alma-ata and Mawson for the storm day and three days prior to and later to it corresponding to epochs (a) 21-1-57, 26-11-57, 11-2-58 and (b) 5-8-57, 21-12-57, 26-3-58.

This was followed by radio emission of type IV at 2140 hours UT on February 9. The terrestrial effect began only on February 11. There were two increases of H, one at 0126 UT and a larger one (500 γ) at 0159 UT on February 11, which probably represent the initial encounter of solar gas cloud with earth's dipole field. The first appearance of aurora was observed at 0126 UT on February 11. At 0623 UT, aurora was found to completely cover the horizon and Yoshida et al report that even at low latitudes as those of Japan, it could be observed. Along with aurora X ray bursts were also observed.

Sarabhai et al have observed three remarkable features in the storm. The first was an anticipatory increase of intensity observed only at the equatorial neutron monitor stations a few hours before the arrival of solar plasma to a distance at which it could interact significantly with the geomagnetic field. The main Forbush decrease almost coincided with the Sc geomagnetic storm and its minimum was larger and occurred later for low energy than for high energy primaries. A second increase which was more prominent at low latitudes and which decreased sharply beyond 50°N and which showed a strong east-west and north-south asymmetry, occurred about 10 hours after the onset of the cosmic ray storm.

However as Winckler et al[232] have remarked, even though the storm was unique for the great intensity of ionospheric phenomena which can reasonably be attributed to an exceptionally high density of solar gas enveloping the earth, the effect on cosmic rays was no way exceptional when compared with other Forbush type decreases.

(6) March 26, 1958 :- A 3^+ flare two days before the storm at 0950 UT on 23-3-58 and a small geomagnetic storm at 1400 hours UT on 25-3-58 accompanied this cosmic ray storm. Chaloupka et al[233] have reported a decrease of about 6% in muon intensity at 16m below ground at Budapest. At Praha, corresponding to a decrease of 8.5% in neutron intensity, meson intensity showed a decrease of only 6.5%.

5.73 Phenomenological examination of each individual storm :- The important characteristics of any storm are (1) the onset time, (2) the amplitude, rate and duration of decrease, (3) association of the decrease with other terrestrial effects such as SC storms and (4) the changes in the primary spectrum involved. The energy dependence of all these characteristics, which may be different for different storms, forms and an important part of the study of storm type decreases. From an examination of figure 31, we describe the characteristics of each individual storm.

(1) January 21, 1957 :- The onset time was same at all the stations and for all the components. The amplitude of the decrease was, however, much larger for neutron intensities than for meson intensities and larger at high latitude stations than at low latitude stations. Similarly the rate as well as

~~well as~~ the duration of decrease was more for lower energy component than for higher energy component. The storm was associated with a Sc geomagnetic storm which occurred at 1253 UT on January 21, 1957. The minimum of the intensities at all stations was reached 20 - 23 hours after the onset time of the decrease. Both east and west intensities showed a fall of about 4.0 ± 0.8%. East-west asymmetry showed a considerable decrease both during the storm and in the later part of the storm.

(2) August 5, 1957 :- The onset time of decrease during this storm was earlier for neutron intensities at Alma-ata and Mawson having lower mean energy of response than for neutron intensity at Kodaikanal. A larger decrease was observed in the lower energy component. The minimum was however reached 30 - 35 hours after the Sc storm which occurred at 1558 UT on August 3, 1957. Even though the rate of decrease was almost same at all stations, the duration of decrease was more for high latitude stations than for low latitude stations and the minimum of intensity was reached later at Mawson and Alma-ata than at Kodaikanal. East-west asymmetry increased during the storm period but came to normal immediately after. B

(3) November 26, 1957 : - The decrease was larger at high latitude stations than at low latitude stations. Whereas the meson intensities in east and west decrease by about 3% and neutron intensity at Kodaikanal by about 4%,

decreases of neutron intensity at Alma-ata and Mawson were 6 and 7% respectively. The rate of decrease, on the other hand, was same at all the stations even though the duration of decrease was found to be more at Alma-ata and Mawson having lower mean energy. The storm was associated with a 2+ flare at 0717 UT on 25-11-57 and a Sc storm 0152 UT on 26-11-57. The minimum at all the stations was reached within about 22 hours after the Sc storm.

Even four days after the commencement of the storm, the intensity having lower mean energy such as meson intensity in west and neutron intensities at Alma-ata and Mawson remained considerably depressed. No significant changes were observed in east-west asymmetry during the main phase of the storm, but it remained considerably depressed during the later part of the storm.

(4) <u>December 21, 1957</u> :- The decrease at Kodaikanal started at 2300 UT on 19-12-57 whereas the decreases at Alma-ata and Mawson started at 1900 UT and 1100 UT of the same day. Thus the onset time of the storm was found to be later for higher energy component than for lower energy component. For a decrease of 4% at Kodaikanal, neutron intensities at Alma-ata and Mawson showed a decrease of 4 and 6% respectively. The rate of decrease similarly was found to be more at high latitude stations having a lower mean energy. Duration of decrease was same at all stations and the minimum was reached more than 48 hours after the start of the decrease. The intensity in west showed a decrease of

4% during the storm whereas no decrease was observed in east. The east-west asymmetry showed a small decrease during the main phase of the storm and returned to normal immediately afterwards.

(5) February 11, 1958 :- The onset time of the storm at various stations was almost the same. The decrease was more for lower mean energy than for higher mean energy component of cosmic radiation. Decrease at Kodaikanal was only about 3% as compared to a decrease of about 5% at Alma-ata. Even though the rate of decrease was same at different stations, the duration of decrease at high latitude stations was more than for low latitude stations. The storm was associated with a Sc storm at 0124 UT on 11-2-58 and the minimum of the intensity was reached about 22 hours after the onset of the storm. The east-west asymmetry did not show any significant change either during the main phase or in the later part of the storm.

(6) March 27, 1958 :- Since the data of neutron intensities at Mawson and Kodaikanal are not available for this storm, it is not possible to comment on the energy dependence of the onset time and the rate of decrease of the storm. From an examination of east and west intensities at Ahmedabad and of neutron intensity at Alma-ata we find that the duration of decrease was almost the same for low as well as higher mean energy. The storm was associated with a 3+ flare at 0950 UT on 23-3-58 and a small Sc storm (60γ) at 1400 UT on 25-3-58. The minimum of intensity was reached

about 28 hours after the commencement of the storm. Meson intensity in both east and west showed a decrease of about 3.0±0.8%. Asymmetry was found to register a minimum during the main phase of the storm and was normal during the later part of the storm.

5.74 <u>Similar and dissimilar characteristics of cosmic ray variations during different Forbush decreases.</u> Table 10 summarises the phenomanological characteristics of various storms discussed above. The common features of all the storms is the larger amplitude of decrease seen in the recorder having a lower mean energy of response. With regard to other characteristics it is clear that the storms fall into either one of the two broad categories.

<u>Type A</u> :- The storms which occurred on January 21, 1957, November 26, 1957, and February 11, 1958 are of this type. The onset time for all these storms was same for low and high energy components. The duration of decrease was also more at high latitude stations having a lower mean energy than at low latitude stations. All the storms were associated with Sc geomagnetic storms and the minimum intensity was reached about 20 - 22 hours after the Sc storm. The east-west asymmetry was found to decrease during the storm period in all the cases. Even during the later part of the storm the east-west asymmetry was found to be depressed for the storms of January 21, 1957 and November 26, 1957.

Table- 16

	21- 1-57	5- 6-57	26-11-57	21-12-57	11- 2-58	26- 3-58
Energy dependence of onset time.	Same for all stations.	Earlier for low energy.	Earlier for low energy.	Earlier for low energy.	Same at all Stations.	?
Energy dependence of amplitude of decrease.	Larger for lower mean energy in all the cases					
Energy dependence of rate of decrease.	Larger for lower mean energy.	Same for all.	Same for all.	Larger for lower mean energy.	Same for all.	?
Duration of decrease.	More for lower energy.	More for lower energy.	More for lower energy.	Same for all.	More for lower energy.	Same for all.
Interval between commencement of fall and intensity minimum.	20 - 23 hrs.	30 - 35 hrs.	About 20 hours.	About 48 hours.	About 22 hours.	About 30 hrs.
Change of asymmetry during the main phase of the storm.	Decreases.	Increases.	Normal.	Decreases.	Normal.	Decreases.
Change of asymmetry during the later part of the storm.	Decreases.	Normal.	Decreases.	Normal.	Normal.	Normal.
	Yes	Yes	Yes	no	Yes	very small

<u>Type B</u> :- The remaining three events of August 5, 1957, December 21, 1957 and March 26, 1958 belong to this type. The onset time was earlier for neutrons at high latitude stations having lower mean energy than for neutrons at Kodaikanal having higher mean energy. Even though the decrease was larger at high latitude stations, the rate of decrease was not significantly different for low and high mean energy components. The intensity reached the minimum about 30 - 35 hours after the commencement of the fall. Similarly the duration of decrease for the events of December 21, 1957 and March 26, 1958 did not depend significantly on the mean energy of the cosmic radiation. Except for a slight decrease in east-west asymmetry seen during the storm of only March 26, 1958, no significant changes of asymmetry either during the main phase of the storm or during the later part of the storm were observed for any of the three events.

We have combined storms belonging to each type by the method of superposed epochs. Type A storms corresponding

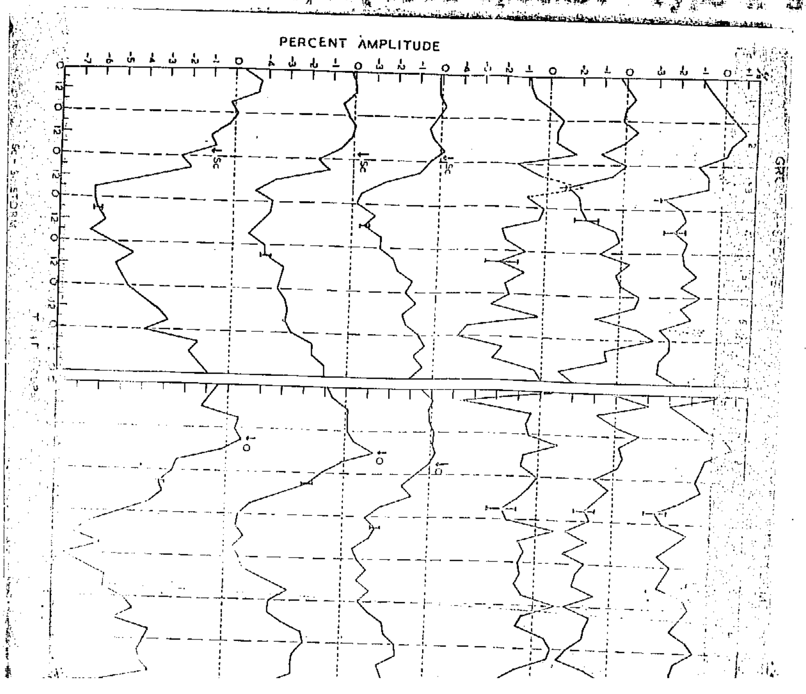


Fig 32. Storm type decreases for type A and type B Storms.

to January 21, 1957, November 26, 1957 and February 11, 1958 are combined such that the occurrence of Sc geomagnetic storm in each coincides. Type B storms which are not associated with Sc storms, are combined coinciding the commencement of the fall at Alma-ata in each event. Fig. 32 shows the storm type decreases for two different types of storms A and B.

5.75 <u>Chief characteristics of two types of storms</u> :- The main characteristics of two types of storms are listed in Table 17. Since the statistical error in the bihourly counts in east and west are large, it is very difficult to draw definite conclusions regarding changes of asymmetry on a day to day basis. Hence the above results are to be taken as indicative of the area in which the future work requires to be done. For this reason we have not entered into further interpretations of the various changes occurring in two different types of storms. The most important characteristics of the two types of storms are summarised below.

Type A storms can be distinguished from their short time interval of about 20 hours between the commencement of the fall and the intensity minimum. We find that in many of the individual storms, as well as in the combined group the minimum in east occurs about 6 hours earlier to that in west. This shows that the distance of source of modulation was far outside the influence of the geomagnetic field. From the equality of the magnitudes of decrease of neutron intensities at widely seperated stations such as Ottawa and Hobart, Fenton et al[230] also came to the same conclusion that the

Table 17

Characteristics of type A and type B storms.

	Type A	Type B
1. Nature of the decrease.	Sharp onset accompanied by a sharp fall of nucleonic intensity.	Gradual onset accompanied by a gradual fall of nucleonic intensity.
2. Energy dependence of amplitude of decrease.	Larger decrease for lower mean energy than for higher mean energy.	Larger for lower mean energy than for higher mean energy.
3. Energy dependence of onset time.	Same at all stations.	Later for low latitude stations having higher mean energy than for high latitude stations.
4. Energy dependence of rate of decrease.	Larger for lower energy than for higher energy component.	Same for both low and high energy components of cosmic radiation.
5. Energy dependence of duration of decrease.	More for low energy than for higher energy component.	-do-
6. Time interval between the commencement of the fall and intensity minimum.	About 20 hours.	30 - 35 hours.
7. Association with Sc storms.	Always associated with large Sc storms.	Associated with weak or no Sc storms.
8. Changes in east-west asymmetry.	East-west asymmetry starts decreasing from the commencement of the fall and is very much depressed in the later part of the storm.	No significant changes in east-west asymmetry either during the main phase of the storm or in the later part of the storm.

scale of the modulating effect must be larger than the earth's dimensions for the storm of 21 Jan, 1957. Since in all the cases even though the intensity in east had recorvered to its normal value in the later part of the storm, meson intensity in west and neutron intensities at high latitude stations were considerably depressed which shows that the lower energy particles, probably particles having energy less than about 22.5 Bev, had a much flatter spectrum as compared to that of higher energy particles during this period. As Dorman has pointed out, these type of storms probably correspond to envelopment of the earth by the head front of a magnetised stream close to the rear lateral edge. The streams are of the second type probably originating within the sun's equatorial region and carrying strong frozen in magnetic field.

On the other hand storms corresponding to B group are very gradual storms reaching their minimum after about 30 - 35 hours after the commencement of the decrease. The onset time at different places and for different components differs considerably, it being earlier for low energy component of cosmic radiation. The east-west asymmetry does not significantly change either during the main phase or in the later part of the storm. Duration of the decrease for low and high energy is almost same. But the magnitude of decrease for low energy is more than that for high energy component. These storms are associated with very weak or no Sc geomagnetic storms.

Storms of type B are probably caused by the streams of first kind postulated by Dorman. Such streams of low velocity and carrying weak frozen in magnetic fields are probably connected with high latitude formations on the sun. Cosmic ray storms of this type are perhaps due to envelopment of the earth by the lateral edge of the first type of streams.

Murakami and Kudo[234] find that the onset time for low energy cosmic rays is earlier than for high energy cosmic rays. From our observations it is clear that this is so only for storms of type B. Similarly Kitamura and Kodama[235] find that, during the storms low energy component recovers later and the spectrum becomes flatter. Our observations show that this is predominantly seen for group A type of storms when even three days after the minimum is reached the low energy component is very much depressed. We believe that the important chriterion distinguishing the type A and type B storms is the time interval between the commencement of the fall and the intensity minimum which is about 20 - 22 hours for type A storms and about 30 - 35 hours for type B storms.

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CHAPTER VI

DISCUSSION AND CONCLUSIONS

6.1 Significance of applying correction for daily variation of temperature of the atmosphere to cosmic ray data.

As has been indicated earlier, the data for the year 1957 and 1958 for east and west intensities recorded by telescopes inclined to the zenith at 45^{o}, have been analysed. Even though the geomagnetic cut off in the west is lower than in east and in consequence the secondaries of primary cosmic rays in the energy range 22.5 - 10.9 Bev are measured exlusively by west pointing telescopes, the percent amplitude of the 12 month mean daily variation before applying correction for atmospheric temperature changes is larger for east than for west. Using the assumption that above 2 km over the ground level there does not exist appreciable diurnal variation of temperature, the west and east intensities have been corrected for temperature variations at ground level, 1 km and at 2 km above ground level. The experimental and theoretical justification for this is given in chapter V.

A major difference in the percent amplitude of the daily variation between east and west directions would pose a serious problem of interpretation, since it becomes difficult to explain any such difference along with the observed phase difference between them, with any reasonable type of spectrum of variation with appropriate cut offs either in the low or high energies and considering a single source of daily variation. The elimination of this difficulty by the application of a reasonable correction for the variation of temperature in the atmosphere, is therefore, a very satisfactory feature of the present study. In our opinion, it lends support to the basic assumptions made regarding the nature of daily variation of temperature at different levels in the atmosphere, which have been derived by meteorologists on experimental and theoretical grounds.

6.2 Comparison of the form of daily variation between east, west and vertical intensities.

Table 18 gives the amplitudes and times of maxima of mean diurnal and semidiurnal components in east, west and vertical directions for different periods of observation. For the period May 1954 to April 1955, Nerurkar conducted an east-west experiment at Ahmedabad with telescopes having semiangular openings of 22° and 37° in the east-west and north-south planes respectively. The telescopes were inclined to the zenith at 45°.

Fig. 33 shows the average daily variation in east, west and vertical for the periods 1954-1955 and 1957-1958. We have also represented the diurnal and semidiurnal

Table 18

Table showing the mean diurnal and semidiurnal components of daily variation for east, west and vertical intensities at Ahmedabad during the years 1954-1955 and 1957-1958.

Period	EAST $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	VERTICAL $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$	WEST $\bar{r}_1$	$\bar{\phi}_1$	$\bar{r}_2$	$\bar{\phi}_2$
May '54 to Apr. '55	0.07 ± 0.04	107°	0.19 ± 0.04	78°	0.13 ± 0.03	135°	0.20 ± 0.03	63°	0.20 ± 0.04	154°	0.16 ± 0.04	11[illegible]
Jan. '57 to Dec. '58	0.16 ± 0.02	173°	0.10 ± 0.02	0°	0.27 ± 0.02	π+30°	0.19 ± 0.02	39°	0.16 ± 0.02	π+45°	0.08 ± 0.02	69

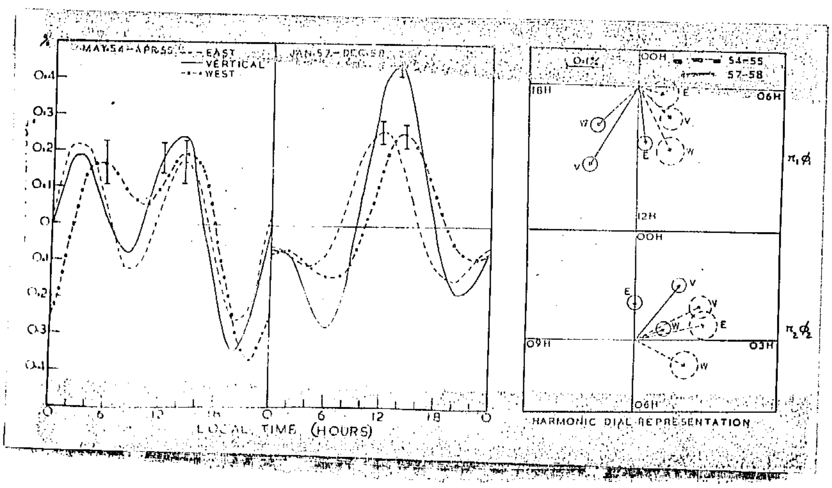

Fig. 33 - The form of daily variation in east, west and vertical during May 1954 to April 1955 and January 1957 to December 1958. The diurnal and the semidiurnal components are also showin in the harmonic dial.

components on harmonic dials in the same figure. The results of comparison of the form of mean daily variation during 1957 and 1958, as already discussed in chapter V, can be summarised as follows.

(a) The percent amplitudes of variation in east and west are comparable.

(b) Diurnal time of maximum in east occurs about 4 hours earlier to that in west.

(c) There is a greater variability in the occurrence of diurnal maximum in west than in east, on day to day basis, for monthly mean or for average over long period.

Comparing the form of the mean daily variation in east and west with that of vertical* for the period 1957-1958, we find that the amplitude of vertical intensity is somewhat larger than in east or west. In an earlier chapter, in determining an energy spectrum for the daily variation, the observed similar amplitudes for east and west directions but with only a difference in the time of maximum was made use of. The vertical intensity measured in 1957-1958 was studied with a telescope with angles of opening (of $22\frac{1}{2}^{\circ}$ in east-west plane and $37\frac{1}{2}^{\circ}$ in north-south plane) only a little different from those in east and west directions. If in fact the somewhat larger amplitude in the vertical represents a feature of physical significance, it would be necessary to consider the suggested interpretation in terms of a spectrum

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* The author is thankful to Mr.H.Razdan for supplying the data of vertical intensity at Ahmedabad.

of average daily variation derived from east and west data. At the present moment, without further experimental confirmation this does not seem to be called for.

The mean daily variation in east, west and in vertical directions exhibit one maximum near noon during the period 1957-1958. Looking at the harmonic components, we find that the diurnal time of maximum in vertical, though not significantly different from that in west, lies intermediate between the diurnal times of maxima in east and west.

During the period May 1954,- April 1955, as can be seen from the diagram, the form of the mean daily variation in east, west and vertical showed two maxima one in the early morning and another at about noon. The peak to peak amplitudes of daily variation in east, west and vertical were comparable and the diurnal time of maximum in the vertical direction, though not significantly different from those in east or west, was still intermediate between the times of maxima in east and west. The diurnal time of maximum in east occurred about 3 hours earlier to that in west. We conclude that, since east pointing telescopes first scan the celestial sphere followed by vertical and then west pointing telescopes, the observed phase differences in the diurnal component of the mean daily variation in east, west and vertical are consistent with a source of anisotropy located, on an average, far outside the influence of the geomagnetic field.

6.3 Long term changes of daily variation

The form of daily variation in east, west and vertical which exhibited two maxima one in the early morning and one at about noon, changedover by 1958 to a curve exhibiting only one maximum at about noon. The early morning maximum is not present in 1958, and the after noon maximum occurs at about the same time but with an increased amplitude.

When we resolve the curves into their harmonic components and look at them, we find that the diurnal components of the mean daily variations of vertical, east as well as of west intensities have shifted to later hours by about 5 hours, from 1955 to 1958. These observations are in agreement with the long term changes of diurnal component observed by Sarabhai et al[9] and Elliot et al[152]. The comparison of the mean daily variations and the diurnal components clearly brings out that a long term change does not involve the movement of the after noon maximum but a gradual disappearance of the morning maximum. The peak to peak amplitudes of the average daily variation in east, west and vertical do not show any appreciable change from 1955 to 1958.

Elliot et al[2, 145] had conducted east-west experiment at Manchester during 1949 and also during May 1954 to April 1955. Since the opening angles of the instruments used during the two periods were different, the results of the two are not directly comparable with each other. However, their results do show an indication of the shift of the time of diurnal maximum to earlier hours from the period of maximum sunspot activity to the period of minimum sunspot activity. The diurnal time of maximum which was at 1300 hours and at 1600 hours for east and west during 1949 shifted to about 0700 hours during May 1954 to April 1955. During 1949, both east and west had almost same amplitude with a phase difference of about 3.4 hours in their time of diurnal maximum, east occurring earlier. However during 1954-1955 no such phase difference was observed between east and west. Since the diurnal amplitude in east was very small ($0.05 \pm 0.03\%$) no conclusions could be drawn. But on the other hand, the high amplitude of diurnal variation ($0.18 \pm 0.03\%$) observed in west, had led them to believe that the source of daily variation may be situated within the influence of the geomagnetic field. Recently Elliot et al[236] have found that this anomaly vanishes if proper correction is applied to the daily variations in east and west for variations of temperature in the upper atmosphere.

The two maxima seen in the mean daily variation curves at Ahmedabad in 1954, are not seen at Manchester. This fact was first pointed out by Sarabhai et al[9] from an examination of mean daily variation curves at Huancayo and Cheltenham. One of the reasons for this would be that the asymptotic directions of primaries whose secondaries are measured at middle and high latitudes are spread out over a much wider range of latitudes and longitudes in the celestial sphere than at stations situated at low latitudes.

6.4 <u>Energy dependence of variation.</u>

Various modulation mechanisms proposed to describe primary variations of cosmic ray intensity can be grouped into mainly two distinct classes.

(1) Particles may pass through a region of space in which they receive a small acceleration or deceleration.

(2) Temporary removal of particles in the cosmic ray beam by scattering, absorption etc. so that at a given position in space there will appear from time to time decreases of integrated cosmic ray intensity.

Attempts have been made by Morrison,[171] Parker[172,173] and Simpson[120] to explain 27 day variation and long term changes of mean intensity and storm type decreases. However, these theories cannot explain the cause of the daily variation of cosmic rays.

Since the importance of solar corpuscular streams in producing many terrestrial effects such as those observed in aurora, ionosphere and cosmic rays is well established, many workers have tried to explain the variations in cosmic rays using the first mechanism. One of the earliest to realise the importance of such beams was Elliot.[2] Since then workers of the Stockholm group,[175] Nagashima,[177] [illegible][178] and Dorman[6] have tried to determine the influence of corpuscular streams carrying frozen magnetic fields from the sun. In chapter I, we have already summarised the theories of Alfven, Nagashima and Sarurkar.

Dorman has developed similar ideas as those of Nagashima, and given quantitative estimate of the daily variation caused by electric and the magnetic fields of the corpuscular beams. According to Dorman, two types of streams exist (1) more rarified streams, probably connected with high latitude formation on the sun which may be responsible for quiet type of diurnal variation and (2) more dense ones, probably origineting within the sun's equatorial region and intimately connected with sunspots.

Assuming that the frozen magnetic field has the same direction as that of earth's field, it can be shown that the cosmic ray particles having the differential energy spectrum $D(E) = E^{-(\gamma+1)}$ and passing through the stream with a magnetic field H, will undergo an acceleration or deceleration due to the electric field in the beam, depending on whether the stream is to the left or to the right of the earth. Using the first type of streams to explain the quiet type daily variation and streams of second kind to explain storm type variation, Dorman has shown that the energy spectrum of variation should be of the form AE^{-1}. His theory predicts both the increase in amplitude of variation and shift of the hour of maximum towards later hours.

From an examination of mean daily variation at different stations averaged over long periods from 1937-1951, Dorman has concluded that the spectrum aE^{-1} where $E > 6.6$ Bev explains the results of mean daily variation satisfactorily. Kopracken[228] found that during 1956-1957, the exponents of the spectra of variation were different for short and long term variations. Representing the spectrum of variation by $E(1+E)^{-\gamma}$, he found a value of 0.6 or 0.8 for γ for short term variations and a value of 1.2 for long term variations. During the same period Kuzmin[229] has reported that a spectrum of the type $aE^{-0.7}$ can explain short as well as long term variations.

As described in chapter V, we have determined the energy spectrum of variation consistent with the results obtained for the mean daily variation in east and west directions during the period 1957-1958. We find that a spectrum of the type $a E^{-\gamma}$ where $\gamma = 0$ for $E \geqslant 20$ Bev and $\gamma = 2$ for $E \leqslant 20$ Bev, is able to explain the observed results. As has already been pointed out in chapter V, a spectrum of the type aE^{0} for all energies will cause a difference of 6 hours in the diurnal times of maxima in east and west. Since the observed difference is only 4 hours, it becomes necessary to assume a spectrum of the type aE^{-2} for primary energies less than 20 Bev, to explain the observed smaller difference in the time of maxima.

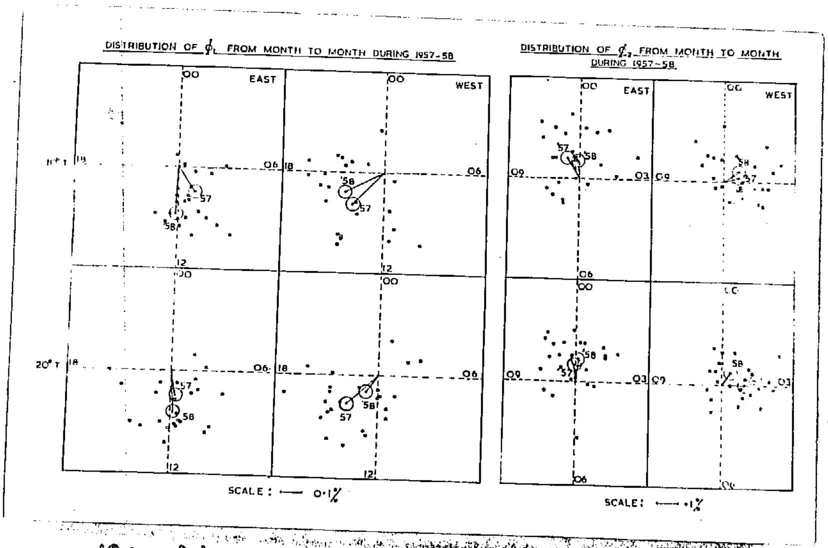
For days of high asymmetry, on the other hand, we find a spectrum of the type $aE^{-0.8}$ explains the observed results. On days of high asymmetry we can undoubtedly relate the daily variation to a source of anisotropy located far outside the influence of the geomagnetic field. The spectrum we get for the average mean daily variation on such days is in agreement with the spectrum of the daily variation which should be expected theoretically from Dorman's theory. On days of low asymmetry, since the diurnal amplitudes of variation in east and west are very small, we have not fitted any spectrum to explain the mean variation on these days.

On the other hand, on days of high C_p when the daily variation has a large significant amplitude in both east and west, the best fit for the spectrum of variation is found to be

$$\delta D(E)/D(E) = aE^{0} \text{ for } E > 20 \text{ Bev and}$$
$$= 0 \quad \text{for } E < 20 \text{ Bev.}$$

Assuming the form of daily variation in west, the form of the daily variation curve in east for 24 month mean variation during 1957-1958 and for mean variation on days of high asymmetry are calculated using the respective spectra of variation. The observed and calculated curves are given in Fig. 34.

The spectrum which we find as the best fit to explain the results of 24 month mean daily variation during 1957-1958 requires a comment. 12 month or 24 month mean daily variation includes days of high asymmetry which are associated with a low geomagnetic activity as well as days of high C_p. It is for this reason that we find a difference of only 4 hours in the diurnal time of maximum between east and west for 24 month mean daily variation. From the above reason we conclude that the spectrum of variation deduced for average conditions is not very meaningful. There are at least two different types of daily variations, one which can be related to an anisotropy far outside the influence of the geomagnetic field and the other caused by a source of modulation having a geocentric origin. On days when the anisotropy is far outside, the spectrum of variation has a form $aE^{-0.8}$ during 1957-1958.



(a) 24 month mean daily variation
(b) Daily variation on high A days.

Fig. 34 - The calculated and the observed curves in east and west for 24 month mean daily variation and for mean daily variation on days of high asymmetry.

Points are the observed ones.

Since on days of high asymmetry we find the spectrum of variation to be consistent with Bormann's theory, let us examine how such a model can explain the observed east-west asymmetry. Assuming that the frozen magnetic field has the same direction as that of the earth's field, we can show that the particles going through such a beam will either accelerate or decelerate depending on whether the stream is to the left or to the right of the earth and the differential energy spectrum will accordingly be changed. Assuming the differential energy spectrum to be of the type $D(E) = KE^{-\gamma}$ under normal conditions, the total intensities measured by east and west pointing telescopes can be written as

$$\bar{N}_E = \int_{E^E_{min}}^{\infty} M(E)\, D(E)\, dE$$

$$\text{and} \qquad \bar{N}_W = \int_{E^W_{min}}^{\infty} M'(E)\, D(E)\, dE \qquad (29)$$

where E^E_{min} and E^W_{min} are the cut off energies in east and west and $M(E)$ and $M'(E)$ are the multiplicity functions in east and west. When a beam is present, the particles of energy $(E - e)$ passing through the beam will get accelerated and will have energy E after suffering an increment of e in their energy. The modified differential energy spectrum will be $D'(E) = K(E - e)^{-\gamma} \sim KE^{-\gamma}(1 + \frac{e\gamma}{E})$ (30)

Let us suppose that the telescopes look at the normal spectrum $D(E)$ for X hours and at the beam for $(24 - X)$ hours. The total intensity as a result of the above process would be

$$N_E = \int_{E^E_{min}}^{\infty} M(E) \left\{ \frac{X}{24} D(E) + \frac{24 - X}{24} D'(E) \right\} dE$$

$$\text{and} \qquad N_W = \int_{E^W_{min}}^{\infty} M'(E) \left\{ \frac{X}{24} D(E) + \frac{24 - X}{24} D'(E) \right\} dE \; . \qquad (31)$$

substituting the values of D(E) and D'(E) in equation (31) it can be reduced to

$$N_E = \int_{E^E_{min}}^{\infty} KE^{-\gamma} \left\{ 1 + \frac{e\gamma}{E} \left(1 - \frac{X}{24}\right) \right\} W(E)\, dE$$

$$\sim \bar{N}_E + \bar{N}_E \int_{E^E_{min}}^{\infty} \left(1 - \frac{X}{24}\right) \frac{e\gamma}{E^2} \int W\, dE$$

and $$N_W = \bar{N}_W + \bar{N}_W \int_{E^W_{min}}^{\infty} \left(1 - \frac{X}{24}\right) \frac{e\gamma}{E^2} \int W'\, dE \qquad .(32)$$

where W and W' are the coupling coefficients in east and west. Increase in asymmetry due to the telescopes looking at the beam for (24 - X) hours is

$$\frac{2\,(\Delta N_W - \Delta N_E)}{N_W + N_E} \cdot 100 \qquad .(33)$$

where $\Delta N_W = N_W - \bar{N}_W$ and $\Delta N_E = N_E - \bar{N}_E$.

Equation (32) can be solved by numerical integration using the values of coupling coefficients in east and west calculated by knowing the latitude effects in east and west (vide chapter IV).

Since the duration of the broad maximum in east and west on days of high asymmetry is about 6 hours, we can keep an upper limit of 4 hours for the time for which the telescopes look at the beam. The following table gives the values of increment e in energy required to explain the observed asymmetry increase of 1.2%, assuming different values for the amount of time during which the telescopes look at the beam.

Time for which telescopes look at the beam (hrs).	Energy increment e in electron volts.
12	0.04×10^8
9	0.06×10^8
6	0.08×10^8
3	0.17×10^8
1	0.52×10^8

Taking an upper limit of 3 6 hours for the duration for which the telescopes look at the beam, we find that the increase in asymmetry is explained if we assume a value of 0.08×10^8 eV for e the increment in energy suffered by particles crossing the beam. Assuming the beam having a width of 5×10^{12} cms to have a frozen in magnetic field of about 5×10^{-6} gauss, the velocity of the beam works out to 3×10^7 cm/sec., which is a very reasonable value. If instead the beam is looked at by the telescopes for only three hours, the velocity of the beam for the same frozen in magnetic field would be 6×10^7 cm/sec.

The peak to peak amplitudes of daily variation in east and west using the above assumptions are found to be 0.6% and 1.5% respectively. The observed peak to peak amplitudes of variation in east and west are 0.9±0.15% and 1.3±0.19% respectively. The fair agreement between the calculated and the observed values and the correct order of constants we get for the various characteristics of beams give us a further confidence in the model used above.

Knowing the angles of drift and the times of maxima in east and west, the value of χ the angle between the direction of additional cosmic rays and the sun-earth line can be calculated as before, for days of high asymmetry. is found to have a value of 112 $\pm$ 10° which agrees well with ~~the~~ Dorman's prediction.

It is, however, well to remember that since the mean daily variation during this period has a single maximum, we find the observations to be in accordance with those predicted by Dorman. It will be however very difficult to find an agreement between Dorman's prediction and the mean daily variation during 1954-1955, particularly at equatorial latitudes, when the form of mean daily variation has two maxima one in the early morning and another at noon.

6.5 Geocentric source of modulation.

As already discussed in chapter V, on geomagnetically disturbed days we find an absence of phase difference in the diurnal times of maxima in east and west. From this we had concluded that the daily variation on geomagnetically disturbed days is caused by modulation of geocentric origin. Results of Elliot et al[148] and of Parsons[149,150] also indicate the presence of such modulating mechanisms of geocentric origin responsible for the daily variation during some periods. From the dissimilarity of amplitude changes at Hobart and Mawson, Parsons[157] concludes that localised mechanism operating close to the earth may play an important role.

Recently Parker[173] has tried to explain the 11 year cycle of cosmic ray intensity by the hydrodynamic outflow of gas from the sun. The outward flow of hydrodynamic gas is inferred by Biermann from observations on comet tails and should stretch out the magnetic lines of force of the solar magnetic field leading to an essentially radial magnetic field in the inner solar system. He has suggested that the Forbush type decreases are local geocentric phenomena produced by the interaction of the outflowing gas from the sun with the earth.

Even though the above processes are not very clear, it is definite that on geomagnetically disturbed days the earth's magnetic field will be substantially altered at a distance of perhaps 4 to 6 earth radii, due to the penetration of geomagnetic field by tongues of ionized gas from the solar wind. Wada and Kamiya[107] have also suggested that the magnetic field of the magnetic clouds ejected from the sun, which may be considered as the superposition of ordered and disordered fields may affect cosmic ray intensity either by changing the magnetic field of the earth or through other effects such as those described by Alfven. Recently Rothwell[237] has shown that a storm cloud moving with a velocity of 3×10^{8} cm/sec. and containing 10^{4} particles/c.c. could modify cut off rigidities even at equatorial latitudes. Further the temporary changes in the intensity of radiation in the Van Allen belts could also produce local perturbations in the geomagnetic field. If this is so, due to the distortion of the geomagnetic field the allowed and forbidden cones may change causing a daily variation of [illegible] origin. At present it is very difficult to explain the mechanism in more quantitative terms and hence we have just indicated one of the possibilities of the origin of geocentric source of modulation causing the daily variation of cosmic rays.

6.6 North-south asymmetry of daily variation.

Daily variation on high and low asymmetry days and their implications have been discussed in the previous chapter. Examination of daily variation of neutron intensity at various stations situated all over the world indicates, as already discussed earlier, that the equatorial stations and stations situated in the southern hemisphere show similar changes in daily variation on high and low asymmetry epochs during the period under observation. Mean daily variation of neutron intensity in northern stations has a high diurnal amplitude for days of high as well as low asymmetry. On the other hand the mean daily variation of neutron intensity in equatorial and southern stations has a low amplitude of variation on days of low asymmetry and has a high amplitude of variation on days of high asymmetry.

The histograms of significant bihourly deviations of neutron intensities at different stations for groups of days when east and west pointing telescopes show significant variations at certain bihours, show that the occurrence of maximum positive bihourly deviations for stations in northern hemisphere occurs 2 to 4 hours later than that for either equatorial or southern stations. As has already been pointed one, similar north-south asymmetry of anisotropic radiation has been reported in literature for storm type variations by Sarabhai et al[97]. Dorman has also shown that one should, from theoretical considerations, expect a north-south anisotropy of diurnal effect, giving rise to a larger diurnal effect in Southern than in northern hemisphere when the frozen in magnetic field in the streams is directed along the axis of rotation of the earth and should give rise to a reverse effect when it is directed from east to west. It will be very interesting to confirm the existence of such asymmetry and determine its nature.

6.7 Daily variation and its relationship with C_p.

In chapter V we have discussed the daily variation and its relationship with C_p, the index of geomagnetic disturbance. We have also discussed that on geomagnetically disturbed days the histogram of occurrence of the diurnal time of maximum in east and west are similar and the phase difference in their time of maximum vanishes indicating that the modulation is of geocentric origin.

From table 14 giving the amplitudes and times of maxima of diurnal and semidiurnal components of daily variation on days of low, medium and high C_p and the figure 29 showing the mean daily variation in east and west on these groups of days, we can easily see that the ratio of the peak to peak amplitude in east to that in west is about 1.32 on high C_p days. In order to explain the above result, we have to assume the daily variation to be caused by a geocentric modulating mechanism having an energy spectrum of the type $\delta D(E)/D(E) = aE^0$ for $E > 20$ Bev and $= 0$ for $E < 20$ Bev.

The mean amplitude of average daily variation does not show any strong dependence on C_p and the time series of mean intensity show that there is a small reduction in mean intensity in east ($0.2 \pm 0.05\%$) two days before epoch and in west one day after the epoch day, only for days when $C_p \geqslant 1.5$. Many authors such as Parsons[157], Venkatesan[95], Sastry[156] and Satya Prakash[109] have reported that one does not always get consistent results either with regard to dependence of daily variation or of mean intensity on C_p. Parsons for example, finds little apparent relationship of daily variation with solar or geomagnetic disturbance indices, despite the fact that the period of his experimentation as in the case of the present author has been a period of exceptionally intense solar activity. Parsons finds that in different relatively long term data groups, increased geomagnetic activity is associated some times with enhanced and some times with smaller mean amplitudes of variations, some times with advanced phase and at other times with retarded phase. As regards changes in mean intensity, even though Van Der Walt[102] concludes that at the time of minimum solar activity cosmic ray intensity minimum precedes K_p maximum and at the time of maximum solar activity it follows K_p maximum, one does not get consistent results at all times. We, for example, find that on days having C_p index ≥ 1.5, the minimum in west is reached one day after the C_p maximum in agreement with Van Der Walt's conclusions but the minimum in east is reached two days before the C_p maximum.

Number of authors have tried to find a direct association of geomagnetic activity with some observed characteristics on the sun. Bell and Glazer[109] found that a maximum geomagnetic activity of 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 such geomagnetic disturbances and are thus associated with C_p minima. The non recurrent type of geomagnetic activity is found to be associated with SC storms and CMP of sunspot groups which are also found to be sources of emission of solar radio noise in 1 meter wave-length.

From the above discussion it is obvious that high C_p does not correspond to an unique condition of the electromagnetic state in the interplanetary space and hence it is not surprising that we should get inconsistent results on days selected with only C_p as the criterion. Thus it is clear that the selection criterion for specifying the electromagnetic state of interplanetary space which is relevant to cosmic ray variations, should be C_p along with either its recurrence characteristics or with certain observed characteristics on the sun such as intensity of green coronal line[105] or radio outburst of type IV[107].

6.8 Conclusion.

In the statement of the problem we had posed a few important questions related to the time variations of cosmic rays on which we would like to gain information. They were

(1) After applying correction for variations of meteorological origin, is the daily variation caused solely by the anisotropy of primary radiation or is there a different source of daily variation which operates on some days ? Is there, for instance, a local source of nonmeteorological origin ?

(2) Is there any source of daily variation which may be considered to be constant over a period of about a year or longer in addition to the source or sources which are responsible for the daily variation of highly variable character on a day to day basis ?

(3) What is the energy dependence of the source of anisotropy?

(4) What is the relation between mean intensity, daily variation and C_p ?

(5) What are the changes occurring in east-west asymmetry and what is their relationship with C_p and daily variation ?

The data of the directional telescopes constructed by the author at Ahmedabad, have been examined with a view to seek answers to some of these questions.

From a detailed examination of 24 month mean daily variation and mean daily variation on groups of days under different conditions in east and west directions, we conclude that there are at least two principal sources of daily variation of cosmic ray intensity, in addition to meteorological sources. The mean daily variation on days of high asymmetry and on days of low geomagnetic activity is caused by an anisotropy situated outside the influence of the geomagnetic field. On geomagnetically disturbed days the mean daily variation of μ meson intensity in east and west directions is consistent with a source of modulation of geocentric origin.

Since the mean daily variation for days averaged over long periods includes both geomagnetically quiet and disturbed days, the energy dependence of 24 month mean daily variation is not very meaningful. The dependence of variation on energy is determined for days of high asymmetry and it is found that the spectrum of variation on such days during 1957 and 1958 can best be represented by $aE^{-0.8}$.

The energy dependence of daily variation on days of high C_p caused by a local nonmeteorological source is found to have a spectrum of the type $\delta D(E)/D(E) = aE^{0}$ for $E > 20$ BeV

$= 0$ for $E < 20$ BeV.

The amplitude of the average daily variation does not show any strong dependence on C_p and the time series of mean intensity shows a small reduction in mean intensity only for days when $C_p \geqslant 1.5$, inspite of the period of observation being one of intense solar activity. It is concluded that C_p does not correspond to an unique condition of the electromagnetic state of the interplanetary space.

Since asymmetry changes can be due to changes in cut off energies or in the primary spectrum, it is concluded that a study of east-west asymmetry and its relationship with daily variation and C_p would be highly fruitful. It is found that on days of high asymmetry, the amplitudes of variation in east and west are significantly large and the phase difference between their diurnal times of maxima consistent with a source of anisotropy located in space, outside the influence of the geomagnetic field. Assuming the variation to be caused by the acceleration of cosmic ray particles crossing streams of second kind, proposed by Dorman, it is estimated that the energy increment suffered by such particles is of the order of 0.1×10^8 eV. Assuming the streams of width 5×10^{12} cms to have a frozen in magnetic field of strength 5×10^{-6} gauss, the velocity of such streams is estimated to be of the order of 5×10^7 cm/sec.

The present study has been limited due to the low counting rate of the instrument and the consequent high statistical error. We believe that a further study with high counting rate directional telescopes at equatorial latitudes during different periods of solar activity would be helpful in confirming our results regarding the nature and energy dependence of the source of anisotropy.

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ANISOTROPY AND THE ORIGIN OF THE SOLAR DAILY VARIATION OF COSMIC RAY INTENSITY

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I. Introduction

We wish to present here some recent experimental results concerning the time variations of cosmic rays. Even though we are not able to understand the details of the physical processes which are involved, we can now see the main characteristics of the phenomena. The results which we show are mainly derived from a series of experiments conducted over the past seven years at three stations near the geomagnetic equator along the 75°E meridian. In all cases triple coincidence telescopes with 10 cm of lead were used and apart from studies on the vertical component by Duggal (1), Razdan and Sastry (2), Rao (3) has followed at one station the intensity from east and west directions inclined at 45° to the zenith. Some interesting new results obtained with the MIT high counting rate mu-meson scintillation telescopes are also presented. These have been obtained by R.Palmeira and relate to a counting rate of about 1000 per second which enables us to follow with precision the details of variations of short period.

Without elaborating on experimental details or precedures of analysis we present results which have a bearing on the following crucial questions which we believe would help us in interpreting variations of cosmic ray intensity. We shall examine

(1) What is the nature of change of solar daily variation that one observes and how is the change related to the cycle of solar activity?

(2) What is the energy dependence of the variations of cosmic ray intensity and anisotropy?

(3) Where is the source of the daily variation located? Under what conditions can the solar daily variation be associated with an anisotropy outside the influence of the geomagnetic field?

Finally we summarise the analysis of Sarabhai & Palmeira (4) concerning the very interesting event which occurred on 10th and 11th of February 1958. For the neutron monitor data used in this analysis we are indebted to Ehmert, Fenton, Miyazaki, Rose, Ryder, Sandstrom, Simpson, Thomson, van Wijk and Wilson. The energy dependence and the east-west and north-south anisotropy associated with this large Forbush type event are studied.

II. The changes in the daily variation of meson intensity.

Fig. 1 shows the time of maximum of the semidiurnal component of the annual mean daily variation at Huancayo from 1939 to 1956. The results are derived from Carnegie Institution ion chamber data for which the authours are indebted to Forbush. The time of maximum shifts by almost 10 hours in 19 years, reflecting as we have remarked earlier (5) the very significant change of form of the daily variation at an equatorial mountain station. The change is most rapid during increasing solar activity, and appears to have a period of 22 years. We would like to emphasise again the importance of the semidiurnal component in the interpretation of the solar daily variation of cosmic ray intensity.

Fig. 2 shows the frequency distributions of the amplitudes of the diurnal and the semidiurnal components, r1 and r2 respectively, of the daily variation on individual days at the three stations Ahmedabad, Kodaikanal and Trivandrum during 1955, 1956 and 1957. During any one year, Kodaikanal which is a mountain station has a smaller amplitude than either Trivandrum or Ahmedabad which are at sea-level. Moreover with increasing solar activity from 1955 to 1957, the frequency distribution is displaced to smaller amplitudes at each station. We have reported earlier (2) the rapid decrease of amplitude of 12 month mean daily variation at Kodaikanal from 1954 to 1956 and our present results show that the same can be observed in the distribution of characteristics on individual days.

Fig. 3 shows the frequency distributions for the diurnal and the semidiurnal components of the times of maxima on the days on which the amplitude of the appropriate harmonic component on an individual day is significant at the 2σ level. A remarkable feature is that with increasing solar activity, the time of maximum has increasing variability and this is an important reason why the annual mean daily variation exhibits a low amplitude during 1957 as compared to the amplitude in 1955.

Results of great statistical significance originating from the MIT high counting rate mu-meson detector are shown in figures 4, 5 and 6. We see firstly in Fig. 4 that the form of the monthly mean daily variation changes significantly from month to month and that in November 1958 its peak to peak amplitude is about 0.8 %. Fig. 5 shows that the most probable amplitude on an individual day is about 0.6 % but there are many days on which the amplitude is considerably greater. With this instrument it is possible to follow the daily variation through individual bihourly deviations as is seen in Fig. 6 where the histograms of the occurrence of hourly positive and negative deviations exceeding $5\sigma \approx 0.5$ % at different hours is shown. We conclude from this analysis that the daily variation of meson intensity has on many days an amplitude large enough to permit us to neglect the atmospheric temperature effect whose influence in the daily variation is of the order of 0.1 to 0.2 %, but with time of maximum which is somewhat uncertain at the present time. The study of the daily variation on individual days is of great interest for an understanding of modulation processes of non-meteorological origin.

III. The energy dependence of the daily variation.

Our observations made earlier by comparing the daily variations at three stations become clearer from a study with east and west pointing telescopes at Ahmedabad during 1957 and 1958. Fig. 7 shows the frequency distributions of the amplitudes of the diurnal and the semidiurnal components and the times of maxima on individual days on which the amplitude is significant. It is seen that

(1) The diurnal amplitude for east intensity is larger than for west intensity. This is not the case for the semidiurnal amplitude.

(2) The diurnal time of maximum for west has much greater variability than for east. This is not so to the same extent for the semidiurnal component.

Since the geomagnetic cut-off energies at Ahmedabad are 10.4 BeV and 20.6 BeV for west and east intensities respectively, we conclude that the amplitude of the daily variation of the component related to low mean primary energy is less than the amplitude for the component related to high mean primary energy. Also the variability of the time of maximum is greater for the former than for the latter. Fig. 8 shows that this effect is most prominent on days of low or moderate geomagnetic activity. For geomagnetically disturbed days with Cp index greater than one, the west telescope has a distribution of diurnal time of maximum which is quite similar to that of east. However the mean amplitude for west telescopes continues to be smaller than for east telescopes in all cases. There is no difference in diurnal time of maximum in the two azimuths, indicating that on geomagnetically disturbed days, the main cause of the daily variation is not located outside the influence of the geomagnetic field.

IV. The location of the source of the daily variation.

When we have the characteristic difference in the times of maxima which should be expected between the daily variations measured by east and west pointing telescopes which at the equator successively scan the same belt in space with the spinning of the earth, we relate the daily variation to a primary anisotropy. But when the daily variations in east and west telescopes have nearly the same times of maxima, we associate them with a source nearer the earth.

At equatorial latitudes where the atmospheric cut-off is smaller than the geomagnetic cut-off a change in east-west asymmetry of daily mean intensity can be associated with a change in primary energy spectrum. Fig. 9 shows the mean daily variation in east and west direction for groups of days with low, medium and high east-west asymmetry, and also through Chree analysis the relationship of low and high asymmetry with mean intensity in each direction and the index of geomagnetic disturbance. It is seen that days with high east-west asymmetry, are associated with low index of geomagnetic disturbance and a large daily variation in east as well as west telescopes with times of maxima consistent with a primary anisotropy. On the other hand, for low east-west asymmetry we have a negligible daily variation in west telescopes. We therefore conclude that on geomagnetically quiet days there is the absence of a local source of daily variation which permits us to observe the daily variation at a greater distance in interplanetary space - most probably connected with beams from the sun carrying within them frozen magnetic fields. We believe that we have atleast two principal sources, both non-meteorological in origin, of the solar daily variation of cosmic ray intensity. The local source now requires further study from a theoretical standpoint. Elliot (6) has also indicated the need for explaining a local source. The abrupt increases and decreases observed by Satyaprakash (7) in neutron monitors at the equator also point to a local non-meteorological cause for the daily variation on some days.

Finally we have new evidence relating to cosmic ray storms. The storm of February 11, 1958 has three remarkable features which are shown in Fig. 10. The first is an anticipatory increase of intensity observed only at the equatorial neutron monitor stations a few hours before the arrival of the solar plasma to a distance at which it inter-acts significantly with the geomagnetic field. The main Forbush decrease almost coincides with the Sc geomagnetic storm and its minimum is larger and occurs later for low energy than for high energy primaries. A second increase which is more prominent at low latitudes than at high latitudes and with strong east-west and north-south asymmetry occurs about 10 hours after the onset of the cosmic ray storm. We believe that in the two increases and the main decrease observed with the cosmic ray storm of February 11, 1958, we have essentially three types of modulation processes. One is directly associated with the moving plasma, probably related to the magnetic field in the shock front and gives increases as well as decreases of intensity along with anisotropy. The second gives decreases of intensity and is related to a process which has a sharp onset but a relatively long time constant of recovery. The first is often more effective for high primary energies than low, but the second is much more effective for low than for high energies.

The large anisotropy parallel to the north-south and east-west directions in the second increase poses an important problem. The different motions of solar particles trapped by the geomagnetic field have been discussed by Gold (8), and before average conditions are established round the globe there is probably a basis for major differen-ces in conditions over the hemisphere and at different meridional sections immediately following the arrival of a new cloud of solar particles. But the time element involved is very short compared to the observed effect which shows up over periods of several hours. Moreover even though changes in the Van Allen radiation belts could perhaps provide an adequate mechanism for the perturbation of the geomagnetic field and through it alter cosmic ray intensity, a quantitative evaluation of the effect has not so far been undertaken.

ACKNOWLEDGEMENTS

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8. Gold, T. - Nature, 183, 355, 1959.

<u>Captions for the figures</u>

Fig. 1 - The long term change of time of maximum of the semidiurnal component of twelve month mean daily variation of cosmic ray intensity at Huancayo from 1937 to 1956 and its relationship with the cycle of solar activity as indicated by Zurich sunspot number R. $\phi_2 = 0$ indicates the semidiurnal time of maximum at midnight or noon local time. (Sastry)

Fig. 2 - Frequency distributions of the amplitudes of diurnal and semidiurnal components of the daily variations on individual days at Kodaikanal, Ahmedabad and Trivandrum during 1954, 1955 and 1956. (Duggal, Razdan and Sastry)

Fig. 3 - Frequency distributions of times of maxima of diurnal and semidiurnal components of daily variation on days on which the variation has significant amplitude at Kodaikanal, Ahmedabad and Trivandrum during the years 1954, 1955 and 1956. (Duggal, Razdan and Sastry)

Fig. 4 - Monthly mean daily variation of cosmic ray intensity from July to November 1958 measured by the high counting rate mu-meson detector at MIT. (Palmeira)

Fig. 5 - Frequency distributions of amplitude of maximum and of minimum of daily variation of cosmic ray intensity on individual days measured by the high counting rate mu-meson detector at MIT from July to November 1958. (Palmeira)

Fig. 6 - Histograms of occurrence of positive and negative deviations of hourly intensity exceeding 5% ± 0.5% at individual hours during the period July to November 1958 for the high counting rate mu-meson detector at MIT. (Palmeira)

Fig. 7 - Frequency distributions of the amplitudes and times of maxima of diurnal and semidiurnal components of the daily variation of cosmic ray intensity on individual days during 1957 and 1958. The results obtained with telescopes having 10° and 20° semiangular opening in the east-west plane and inclined to the zenith at 45° east and 45° west are separately shown. (Rao)

Fig. 8 - The mean daily variation in east and west pointing telescopes during 1957 and 1958 at Ahmedabad for groups of days with low, medium and high geomagnetic disturbance. The frequency distributions of the occurrence for each bi-hour of the times of maxima of diurnal and semidiurnal components on days on which the amplitude of variation is significant are shown separately for groups of days of low, medium and high geomagnetic disturbance. (Rao)

Fig. 9 - The mean daily variation in east and west pointing telescopes during 1957 and 1958 at Ahmedabad, for groups of days with low, medium and high east-west asymmetry. Results of Chree analysis of the daily mean intensities in east and west, east-west asymmetry and Cp for epochs of high and low asymmetry during 1957 and 1958 are also shown. (Rao)

Fig. 10 - Cosmic ray intensity changes and associated solar and terrestrial effects for the cosmic ray storm of February 11, 1958. Relationships of changes are indicated separately in A for low and medium latitudes and primary energy response, in B for meridional sections and in C for hemispheres. (Sarabhai and Palmeira)

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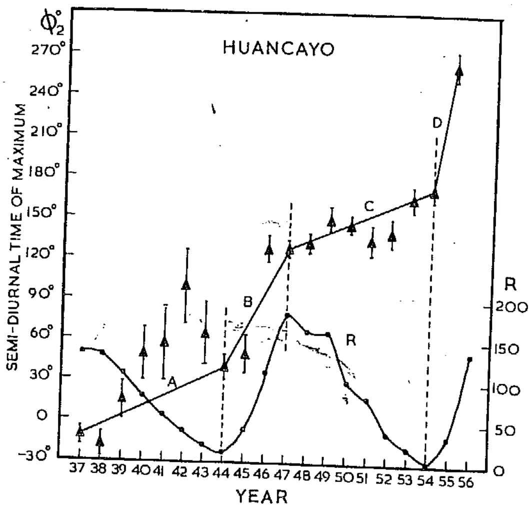

HUANCAYO
SEMI-DIURNAL TIME OF MAXIMUM
YEAR
R
A
B
C
D

Fig 1

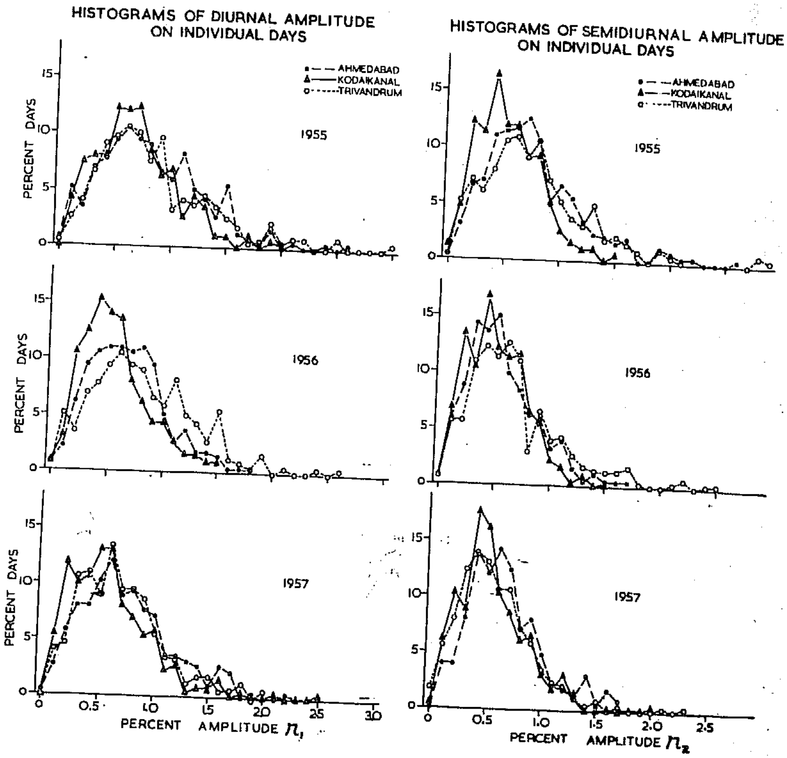
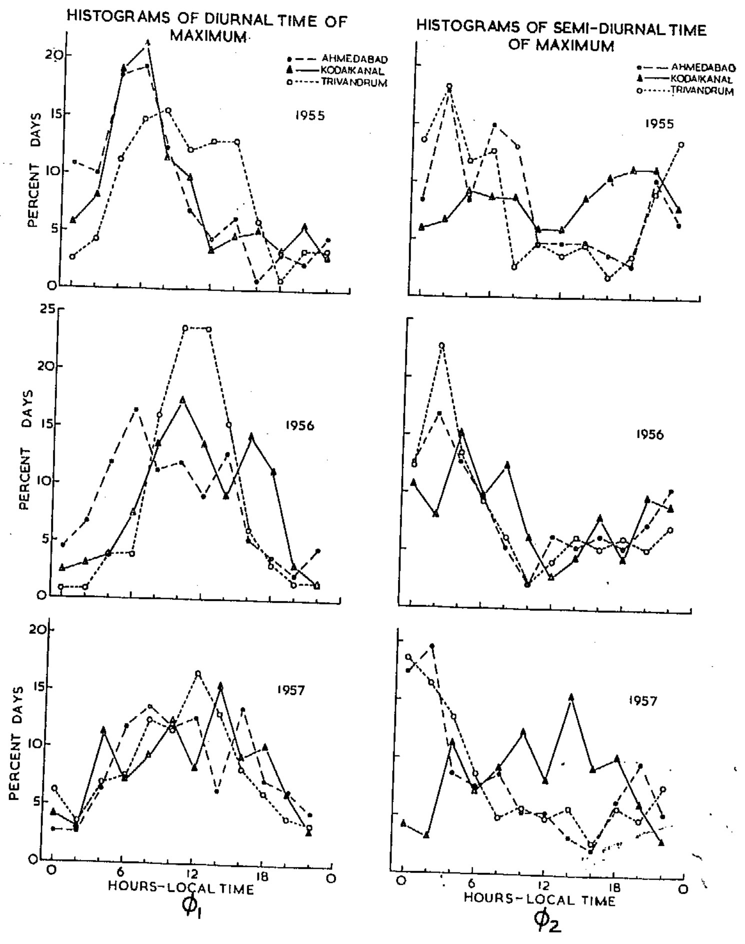

HISTOGRAMS OF DIURNAL AMPLITUDE ON INDIVIDUAL DAYS
HISTOGRAMS OF SEMIDIURNAL AMPLITUDE ON INDIVIDUAL DAYS
AHMEDABAD
KODAIKANAL
TRIVANDRUM
1955
1956
1957
PERCENT DAYS
PERCENT AMPLITUDE r_1
PERCENT AMPLITUDE r_2

Fig 2


HISTOGRAMS OF DIURNAL TIME OF MAXIMUM
HISTOGRAMS OF SEMI-DIURNAL TIME OF MAXIMUM
AHMEDABAD
KODAIKANAL
TRIVANDRUM
1955
1956
1957
PERCENT DAYS
HOURS-LOCAL TIME
ϕ_1
ϕ_2

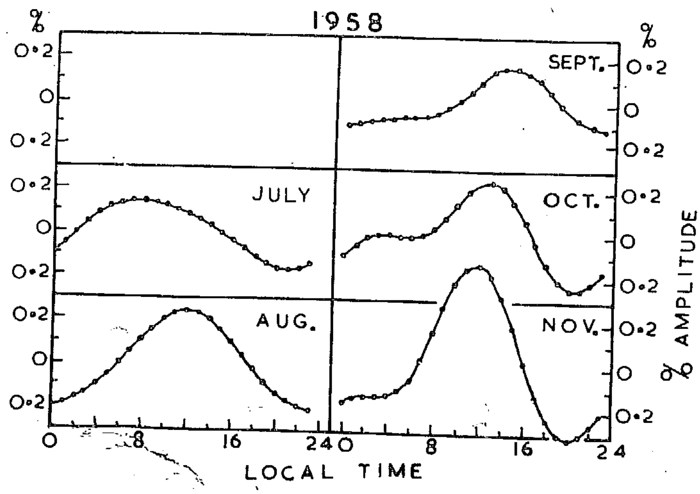


Fig 4

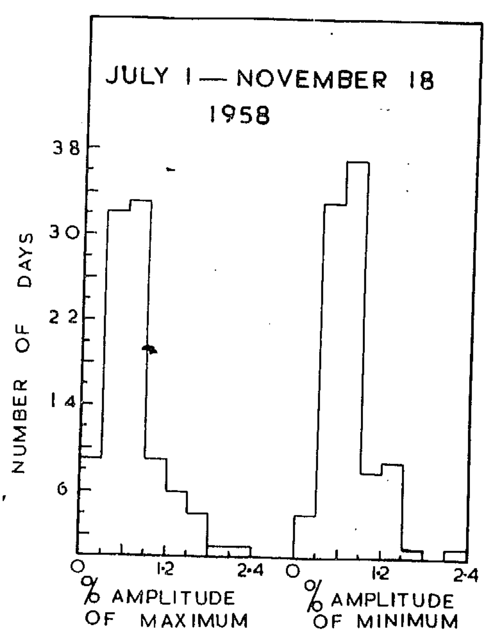


Fig 5

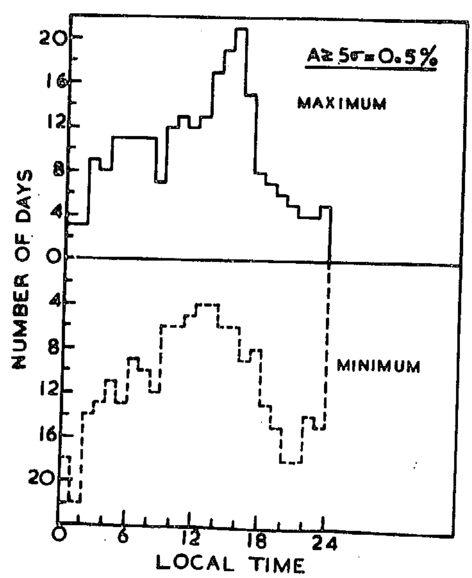


Fig 6

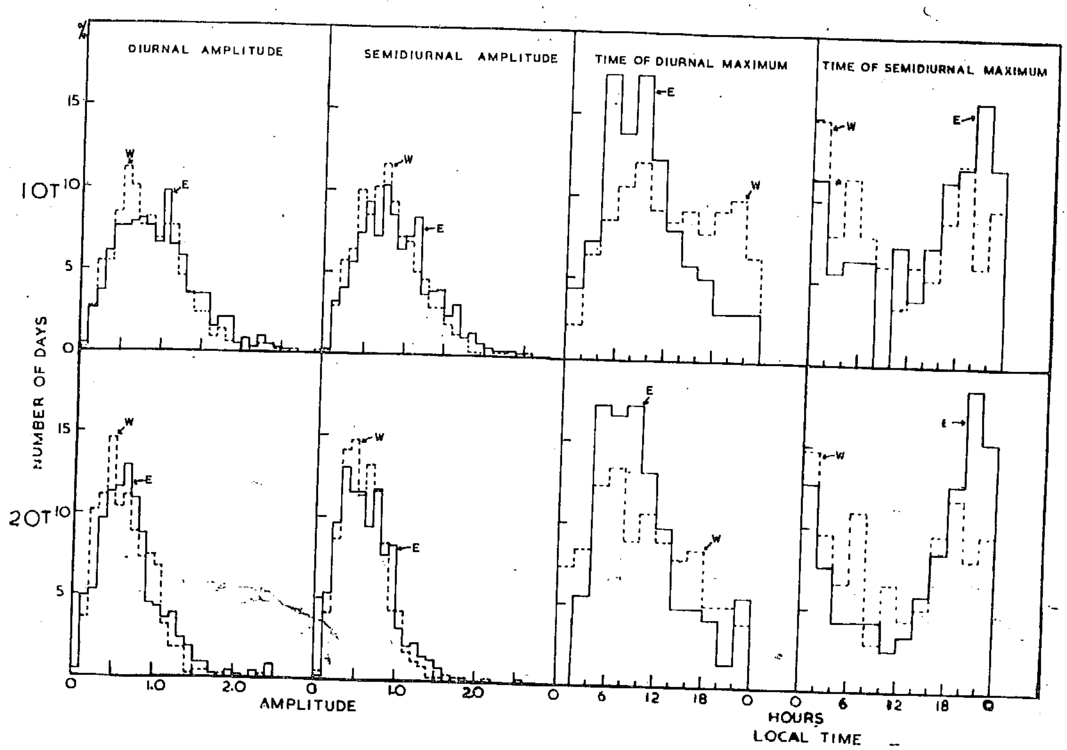

DAILY VARIATION IN E-W TELESCOPES IN 1957-58 AT AHMEDABAD
DIURNAL AMPLITUDE
SEMIDIURNAL AMPLITUDE
TIME OF DIURNAL MAXIMUM
TIME OF SEMIDIURNAL MAXIMUM
NUMBER OF DAYS
10T10
20T10
AMPLITUDE
HOURS
LOCAL TIME

Fig 7

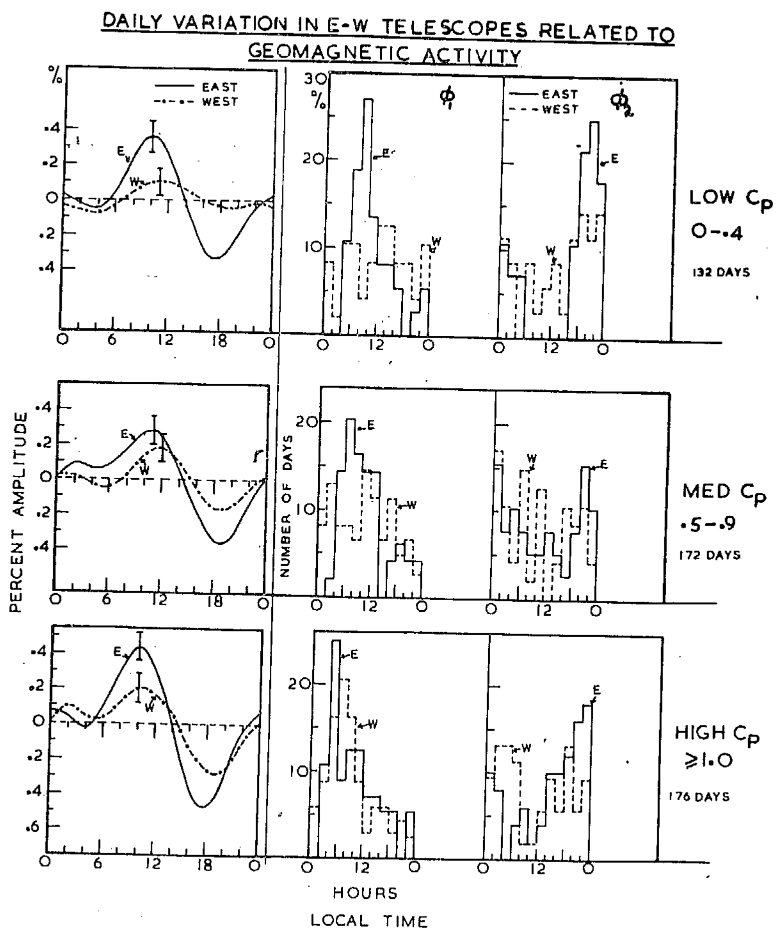
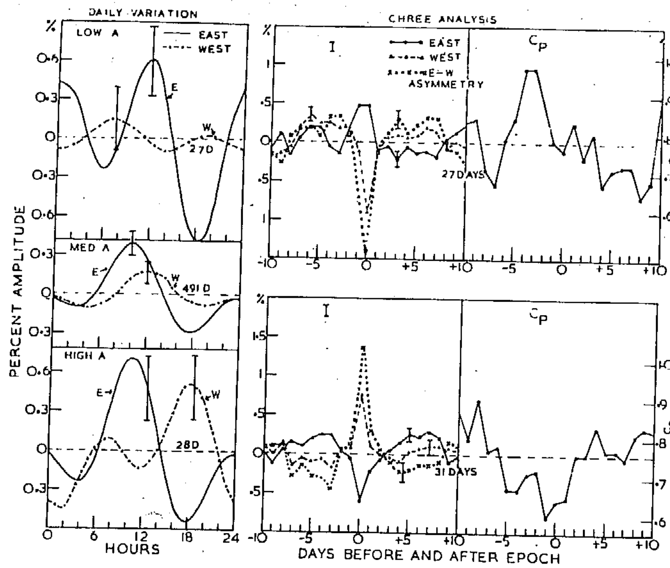

DAILY VARIATION IN E-W TELESCOPES RELATED TO GEOMAGNETIC ACTIVITY
EAST
WEST
PERCENT AMPLITUDE
NUMBER OF DAYS
LOW C_p
0-.4
132 DAYS
MED C_p
.5-.9
172 DAYS
HIGH C_p
≥1.0
176 DAYS
HOURS
LOCAL TIME

Fig 8



DAILY VARIATION IN E-W DIRECTIONS RELATED TO E-W ASYMMETRY

Fig 9

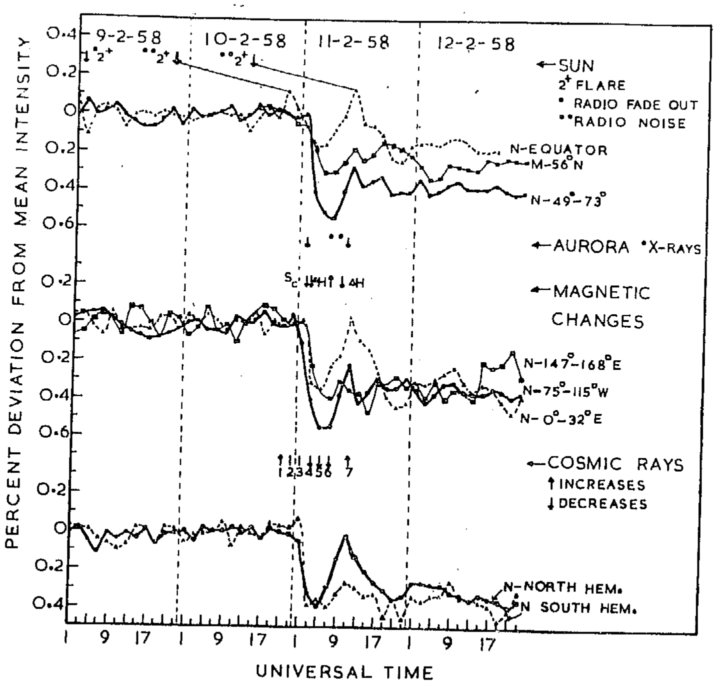


Fig 10